DDT and its Metabolites in the Willamette River Basin

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I. Introduction

Over the last century, the use of pesticides has become essential to American agriculture. Growing exponentially in levels of use, pesticides have helped farmers reach record high levels of production, and propelled the United States to be one of the world's top producers of food. But this apparent success has not come without costs. As our awareness of the environment has grown, we have come to realize the immense and often irreversible damage some of these chemicals have done to both our earth and our bodies. Many of these same "miracles" have contaminated our hydrologic system, which supports all life (Larson et al.: 1997; Rinella, J.F. et al.: 1993). Now, as clean water is becoming more and more precious, the contamination of our waters may be one of the single greatest problems we face in years to come.

II. History of DDT

DDT (*Dichloro Diphenyl Trichloroethane*, known scientifically as *1,1,1-trichloro-2,2-bis-(p-chlorophenyl) ethane*), was first synthesized in 1874 by German Scientist Othmar Zeidler, but was not put into any practical use until 1939, when Swiss chemist Paul Müller identified its effectiveness in controlling pests. Following his discovery, DDT would come to widespread use controlling agricultural pests, human and animal parasites, and disease-carrying organisms such as mosquitoes. One particularly notable use was by the Allied Forces throughout WW II as a personal insecticide. Because it had no immediately apparent effects on human health, DDT soon became hailed as a "miracle insecticide." Following the war, it came to be used throughout the world in agriculture, forestry, urban areas, and many consumer products from blankets to paint. Overall, from 1940 to 1970 over 4 billion pounds of DDT was used worldwide, and accounted for almost one fourth of all insecticide use in the United States (Rinella, J.F. et al.: 1993, p. 9; Steingraber: 1998). Today it remains one of the most frequently detected pesticides in surface water, found in a whopping 75 percent of all test sites (Larson: 1997, p.19).

The Willamette Valley was no exception to the widespread use of DDT. Applied extensively on agricultural crops, and in forest management to control pests such as the gypsy moth, DDT became a significant contaminant throughout the basin. This contamination was further augmented by direct contamination from chemical plants that produced DDT and DDT-containing products (Gregory: 1999, Anderson et al.: 1997, DEQ: May 2004).

III. Chemical Properties of DDT

DDT is part of a group of pesticides known as "organochlorines," which are a type of chemical that consists of chlorinated hydrocarbons, that is carbon, chlorine, and hydrogen. Although DDT is a synthetic chemical, it is carbon-based, making it possible for DDT molecules to interact with the biological processes of living organisms. While it is this property that makes DDT useful to man, it also makes it dangerous. For, inside the human body it has been shown to interfere with major operations, from damaging DNA to disrupting endocrine functions. Likewise, in the environment, DDT is highly toxic to fish and invertebrates, and has been shown to have a significant impact on birds and mammals (Fuhrer et al.: 1999; Toxicological Profile: 2002).

While DDT has many toxic properties on its own, the biggest concern comes from the fact that organochlorines are very slow to break down (if they break down at all). A major part of this is because both DDT and its metabolites are water insoluble. While environmental conditions may determine its rate of degradation (e.g., it has been shown to break down more quickly in tropical areas than temperate, and likewise extreme anaerobic conditions cause it to decompose faster) its half life is often seven years or longer, resulting in significant levels of contamination decades after application (Toxicological Profile: 2002; Gambrell: 1981; Anderson et al.: 1997). Further, extensive evidence shows that the breakdown products of DDT, namely DDE, DDA and DDD, are also toxic, presenting many of the same impacts on life. This is particularly alarming because DDE does not break down any further (Toxicological Profile: 2002)

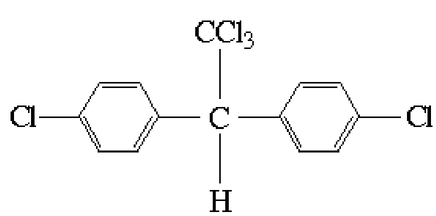

Fig. 1.1 Structure of DDT Molecule (Toxicological Profile: 2002)

