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Agent Orange Chemical Plant Locations in the United States and Canada: Environmental and Human Health Impacts

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Abstract

During the Vietnam War, millions of liters of six tactical herbicides were sprayed on the southern Vietnam landscape to defoliate forests, to clear military perimeters and to destroy enemy food supplies. The environmental and human health impacts of spraying these herbicides, especially Agent Orange and those formulated with mixtures that included 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) which was contaminated with 2,3,7,8-tetracholorodibenzo-p-dioxin (TCDD) have been documented over the last 60 years. The dioxin TCDD clean-up efforts at former military bases and other Vietnam hotspots are ongoing. However, the lesser-told story was the environmental and human health impacts on the communities and chemical plant workers who manufactured Agent Orange and other herbicides that became contaminated with dioxin TCDD in the manufacturing processes at seven locations in the United States and one site in Canada. The pollution at these chemical plant sites, adjacent rivers and groundwater is well known within each affected state or province but not widely recognized beyond their localities. In this paper we assess the national long-term effects on land, groundwater and river resources where Agent Orange and other agricultural herbicides containing 2,4,5-T with unknown amounts of dioxin TCDD were manufactured, transported, and temporarily stored. The sites where residual tactical herbicides with contaminated by-products were applied to public lands or disposed of by military and civilian workers within the United States and Canada are identified. After 60 years, these communities are still paying the price for the U.S. Government, DOD and USDA decisions to provide and use agricultural herbicides as tactical chemical weapons during the Vietnam War (1962-1971).

There have been human health issues associated with the chemical manufacture, transport, storage and disposal of these herbicides related to workers who moved these chemical weapons from United States and Canada to SE Asia. Most of these dioxin contaminated tactical herbicides were transported via railroads to ports at Mobile, Alabama and Gulfport, Mississippi. They were then loaded on ocean-going ships and transported via the Panama Canal for use during the Vietnam War. The objective of this study is to document the environmental and human consequences of the manufacture of tactical herbicides with dioxin TCDD and arsenic on the chemical plant, transportation, application, storage and disposal workers. The costs of cleanup of these North America chemical plant sites, transportation corridors, temporary and long-term storage areas, supply chain storage facilities with residual tactical herbicide, application, and disposal sites to date, is in the billions of dollars. Billions have been spent on hazardous waste incineration to destroy the dioxin TCDD or bury it in certified landfills. Government mandated environmental covenants are on titles of properties still contaminated with high levels of dioxin TCDD. If landowners attempt to rescind land use restrictions, many more billions of dollars will be needed to finish the environmental cleanup and restore natural resources. These cost estimates do not include the billions of dollars needed to treat the effects of dioxin TCDD exposure of U.S. and Canadian civilian workers who manufactured and handled these contaminated herbicides during the Vietnam War as well as address human health issues of their offspring.

Keywords

Dioxin TCDD, Arsenic, Chemical Plant Workers, Chloracne, Cancer, Herbicides, Cacodylic Acid, Monsanto, Dow, Nitro, Midland, Elmira, Uniroyal, Times Beach, Missouri, Gagetown, Incineration, Certified Landfill, Environmental Covenants

1. Introduction

The United States (U.S.) Government passed the Defense Production Act in 1950. This gave the government authority, as a nation at war, to compel U.S. chemical companies to create, produce, and supply tactical herbicides including Agent Orange, to the U.S. military. From 1965 to 1969 eleven wartime government contractors manufactured Agent Orange and other herbicides formulated with mixtures that included 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) for military use [1]. Post-1969, these companies continued to manufacture very similar commercial herbicide products, containing 2,4,5-T (with unknown quantities of dioxin TCDD) for agricultural use but with different product names [2] [3]. TCDD, a highly toxic dioxin (2,3,7,8-tetrachlorodibenzodioxin) was an unintended byproduct of the accelerated combustion process used in the manufacture of herbicides containing 2,4,5-T. These herbicides have frequently been

blamed for soil and environmental contamination as well as long-term human health problems; however, the real source of harm is the contaminate dioxin TCDD [1] [3].

In 1949, an explosion at a Monsanto chemical plant producing 2,4,5-T herbicides in Nitro, West Virginia affected the chemical plant workers (**Figure 1**) [4] [5]. In 1953, another 2,4,5-T manufacturing explosion occurred at a BASF facility in Europe [3]. However, the cause of the human health impacts (chloracne and cancer) at the Monsanto chemical plant in Nitro took four years or more to determine [4]. There is evidence that by the mid-1950s medical doctors [5], chemical companies and government agencies such as USDA, VA and DOD should have been aware that dioxin TCDD causes chloracne, cancer and other medical issues in workers who are exposed to dioxin TCDD for a significant period of time [3] [4] [5]. Despite this early alarming evidence, harm to human health was not widely shared, seems to have been ignored, and/or was not codified as established medical science.

Figure 1. The North American locations of the eight Agent Orange chemical manufacturing plants, the primary Agent Blue chemical manufacturing site and the two Ports on the Gulf of Mexico where tactical herbicides were loaded on ocean-going ships. Map created by Cruz Dragosavac.

Thus, in 1960 and 1961, the United States Government, DOD, and USDA decided to use the tactical herbicide Agent Purple with 2,4,5-T containing an unknown amount of dioxin TCDD and Agent Blue, an arsenic-based herbicide as defoliants to support military efforts in the southern Vietnam landscape. Agent Purple was replaced in 1965 by Agent Orange, an herbicide formulated with equal amounts of 2,4-dichloro phenoxyacetic acid (2,4-D) and 2,4,5-T (with unknown amounts of dioxin TCDD). Agent Orange became the dominant herbicide used during the Vietnam War as it could be produced at lower cost and more quickly than the other 2,4,5-T tactical herbicides.

The primary objective of this study is to explore the environmental and human health impacts on chemical plant workers and their communities in the U.S. and Canada from the chemical manufacture of 2,4,5-T herbicides, predominantly Agent Orange containing unknown quantities of the dioxin TCDD. This includes exploring the timeline when chemical manufacturing companies and the U.S. Government administration—DOD, VA, CIA and USDA, knew that dioxin TCDD was a human health hazard. We ask, what is the evidence that the DOD knew of potential safety concerns prior to authorizing the use of Agent Orange and other tactical herbicides in the Vietnam War (1961-1971)? What prior knowledge about the environmental and human health impacts of Agent Orange, with unknown quantities of dioxin TCDD, on chemical plant and supply chain workers existed and how widely was it known? The cleanup efforts of these herbicide manufacturing sites and the use of incinerators and landfills certified to receive hazardous waste to date are documented. We ask if the current clean-up efforts are adequate and whether additional mitigation, cleanup and remediation at these former Agent Orange manufacturing site environments are needed. What additional natural resource and river restoration at the eight chemical plant sites are critical to ensure human and ecosystem health?

The use of environmental covenants restricting land use to prevent future human exposure is reviewed. The human health issues of those civilian workers who were exposed to dioxin TCDD, including their offspring, are also discussed.

2. Agent Orange Manufacturing Companies and Site Locations in United States and Canada

Wartime chemical companies that the U.S. government contracted with to manufacture tactical herbicides were: Dow Chemical, Monsanto Chemical Company, Hercules Inc., Diamond Shamrock Corporation (previously Diamond Alkali), Hooker Chemical Company, Riverdale Chemical Company, Ansul Chemical Company (Agent Blue), Uniroyal Inc. (Canada), Occidental Chemical Company, N.A. Phillips Chemical Company, Syntex, Thompson Chemical, and Thompson-Hayward Chemical Company. Manufacturing sites were geographically located on major rivers in north-eastern and mid-west U.S. and the Great Lakes regions of U.S. and Canada (Figure 1). The U.S. Government and Department of Defense (DOD) specified how Agent Purple, Agent Orange and the other tactical herbicides used during the Vietnam War would be formulated and manu-

factured; and controlled the transportation, storage, distribution, and use of these herbicides produced for military use [1].

2.1. Dioxin TCDD Toxic Effects on Chemical Plant Workers

On March 8, 1949, the Monsanto Chemical Plant manager in Nitro, West Virginia (**Figure 1**) heard the noise of high-pressure gases rushing through a vent on an oven. The factory whistle, intended to alert the workers, was drowned out by the sound of chemical vapors spewing up into the air of the chemical manufacturing plant. Since no one was injured, the "explosion" was relatively "unremarkable" [4] [5]. Safety devices actually worked and the accident was not considered newsworthy (in other words there was no need to tell the media or public). With the passage of time, it became a most "unremarkable" episode in environmental and occupational health history. Perhaps the most important single event in the United States related to the effects of "dioxin" on chemical plant workers and their community was buried in a company report.

It was not until after the 1953 BASF plant explosion in Europe that the chemical company manufacturer's medical doctors, the U.S. Government (USDA, VA, CIA and DOD) knew that trichlorophenol was contaminated with dioxin. The BASF chemical company, with the assistance of Dow Chemical, discovered the dioxin TCDD negative health effects, including causing chloracne and cancer, on workers after this European explosion in 1953 [3].

Elmore [4] [5] suggested: "If the Monsanto chemical plant at Nitro (West Virginia) had been shut down and its dioxin TCDD problems exposed to the public in the early 1950s (instead of being covered up by Monsanto and their medical doctor reports hidden from the workers, media and public), the toxic hazard of 2,4,5-T, with unknown amounts of dioxin TCDD, might never have been exported and sprayed during the Vietnam War. There, half way around the world, hundreds of thousands of American soldiers and millions of Vietnamese soldiers and citizens would later be exposed to dioxin TCDD and come to know about dioxin's dangers." By the early 1950s, the U.S. Government, DOD, VA, CIA, USDA, medical doctors and chemical companies, (including Monsanto, BASF and Dow) were aware of the environmental and health consequences of the contaminant dioxin TCDD [3] [6] [7] [8]. It took until 1985, for the production of 2,4,5-T to be banned for worldwide agricultural use. During those 30 years, tens of millions of people were impacted from dioxin TCDD exposure and their offspring are still being affected 60 years later.

Tactical herbicides, with 2,4,5-T and the contaminate dioxin TCDD, were used during the Vietnam War, starting in the 1960s, and continued to be used in agriculture until 1985. During the Vietnam War, these chemicals may have provided limited strategic value since Agent Orange, a systemic herbicide spray required 14 days for the jungle vegetation leaves to fall off. Even the "enemy" could figure out that after an area was sprayed it was time to move before U.S. military bombed the area [1]. Some members of the U.S. civilian leadership team

unsuccessfully challenged the usefulness of this military tactical herbicide strategy. The military solution to the problem of the delayed loss of leaves was to mix the Agent Blue herbicide with Agent Orange and apply a combination of these herbicides to reduce the time it took for the tree and shrub leaves to drop off and expose the enemy. Even more problematic is that Agent Blue contains water soluble arsenic, which has no half-life and remains in the Vietnam landscape to this day [1] [9].

2.2. Agent Orange Manufacturing on the Passaic River in New Jersey

In the 1950s, the Diamond Alkali facilities on the banks of the Passaic River in Newark, New Jersey (Figure 2), were used to manufacture Agent Orange. Diamond Alkali workers testified in court that they were exposed to Agent Orange,

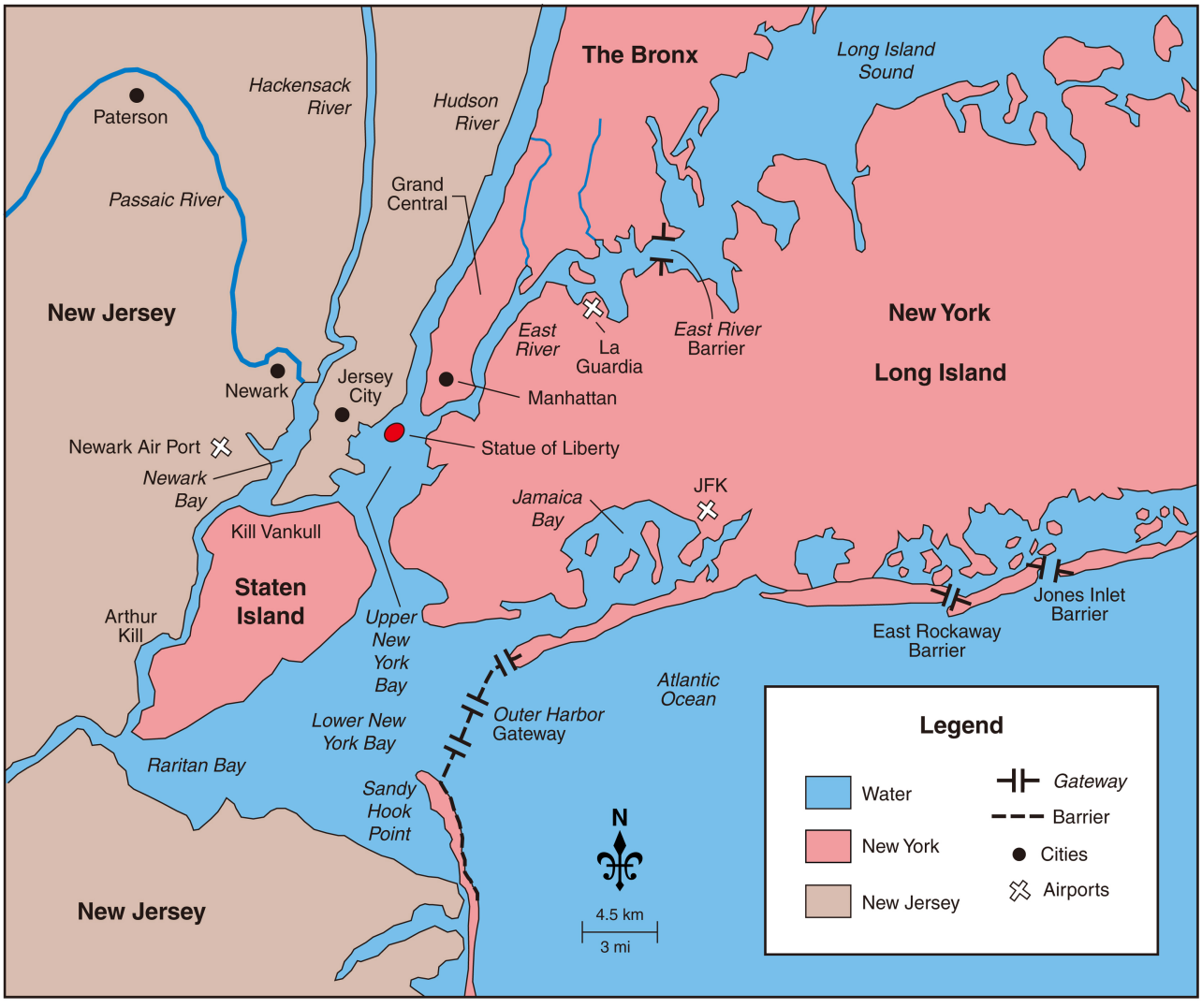

Figure 2. Passaic River, a 27 km dioxin hotspot near Newark, New Jersey and flows into Newark Bay, Hudson River and the Atlantic Ocean. Published with copyright permission from Editor of Open Journal of Soil Science [6]. Map created by Mic Greenberg.

which contained the herbicide 2,4,5-T with by-product dioxin TCDD. These workers claimed that the chemical factory floors in the 1950s and 1960s were slick after Agent Orange was spilled or leaked and it was treacherous to walk on them. The contaminant dioxin TCDD which was in Agent Orange, was washed by poorly protected workers into trenches, drains and pipes, which emptied into the Passaic River [6].

In 1971, Diamond Alkali sold the Lister Avenue, New Jersey, facility. The Passaic River, a tidal river, carried dioxin TCDD upstream and downstream, contaminating a 27 km section of the riverbed in one of New Jersey and New York's most populated areas. The river linked to Kill Van Kull and Hudson River, which flows adjacent to and past New York City [6]. The dioxin-contaminated sediment has reached Newark Bay, which is connected by the Kill Van Kull to Hudson River just north of Staten Island.

The Passaic River (**Figure 2**), which parallels the near-by Hudson River, was an industrial river, with chemical plants that manufactured Agent Orange for use during the Vietnam War during the 1950s and 1960s [6]. Stretches of Passaic River in Newark, New Jersey are post-industrial abandoned landscapes and the sediment in the Passaic River near Newark Bay remains contaminated with dioxin TCDD, PCBs, and Hg. The USEPA designated this 27 km stretch of the Passaic River as a Superfund site.