IV. Impacts on Life

The negative impacts of DDT on wildlife were first brought to the public eye in 1962 with the publishing of Rachel Carson's famous book *Silent Spring*. As Carson so meticulously recorded, the extreme consequences of pesticide use were even then becoming quite apparent. Thousands of song birds, small mammals, and fish were being discovered in the throes of death from acute DDT poisoning, and aside from these observed deaths, national numbers of predatory birds were on the severe decline. Still, despite the damning evidence Carson brought forth, it would take another decade before DDT would be banned (Carson: 1962; Steingraber: 1998). While levels of DDT in the environment have significantly decreased since, large amounts still remain in our bodies and ecosystems at levels potent enough to impact life (Fuhrer, et al: 1999).

One of the major contributors to DDT's toxicity comes from its extreme persistence in the environment. Because it cannot be broken down metabolically, it ends up being stored in the body's fat, accumulating to create what is called a chemical load. Through a process called "biomagnification" these chemical loads move up the food chain. This happens because when other organisms ingest those with chemical loads, the same chemicals are taken up by their bodies. Thus as it moves through the environment, DDT concentrations and volumes increase until the lipids of the highest organisms become saturated. Consequently, certain predatory species (including humans) are much more susceptible to high concentrations of DDT in their bodies than animals lower on the food chain. While on the short term these larger predatory species may be able to tolerate high chemical loads, a continued presence of DDT and/or its metabolites results in negative health effects (Rinella, J.F. et al.: 1993; Orris et al.: 2000; Toxicological Profile: 2002).

The physical consequences of DDT exposure vary according to species. It is extremely toxic to fish and invertebrates, creating developmental defects, causing neurological and behavioral defects, and severely damaging reproductive capacity (Cooke: 1970, Clark: 1990; Guillette et al.: 1994; Harri et al.: 1979; Woodward et al.: 1993). Water fleas, stone flies and many other types of aquatic invertebrates have proven extremely sensitive to its toxicity, and are prone to die in high numbers upon any significant exposure (Clark: 1990). That it is extremely toxic to birds has been well documented also. Like fish and invertebrates, developmental, neurological and behavioral effects have been shown to occur in birds in similar ways. But the most pronounced effect in avian species has been the disruption of reproductive capacity.

Because of DDT's function as an endocrine disrupter, it interferes with hormonal functions, leading to malformed reproductive organs and smaller clutches. Further, DDE leads to severely thinned eggshells (Carson: 1962; EPA: 1975; Cooke: 1973; Toxicological Profile: 2002).

While similar effects were observed in mammals, there is a lack of substantiating data on the precise physiological implications of DDT exposure on wild populations. Still a wealth of data indicates there are substantial consequences in mammal hormonal and neurological processes (Toxicological Profile: 2002). There is an added concern of contaminants passing from mother to young. Though minimal, some DDT has been shown to pass through the placenta. But more importantly, significant amounts of DDT can be passed on through breast milk to young mammals (Toxicological Profile: 2002). This is of particular concern because young animals consume more food per pound of body weight than adults, and are less capable of processing and excreting foreign chemicals; thus, they are much more susceptible to chemical poisoning than adults. Most importantly, due to the way DDT disrupts hormonal processes, it may interfere with important stages of bodily development (Edmunds et al.: 2000; Schafer: 2002; Toxicological Profile: 2002). In its entirety, the body of work specific to wild mammals is relatively small compared to that of birds and reptiles. Because of mammals' importance to ecosystems, any additional studies would be immensely useful. Likewise, due to the close ecological relationship between humans and mammals in the wild (NRC: 1991), any additional studies would be helpful in understanding how such chemicals may be affecting our own health.

Humans, like other species, are prone to a number of health effects from DDT exposure. Because DDT acts as an endocrine disruptor, it has the ability to interfere with a number of important processes, particularly during critical stages of development. Learning disorders, immune system impairment, reproductive dysfunction and diabetes have all been connected to DDT contamination in the human body (Center for Health and Environmental Justice: 2000; Orris et al.: 2000; Toxicological Profile: 2002). While these are all causes of concern, it must be noted that we are exposed to a many chemicals in our everyday life, which may potentially cause similar effects, making it difficult to assess precise risks from DDT exposure. Nonetheless, the strong correlations between these disorders and DDT exposure warrant caution, particularly in the case of children, who are especially susceptible to damage (Wolff: 2002). Even in small amounts, any DDT contamination should be considered a possible risk to human health and wellbeing.

Aside from these particular disorders, one area of major concern is the possible effect of DDT and its metabolites on the occurrence and severity of cancer. While DDT has been listed as a probable carcinogen for some time, studies of recent years have produced some of the most damning evidence. In the early 1990s, four different studies from Finland to New York examined the association of metabolized DDT in fatty tissues and the occurrence of breast cancer. In all four studies, a strong correlation was found between high levels of DDE in women's bodies and the incidence of cancer (Russalo-Rauhamaa et al: 1990; Falck et al.: 1992; Wolff et al.: 1993; Hunter et. al: 1993; Dewailly et al.: 1994). According to the New York study women with breast cancer had an average of 35 percent more DDE in their bodies than healthy women (Wolff et al.: 1993). A following study in Quebec was even more striking, showing that DDE levels were much higher in women who had estrogen-receptor positive cancers, a condition directly correlated to the endocrine disrupting characteristics of DDT (Dewailly et al.: 1994, Keith: 1997). Supporting these claims, a number of studies have indicated that DDT may result in both DNA fragmentation and the unnatural disruption of hormonal balances, accelerating tumor growth (Cocco: 2000; Scribner et al.: 1981; Toxicological Profile: 2002). While the evidence remains inconclusive on the precise way metabolized DDT may contribute to the incidence and severity of cancer, the possible connection suggested by these studies warrants a degree of concern and caution on our part.

V. Sources and Levels of Contamination in the Willamette Valley

The majority of the data available on DDT levels in the Willamette comes from a series of Water Quality Assessment studies performed by the U.S. Geological Service, in cooperation with the Oregon DEQ and federal EPA. Beginning in the early 1990s and culminating in 1998, these assessments attempted to give a clear and comprehensive view of water quality issues in the Willamette Basin. However, while the data accumulated in these studies give us a good starting point, testing for organochlorines constituted only a small part. The overall picture of how and where DDT contamination exists is still full of gaps and inconsistencies. One reason for this may be that DDT is often difficult to test for. The lower thresholds of testing equipment may be too high to detect levels present (Larson: 1997) Also, these studies did not include extensive analyses of possible sources of contamination (Anderson et al.: 1997). Despite these shortcomings, we are still able to draw certain conclusions about the status of DDT in the watershed.

While levels of DDT have been detected numerous times throughout the Willamette watershed, it appears that contamination tends to be uneven and site-specific (Anderson et al.: 1997). Nonetheless, DDT and its metabolites have been found in water, sediment and tissues throughout the watershed at levels above the National Academy of Science guidelines for the protection of fish predators (Anderson et al.: 1996; DEQ: 1994; DEQ: 1996; Edwards: 1994; Larson: 1997; NCAP: 1997; Rinella, F.A.: 1993; Rinella, F.A.: 1997). Likewise, DDT remains the most commonly detected organochlorine in Willamette Basin fish (Anderson, et al: 1997; Curtis et al.: 2003; DEQ: 1994). Nationally, the Willamette Basin remains in the highest 25th percentile for levels of organochlorine contamination (of stream beds) for both urban and rural waterways (Fuhrer: 1999). In regional studies, the Willamette continues to be named as an important potential source of DDT in the Columbia River (Anderson et al.: 1997). Also, recent tests by the Oregon Department of Environmental Quality shows that DDT metabolites are currently present in the valley's groundwater (DEQ: March 2004). Thus, while there is no clear mean level of contamination for the Willamette and its tributaries, it is clear that DDT remains a significant issue.