During the manufacturing process, the workers at the New Jersey Diamond Alkali facility were exposed to dioxin TCDD [6] as was the lower Passaic River and Newark Bay. Agent Orange was stored on site at Diamond Alkali in 208-liter barrels painted with an orange stripe, then loaded on ocean-going vessels on the Passaic River, and shipped via the Panama Canal Zone [10] to the South China Sea and the coast of Vietnam.

In 1983, sampling of soils and sediments, by the State of New Jersey and U.S. Environmental Protection Agency (USEPA), near 80 Lister Avenue in Newark and the adjacent Passaic River west of Newark Bay, revealed high levels of dioxin TCDD [6]. There were also high levels of PCBs and Hg because of the manufacture of other chemical products. In 2001, the USEPA, in partnership with New Jersey and other federal agencies, cleaned up the Lister Avenue manufacturing site on the Passaic River in Newark, New Jersey. The buildings were torn down and hauled to a landfill (**Figure 3**). The site became a gravel parking lot and the dioxin-contaminated soil was removed and incinerated. Today, only a gravel lot remains as part of an abandoned industrial complex [6]. The remediation actions taken in the Passaic River included a pre-1998 floodwall and subsurface treatment system.

The contaminated sediment in the river originating from the Lister site and neighboring lots was covered to prevent additional release of dioxin TCDD into the river. Occidental Chemical Corporation [11] monitored the site [12]. In 2005 the State of New Jersey sued Maxus Energy Corporation (the U.S. unit of Argentina's oil giant YPF Sociedad Anomima) and OxyChem over a delay in the

Figure 3. Gravel parking lot of the former Diamond Alkali Company. The dioxin contaminated building was torn down and contaminated building materials were placed in a landfill. The contaminated soil was incinerated. The former chemical plant site was on the Passaic River bank. The site was made into a gravel parking lot. Published with copyright permission from Editor of Open Journal of Soil Science.

cleanup. The US$220 million that the state spent cleaning up a section of the river was recovered from Maxus and OxyChem partnership under terms of a court settlement. Cleanup activities by the partnership in 2012 and 2014 included the removal and disposal of dioxin TCDD, PCBs, and Hg-contaminated sediment from two areas along the Passaic River [13] [14].

Tierra Removal dredged the most concentrated inventory of dioxin TCDD contaminated sediment in the river adjacent to the Lister Avenue site. At river mile marker 10.9 the concentrated inventory of highly contaminated mudflat on the east bank of the river near Lyndhurst was dredged and capped [15] [16]. The Passaic River is one of the most polluted hotspots in the United States and site of one of the largest cleanup efforts ever conducted.

In 2014, the USEPA announced a US $1.7 billion plan to remove 3.2×10^6 m^3 of toxic sediment contaminated with dioxin TCDD, PCBs, and Hg [6]. The sediments in the lower 13 km of the Passaic River were found to be a major source of the contamination in other sections of the Passaic River and Newark Bay. In March of 2016, a remedy was chosen for the contaminated sediment of the lower Passaic River which included an engineering cap being installed from riverbank to riverbank.

In an attempt to avoid increasing future Passaic River flooding hazard and to maintain the navigation channel, part of the dioxin TCDD-contaminated sediment had to be removed to make room for the cap. The removed dredge material was dewatered and transported by barge to a sediment permitted processing facility on the banks of Newark Bay for disposal [6] [17] [18]. The estimated cost was US $1.38 billion. The USEPA estimated the cost of the cleanup of the lower 27 km of the Passaic River and Newark Bay to be US $6 billion, in addition to US $6 billion in earlier natural resource damages. Cleanups for the remainder of Newark Bay and lower Passaic River are still being planned [11] [14].

Exposure to even low levels of contaminants through crab and fish consumption may have long-lasting health effects on people living along the lower Passaic River. The USEPA alerted the public about the prohibitions and advisories on harvesting crabs or fish in the tidal Passaic River and Newark Bay. The advisories and prohibitions, based on levels of Hg, PCBs, and dioxin in tested crabs and fish, are difficult to enforce.

In 2013, several corporations agreed to pay New Jersey US $130 million for ecological damages related to the Passaic River pollution [14]. After 60 years, U.S. companies, such as Diamond Alkali (now Diamond Shamrock), stopped manufacturing Agent Orange with the by-product dioxin TCDD. However, the contaminant has a very long half-life when attached to sediment under water (anaerobic conditions) and remains an environmental problem in the tidal Passaic River and Newark Bay. To this day, fish and crabs from the Passaic River are too contaminated with dioxin TCDD for human consumption and remain a threat to the food supply and human health [6].

2.3. Agent Blue, the Arsenic Based Herbicide, Manufacturing on the Menominee River

The Menominee River flows into Lake Michigan via Green Bay (**Figure 4**). The Ansul Chemical Company at Marinette, Wisconsin manufactured Agent Blue, an arsenic containing herbicide, used during the Vietnam War in the 1960s and 1970s. The Agent Blue was shipped via Green Bay and the Great Lakes and the St. Lawrence Seaway to the Atlantic Ocean. Almost all (98%) of the Agent Blue used during the Vietnam War from 1962 to 1971 was manufactured at Ansul Chemical plants (**Figure 5**) on the Menominee River in Michigan and Wisconsin [9]. The contaminated surface water and sediments near Ansul manufacturing plant flowed into the Menominee River. The groundwater and the river bottom sediments are heavily contaminated with arsenic, which was released by

Figure 4. Aerial view of the former Ansul company chemical plant on the Menominee River in Marinette, Wisconsin (L) and Menominee, Michigan (R). Published with copyright permission from Editor of Open Journal of Soil Science.

Figure 5. Ansul chemical plant on the Menominee River. The ships can travel through Green Bay, Lake Michigan and then to the Atlantic Ocean via the St. Lawrence Seaway. Published with copyright permission from Editor of Open Journal of Soil Science.

Ansul Company from 1957 to 1971 resulting from the manufacture of Agent Blue. Ocean going-ships carrying Agent Blue passed through the Panama Canal (**Figure 6**) and the Pacific Ocean on the way to the South China Sea.

In 2009, the Ansul Company operated under two consent orders for environmental mitigation; one from the Wisconsin Department of Natural Resources and another from the USEPA [9]. In September of 2009, Ansul Company agreed to spend an estimated $28 million on:

1) Removal 56,600 m^3 of arsenic-contaminated sediments from the Menominee River;

2) Construction of an impermeable barrier to bedrock for about 160,000 m^2 of sediment;

3) Cap or remove 17,000 m^2 of surface soils contaminated with arsenic levels above 16 - 32 ppm;

4) To pump and treat contaminated groundwater;

5) The total remediation costs were: 1976-1984, $11 million to pump and treat contaminated groundwater at the southern property border and to install a groundwater interceptor trench [9] in 1998-1999, $12.4 million to remove arsenic-contaminated sediment from the 8th Street section of the Menominee River and;

6) An impermeable barrier system was installed to bedrock near the 8th Street slip and adjacent salt vault.

In 2012-2013, approximately $25 million was spent to dredge and then cap contaminated river sediments due to an EPA order of the removal of 190,000 m^3 of sediment from the main channel. The project cleanup began in July of 2012 after Ansul (Tyco) Company hired Stevenson Environmental Services of New York as the general contractor.

Arsenic toxicity and health effects are complex and the impact of Agent Blue on human health was not well known for many years. Post-Vietnam War, arsenic-based industrial wood preservatives and herbicides with cacodylic acid

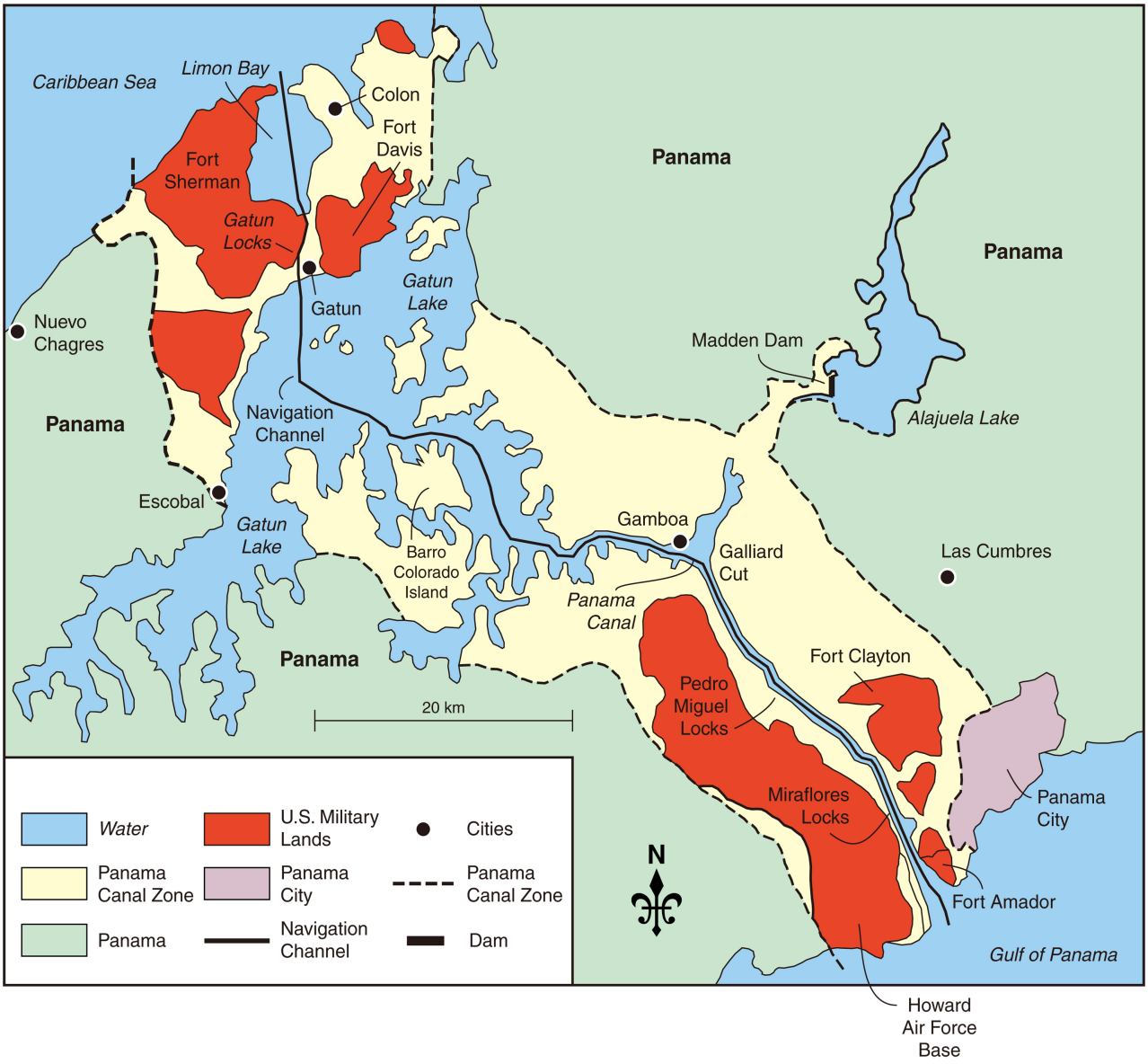

Figure 6. Panama Canal Zone map, showing Panama Canal, Lake Gatun, military bases and Panama City. Reprinted with copyright permission from Editor of Open Journal of Soil Science [10]. Map created by Mic Greenberg.

were used throughout the U.S. in wood products, golf course management, and cotton fields for desiccating agricultural crops prior to harvesting [18]. Today, none of these herbicides is commercially available with the exception of the weed killer monosodium meta-arsonate (MSMA) for use on U.S. cotton [9]. The frequent use of manufactured arsenic products in industry and agriculture has resulted in human exposure by way of inhalation, contaminated drinking water, and food. Epidemiological evidence and animal studies show excessive risks of lung and skin cancers as well as delayed health effects at relatively high exposure rates [9] [19].

The spraying of arsenic-based Agent Blue was field tested in United States, Puerto Rico, Canada and Thailand. Often, Agent Blue was used at full strength

during the Vietnam War. The Cancer Assessment Group of EPA currently puts arsenic in the top category of cancer-causing chemicals. Arsenic, even at low doses has been found to be responsible for lung, bladder, and liver cancer and the arsenic is able to cross the placenta to create cancers in the fetus as well as both birth defects and childhood cancers have been linked to arsenic [19]. The effects of arsenic are delayed and can take decades to appear in humans [20]. Arsenic can cause damage to human DNA, which can adversely affect future offspring. Arsenical herbicides containing cacodylic acid as active ingredients are still being used today as weed killers and crop desiccants. Less toxic formations of arsenical herbicides sold over the counter today can cause headaches, vomiting, dizziness, profuse and watery diarrhea, followed by dehydration, electrolyte imbalance, and gradual fall in blood pressure, convulsions, stupor, general paralysis, and possible death in 3 to 14 days [21] [22].

The New Jersey Department of Health and EPA regard sodium cacodylate as a Special Health Hazard. The Agency for Toxic Substances and Disease Registry suggests, "Arsenic cannot be destroyed once added to the environment".

2.4. Exposure of American and Canadian Chemical Plant Workers to Dioxin TCDD

Dow Chemical and Monsanto, two of the largest chemical manufacturers of Agent Orange discovered ways to manufacture Agent Orange faster and cheaper (to help support the war effort) by raising the temperature 9 degrees F [1] [6] [23] [24]. These Chemical Companies delayed telling the U.S. Government and DOD about the manufacturing process modification and increased dioxin TCDD levels at the higher temperature [6] [24]. However, once the military officers were eventually told by the chemical companies [24] [25] [26] about the "manufacturing process contamination problem", the military was asked to make a decision, since they controlled the process, about which manufacturing process should be used in the future. The U.S. Military officers opted for the faster and cheaper manufactured product with higher levels of dioxin TCDD contaminate; they were running out of Agent Orange and key ingredient 2,4,5-T and the U.S. was in a war.

The dioxin TCDD by-product was in four tactical herbicides formulated with 2,4,5-T. These included Agent Purple, Agent Orange, Agent Green and Agent Pink (all but Agent White and Agent Blue). Thus the manufacture of these four contaminated herbicides are associated with risks to the environment and the health of chemical plant and transportation workers who handled tactical herbicides with unknown amounts of dioxin TCDD contaminant [23] [24] [25].

In 1970, President Nixon, the Commander-in-Chief, ordered the DOD to stop spraying Agent Orange. The next year, DOD ordered that all other tactical herbicide spraying be stopped including Agent Blue the arsenic-based herbicide used to destroy the rice crop. Soldiers and Vietnamese support workers removed all remaining tactical herbicides from Vietnam military bases. Agent Orange barrels from these Vietnam military airbases were collected at Bien Hoa Airbase

(located about 32 km northeast of Saigon/Ho Chi Minh City) and shipped to Johnston Island Atoll in the Pacific Ocean as part of Operation PACER HO. Many of the Agent Orange barrels were damaged in shipping, leaked, and had to be re-drummed or resealed. This exposed the barrel handlers, transporters, and site monitors to 2,4,5-T herbicides contaminated with dioxin TCDD, a cancer-causing substance. Many Vietnam Era veterans who worked in the supply chain and/or were involved in the spraying, Operation Ranch Hand and Operation PACER HO have applied for VA benefits because of their exposure to dioxin TCDD. Each case was handled separately, and most often their attempt to qualify for VA benefits failed initially and their potential benefits were delayed for years. Eventually, after the passage of a 1991 Federal Law most Vietnam Veterans, with boots on the ground in southern Vietnam and exposure to dioxin TCDD were awarded benefits [24] [26]. Because of these initial delays, as their health was deteriorating, Vietnam Era veterans filed a class action litigation in 1977, which took until 1984 to resolve [24].

2.5. Agent Orange Product Liability Litigation

In 1965, Dr. R. Emmet Kelly, a Monsanto medical doctor based in St. Louis, Missouri wrote that dioxin was "a potential contaminant" and very likely a potential carcinogen that could cause another epidemic [4] [5]. The Dr. Kelly memo was written near the start of the official American-Vietnam War and at the same time when the U.S. military was ramping up requests for Agent Orange. Four years later, the U.S. State Department terminated its contracts with Monsanto's Nitro Chemical Plant [4] [5]. During those 4 years, the U.S. military exposed thousands of U.S. Vietnam veterans and millions of Vietnamese citizens to dioxin while both Monsanto and Dr. Kelly knew about the dangerous consequences of exposure to dioxin. Monsanto's legal team claimed that Monsanto made improvements at the Nitro Chemical plant (in the 1950s) that reduced worker's exposure to explosion residues. According to the Monsanto legal team, the "systematic residue exposure problems disappeared". However, the workers kept reporting health problems for the next 30 years and long after the 1949 Nitro explosion and subsequent cleanup [5].

On January 8, 1979 Victor J. Yannacone, filed a class action suit, RE: Agent Orange Product Liability Litigation (1979-1984) [24] [26] on behalf of all the Vietnam Era veterans who were exposed to Agent Orange containing unknown quantities of dioxin TCDD and other tactical herbicides. By the end of the year, Yannacone and associates represented 8300 Vietnam veteran clients in a lawsuit against 11 chemical companies including: Dow Chemical, Thompson-Hayward, Diamond Shamrock, Hercules Inc., Monsanto, Ansul Company (the manufacturer of Agent Blue), Riverdale Chemical Company, Uniroyal (Canada), Occidental Petroleum, Hooker Chemical Company and N.A. Phillips [1].

These chemical companies testified in Federal Court that the U.S. Government was responsible for the injuries claimed by the Vietnam veterans and their families [24] [26]. In addition, the companies argued that the U.S. Government,

DOD and USDA, controlled the manufacturing, distribution, and application of Agent Orange (and other tactical herbicides which included the contaminant dioxin TCDD) processes and their government contracts were thought to protect these chemical manufacturing companies. The Chemical Companies claims were eventually dismissed since the U.S. Government has sovereign immunity in the United States court systems [18] [24].

In May 1984, the Vietnam War Veterans and chemical manufacturers settled out-of-court for $180 million. These chemical companies could then renounce future liability [3] [24]. Raising the heating temperature during the manufacturing process of Agent Orange accelerated chemical reactions and increased the dioxin TCDD levels up to 3000 times of previous military and commercial products, thereby magnifying the toxicity of Agent Orange [3] [24]. This enhanced Agent Orange was in the supply chain when (1970 and 1971) DOD was told to stop the spraying of tactical herbicides during the Vietnam War. The supply chain residual at Kelly Air Force base, Agent Orange and components, were disposed of on the western United States forest and rangeland managed by the Bureau of Land Management and USDA, Forest Service [9] [12]. The effects of Agent Blue, the arsenic-based herbicide used to kill rice, on human health were not addressed in a 1984 out-of-court settlement. The manufacturing process for Agent Blue was different and the process was not affected by dioxin TCDD contaminants.

Many of the 52,000 Vietnam Veterans were dissatisfied with the amount of the settlement ($3800.00/veteran or the family) [24]. The judge ruled the out-of-court settlement was fair. The funds were distributed by 1997. After the settlement, the U.S. Government established an Endocrine Disruptor Screening Program to test industrial and agricultural chemicals for endocrine effects prior to marketing and use. The goal was to prevent future unanticipated consequences of the use of new chemical or herbicide weapons [7] [26] [27].

The Agent Orange Product Liability Litigation (1979-1984) [24] records retained by the New Jersey State Council, Vietnam Veterans of America, Inc were transferred in 1000 legal boxes to the Vietnam Center and Archive (VNCA) at Texas Tech University (personal communication from Executive Director Stephen Maxner). These records are of immense importance to further understanding of how tactical herbicides, with dioxin TCDD and arsenic (Agent Blue), were manufactured and sprayed during the Vietnam War [24]. This specific collection is unique, as it represents the years of document and material collection in preparation for the landmark, "Agent Orange" legal action with regard to its contaminant dioxin and could include information and records about other tactical herbicides, including Agent Blue.

The resulting out-of-court settlement was of crucial importance in providing countless Vietnam veterans and their families exposed to dioxin and perhaps arsenic with much needed financial support and restitution [24]. The settlement also resulted in the temporary storage of nearly 1000 boxes of printed materials

that provide detailed information regarding the 11 chemical manufacturers involved in tactical herbicide production including Ansul Chemical Company which manufactured Agent Blue [18] [22].

2.6. 2,4,5-T Product Liability Litigation

Liability litigation for 2,4,5-T products post-Vietnam war continues to gather evidence of the toxic effects associated with the herbicide manufacturing processes. In 1976, there was an explosion at a 2,4,5-T manufacturing plant in Seveso, Italy. More than 170 workers and residents had chloracne and thousands of animals died providing additional evidence that dioxin associated with 2,4,5-T is extremely toxic. In the 1970s, Caro Van Strum, a mother of five living in Rivers Valley region of Oregon and in Pacific Northwest created a Citizens Against Toxic Sprays (CATS) to challenge the USDA, Forest Service continued use of 2,4,5-T in the 1970s [10] [13].

Attorney Stuart Calwell, of Charleston, West Virginia was approached by Monsanto workers from Nitro, West Virginia in the late 1970's who were suffering a variety of medical issues they believed were caused by their work environment, on the production of 2,4,5-T with the by-product dioxin TCDD, for the Vietnam War effort and for agricultural use. Attorney Calwell's client list included James Ray Boggess (a plaintiff). Their initial health concerns related to the 1949 Nitro plant autoclave explosion that injured Nitro chemical plant workers, an event that occurred more than 30 years before and the workers continued to be ill [5]. They assumed that their health issues related to the, 2,4,5-T product production conditions which continued until 1985 while they worked there. Many of these workers did not work in the Nitro Chemical plant during the explosion nor participated in the clean-up the explosion chemical residues. Monsanto feared a negative verdict in the 2,4,5-T case and tried to keep Nitro worker's health problems, associated with 2,4,5-T production with the by-product dioxin TCDD, out of the public spotlight. In 1978, Vietnam Era Veterans sued the manufacturers of Agent Orange (see the previous section 2.5) after the Vietnam War, which ended in January of 1973.

In January of 1979, railroad cars transporting dioxin-contaminated wood-treatment chemicals produced at the Monsanto's Sauget Plant in Illinois crashed in Sturgeon, Missouri. President Jimmy Carter's administration acted, in December of 1979, to create an Interagency Task Force [5]. An internal Monsanto document dated January 24, 1979 indicated, "Ours (the Monsanto process at Nitro) was a 'dirty' process with higher dioxin levels than were produced by Dow and other Chemical companies (manufactured at a higher temperature)". That statement would be used later in the Nitro workers 1980s legal case.

Marie-Monique noted in an article that Monsanto understood in 1978, that it "controlled" all of the dioxin TCDD health data going back to Nitro Chemical Plant explosion in 1949 [5]. The company had become the "lord of information" which, unfortunately, shaped the dioxin toxicity discourse for many years.

Monsanto company doctors at Nitro, West Virginia examined the workers affected by the 1949 explosion. In addition, Monsanto contracted with University of Cincinnati Kettering Professor Raymond Suskind to examine the Monsanto workers after the autoclave explosion at the Nitro plant. Professor Suskind conducted a Monsanto funded study ($90,000) involving 120 Nitro employees and associated family members of the plant accident [5]. Suskind and Zack co-authored a paper in the Journal of Occupational Medicine, which followed a group of workers exposed to high levels of dioxin. Later Professor Suskind co-authored another paper with Vicki Hertzberg in the prestigious Journal of American Medical Association. The study included 436 employees at the Nitro plant who may or may not have been exposed to dioxin between 1949 and 1969 [5] but did work for Monsanto. Beyond chloracne there were no "noted" serious health effects or mortality rate effects from their associated dioxin exposure. This became a "huge legal asset" for Monsanto leadership team since it showed that dioxin was "not a carcinogenic" and did not increase the death rate in this rather small sample and company funded study. Monsanto attorneys in future legal benefit cases filed by Attorney Calwell (Charleston, West Virginia) on behalf of exposed Nitro chemical plant workers used this data in Federal Court.

In 1991, Marilyn Fingerhut of the National Institute of Occupational Health and Safety conducted a much larger study which included all types of cancers in dioxin exposed workers and mortality data. In all there were 5172 people selected at 12 U.S. chemical plants, which manufactured products 2,4,5-T with dioxin TCDD. The data contradicted the Monsanto funded studies, which were published by Professor Raymond Suskind [5] and his colleagues at the Cincinnati Kettering Institute of the University of Cincinnati. The National Institute of Occupational Health and Safety then conducted a second study with 21,863 workers and the findings of their first study were supported [5] [27] casting considerable doubt on the original Monsanto funded study conducted by Professor Suskind.

Chemical pathologist and University of Leeds professor Alastair Hay and Ellen Silbergeld, of the Environmental Defense Fund, published a 1985 article in Nature [27], which noted 19 people died of circulatory disease or cancer while working at the Nitro chemical plant and found the Suskind papers were inconsistent with other research study findings [5]. Dr. Linda Birnbaum, Environmental Health Sciences found that dioxin adversely affected the heart, vascular system and immune system were all affected and "dioxin is a human carcinogen".

In 2001, U.S. Department of Health and Human Services, National Toxicology Program found dioxin to be a "human carcinogen" [4] [5] [27]. Boston University Cancer epidemiologist Richard Clapp called dioxin the "Darth Vader' of toxic chemicals because it effects so many of the body systems" [5] [27]. So how did Dr. Suskind and fellow researchers get the medical science so wrong and why? In court, Lawyer Stuart Calwell alleged Dr. Suskind was doing the bidding

of Monsanto who funneled thousands of dollars towards Professor Suskind program at the Kettering Institute. A poor research design and small sample size in the Professor Suskind study may have resulted in findings that subsequent research did not support.

3. Results and Selected Agent Orange Manufacturing Study Site Findings

After an extensive literature search, North America herbicide manufacturing sites where 95% of the Agent Orange with 2,4,5-T and unknown amounts of the dioxin TCDD contaminate was produced were identified and evaluated. Authors collected data on seven chemical plant sites in the United States and one in Canada (**Figure 1**) to assess environmental impacts and current mitigation and monitoring conditions. The EPA has identified many of these same sites and some are designated as EPA Superfund sites.

3.1. Case 1. Monsanto in Nitro, West Virginia

The city of Nitro, West Virginia (WV) (**Figure 1**) on the muddy Kanawha River 24 km from Charleston, WV was founded in December 1917. The site of a government gunpowder and explosives manufacturing complex, Nitro became one of the top munitions manufacturing centers during World War I (WWI). Near the end of WWI, the Rubber Services Laboratory with headquarters in Akron, Ohio built a facility in Nitro. Later, in 1929, Monsanto acquired Rubber Services as one of a series of Monsanto acquisitions by owner Edgar Queeny just before the start of the Great Depression [5]. During the 1930s and 1940s, Nitro chemical plant facilities became a central hub for Monsanto's synthetic rubber business and a site for future agricultural chemical manufacturing (**Figure 7**). One of

Figure 7. A black and white photograph taken in the 1950s at Monsanto Chemical Plant in Nitro, West Virginia. Photo Credit: Terry Humphreys. Pinterest.

the chemicals produced was 2,4,5-trichlorophenoxyacetic acid, or 2,4,5-T, a powerful dual-purpose herbicide used by both the military and by agriculture, including cotton farmers to manage unwanted vegetation and weeds.

The 2,4,5-T herbicide was one of the chlorinated herbicides brought to the attention of the U.S. Military by Dr. Matthew Kraus, a plant physiologist at the University of Chicago during World War II (WWII). During WWII, in the early 1940s, researchers in both Great Britain and the United States discovered that plant hormones regulate the growth and development of plant cells and when these hormones are chemically stimulated by herbicides, plant stem and leaf growth are abnormally accelerated [1]. As the herbicide is transported throughout the plant, it literally "grows" itself to death. Large concentrations of 2,4,5-T and 2,4-D essentially stimulated cancerous growth of plant cells. During this time, military researchers at Camp Detrick, Maryland (and USDA agricultural scientists at Agricultural Center at Beltsville, Maryland) were experimenting with possible uses of 2,4-D and 2,4,5-T as vegetation defoliants [9]. WWII ended abruptly, after the United States dropped two atomic bombs on Japan. Consequently, the war-time use of defoliant herbicides plan was not activated.

However, agricultural researchers realized the potential of herbicides to control weeds in crop production could be a game changer by reducing/eliminating weed pressure thereby improving crop access to water and nutrients needed for increased yields. In 1945 the USDA approved the use of 2,4-D and 2,4,5-T as herbicides for the domestic market. These chemicals were highly effective, reduced labor-intensive weed management, and were quickly adopted by farmers to control weeds in their cropping systems and by homeowners seeking dandelion-free lawns and productive home gardens with less hand-weeding. American Chemical Paint Company sold 2,4-D and 2,4,5-T mixtures in the 1950s using the name "Weedone." This is the first known use of these two herbicides in combination (10 years before the decision to use Agent Purple in the Vietnam War and 15 years before Agent Orange). The company claimed the product would kill over 100 different kinds of weeds and woody plants. Suburban homeowners could easily wipe out unwanted weeds and shrubs in their gardens and create weed-free green lawns. American Chemical advertised that it was "harmless to people and pets" and that claim was not evaluated or challenged by public agencies [26]. Environmental and medical studies on herbicides with dioxin contaminated by-products were not well known at that time and the US Environmental Protection Agency (US EPA) was not created or authorized to challenge these claims until 1970.

USDA's approval of herbicide uses in 1945 advanced investments in the synthetic chemicals that underlie the productivity of modern agriculture and ushered in the Age of Chemicals. Dow Chemical Company and Monsanto were two of the first companies to manufacture synthetic auxins (a class of plant hormones). Monsanto in 1945 invested in the manufacture of 2,4-D in St. Louis, Missouri (Case Study no. 4) and in 1948, began 2,4,5-T production at its Nitro,

WV facility (Case Study no 1). This was the start of Monsanto becoming a major player in the agricultural chemical business.

In 1948, USDA, Forest Service began experimenting with 2,4-D and 2,4,5-T in the Siuslaw National Forest [5] [10] [13] to destroy underbrush. In the late 1940s and 1950s, huge public forests, the terrain under power lines and railroad right-of-way environments were sprayed with approval of public officials and agencies. National newspapers published testimonials promoting the virtue of synthetic auxins for use as herbicides on lawns and gardens. "The Garden Doctor" column published in the LA Times [5] urged people to use 2,4,5-T and 2,4-D to eliminate weeds. The Garden Doctor also recommended people wear gloves when ripping up poison ivy, but provided no such warning for synthetic herbicides. The presence of the contaminant dioxin TCDD in the manufacture of 2,4,5-T was not known until the early 1950s. Elmore wrote in his 2021 book, *Seed Money,* "Forests, gardens, lawns, and fields, these chemicals go everywhere and they did. Long before Vietnam became the target of Agent Orange spraying, America used these herbicides to fight a 'war against weeds' at home" [5]. The national embrace of herbicides to control weeds set up profitable "agricultural services" business for Monsanto and other chemical companies.

The West Virginia Kanawha River Valley (**Figure 8**) between Nitro and Belle was known as "Chemical Valley." Chemical manufacturing reached a peak in the 1950s and 1960s. The West Virginia Division of Water Resources, DNR claimed in 1974 that this region was the world's leading producer of chemicals [28]. The Kanawha River and its New River tributary drains 31,683 km^2 in West Virginia, Virginia and North Carolina. The Kanawha River watershed is mountainous; and the only flat land is on the floodplains and stream terraces. Agricultural land use was primarily raising cattle. During the year 1998, about 75 million tons of coal were mined in the Kanawha River basin. This figure represents 45% of the

Figure 8. Nitro, WV. Kanawha River with a boat dock and barges being pushed by a tug boat. Photo Credit: Pam Olson.

coal mined in West Virginia and 7% of the United States total.

Soils of the Kanawha River Valley consist of three phases: liquid, gas and unconsolidated soil solids that are capable of growing plants [29] [30]. The solid phases include organic materials derived from plants and minerals derived from weathered rocks. Soil development processes are affected by bedrock composition, climate, biological activity, topography and time and are known as the five soil forming factors (in Soil Science (America) and Pedology (Europe)).