The possible sources of this pollution are varied. Due to the constant movement of rivers, water can remain contaminated at a single point only if materials are continually introduced through direct point-source pollution, air deposition, the contamination of the water's source, or the non point-source input of surrounding soils and sediments from both in and nearby the waterway. Pollution from the atmosphere is unlikely in this case because a) DDT is no longer sprayed, b) DDT does not last long in the atmosphere, and c) atmospheric depositions are too irregular to account for a particular site-specific problem. Direct point-source pollution is also an unlikely source, since DDT is no longer used for any industrial processes, nor is likely to be found in any large amount in municipal discharges (Toxicological Profile: 2002). While source contamination may be a possibility for some of the river's most polluted tributaries (e.g., the Tualatin River and Amazon Creek), this is not likely an issue for the river's main stem, whose headwaters are remarkably clean. However, waters flowing from certain highly polluted tributaries may be a critical component of main-stem contamination. Due to the relative scarcity of data, more comprehensive tests are needed to draw any definite conclusions as to how certain tributaries contribute to the contamination of the Willamette River. Finally, it is also possible that a significant amount of DDT directly enters the main stem from irrigation run-off and contaminated riparian areas. In both scenarios, it is likely that most DDT enters the water by the leaching, flooding, and run-off of contaminated soils, as organochlorines have been shown to persist the longest in sediments (Toxicological Profile: 2002). Supporting this hypothesis, studies in Washington and California have shown that in areas of heavy agriculture, soil leaching and runoff remains the single greatest cause of surface water contamination with DDT (Larson, et al.: 1997).

Historically, there were many opportunities for DDT to contaminate Oregon soils. Current pollution levels, along with government documents show that not only was DDT used heavily for agriculture but in forestry, and in homes and businesses as well (Anderson et al.: 1996; Anderson et al.: 1997; Fuhrer: 1999). Even after its ban, the U.S. Forest Service continued to use DDT for several years in efforts to eradicate the gypsy moth (Williams: 1978). Further, even those areas where DDT was not directly applied may be polluted, as numerous studies have shown the vast ability of organochlorines to shift and cover large areas (Toxicological Profile: 2002). As a consequence of these factors, virtually all types of land may be suspect. Unfortunately, except for a few isolated studies, we currently lack extensive data on the presence of DDT and its metabolites in the valley at large, making it difficult to determine how soils in certain areas may be contributing to the river's pollution more than others. Nonetheless, based on national studies of contamination patterns we can determine that certain types of sediment are more likely to be heavily contaminated.

Because large amounts of DDT were used in forestry, it is likely that a significant amount of DDT residues remain in forested areas (Larson: 1997). Fortunately, because forested landscapes tend to act as filters in hydrologic systems, it is unlikely that a great amount of DDT is washing out of them. Rather, the vast majority of the chemical is probably tied up in the trees, underbrush, and soil. There is a possibility that significant amounts of DDT are captured within trees. Both within the forest, and in processed wood, this may pose risks to animals and humans alike, but further study would be necessary to determine how and to what extent. Under natural circumstances, erosion is not a major problem in forested areas. But due to logging, whole hillsides can be swept away in mudslides. Aside from the obvious damage caused by such a massive loss of topsoil, the dissemination of DDT should also be considered as a possible environmental impact. Thankfully, the instances when slides move sediments directly into waterways are relatively infrequent.

Because 80 percent of DDT was used in agriculture, areas of intense farming continue to have some of the most contaminated soils, particularly where orchards and row crops dominated (Rinella, J.F. et al: 1993; Toxicological Profile: 2002; Larson: 1997). These areas are of particular concern because, due to both the geographical layout of most farmland and the modifications of irrigation, they are especially prone to the movement of sediments, from regular run-off to major flooding. When large amounts of these sediments are moved, trapped chemicals may be released into the environment with dangerous results. Such situations have been documented around the nation. For example, a study conducted the San Joaquin Valley discovered that approximately 136 grams of DDT made it into the river each day as a result of normal irrigation practices. Then, in January 1995 a massive storm sent large amounts of sediment, and with it, more than 4,500 grams of DDT (including all metabolites) into surface waters each day, more than a whole season's worth of contamination, all in one shot (Toxicological Profile: 2002). Thus, while DDT has not been introduced to the environment via agriculture for many years, agricultural run-off continues to pose a massive threat to water quality.