During WWI, the U.S. Government built an $80 million complex in Nitro, West Virginia to manufacture explosives and chemicals for the War effort. The chemical manufacturing site was a 7.3 km^2 cow pasture on the Kanawha River floodplain. The chemical plant facilities were placed in public service to produce gunpowder for the War effort in November 1918, near the end of WWI.

Monsanto Chemical Company (Headquartered in St. Louis, Missouri) set up operations in the Kanawha River Valley to manufacture a wide range of chemicals including the commercially successful herbicide, 2,4,5-T. Starting in the 1940s, workers producing 2,4,5-T experienced skin lesions [24] [30]. Monsanto's solution was to have the workers shower and change their clothes after work. However, the problem persisted into the 1950s, 1960s, 1970s and 1980s. The cause of the skin lesions, (chloracne) was eventually established to be dioxin TCDD created during the 2,4,5-T manufacturing process and not just the chemical residues on skin and clothing during the 1949 explosion. Dioxin TCDD was the most toxic compound that Monsanto, Dow Chemical and other companies ever produced and is the reference used by US EPA to calculate toxic equivalents (TEQs) in assessments of human health risks associated with all dioxin-like compounds [1].

In 1949, Building 41 (2,4,5-T) at the Monsanto Chemical plant in Nitro, WV exploded on March 8th [4] [5]. The plant manager recalled a deafening shriek, the noise of high-pressure gases rushing through a vent. The whistle, intended to alert the workers that the factory was in trouble, was drowned out by the sound of chemical vapors spewing up into the air of the plant. Since no one was injured, the "accident", "explosion", or "incident" was relatively "unremarkable". Safety devices worked and the "explosion" was determined by Monsanto to not be newsworthy. Thus, Monsanto and their company doctors did not make the details of the 1949 explosion public for many years. With the passage of time, it became an "unremarkable" episode in environmental and occupational health [4] [5]. However, it was perhaps the most important single event in the United States related to the effects of "dioxin" on people.

Elmore [4] [5] in his 2021 book, *Seed Money*: *Monsanto's Past and Our Food Future* wrote "If the Nitro plant had been shut down and its problems exposed to the public in the late 1940s and early 1950s, the toxic hazard of 2,4,5-T might never have been exported to Vietnam for use in the Vietnam War. There, halfway around the world, hundreds of thousands of American soldiers and Republic of Vietnam soldiers and citizens would soon come to know about dioxin's

dangers."

Chemical manufacturing in Nitro, West Virginia has had environmental and worker health impacts and contentious histories. The Kanawha River water and groundwater in the alluvium have been adversely affected by industrial activities [31]. The Fike/Artel Chemical site was determined to be environmentally impaired and placed on the EPA National Priority List of Superfund sites (**Figure 9**). The site is a former WWI chemical munitions plant where subsequent chemical manufacturing, including Agent Orange, reclamation and waste disposal occurred.

Dioxin was recognized as a health risk nationally and internationally in 1949 [3] [4] [5]. However, it was not until 1953, the chemical manufacturers (BASF, Dow Chemical and Monsanto) and their company doctors knew that trichlorophenol was contaminated with dioxin. The defoliant Agent Orange formula was 50% 2,4,5-T (contaminated with unknown amounts of dioxin TCDD) and one of the chemicals later manufactured in the "Chemical Valley" for the Vietnam War effort (1960s).

In early 1980s trial of Nitro Chemical Plant workers vs. Monsanto (see section 2.6), the lead Attorney Stuart Calwell had to prove Monsanto knew it "had exposed its workers to a deadly chemical, even though the published studies funded by Monsanto downplayed the health effects of dioxin exposure." The company successfully refused to share company files including company worker health records.

On June 25, 1984, Attorney Stuart Calwell and his legal team went into the U.S. Courthouse in Charleston, West Virginia to represent the ill Nitro chemical workers vs. Monsanto. Monsanto claimed that the sick Nitro chemical plant

Figure 9. Nitro, WV. Dioxin waste disposal are area being monitored by Solutia Inc. Picture taken of posted no trespassing fence with the Kanawha River side slope in the background. Photo Credit: Pam Olson.

workers were ill because of their own "lifestyle" choices (many were smokers and drinkers*)*. The jury trial lasted for almost one year. The Calwell legal team, which was partially funded by the U.S. Steel Workers Union, had to prove that Monsanto "knowingly exposed its workers to chemical contamination" at its Nitro plant. Monsanto was less than forthcoming about health risks when working at the 2,4,5-T chemical plant in Nitro. Dr. R. Emmet Kelly did not inform 2,4,5-T chemical plant workers of potential "health risk" since the "risks were only suspect". A lot of money was on the table; a judgement against Monsanto would have meant billions of dollars, not millions, in liability and the company could not afford to lose such a high profile case.

After 5 days of deliberation, the jury, having a moral dilemma, emerged with a verdict and a "consensus statement of our feeling" to be read into the court record after the verdict was announced [5]. The jury admitted that a "preponderance of the evidence showed dioxin contributed to some of the health effects the plaintiffs now exhibited". However, the jury could not find in favor of the plaintiffs because "Monsanto did not show a willful, wanton, and reckless attitude towards its workers health and safety," a legal bar established by the Mandolidis precedent (greatly expanded a worker's right to sue an employer even if covered by workers' compensation program). The jury did chastise Monsanto for not trying to determine the full impact of dioxin on the health of its workers. However, the Monsanto workers must also exercise reasonable judgement in insuring their own good health and they should also have asked safety questions of Monsanto when the health problems became commonly recognized.

After the Monsanto legal team won, they made an astonishing legal move that was accepted by a Federal Judge. On May 17, 1985, Judge John Thomas Copenhaver, a President Ford appointee, approved Monsanto's request for recovery of court costs from the plaintiffs. Monsanto's legal team claimed that their incurred legal expenses, over the previous 4 years, were $500,000 (later reduced to $300,000). The plaintiffs, mostly sick Nitro chemical plant workers could not pay the court placed liens on all their homes. If the workers did not or could not pay these legal costs, the former Nitro chemical workers were going to lose their homes and have to find another place to live. One of the plaintiffs told his lawyer "they can have my house, and I just need 30 days to get out. Do you think Monsanto would give me that?" This story was picked up in the local media since Monsanto's legal team had apparently thought that bringing financial pressure to bear on these sick 2,4,5-T workers would break them, but it actually emboldened the litigants [5]. If workers cannot sue a big employer without losing their homes, then can there be any justice? Judge Copenhaver lifted the residential liens a few days later.

The jury immediately had 2nd thoughts and they did not feel right about their decision. They believed that the Judge Copenhaver's final instructions did not leave them much choice. The jury reasoned that Judge Copenhaver made it clear that it "had to be certain that Monsanto knew about the dioxin problem and engaged in 'willful, wanton, and reckless' behavior that perpetuated health studies

of Nitro workers came from company-financed labs." It was impossible for the jury make such a determination [5].

The jury members said later that not enough evidence was available to convince them that Monsanto had been reckless in handling of chemicals. However, the evidence did exist. In 1983, the EPA had produced a map of the area surrounding the Nitro chemical plant which showed numerous dioxin hotspots. Judge Copenhaver had stated, on the record, that the EPA map had no bearing on what Monsanto did in 1950s and 1960s and blocked the map as evidence. A few months later, the jury found out about the map. The jury foreman said the map would have changed his opinion and could have affected the jury verdict. By then, the Calwell legal team had filed an appeal to the U.S. Court of Appeals for the Fourth Circuit. To the surprise of many, the Federal Appeals Court upheld the lower court verdict. In the end, Monsanto paid no compensation for the 2,4,5-T and associated dioxin health problems of the Nitro chemical workers.

Attorney Stuart Calwell, of Charleston, West Virginia kept fighting for the 2,4,5-T workers who were exposed to dioxin TCDD in Nitro, West Virginia for the next 35 years. He led a class action lawsuit, Bibbs vs. Monsanto [5]. In 2018, Bayer of Leverkusen of Germany bought all of Monsanto's assets for $53 billion and assumed all of its liabilities. This suit included hundreds of litigants who claimed that Monsanto polluted the entire town of Nitro (**Figure 10**). These litigants demanded that Monsanto pay the cost of monitoring the health of approximately 5000 residents of Nitro, WV. The case never went to trial [5]. In 2012, Monsanto agreed to pay the $93 million settlement to fund the 30 years of medical monitoring and to pay for residential cleanup in Nitro. Further, if Nitro resident blood samples revealed elevated dioxin levels, the plaintiffs retained the right to file another suit against the chemical company.

Figure 10. Nitro, WV. The Solutia Inc monitoring facilities behind a controlled gate with guard dogs. A bridge on the Interstate is visible in the background. Photo Credit: Pam Olson.

3.2. Case 2. Dow Chemical Company in Midland, Michigan

The Dow Chemical 770 ha facility adjacent to the Tittabawassee River (Figure 11) in Midland, Michigan (Figure 1) began operating in 1897 (Figure 12). Past waste disposal practices at the Midland Chemical Plant have resulted in both on- and off-site contamination. Contamination has been exacerbated by flood events (Figure 13) when contaminated sediment settled on the floodplains and created natural levees along some riverbanks (Figure 14). Elevated dioxin levels downstream, in and along the river, have been primarily attributed to particles in liquid wastes that were historically discharged into the river from the Dow Chemical facility during the manufacturing of chlorine-based products in early 1900s [32]. Dioxin attaches to eroded soil particles [1] and sediment and was transported over 80 km downriver through the Tittabawassee and Saginaw Rivers and into Saginaw Bay and Lake Huron.

From the 1950s until the early 1970s, the Dow Chemical company produced Agent Orange at their Midland plant [33]. In 1978, Dow Chemical posted advisories warning that fish in the river had high levels of dioxin. In 1981, President Ronald Reagan appointed Valdus Adamkus to Regional 5 office of the USEPA with the task to study how dioxin pollution was leaking into the Great Lakes [32]. The Adamkus report found that the Midland "Dow Chemical plant was

Figure 11. Map of the rivers in the Lower Peninsula of Michigan. Photo Credit: J. Lopez.

Figure 12. Historic black and white photograph of Dow Chemical Plant in Midland, Michigan.

Figure 13. Flooding of Midland Michigan near the Dow Chemical Plant headquarters.

responsible for some dioxin pollution and a cancer risk". The media reported that Dow Chemical called the USEPA report "trash". In 1983, Congressional hearings were held and Adamkus revealed that Dow was allowed (by USEPA) to help rewrite the report on dioxin contamination in the waterways [34]. Adamkus testified that, "It was unusual, unethical, and unprofessional to get the internal document approved by an outside private company."

In 1985, Dow denied it was the source of high dioxin levels found in fish. However, shortly thereafter, Dow was forced to stop releasing dioxin into the Michigan waterways. In 1985, President Ronald Reagan presented Valdus

Figure 14. Tittabawassee river valley including the Dow Chemical settlement basins.

Adamkus the Distinguished Executive Presidential Rank Award for his integrity [32]. In 1996, USEPA started to turn over environmental enforcement to the Michigan Department of Environmental Quality and Michigan officials negotiated a cleanup plan in 2003 but little was actually done. It was not until later that the EPA, the State of Michigan and Dow negotiated the environmental cleanup of the extensive dioxin contamination in Midland along the Tittabawasseee and Saginaw Rivers and the Saginaw Bay area. Cleanup efforts are still on going and are focused on the removal of dioxin contaminated riverbed sediments and riverbank soils. At least 21 residential properties along the Tittabawassee River floodplain have more than 250 ppt of dioxin in their soils [35]. The contaminated soil at these residences will need to be removed and replaced with clean soil and new vegetation. Dow now faces extensive lawsuits, including a case already settled for $77 million for natural resources restoration of areas contaminated by the Dow Chemical Plant [35].

In 2007, under Mary Gade, the EPA found the dioxin levels downstream from the Dow complex were higher than previously found anywhere in the United States. The hotspot was 40 km downstream from the Midland Dow facility and Mary Gade used emergency powers to require Dow to cleanup sections of the Tittabawassee and Saginaw Rivers [32]. Cleanup started in 2007 but in 2008, Mary Gade was forced to resign to avoid being fired. A Dow spokesperson told the public that, "The Environmental Report" Michigan and the USEPA were using was "bad science" and that "dioxin is not as dangerous as the public thinks".

The American Chemistry Council asked EPA to withdraw the Dow dioxin report from interagency review, since the EPA did not consider the "economic impact of the report" and therefore the assessment was flawed. Starting in 2013, EPA had a plan for cleaning up soil and sediment contaminated by dioxin [31]. Dioxin has a long half-life (over 100 years) when attached to sediment and under water (anaerobic conditions) [1]. The cleanup plan called for the project to be

completed in the year 2021.

3.2.1. Cleanup of Tittabawassee River and Dow Facilities in Midland, Michigan

In 2009, Dow and the EPA reached an agreement about cleaning up dioxin [35]. Over the years, Dow selected specific dioxin hotspots to clean up. Besides fish, it was determined that people should not eat chickens they raised or eggs because the birds pecking in the contaminated soil could result in the consumption of dioxin and could be introduced into the human food chain. Hunters were warned not to eat any game killed along the Tittabawassee and Saginaw Rivers due to the potential for bioaccumulation of dioxin [1].

Dow is implementing site cleanup under EPA oversight. To effectively manage the cleanup effort, the Tittabawassee River was divided into 7 segments ranging in length from 5 to 6 km. Work was done in stages starting at the Dow facility and working downstream [35].

Segment 1 is a 5 km stretch of river next to the Midland Chemical Plant (**Figure 15**). The cleanup started in 2012 and was finished in 2013. A dense non-aqueous phase liquid (DNAPL) was removed and treated. A containment system was installed at sediment management areas (SMAs) to isolate contaminated sediment. Since 2013, Segment 1 has been monitored and containment systems were maintained [34].

Segment 2 is a 6 km stretch of the Tittabawassee River below the Midland Plant. Cleanup occurred in 2014 and 2015. The cleanup plan called for removing the dioxin-contaminated sediment in some areas and stabilizing contamination to stop it from moving. Nearly (17,585 m^3) of contaminated sediment was removed and about 1 ha of contaminated sediment was isolated and contained. Approximately 2 km of riverbank were stabilized to keep contaminated soil from eroding back into the river [35].

Segment 3 is a 6 km stretch of river, which starts 10 km below the confluence

Figure 15. The Dow Chemical plant in Midland, Michigan with train tracks for easy shipping of chemical products.

of the Tittabawassee and Chippewa Rivers. The cleanup of this segment occurred in 2016 and included stabilization of about 2 km of eroding Bank Management Areas (BMAs) [34]. Many different stabilization technologies were used on the BMAs. One of the most important was to place deep-rooted native plants along the riverbanks. Two Sediment Management Areas (SMAs) were cleaned by removing dry contaminated sediment and the covering up the contaminated sediments to keep them safely in place.

Segments 4 and 5 consist of 10 km stretch of the Tittabawassee River that starts 18 km downriver from the Dow Chemical Company facilities. The EPA selected cleanup plan included distinct SMAs and BMAs similar to the ones used in the upriver sediments. For the SMAs a combination of technologies was implemented. These included digging up and removing some contaminated sediment, safely covering other areas with dioxin-contaminated sediment and monitoring areas where contamination was already buried. Cleanup technologies were applied to the BMAs to stop the erosion of contaminated riverbank soil was well.

Segments 6 and 7 consist of an 11 km stretch of river starting 18 km downriver from the Dow Chemical facilities at Midland. A cleanup plan was implemented in 2019 for seven BMAs and four SMAs. Dow and EPA learned much while implementing Segments 1 to 5 plans and those lessons learned are now being used on Segments 6 and 7.

3.2.2. Tittabawassee River Floodplain

In 2015, the USEPA selected a cleanup plan for contaminated soil in frequently flooded areas along the Tittabawassee River. EPA and Dow suggested it would take at least 10 years to implement any final cleanup plan. The floodplain includes about 1820 ha and extends about 28 km downriver from the Midland Chemical Plant. EPA reached a deal with Dow to clean up about 1400 residential properties in the Midland area and on the Tittabawassee River. Not all areas in the floodplain will require soil replacement. The floodplain has a number of different land uses that will need different remedial approaches. In homeowner's yards, if tests show greater than 250 ppt (parts per trillion), the soil will be dug up and hauled away. Soil would then be replaced and grasses and plants restored. The replacement standard was much higher, 2000 ppt or eight times higher, for other land uses including farms, parks, commercial properties and natural areas [35]. If the soil in these land use categories exceeds the standard, then either it would be dug up and hauled away or covered with clean soils. EPA worked with each landowner to find an appropriate remedy. The pace of cleanup accelerated each year and would have been completed by 2021 if the historic Tittabawassee River flood of 2020 had not occurred.

In 2020, a flood on the Tittabawassee River resulted in two dam breaches and many areas in Midland County were flooded including the superfund Dow Chemical cleanup sites. This event undid some of the remediation that had previously been completed. Olson and Morton [1] suggested that dioxin, which is

not water-soluble, attaches to eroded soil particles and sediment and can be transported by river systems [32]. In the case of the Tittabawassee and Saginaw Rivers the flooding re-suspended the dioxin contaminated sediment in the river channel and transferred it to downriver floodplains during the past flooding events and into Saginaw Bay. Hazardous waste and other kinds pollutants were stored at Dow and Dow-Corning facilities along the river [32]. These facilities were "significant non-compliers" of the Resource Conservation and Recovery Act, which stated how hazardous and not-hazardous waste should be handled. On May 20, 2020, Dow confirmed there were floodwaters commingling with the on-site containment pond used for storm water and brine system/groundwater remediation. The contingency plan approved by the State of Michigan indicated the containment pond was to be protected against a 100-year flood, but the flooding impact still happened. For years, Dow dumped or incinerated wastes that contaminated the Tittabawassee River and Saginaw River and Saginaw Bay (Lake Huron) with dioxins and other toxic compounds, which resulted in an 80 km stretch of river and adjacent watershed being placed on the EPA's Superfund site list [32].

During the 2020 flood, there were no reported product releases but floodwaters entered an on-site brine pond used for groundwater remediation [32]. According to Dow Chemical the material from the brine pond did not create any risk to local residents or the environment. "However, all the clean-up work could have been impacted with these high flows, and the contamination that was there from the dioxins, could have been moved either further downstream or out on the floodplains", according to Allen Burton, professor of environment and sustainability and of earth and environmental sciences at University of Michigan [32]. Dr. Burton, also observed, "It's going to be challenging for Dow to go back in and essentially restart all clean-up activities and rebuild the riverbanks and find where the new dioxin hotspots are".

Construction occurred on Segments 6 and 7 in 2020 and 2021 despite the challenges of historic flooding and the COVID-19 pandemic. In areas where water levels were manageable, work was carried out and COVID-19 safety protocols were followed. Later in 2022, the work will resume on Segment 6 and 7 SMAs, BMAs, and floodplain properties. Over the course of the spring and summer of 2022, EPA plans to work with EGLE (Environment, Great Lakes, and Energy) and Dow to inspect and evaluate all previously constructed areas and determine which areas require additional maintenance [35].

3.2.3. Middleground Island on the Saginaw River

In early 2020, EPA proposed a cleanup plan for the residential properties on Middleground Island in the Saginaw River. Middleground Island is located 11 km upriver from Saginaw Bay. About 6 ha of the 71 ha island was anticipated to require cleanup, soil removal and replacement. Not every home will need a cleanup. At residential properties where soil tests show dioxin levels above 250 ppt the dioxin-contaminated soil will be removed, replaced with clean soil, and

the grasses and plants restored [35].

3.3. Case 3. Agent Orange Manufacturing at Elmira, Ontario, Canada and Use at Canadian Forces Base (CFB) Gagetown, New Brunswick, Canada

Naugatuck Chemical Company built a chemical manufacturing plant in 1941 (during WWII) in Elmira, Ontario, Canada (**Figure 1**) (**Figure 16**). The Elmira factory (**Figure 17**) got its start by helping to make explosives during the Second World War [36]. In 1945, it began producing herbicides and then later Agent Orange, the defoliant herbicide sprayed during the Vietnam War (1962 to 1971). Uniroyal Chemical had acquired these facilities and used them to manufacture Agent Orange in the 1950s and 1960s. The chemical plant was later purchased by Crompton Company, then sold to Chemtura, and is now owned by LANXESS, headquartered in Cologne, Germany which bought the factory in 2017.

This is the only known site, outside the United States, that formulated and manufactured Agent Orange [37] [38]. However, there were other sites, including

Figure 16. Downtown Elmira, Ontario, Canada. Photo Credit: Gary McWilliams.

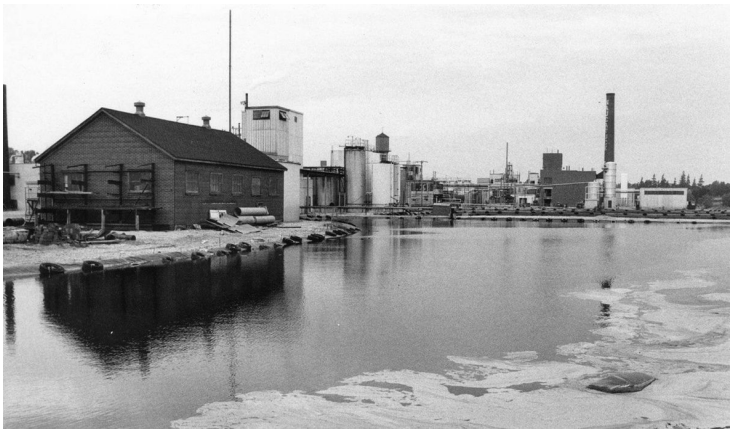

Figure 17. Black and white photograph of the former Uniroyal Chemical plant in Elmira, Ontario, Canada. Photo Credit: Maria Babbage. The Globe and Mail.

New Plymouth, New Zealand, that made components of Agent Orange, such as 2,4,5-T, after the U.S. military took all the commercially available 2,4,5-T, originally produced for agricultural production off the market. As a result, other countries provided the herbicides, 2,4-D or 2,4,5-T, for worldwide agricultural use.

The pollutant NDMA (nitrosodimethylamine), a known toxin, was found in Elmira's water supply in 1989. Decades of chemical production poisoned Elmira's groundwater and the town residents had to pipe in drinking water beginning in the early 1990s. Cleanup (**Figure 18**) typically involved containing pollution on the factory property while pumping and treating tainted groundwater on and off site [36]. Ontario Environmental Ministry said "Significant progress has been made in the remediation of the municipal aquifer, and environment monitoring is generally showing decreasing trends of contamination."

A new documentary, Toxic Time Bomb, by Ron Harpelle in 2020 explored the impact of the decision to bury a veritable cocktail of compounds at Elmira Chemical plant site during the 1940s to 1970s [39]. The film documents the story of local environmental activists who found three or four Agent Orange (dioxin TCDD hotspots) along Canagagigue Creek and have lobbied for years to get the contaminated sediment removed from the bottom of the creek and the streambanks [39].

The Naugatuck Chemical Company buried waste in pits from the 1940s to 1970s. In 2009, approximately 565 tons, of waste and fill, were excavated and removed from the Elmira chemical manufacturing plant site. This cleanup process may have put soil particles contaminated with dioxin into the air and blown off site as dust or picked up by surface runoff water as contaminated sediment.

In 2017, soil sampling revealed dioxin contamination of farmland owned by Ron Stroh adjacent to the chemical plant site. The dioxin contaminant had been

Figure 18. Environmental cleanup efforts included wetland treatment of runoff waters.

transported, either by wind or water action, from the adjacent chemical plant site to his property. In 2019 LANXESS launched a cleanup of the Stroh farm soil which exceeded the Ontario farmland dioxin standard. There is now a 10-year cleanup and farm mediation plan in place.

The human and environmental concerns related to the use of the herbicide, 2,4,5-T with unknown quantities of dioxin TCDD, was not well known by the Canadian Government nor accepted until 1985, the year the manufacture of 2,4,5-T was banned world-wide. This herbicide had been widely used in Canada for at least 10 years after the Canadian involvement in the Vietnam War ended in early 1973 and there were considerable Agent Orange and component residuals remaining in the supply chain. When the Canadian Government approved the use of an herbicide, everyone in Ontario could have used it, including private companies, municipal governments and provincial governments. Canadians believed that the 2,4,5-T product was safe to use until 1985 [37]. Dioxins (and furans) have been linked to skin disorders, liver problems and cancers. Human health impacts of dioxin depend on the level and duration of exposure.

Canada tested Agents Purple, Orange and White in cooperation with the U.S. military at CFB Gagetown (**Figure 19**) (**Figure 20**) in 1966 and 1967 [37]. Over 300,000 Canadian personnel passed through CFB Gagetown during this 28-year time period. However, this was not the only use of tactical herbicides between 1956 and 1984. The use of Agent Orange and other tactical herbicides in New Brunswick became public knowledge in the 1980s. This resulted in New Brunswick Power employees' creation of the Sprayers of Dioxin Association to advocate for compensation. The employees were eventually compensated.

In 2004, the widow of a retired general who had commanded the Black Watch regiment at Gagetown rekindled public interest in Agent Orange. She revealed that when her husband received a disability pension, the Canadian government had admitted to using Agent Orange and components at CFB Gagetown [40]

Figure 19. The Gagetown CFB headquarters sign. Photo Credit: Bobbi-Jean MacKinnon, CBC news.

Figure 20. The United States and Canadian militaries held joint training exercises at Gagetown CFB during the Vietnam War.

[41]. This acknowledgement kicked off renewed interest and investigations by various journalists. The flurry of attention then led the Canadian government to begin its own investigation. In 2006 and 2007 the government investigated the use of 2,4,5-T at CFB Gagetown in New Brunswick, where the U.S. military conduced Canada-approved spraying exercises. The issue then turned to compensation. Nearly 400 people filed exposure claims with the Canadian Work Safety and Insurance Board [41]. By late November 2005, 300 of the 800 troops of the Black Watch stationed at CFB believed to have been exposed to Agent Orange—had already died. By the fall of 2007, the Canadian Government allocated nearly $96 million to provide individual compensation up to $20,000. Over the next few years, the government expanded the scope of who could receive compensation. However, the amount was still criticized by the Canadians exposed to dioxin TCDD and their families as too little. The number of Canadian's compensated was between 4000 and 5000 vs. the potential 400,000 claimants [41].

Commercially available toxic herbicides similar to Agent Orange contaminated with dioxin TCDD were used in Northern Ontario in the 1950s-1970s. The chemical compounds in Agent Orange, 2,4-D and 2,4,5-T, with unknown amounts of dioxin TCDD, were utilized to clear vegetation along railways and power lines.

The Canadian Health Minister [37] could not answer the question of whether or not Agent Orange was used in Ontario. However, public media outlets observed that it was commonly known that anyone who wanted to control brush and weeds would likely have used this very effective herbicide. The Canadian government used a mixture of two commercially available herbicides 2,4-D and 2,4,5-T to clear vast tracts of Crown land and control growth along highways. Agent Orange formulation was a 50:50 mixture of these same two herbicides, 2,4,5-T and 2,4-D.

Dr. Len Ritter, a leading Canadian toxicologist, and committee chair told the public "The panel had no reason to believe that the herbicide mixture used in

Ontario was different, qualitatively, from the herbicide mixture used in Vietnam". The formulation of the commercial herbicide mixtures used in Canada were unknown; but if Agent Orange was used it would have been a 50:50 mixture with unknown levels of dioxin TCDD contamination.

Minister of Natural Resources, David Orazietti, apologized to Canadian workers who handled the 2,4,5-T herbicide with unknown amounts of dioxin TCDD [37]. Hydro path, forestry and road workers in Ontario were likely exposed to Agent Orange, the same weed-killing, disease-causing chemical used during the Vietnam War, and/or a similar commercial version. Jeanne Stellman commented regarding findings from a 219-page report commissioned by the province in 2011 and released in 2013, "These are conditions that just would not be tolerated today… And it is not surprising that some people are going to be sick" [41].

Stellman was a co-author of the long awaited, independent, report on the use and impact of the herbicide 2,4,5-T by the provincial agencies from 1947 to 1979. The committee report was delayed several times after receiving more records that expected. Approximately 4700 of the records were used in the national report, which was posted on the Ministry of Natural Resources website [41]. The Ministry of Natural Resources alone, treated more than 647 ha of woodlands with the herbicide, 2,4,5-T contaminated with unknown amounts of dioxin TCDD. In the 1950s, spray crews used as much as 64 liters per ha of Agent Orange on one plot in Cochrane, Ontario. Most plots used much lower concentrations [40]. The U.S. Department of Defense's (DOD's) Advanced Project Agency cited a concentration of 11 liters per hectare as the targeted use in the Vietnam War.

3.4. The Four Case Studies West of Mississippi River

Agent Orange herbicide production west of the Mississippi River found support in established farm chemical manufacturing facilities. Four sites discussed in this section are: 1) a small production plant in St. Louis that never had more than twelve full time employees located behind a city levee on the Mississippi River floodplain; 2) a Kansas City, Kansas plant located on a floodplain in a bend of the Kansas River; 3) a large rural Arkansas facility on a corner of the Mississippi Embayment; and 4) a briefly operated Agent Orange plant near Verona, a rural Ozark Southwest Missouri community where improper disposal of the dioxin contaminated herbicide spread contamination throughout the state and led to the evacuation of Times Beach. The health risks and outcomes from herbicide and chemical exposure on chemical plant workers, nearby civilian communities and the soil and water environment because of internal plant mismanagement, accidents and improper waste disposal varied greatly at each of these four chemical plants located west of the Mississippi River.

3.4.1. Case Study 4

The St Louis superfund site located just two kilometers south of the Gateway

Arch (Figure 1) (Figure 21) had 238 drums of waste removed in 2013. Currently the Superior Solvents and Chemicals Inc. manages a solvent transfer station on the site. Originally the waste was generated by Thompson Chemicals (TC) when the company manufactured sodium-2,4,5-trichlorophenate (NaTCP), 2,4,5-trichlorophenoxyacetic-acid (2,4,5-T), and esters and amines of 2,4,5-T from 1949 through 1970. The plant manufactured Agent Orange for the Air Force from 1967 until 1969 [42]. As a consequence of an accidental fire in the NaTCP production process nine workers developed chloracne. The CDC in 1991 determined all TC workers from 1949-1970 were eligible for inclusion on the Dioxin Registry [43]. The TC Company filed for bankruptcy in 1970.

Figure 21. Walk way under the Gateway Arch in St. Louis, Missouri. The Gateway Arch and Bush Stadium are less than 2 km north, and west respectively, of the Thompson Chemical Superfund site currently managed by Superior Solvents and Chemicals Inc. These attractions attract 2 million visitors a year. Photo Credit: D. Speidel. May 30, 2022.

3.4.2. Case Study 5

Upstream of the Missouri River near Kansas City, another Agent Orange manufacture site on the Kansas River (Figure 1) overseen by the current Harcros Chemicals Inc., was established in 1999 to monitor nine Solid Waste Management Units. The original plant, Thompson Hayward Chemical Company (THCC), was operational in 1960 to produce 2,4-dichlorophenoxyacetic acid (2,4-D). In 1963 another building was built to process 2,4,5-T and small amounts of the dioxin TCDD contaminant would likely have been created during the manufacture of the herbicide. In 1967, the U.S. Government directed THCC to produce Agent Orange II for 1 1/2 years. The plant, privately owned, has continued to operate under new management/names. Although the manufacture of phenoxy herbicides ceased in 1977, solvent recovery and surfactant production continued. Two lawsuits were filed against THCC related to their manufacturing operations. One

lawsuit was filed on behalf of a passer-by injury, the other lawsuit was for unauthorized storage of hazardous chemicals (Figure 22). Neither lawsuit involved dioxin TCDD. Currently groundwater is being monitored for volatile organic compounds in the lower Republican Watershed [44]. However, the release by the Kansas Department of Health and Environment (KDHE), of 1568 pages of archived records, describe many more details of the dioxin experience in Kansas.