While soils in agricultural areas are often highly contaminated, urban areas tend to have higher overall levels of contamination (Fuhrer: 1999; Toxicological Profile: 2002). Though few tests have been done on patterns of contamination within urban zones, it is likely this pollution comes from a number of sources: old chemical plants, home lawns and gardens, public parks and open spaces, and discarded consumer products. With exception to industrial sites, it would be difficult to assess and control the flow of contaminants in these areas, due to the widely diffuse nature of these sources. Still, great care should be taken to prevent the flow of sediments from urban areas into waterways, either from open lots, bare riparian areas, or construction sites. Care should be especially taken with the sites of former chemical plants, as these pose one of the greatest of threats of dioxin contamination (Larson: 1999; Toxicological Profile: 2002).

Finally, aside from these areas, parts of the hydrologic system itself may harbor and contribute DDT. Lakes, especially those created by dams, block large amounts of sediment from moving downstream. Consequently, they often become repositories for all kinds of chemical pollutants moving through a river system (Francisco: 2004). In the Willamette Basin, there are a total of 13 such dams, all of which were built and maintained prior to the banning of DDT. Likewise, low gradient portions of rivers, wetlands, floodplains all may act as repositories for organochlorines (Toxicological Profile: 2002). Any one of these sites can become a dangerous source of pollution if their sediments are disturbed.

VI. Assessing the Risks and Making Recommendations

While it is clear that the presence of dioxins in the Willamette Valley harbors significant problems for the basin's health, to what degree this poses a risk is somewhat uncertain. There are many variables that impact the patterns and levels with which local populations may become contaminated, particularly in the case of humans. Likewise, there remain many other pressing health and environmental issues. DDT is only one of a whole long list of toxic pollutants that pose major risks throughout our ecosystem. Our knowledge of many of these remains extremely small, and smaller yet when we consider what effects they may have when combined in our bodies and environment. Still, many of the same mechanisms that release DDT into circulation release others as well. Even with such variables, it is possible to identify clear risks and how we might avoid them.

First, the movement of sediments should be carefully monitored, and all purposeful movements should be done with care. Sediments in lakes, reservoirs and lower gradient portions of the river should be treated with just as much care as farmland, for activities like dam removal and dredging may release high levels of stored DDT. Likewise, flash flooding can have disastrous consequences for the spread of contaminants.

Second, additional studies on levels and patterns of pollution in the basin are badly needed, and with this we need to better educate the public. Even though we know DDT to exist throughout the basin, a lack of comprehensive testing that allows for irregular levels of contamination has resulted in there being only one listing for DDT on the state's 303d list of polluted waters. Likewise, considering the dangerous nature of DDT residues in soil, both as run-off, and as contaminators of our food supply (Schafer: 2002), it would be judicious to instigate a soil testing program through the state Extension Service, so that local farmers may determine levels of chemical pollutants in their farmland. Such a study would not only help ensure the safety of our food source, but give greater insight into major sites of water contamination. Then, all information concerning patterns of DDT pollution should be published in the public domain.

Third, I was unable to locate but a few studies that addressed DDT levels in wildlife specific to the Willamette Basin. We cannot know the full extent that these pollutants are affecting our ecosystems without further data on the chemical loads of local wildlife.

Finally, while numerous studies have been done on the role of fish consumption in human DDT contamination, little work has been done on the other ways such pollutants now reach us. General studies of mean human chemical loads should be carried out to help determine at what level DDT may be affecting public health. As a part of this, local incidences of cancer could be studied in tandem with levels and locations of DDT contamination. These environmental pollutants may give us some insight into our diseases.

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