Starting in 1971, after an inspection by KDHE, THCC, planning to install a liner for the process waste aeriation lagoon was started, environmental discrepancies are recorded. In January, 1975 the chemical company management requested an Independence, Missouri landfill service to contract to remove 11,356 liters per week of waste, described as hazardous brine and a statement that every precaution must be taken to prevent runoff into streams. The service, Rumble Services Company, after two months reached out to KDHE for approval to inject, 11,356 liters per week of THCC waste, into sealed, 457 meters deep, Kerr-McGee Company, Kansas wells. KDHE rejected the request in August, 1975. November, 1978 sludge from the lagoon, during maintenance, was stock piled on the riverside of the lagoon. In December, 1979, company was fined for unpermitted discharge. KDHE 1980-81 tests determined the sludge as hazardous waste. In 1981, without informing KDHE, THCC conducted a private dioxin survey of the plant. In 1983 KDHE, the lead agency, not EPA, planned a dioxin study of THCC and THCC shared its private dioxin survey with KDHE.

The 1983 plan objective was to neutralize the hazard of human contact with

Figure 22. Several decades old laboratory chemicals were found inside storage building cabinet, during a routine hazardous waste inspection of Harcros Chemical. The capped aeriation lagoon, the paved over dioxin soil causeways and the sealed processing building are inside Kansas River levees about 3 km from Interstate 635. Photo credit: KDHE picture was taken on December 17, 2006.

dioxin above set thresholds. Three main tasks were outlined: 1) seal the production building to include vacuuming the roof, 2) cap the lagoon which had been closed with current operations using the city water treatment plant since 1982, and 3) vacuum dust from all contaminated areas before sealing them with asphalt. An additional task included drafting covenants for filing on the property titles to restrict future use of the contaminated area. Also, during 1983 TCHH was fined $30,000 by KDHE for failing to have a landfill approved for hazardous waste dispose before actually shipping the waste. Eventually a Texas landfill was approved to receive hazardous waste. In the fall of 1984, 40 drums were found on the riverside of the levee and identified as hazardous waste and disposed of. The first draft of the covenants was made in 1984, with follow up comments by KDHE in 1986. No records that restrict land use have been found filed within Wyandotte County, KS [45] [46] [47].

3.4.3. Case Study 6

The US EPA managed and operated for 32 months a Superfund incinerator in Jacksonville, Arkansas. It started in 1992 but was stopped twice by injunctions and protests. The incineration, at $3500 per mt, destroyed 8800 mt of still bottoms waste, 900 mt contaminated soil, plus an additional cost of four million dollars to transport out of state for incineration 1080 mt of remaining 2,4,5-T after operations ceased due to the second injunction [48]. The waste was stored in 29,000 barrels and found during the 1978 US EPA National Dioxin Survey (**Figure 23**). In 1979, the Jacksonville plant (**Figure 1**) owned by Hercules Powder Corporation was ordered by US EPA to improve operations [49]. Herbicides were manufactured on the site from 1948 until operations ceased in 1987 [50]. The mismanagement of the waste storage was extensive with approximately, 15,000 of the 29,000 barrels left exposed. Furthermore, the Agent Orange manufacturer, Hercules Powder Corporation, after buying the plant from Reasor-Hill in 1961, started to bury the barrels left from production of 2,4-D (1955)

Figure 23. Hercules Powder Company stored over 10,000 drums outside. Now the Vertac Superfund site is managed by Terracon Consultants Inc. Photo Credit: Arkansas Encyclopedia Archive Photo.

and 2,4,5-T (1957). It is unclear from archival records if the incinerated landfill waste was from Hercules actions or other operations (**Figure 24**). In addition, 585 mt of contaminated sludges, liquids, and solids were found abandoned in approximately 100 of the 190 production tanks that had been used in the manufacturing process.

Hercules, one of the largest U.S. producers of Agent Orange for the DOD, manufactured more than 6.36 million kg of herbicide at this plant [51]. The public health impacts of Hercules Powder Corporation production processes were very high. After Arkansas health officials found, in June 1979 that 13 of 74 current employees had indicators of chloracne, the company requested assistance. A 25-member team of medical specialists began on July 25, 1979 to seek clues to this dioxin Vietnam War legacy starting with 150 past and current employees [52]. The investigation became part of "the nation's poster child for industrial negligence" and led to the 1980 passage of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as the Superfund law. Created to deal with abandoned sites of industrial pollution, CERCLA was authorized to tax and fine companies to recover clean-up costs [53]. Hercules sold the operation to Vertac in 1976, but the sale was protracted and not concluded until after 1999 [54].

Figure 24. Jacksonville, Arkansas municipal landfill road ditch water after a week of high temperatures. Photo Credit: D. Speidel, June 23, 2022.

3.4.4. Case Study 7

From 2011 to 2017, in the serene country landscape of the Springfield Plateau, known for its karst features and spring fed streams [55] the bitter history of dioxin contaminated herbicide manufacturing, mismanagement and waste disposal re-emerged (**Figure 1**). An Amish family made their living from farming the land near Verona, Missouri on the Springfield Plateau. Then in 2018 they disappeared, the year after their and their neighbor's children became sick from

drinking the well water. Their 24-ha farm was located downstream from an old Hoffman-Taff chemical plant [56].

The chemical plant is now owned by BCP Ingredients, a subsidiary of the Balchem Corporation, and part of Syntex the defendant in a 1985 environmental lawsuit with the U.S. Government (**Figure 25**). By 1989 their community of Verona, Missouri had thought its environmental trial was over when the USEPA's "Blue Goose" mobile incinerator (**Figure 26**) had destroyed over 4500 mt of solids and liquid dioxin and VOC waste [57] left from the 1949-1969 Hoffman-Taff

Figure 25. A 0.5 ha landfill hidden on steep, wooded, hillside, west of a low water crossing over the Spring River inside the fenced Balchem Plant in Verona, Missouri. Photo Credit: D. Speidel, June 20, 2022.

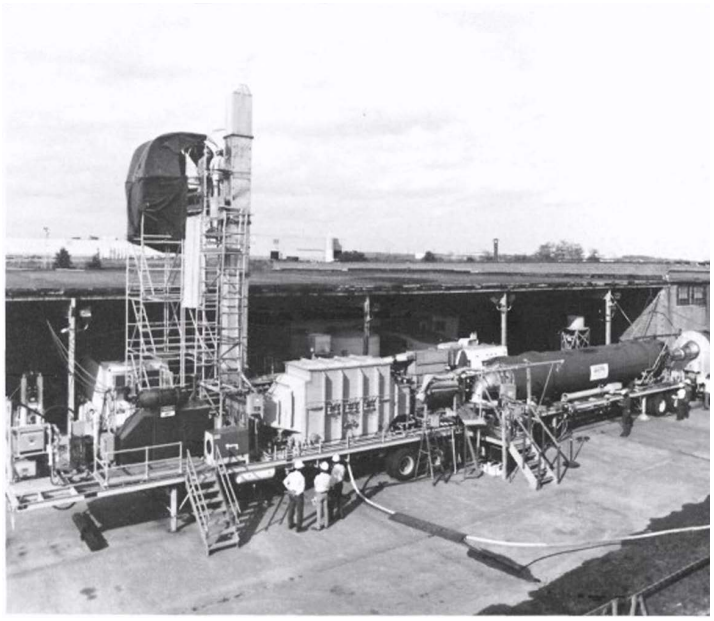

Figure 26. Photograph of the 1982 Blue goose incinerator test in New Jersey. Photo credit, EPA Journal October 1985.

Inc. herbicide plant in Verona, Missouri. Since 1970, soap, disinfectants and other pharmaceutical chemicals were manufactured at the plant by the new leaser NEPACCO. By-products of some chemical mixtures capable of creating dioxin were stored in the same 17,400-liter storage tank previously used by Hoffman-Taff. Thus, the legacy of Agent Orange contamination continued when the commercial grade dioxins and VOCs were mixed in this storage tank [55] [56].

Sediment was sampled for dioxin at over a dozen sites across the Spring River, which bisected the Hoffman-Taff Verona plant, after dioxin was found in fish tissue. EPA well monitoring was considered only a precaution since dioxin was thought to be immobile in groundwater. Monitoring found chlorobenzene, the same chemical family as toluene currently manufactured at the plant and also 1,4-dioxane, a colorless liquid substance which can easily leach from soil into groundwater [57] [58] [59].

Although the of quantity was small and the time period short that contaminated Agent Orange herbicide was manufactured at this plant compared to other sites, there is much to be learned from the consequences of human fallibility and mismanagement of waste storage. Four plant employees were responsible for waste disposal. Two senior plant officers, a foreman and an employee allowed at least 85 barrels of waste to be dumped on the employee's Barry County farm in July 1971. Earlier that year a St Louis based firm, Independent Petrochemical Corp, brokered a deal with the NEPACCO company president to have a private waste oil hauler between February and October 1971 haul at least 66,240 liters of still bottoms using a 13,250-liter tanker truck. Still bottoms are the thick sticky layers of solids that accumulate at the bottom of the chemical reaction tank during manufacturing at high temperatures. Not all of the waste products were mixed with used crankcase oil from 1000 to 2000 service stations and delivered to refineries for disposal. Instead, the hauler used the mixed oil waste and applied it at thirty different locations to control dust in horse arenas and on dirt roads in the town of Times Beach, Missouri. Nearly 100 horses, hundreds of birds and wildlife died. Children, adults, arena owners and others were sickened. Homeowners in Times Beach reported illnesses which Missouri Health, Centers for Disease Control (CDC), and US EPA determined to be dioxin based.

This determination was made one month before the Merrimac River flooded the entire community with 3 m of water. This caused closure of the town with a 2500 population in December of 1982 due to dioxin contamination. Earlier in October 1979, an anonymous tip was made to the USEPA regarding hazardous wastes that had been dumped on a Verona farm. Much earlier, in 1973, before either of these discoveries, one horse arena owner working with a 23-year-old state health department veterinarian provided documentation of dioxin contaminated waste oil spraying linked to the animal's sickness [59]. However, Missouri state agency leadership did not act on this report [60] [61].

US EPA defines a "superfund" as a contaminated site where hazardous waste has been dumped, left out in the open or otherwise improperly managed and presents risks to human health and the environment. Another superfund, dis-

covered in a 1984 public health advisory memo filed with KDHE records was connected to the Verona plant. During NEPACCO operations, 4165 liters of waste in 1970 was dumped in a remote pasture, located in the Lawrence County, Missouri Turnback Creek Watershed. EPA tested the soil and found 6.2 ppb dioxin in 1983. Although this site has not been listed on the National Priority List due to its remoteness, the EPA advises not to allow cattle to graze the grass due to the potential of ingesting the dioxin-laced soil [62].

3.4.5. Review of Case Studies 4 to 7

Is there any connection between the four west of the Mississippi River chemical manufacturing sites and environmental and human health events? The first common link is dioxin TCDD contaminated herbicides. The two rural sites sustained, by far, the greatest public and environmental harm [63] [64]. At the largest site, in Jacksonville, Arkansas, the dioxin contamination extended only two kilometers beyond Pulaski County. Nor were there ever any anonymous complaints in Jacksonville. Why? One explanation might be the 39 ha plant's legacy link to WWII which was fought in national defense. The Arkansas Ordinance Plant (AOP) preceded the herbicide plant. Thousands worked at the facility from 1941-45, so there may have been an inherited loyalty to support the government based on a unified war effort. Furthermore, the AOP may have already been considered damaged beyond repair, since much of the 160,000 ha was declared unusable due to the military ranges and unexploded ordinance in the Bayou Metro Watershed [49] [50] [51] [52].

Verona, Missouri was much different. The surrounding community and countryside of the 30 ha chemical plant was perceived by the community as pristine. The original chemical plant owner was local but the new owner was a corporation. After the DOD decided to stop all herbicide spraying in southern Vietnam in 1970-1971, the military and manufacturing companies were required to get rid of bulk residual herbicides and waste but not required to obtain individual state disposal permits [65]. In later years, the US EPA inspectors for Verona found Agent Orange barrels 12 km south of the plant on an employee's farm, buried by Syntex [65]. To the east 10 km, TCDD soil contamination was found in an Aurora Park and a 1970 dump site on the Talley Farm 19 km away [62] [66]. The most recent Missouri Natural Resources—USDA Natural Resources Conservation Service publication on the Spring River Watershed lists 30 landfills of concern, but the report does not list the superfund site at Verona even though the Spring River divides the superfund site [55]. The decision to use company employees to dump barrels was likely a cost saving decision since the DOD was no longer paying for the tactical herbicide products and/or for their proper disposal [67] [68]. Why did it take so long for workers, waste disposal contractors and health departments to recognize and act on reports of animal and human health problems and the connections to the disposal of dioxin contaminated waste materials? Verona now has an action committee which has obtained a grant to conduct a community cancer related health study [69].

The Thompson-Hayward Chemical Company had two unique differences compared to the other sites. First it is a privately held company with a VP engineer with twenty years of continuity, and accompanied inspections, plus employed an environmental consultant starting in 1981. Second, the environmental lead was the State of Kansas, not the US EPA. The basis for anonymous complaints, mostly from former employees, was often already addressed by the company before the complaint reached the authorities. For example, one such complaint resulted in the search for buried metal production kettles that summer, but the State received the complaint in September. This almost a hand-glove relationship between the company and the state is found in the voluminous records created. One good illustration is a unique map the consultants proposed in January 1984 of restricted and unrestricted zones for worker safety. This and other consultant products were used in the KDHE Dioxin TCDD containment plan that summer [47]. The 1984 draft covenant for Thompson-Hayward had a restriction clause not to disturb the soil by digging. This clause was set to expire in 1990 [45]. Whether this clause was ever or will be filed with the Wyandotte Kansas County is not known, but it does show the advantages of establishing a close working relationship.

3.4.6. Disposal of the Still Bottom Byproduct, the Hazardous Waste Tetrachloro-Dibenzo-Para-Dioxin, or TCDD by Two Decades of Dumping, New Incineration Technology, Landfills, and Environmental Covenants

One way to understand how this contamination happened in the U.S. is to look back at this time in history and how people perceived the environment and viewed their actions. Recent interviews with seven concerned citizens in Verona offer insights into rural community perceptions: "We had brothers and cousins in Vietnam, the work our fathers and uncles did at the plant was our way to contribute." "They worked at what we called 'The Government Project'". "We lived on dirt roads then." "It was common, including main street and the farm road leading into Barry County, MO, to spray the roads with waste oil to keep the dust down." "As a teenager, around 68 - 71, while metal scrapping with my father in a local dump, I observed barrels being dumped" [69].

The municipal dumps became part of dioxin TCDD's spread in the environment when chemical plant ownership changed. Plant cleanup and modernization of equipment required making room by disposal of on-site stored waste. Thus, in Jacksonville, Vertac used the Jacksonville Municipal Landfill (**Figure 27**) and also the private Rogers Road Landfill to dispose of a small amount of the stored 208-litter drums of still bottom byproduct. How much would have been disposed of is unknown, since the State of Arkansas did not renew the landfill permit in 1974 due to high water table caused by the nearby Metro Bayou [70].

In the early 90's over 152 cubic meters of dioxin contaminated soil was removed from Rogers Road Landfill and transported 10 km across Jonesville, AR to the incinerator at the Vertac plant [71]. In Missouri, transport of dioxin waste and contaminated soil to and from dumps was more extensive.

Figure 27. View of north side of Sedimentation Vault and portion of North Landfill (Hercules-Transvaal Landfill). Vetac Inc superfund site. Photograph No. 6a. dated September 26, 2018. Well maintained.

The Aurora, MO Baldwin Park, a dump for municipal trash was also used by Hoffman-Taff Corporation to dispose of TCDD contaminated wastes. The dump was closed in the 1970s. By 1987 190 cubic meters of contaminated soil, exceeding 20 ppb TCDD was excavated at the old dump and transported to the incinerator in Verona, Missouri. Then in 1988 Syntex Springfield transported TCDD and other wastes to the Denney Farm for incineration. In 1983, these wastes had been removed from a leaking storage tank and the surrounding sludge to prevent more contamination of Jordan Creek, a stream in Springfield, Missouri. [64] [66]. The EPA incinerator was a key part of the environmental solution.

The first EPA mobile incinerator system (MIS) was tested at the Denney Farm Site February to April 1985 [67] [72]. The "Blue Goose", name for the MIS was EPA new technological tool (**Figure 26**), carried on three trailers was designed to destroy hazardous waste on site and protect the public from the danger of transporting hazards through public areas. The experimental trial on the Denney Farm was a success when all of the 88 drums of dioxin waste the Syntex Verona Plant managers paid an employee to bury on his farm were destroyed.

On-site support for the MIS was a small assemblage of storage tanks and buildings. The 0.8 ha site at the end of a newly graveled half mile road included a well installed to support the 56,780 liters waste water needed for cleaning. In addition, a reinforced concrete pad was installed for the incinerator's three trailers, worker decontamination building, a fuel tank, equipment and supply storage building and the supervisor's office and employee parking. EPA arranged with the Missouri Department of Conservation to dispose of the charcoal filtered waste water used to clean the remaining dioxin to safely discharge the remaining

waste water. Originally the site was scheduled to close at the end of 1985. However, the closure was postponed until after 1987 and then 1988 as more dioxin waste was transported to the site for incineration. The wide spread contamination by the Syntex Plant in Verona is notable. Hazardous waste was moved much further than 11 km to the Denney Farm from the Verona plant. Balwin Park in Aurora was 22 km distance and the Syntex Plant in Springfield, Mo was 88 km. The dioxin contaminated waste was transported 400 km from Verona to the Bliss Tank Farm and later incinerated at Times Beach along with the 27 contaminated horse arena scrapings. Hazardous waste disposed of on the Talley Royal Farm 19 km from the plant was not recovered; and fish with detectable dioxin were found 96 km downstream [62] [66] [67] [68].

The Blue Goose had proven its capacity to destroy hazardous wastes (**Figure 26**). However, it was limited to smaller sites and did not lead to the exceptional environmental damage that Times Beach, Missouri experienced [70]. The MIS was not completely mobile as the one hectare support infrastructure demonstrated. Thus the Blue Goose did not always protect the public from hazards of transporting waste through populated areas. US EPA MIS were installed on existing infrastructure. For example, the Vertac Plant in Jacksonville, Arkansas mobile incinerator treated 9000 mt of still bottom waste, soil, and debris in 1992-94. After public outcry due to worry of ash drift exposure, the remaining Vertac Superfund waste was moved to Coffeyville, Kansas for incineration [72].

The last recorded use of the "mobile" EPA incinerator was the 1996-1997 disposal of 400 mt of soil and material from the Bliss Tank Farm, Frontenac, Missouri, a St. Louis suburb located along Deer Run creek. Soil was excavated four feet below the six waste oil storage tanks Russel Bliss used to store recycled oil and mixed in 1971 with dioxin TCDD contaminated sludge from the Hoffman-Taff Corporation. The tarp covered dump trucks drove down Lindbergh Blvd to the incinerator to dispose of the soil. The incinerator for Times Beach cleanup, was set up in mid-1990s for visitors to view at the Route 66 State Park [73].

Maintenance of the superfund landfills was planned as part of each hazardous waste cleanup. Maintenance of superfund sites has been dependable when large corporate owned chemical plant or municipal ownership ensures a source of funds, labor and equipment. However, where there is private ownership, reliable quality maintenance is problematic. A tale of two consent maintenance agreements illustrates this. One is funded and staffed; the other orphaned.

The Vertac Superfund site in Jacksonville, Arkansas is maintained and staffed by the Terracon Consultants, Inc. The Jacksonville Municipal Landfill Superfund site is maintained by the city which is directed to maintain the privately owned Rogers Road Landfill Superfund site [71] [72] [74] [75]. The Denny Farm had a consent agreement with Syntex drawn in 1980. Today with dioxin waste still detectable in the trench used to dump drums of waste the site is neglected (**Figure 25**). In spite of a letter from Missouri to Syntex in 2020, the invasion of trees and animal damage to critical sections has not been corrected [66] [76]. During the inspection in 2022 the Missouri DNR staff stated the owners of the private land

could not be found [77]. Apparently, the chemical company Syntex, because they never owned the land, did not accept the responsibility of maintaining the superfund landfill; first a private dump and then used by EPA as the incinerator site. Other dumps which are also private appear similarly neglected which indicates a systemic problem [70] [76].

Both superfund site inspections found animal damage with different outcomes. Inspectors were accompanied by a company maintenance supervisor and the damage was repaired the same day (**Figure 27**). Material, gravel base rock, tools and labor were funded and available. The damage observed in 2018 and letters sent to the private company in 2020 had no affect (**Figure 28** and **Figure 29**). Concern for the integrity of the plastic liner, only 50 to 75 cm below grade, from animal damage and also tree root penetration has not been addressed [74] [75] [76] [77].

Recognizing that remediation to remove public health hazards from waste disposal sites could be a perpetual problem the EPA wrote initial agreements as the basis for eventual land use restrictions or environment covenants to be recorded on the affected property's title. Several of the superfund sites are just now having these title land use restrictions filed. The earliest environmental covenant restricting a property's use is the 1999 Lonoke County, Arkansas, Jacksonville Landfill Superfund site. Only ground water use is restricted. Initially the nearby Rogers Road Landfill Superfund site initially had the same restriction; however, the Rogers Road Landfill's title was amended in 2008 with an environmental covenant which further restricted any agricultural use, residential use, restricted general access (hunting) (**Figure 30**) and food preparation. This superfund site,

Figure 28. Missouri Department of Natural Resources staff looking for Trench Monuments on Denney Farm site. Site was over grown with invasive thorn trees and weed grasses with potential to damage neighbor pasture. Photo credit. D. Speidel, June 28, 2022.

Figure 29. Denney Farm trench with monument marker with animal Damage. Photo credit. D. Speidel, June 28, 2022.

Figure 30. Deer blind on property adjacent to Rogers Road Super fund site. Near Jacksonville Landfill Superfund site. Photo Credit: EPA inspection team. Feb. 2020 taken during the 5th 5year review of the Rodgers Road Super fund site.

while maintained by the city, was determined to have a private owner, who signed the new covenant. This may be the reason for the amendment. Also, pressure from outside users requesting to hunt in the Metro Bayou woodlands may have contributed to the amendment. An interview with one neighboring landowner on June 23, 2022 provides insight into the situation. The landowner stated he had purchased 17 ha of these woods and had been encouraging deer hunting. He further stated did not know anything about a previous landfill in the area. One of requirements of the last five year review was for the City of Jacksonville to place "No Hunting or Trespassing" signs on the 4 ha superfund peri-

meter [72].

The Denney Farm Superfund Site use of an environmental covenant similarly limits uses by private ownership and specifies funding of ongoing maintenance. Syntex has developed three covenants. In 2018 a covenant of Syntex Superfund East, the BCP Inc. plant in Verona, Missouri restricts only soil disturbance and ground water use. In 2022 two covenants for Syntex North, restrict groundwater use, and Syntex West restricts not only groundwater but also residential development, agricultural, forestry, recreation, and general access. The groundwater concern is due to a new contaminate, 1,4-dioxane found in 2016 [78].

These restrictions are designed to keep people from coming into contact with hazardous substances. The lack of covenants at Vertac, Jacksonville Superfund Site and the continued monitoring at Rocky Branch and a lake feeding the Meto Bayou for dioxin in fish tissue are important measures [75]. While fish dioxin levels are currently below FDA health advisory limits, one might ask whether hunting of wildlife that dig and burrow in the soil of the Superfund site should be monitored and limited? Research suggests if the grassy areas on these private Superfund site properties are maintained some wildlife use, with precautions, may be an appropriate use of the site [79] [80].

3.5. Agent Orange Transportations from United States and Canada to the South China Sea via Railroads to the Gulf of Mexico and Ocean-Going Ships Which Traveled through the Panama Canal

It appears that Agent Orange was stored in 208-liter barrels at the manufacturing sites and then put in crates of four barrels. Each crate weighed 2 mt and was lifted using a crane. The Agent Orange crates were loaded on ocean-going ships on the Passaic River in Newark, New Jersey. The ships then traveled via the Atlantic Ocean, Panama Canal (**Figure 6**) and Pacific Ocean to South China Sea for use in the Vietnam War effort. The Agent Orange produced at the Uniroyal Chemical plant in Elmira, Ontario, Canada was primarily for domestic use, for Canadian and U. S. military use at CFP Gagetown or shipped to the South China Sea via the St. Lawrence Seaway. The fate of all the Agent Orange and components and similar commercial herbicides produced in Canada is still not clear. It appears that most of the Agent Orange and components, such as 2,4,5-T, were used by the military in Canada or by the government and the private sector for brush control along power lines and road-right-a-ways.

Agent Orange produced at chemical manufacturing sites in the Midwest (Michigan, Missouri, West Virginia, Kansas, and Arkansas) would have been loaded as crates of Agent Orange on railroad cars and moved via railroads to Gulfport, Mississippi or Mobile, Alabama. The Agent Orange barrels and crates were then loaded on ocean-going vessels, which then passed through the Gulf of Mexico and the Panama Canal on the way to South China Sea. The major Agent Orange manufacturing sites which loaded Agent Orange on railroad cars included Nitro, West Virginia; Midland, Michigan (could have used St. Lawrence

Seaway as an alternate route); Jacksonville, Arkansas; St. Louis, Missouri; Verona, Missouri and Kansas City, Kansas.

All these sites had good rail service to Gulfport, Mississippi or Mobile, Alabama. There is good documentation, that these Agent Orange barrels and crates were off loaded from railroad cars using cranes and stored on the Gulfport Navy base (**Figure 31**) or Mobile and Gulfport docks for loading onto ocean-going ships (**Figure 32**). However, the Gulfport base commander claims that the records about Agent Orange storage on the base before 1982 (including the Vietnam War years from 1962 to 1971 when tactical herbicides were sprayed) were virtually non-existent [81].

Former dock workers who unloaded railroad cars full of Agent Orange weekly at the Port of Gulfport for eventual shipment via the Panama Canal to Vietnam from 1967 to 1969, have their own stories to tell. Frank Ladner, a former dockworker who retired from the port in 1985 [81] stated that dockworkers accidently spilled a lot of the herbicides and chemicals onto the docks and into the

Figure 31. Naval Construction Battalion sign at Gulfport, Mississippi. Photo Credit: MilBases.com.

Figure 32. An ocean going ship being loaded with chemicals, similar to the ones used to transport tactical herbicides to South China sea via the Panama Canal. Photo Credit: MilBases.com.

harbor. Ladner claimed this happened when former dockworkers workers were unloading the railroad cars full of Agent Orange using forklifts. Occasionally the forklifts would punch holes in the 208-liter steel barrels and a black fluid sprayed-out. In addition, when the four-barrel crates were lifted onto a ship and one or more of the barrels would drop off the pallets (or out of the four-barrel crates) while in the air and rupture on impact, Agent Orange with unknown amounts of dioxin TCDD would spill onto the dock, into the ship and harbor.

3.6. Temporary Storage of Agent Orange at the Gulfport Navy Base, Port Gulfport, Mississippi and Port Mobile, Alabama

The temporary storage area soil at the Naval Construction Battalion Center (NCBC) (**Figure 33**) in Gulfport, Mississippi (**Figure 34**) was treated with cement and compacted during the 1940s. The treatment created a 30 to 45 cm layer of cement/soil that was relatively impervious to water and herbicides. The layer was located 8 cm below the soil surface and covered with top soil [82]. The site was then covered with oyster shells or a similar material after completion of de-drumming, storage and transfer operations.

Beginning in 1967 and through 1968, more tactical herbicides were delivered to Port of Mobile (Alabama) than were shipped to Southern Vietnam. The Port of Mobile inventory become so large that additional temporary storage was required [82] [83] [84]. The Naval Construction Battalion Center (NCBC) in Gulfport, Mississippi was selected to receive the surplus drums of the tactical herbicides [84]. By December of 1968, 66,700 drums had been moved from Mobile, Alabama to NCBC in Gulfport, Mississippi. For the next eight months (during 1969), the drums were stored and then shipped to Southern Vietnam from both the Gulfport and Mobile ports.

The enormous amount of Agent Orange sent to Mobile, Alabama and Gulfport,

Figure 33. Soil sampling and transport by the Navy Construction Battalion. Photo Credit: MilBases.com.

Figure 34. Operation PACER HO. The ship with an incinerator which was used to destroy the remaining stockpiles of Agent Orange stored at Port of Gulfport and Johnston Island from 1972 to 1977. Photo Credit: ResearchGate.

Mississippi required the temporary storage of Agent Orange barrels and crates on the port and harbor docks, which were insufficient to meet military needs. While in temporary storage some of the barrels leaked. As environmental concerns increased over time, federal agencies tracked the pollution in the soil and water including the groundwater. However, the residents of the nearby neighborhood suggested in a U.S. Navy sponsored survey that human health issues did not receive sufficient attention. Surveyors and civilians hired by the Navy walked the streets around the base to talk with the residents [81]. What they discovered left some of the surveyors with "significant emotional stress".

Suzanne Collum, who grew up a block north of the Gulfport Navy base lost her father to cancer and had an infant daughter diagnosed with leukemia. Her neighbor had two learning disability children. Her own children suffered re-occurring reproductive problems. Collum said the neighborhood had a lot of heart problems, liver problems, and especially kidney problems. The neighborhood, a few blocks from the Gulfport Navy base had 13 disabled children in a five-block area.

3.7. Long-Term Storage at Gulfport Construction Battalion Navy Base in Gulfport, Mississippi

NCBC located in Gulfport, Mississippi (**Figure 31**) was 3 km from the docks with convenient access to the railroads. The storage site was fenced and isolated from public traffic while security personnel monitored the site. Long-term storage area at NCBC was constructed (**Figure 32**) in early 1969 but was not available for use until late 1969 [85]. The inventory included 13,855 drums of Agent Orange and 1545 drums of Orange II. The long-term inventory at NCBC was removed from the longer storage site between 24 May 1977 and 10 June 1977 as part of Operation PACER HO (**Figure 34**) and destroyed by sea incineration

[84] [86].

3.8. Transport and Fate of Agent Orange and Commercial Herbicides 2,4-D and 2,4,5-T

A recently released report of the United States Government Accountability Office (GAO) focused on the actions needed to improve the accuracy and communication of information regarding storage and field-testing locations of Agent Orange outside of Vietnam [87] including Kelly Air Force Base in Texas [88]. This GAO report confirmed that the Military Sea Transportation Service directly chartered merchant vessels to carry tactical herbicides [89] through the Panama Canal during the Vietnam War (**Figure 6**). These tactical herbicides, including Agents White, Purple, Blue and Orange were stored vertically on pallets in internal storage compartments on the vessels.

The GAO found incomplete and inaccurate information on the DOD's list of tactical herbicide test and storage sites such as Kelly Air Force Base in Texas (**Figure 35**). GAO obtained command histories and original DOD reports which provided operational details about the procurement, distribution, use, and disposition of Agent Orange [87] [90] and its components, 2,4-D and 2,4,5-T containing unknown amount of dioxin TCDD. GAO concluded that there was extensive documentation on the herbicide management program at Kelly Air Force Base (**Figure 35**) for the American Vietnam War and more specifically years 1966-1973. According to an Air Force Logistics Command's Office of History monograph [87], the command directly responsible for managing Agent Orange was the Directorate of Aerospace Fuels at the San Antonio Air Material Area located at Kelly Air Force base [87]. During the Vietnam War, Kelly Air Force Base was also a subcomponent of the U.S. Air Force Logistics Command. GAO documentation shows that quantities of the two components of the tactical herbicide, Agent Orange with the contaminate dioxin TCDD, were stored at Kelly

Figure 35. Kelly Air Force Base in Texas. This was the command headquarters for shipping tactical herbicides through the Panama Canal Zone. Agent Orange and Agent Blue were stored at the Base. Credit Line: Photograph courtesy of Kelly Heritage and the Houston Chronicle. Published with the copyright permission from Editor of the Open Journal of Soil Science.

Air Force Base in Texas in 1972. There were 147,400 liters of 2,4,5-T containing unknown amounts of dioxin TCDD and 402,238 liters of 2,4-D stored on the base [87].

The uneven quantities of these two herbicides suggest that not all the tactical herbicides in storage were in the pre-mixed to form of Agent Orange, Herbicide Orange or Butyl Ester. Perhaps Agent White, a tactical herbicide used when Agent Orange was in short supply, which contains only 2,4-D but not 2,4,5-T with the dioxin TCDD contaminant, was also in Kelly Air Force base storage but the presence of Agent White at Kelly Air Force base could not be confirmed [87]. After the American Vietnam War ended in 1973 the tactical herbicide Agent Orange with 2,4-D and 2,4,5-T containing an unknown amount of dioxin TCDD herbicide and Agent Orange components in the stock pile were apparently transferred to the United States Department of Agriculture (USDA) [87].

The USDA, Forest Service and other federal agencies used these herbicides for brush control. This could have been one of the sources of the herbicides used by the Forest Service and their partners in the Western United States in the 1970s to control the brush and broadleaf weeds after clear-cutting and planting seedlings (**Figure 36**). This was the subject of a 2021 PBS documentary by Independent Lens on "People vs. Agent Orange" [91] and a Vietnam Veteran News podcast 2086 by Mack Payne [13].

In order for the tactical herbicides stored at Kelly Air Force base to be transferred to the USDA for agency use in the Western United States, it appears that the tactical herbicides would have had to be reclassified from formulated "Military Specifications" [2] to formulated "Federal Specifications". Before being approved for use and applied by the Forest Service, timber companies and chemical company partners in the Western United States to prevent shrub and

Figure 36. Spraying of the clearcut forest in Western U.S. The U.S. military transferred tactical herbicides to the USDA, Forest Service and other federal agencies to spray on the western U.S. forest. Photo Credit: Judith Lewis Mernit. High Country News.

broadleaf weed regrowth competition with trees on clear cut public forest lands, the Forest Service would have had to have been approved by USDA. The USEPA, established in 1970 had not started to monitor tactical herbicide transfers and use within federal agencies). USDA would have had to approve the use of these herbicides, by their own agencies and other federal agencies, on the western U.S. Forest.

3.9. Fate of Tactical Herbicides Stored at Kelly Air Force Base at the End of the American Vietnam War

GAO records also show that approximately 658,321 liters of the tactical herbicide Agent Blue [87] containing cacodylic acid (As) was also stored at Kelly Air Force base. It is not clear how this massive amount of arsenic-rich Agent Blue was disposed of after the American Vietnam War officially ended in January of 1973. It could have been transferred to USDA, including the Forest Service, for brush control along with the Herbicide Orange (Agent Orange) components 2,4-D and 2,4,5-T containing TCDD. If DOD transferred the tactical herbicide Agent Blue to USDA, the transfer of a herbicide, originally formulated to "Military Specifications" [2] to a federal agency with only the ability to use herbicides formulated to "Federal Specifications", for another federal agency use to control brush would have required Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) approval. If the USDA, Forest Service in the 1970s, applied Agent Blue arsenic, which does not have a half-life, it would have remained in the Western United States soils. However, it is not clear if Agent Blue was ever transferred by the DOD with proper FIFRA approval from Kelly Air Force base chemical stockpile to USDA along with other tactical herbicides, including Agent Orange with 2,4-D and 2.4.5-T containing an unknown amount of TCDD for brush control. This could have been one of the sources of the herbicides used by USDA, Forest Service (**Figure 36**) in the Western United States [91] in the 1970s. If Agent Blue was not used on Federal lands in Western United States, then what happened to the 658,250 liters of Agent Blue that were stored at Kelly Air Force base after the tactical herbicide was no longer needed in South Vietnam? Was Agent Blue destroyed in Kelly Air Force base burn pits? If so, the smoke coming from the burn pits would've become an environmental problem since the particulate and ash would have contained toxic As contaminants and aerosols. The military base personnel could have been exposed to inhaled arsenic laden smoke. Was it buried in the soil at Kelly Air Force base? If so, the water soluble As would likely eventually leak from the barrels in the last 50 years and into the groundwater. If so, the military base personnel could have been exposed to arsenic; some Kelly Air Force Base Vietnam Era Veterans [92] have already filed VA claims for benefits as a result of exposure to either TCDD or arsenic. The fourth option would have been to transport the Agent Blue to Davis-Monthan Air Force Base in Tucson, Arizona for weed control around the aircraft and perimeter fence (**Figure 37**). This would have been in addition to the Agent Blue barrels shipped from South Vietnam directly and from Johnston

Figure 37. Perimeter fence at Davis-Monthan Air Force base in Arizona where the U.S. military planes go to die. Published with the copyright permission from Editor of the Open Journal of Soil Science.

Island indirectly [93] between 1972 and 1977. So how did the DOD use up or destroy all of the arsenic-based Agent Blue left over from the American Vietnam War, including the storage stockpile at Kelly Air Force base in Texas, after President Nixon stopped the spraying of all tactical herbicides in 1971?

4. Summary

The human health impacts on the chemical plant workers who manufactured Agent Orange at seven locations in the United States and one site in Canada have been documented. More than 1600 civilian workers who were exposed to dioxin TCDD have become ill and many died prematurely. The pollution at these chemical plant sites adjacent rivers and in groundwater is well known within each affected state and location. In this paper we assessed the long-term effects on land, groundwater, and river resources at the sites where Agent Orange and commercial agricultural herbicides formulated with 2,4,5-T and contaminated with unknown amounts of dioxin TCDD were manufactured, transported, and temporarily stored. We have also identified the sites where the final destruction occurred or where residual supply chain tactical herbicide remnants and by-products were applied to public (Western United States forests) lands or disposed of by civilian workers within the United States and Canada. After 60 years, these countries are still paying the price for the U.S. Government, CIA, DOD and USDA decisions to manufacture and use agricultural herbicides as chemical weapons during the Vietnam War. There have been human health issues related to the chemical transportation, storage and disposal by workers who moved these chemical weapons from United States and Canada to South China Sea. Most of the tactical herbicides were transported, via the railroads to ports at Mobile, Alabama and Gulfport, Mississippi. These tactical herbicides were loaded on ships and transported via the Panama Canal for spraying

during the Vietnam War. The cost of the cleanup of chemical plant sites, transportation corridors, temporary and long-term storage areas, supply chain storage facilities, and utilization and disposal sites is in the billions of dollars. Many more billions of dollars are still required to finish the cleanup and to restore the sites' natural and environmental resources. This does not include human health benefit costs to treat exposures of the U.S. and Canadian civilians who handled these chemical weapons, who were exposed to dioxin TCDD during and after the Vietnam War and treatment of their offspring.

5. Discussion

In the early 1960s, President Kennedy and senior civilian leadership team, with the advice and support from DOD, CIA and USDA, made a huge mistake, as a result of the costs in human health and environmental cleanup, when they decided to spray tactical herbicides contaminated with dioxin TCDD and arsenic on southern Vietnam during the Vietnam War. The U.S. Military did not spray tactical herbicides on the lands of northern Vietnam. The decision to spray tactical herbicides adversely affected hundreds of thousands of U.S. Vietnam Era veterans and millions of Vietnamese living in southern Vietnam. By 1955, many of those in leadership positions in the U.S. government knew about the human health risks (carcinogen) of dioxin TCDD. The U.S. government and federal agencies, American, European and Canadian chemical companies had early evidence that dioxin TCDD was a chloracne and cancer causing substance and should've been alarmed by impacts on workers at the 1949 Monsanto Chemical 2,4,5-T chemical plant explosion in Nitro, West Virginia and the subsequent BASF chemical plant explosion in Europe in 1953. The herbicides with the contaminant dioxin TCDD were toxic and a huge risk to animals and humans.

By 1954, BASF, with the help of Dow Chemical finally figured out that the chemical workers at the plants that exploded had been exposed to dioxin TCDD which caused chloracne and cancers. The U.S. government likely knew by 1955 of the dangers of dioxin TCDD before the media and public were finally made aware. However, despite five or six years of advanced notice of toxic effects of dioxin TCDD, the U.S. Government (President Kennedy) still decided in 1960 and 1961 to authorize the U.S. military to spray tactical herbicides, including Agent Blue, Agent Purple, and Agent Orange on the remote areas and food supply of rural southern Vietnam. Knowing the environmental and human health risks that dioxin TCDD and arsenic posed, why would U.S. leadership introduce tactical herbicides that likely contained the harmful dioxin by-product into the Vietnam War? At the time DOD, CIA and USDA may have underestimated the longevity of dioxin TCDD in the environment under anaerobic soil (50 years or more) conditions or underwater (up to 100 years) but they should have known that arsenic in Agent Blue (cacodylic acid) had no half-life and would remain in the southern Vietnam landscape. Prior herbicide research and testing was focused on the less harmful herbicides, 2,4-D and 2,4,5-T, with

shorter half-lives and assumed to have a short-term impact on the environment and human health. Nevertheless, after these chemical plant explosions while manufacturing 2,4,5-T, U.S. government leadership surely should've realized that the contaminant dioxin TCDD and arsenic (with no half-life) in herbicides were toxic to animals and humans as well as the targeted forests and food crops.

The military strategies to defoliate the jungle to expose the enemy hiding places and storage areas and to eliminate the enemy's local food supply were rather ineffective according to the U.S. military's own internal assessments. There is considerable evidence that destroying the rice food supply of 17 million Vietnamese living in southern Vietnam would not have stopped the 250,000 communist insurgents from North Vietnam from attacking Saigon. However, the herbicide spraying during the Republic of Vietnam's (Khai Quang program) did adversely affect the food supply of the rural southern Vietnam sufficiently to result in more than 2 million rural Vietnamese living in southern Vietnam migrating to the slums of Saigon and other urban areas as part of a Republic of Vietnam strategic hamlet strategy. After the rice paddies were sprayed and destroyed, the Vietnamese living in rural southern Vietnam could no longer feed themselves or their families.

Operation Ranch Hand, an attempt to defoliate the jungle and expose the enemy was rather ineffective as well. It took two weeks to get the required leaf drop after Air Force spraying with Agent Purple or Agent Orange by C-123 planes. By then the communist insurgents had left the area. Finally, the military mixed in Agent Blue to get a quicker leaf drop and then sent our own troops in before the leaves had dropped exposing them to the dioxin TCDD contaminant and cacodylic acid (arsenic) residues. As a result hundreds of thousands of U.S. military soldiers and millions of Vietnamese soldiers and civilians were exposed to both dioxin TCDD and arsenic. U.S. Vietnam Era veterans who claimed VA benefits related to exposure to dioxin TCDD and/or arsenic were then denied these benefits until the passage of a Federal Law in 1991.

After that, if U.S. Vietnam soldiers "had boots on the ground in Vietnam" it became easier for them to qualify for VA benefits. However, if a U.S. Vietnam Era veteran served in the Blue Water Navy, the Air Force in Thailand, Guam, at the Jungle School (Fort Sherman) in Panama Canal Zone, CFB Gagetown, and at many other locations veterans did not meet the boots on the ground in Vietnam VA criteria and benefits were denied.

Sixty years later, the impacts on both the environment and human health are still being felt by those exposed to dioxin TCDD and arsenic as well as their offspring. The genetic impacts and health consequences have now extended for 3 or 4 generations. This is especially true in the Vietnamese who had much more extended exposure to dioxin TCDD and arsenic. The medical consequences are still being documented. The tactical herbicides contaminated with dioxin TCDD or formulated with arsenic used by the DOD during the Vietnam War were not harmless to animals or humans as claimed. To date, no one in the U.S. Govern-

ment administration and military has ever been held accountable (except possibly by the U.S. voters during 1964, 1968, and 1972 U.S Presidential Elections) for these rather significant Vietnam War strategic mistakes. The decision to use tactical herbicides during the Vietnam War has continued to haunt the U.S. government and military for more than 60 years.

After USAID funded studies, the DOD contributed $330 million to Vietnam to help clean up the dioxin TCDD hotspots, including Bien Hoa. Nine senators traveled to Vietnam in 2019 to provide $30 million (USAID has contributed funds) to help address the Vietnamese health issues from exposure to dioxin TCDD and arsenic during the Vietnam War. In addition, the VA, over time, has made it easier for U.S. Vietnam Era veterans to qualify for benefits if they were exposed to dioxin TCDD or arsenic. Both the United States and Vietnam environments and people were harmed.

An overlooked group was the U.S. civilian workers, including chemical plant workers, transport workers, railroad workers, dockworkers and herbicide applicators and disposal workers, who were exposed to dioxin TCDD and arsenic while manufacturing, transporting, applying or disposing of tactical herbicides during and after the Vietnam War. The U.S. Government as in past conflicts, mobilized its industrial sector, but this time a niche commercial sector to produce the tactical herbicides. These chemical plants, located at the transportation junctions of rail lines, rivers and ports exposed a wide sector of our chemical and agricultural industry's workers to carcinogen agents. The workers, then, were both loyal and patriotic. Today, many of those still living and their families are asking questions. What happened during those years working on the "Government Project"? Are the "Brownfields" of dioxin-tainted production buildings and parking lots, loading docks and treatment lagoons, the pastures and woodlands covering the remaining dioxin encased clay sediments, and streams and lakes with dioxin in fish tissue safe for re-use? What must yet be done to make them safe?

Clearly more research on these questions is needed. One critical concern is the level and funding of on-going site monitoring and maintenance programs necessary to ensure remediation efforts are effective and public health is protected. Covenants on titles will inform prospective land buyers of superfund properties, but only where recorded and only transactions requiring searched titles. Neighboring land sales, next to superfund sites, are and will remain uninformed sales unless maintained fences have visible signs indicating a superfund site is next to the property line. Action groups to study carcinogen impacts are a positive action, but ineffective without local County and State Health guidance. The business-government relationship model needs study. To achieve socially responsible desired outcomes, it is not enough for government bureaucracy to only deny actions of contracted business without fuller understanding by all parties of the remediation and necessary maintenance required to ensure safe land uses. Business-sociological studies of ethical methods and business model relations with

government contracts (between private businesses and the military) will better prepare our nation in times of war for better future outcomes.

6. Conclusions

During the last 60 years, environmental and human health impacts of spraying tactical herbicides, containing 2,4,5-T with unknown amounts of dioxin TCDD, in southern Vietnam during the Vietnam War, have been documented. Clean-up efforts of dioxin TCDD hotspots in Vietnam are ongoing. However, the lesser-told story is the environmental and human health impacts on the chemical plant workers who manufactured Agent Orange at seven locations in the United States and one site in Canada. The chemical plant workers and their families are continuing to live with the consequences of the early 1960s U.S. government and military decision to use tactical herbicides during the Vietnam War. These workers were exposed to dioxin TCDD during the chemical manufacturing process. By 1955, if not sooner, there is evidence that the United States government, military, chemical companies, including Monsanto and Dow Chemical, and their company medical doctors likely knew that tactical herbicides with 2,4,5-T were contaminated with unknown amounts of TCDD. A known carcinogen; and were potentially harmful to those exposed to them during manufacture, transport and use in southern Vietnam during the Vietnam War.

Historical supporting evidence includes 1949 Monsanto chemical plant explosion in Nitro, West Virginia which occurred while producing 2,4,5-T with unknown amounts of dioxin TCDD. Unfortunately, Monsanto and their company doctors did not share their medical information and findings with their chemical plant workers, the media or the public. When a similar explosion occurred in 1953 at the BASF chemical plant in Europe, while producing 2,4,5-T, the company and their medical doctors, with the assistance of Dow Chemical were able to determine the cause of chemical plant workers chloracne and cancers as exposure to dioxin TCDD. By 1955, BASF made their finding available to their chemical plant workers, the media and the public.

Unfortunately, six years later, U.S. government and military ignored the findings that 2,4,5-T with unknown amounts of dioxin TCDD was a carcinogen. In the early 1960s using the War Powers Act of 1950, President Kennedy and his administration decided to require 11 American chemical companies to manufacture, using a pre-determined formulation, tactical herbicides containing 2,4,5-T for the Vietnam War. In addition to U.S. and Vietnamese soldiers on the battlefield, American civilian chemical plant and transport workers were also exposed to 2,4,5-T with unknown amounts of dioxin TCDD, a known carcinogen, at manufacturing facilities at seven sites in the United States and one in Canada. After more than 60 years, the human health and environmental consequences of the manufacture of tactical herbicides, a military and environmental chemical weapon, on United States civilian workers and local environments persists and still requires education, remediation, and mitigation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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