



**Final
Rayonier Mill Off-Property Soil
Dioxin Study
Conceptual Site Model Document**

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Table of Contents

<u>Section</u>	<u>Page</u>
1.0 Introduction	2
1.1 What Are Dioxins/Furans?	2
1.2 Where Do Dioxins/Furans Come From?	3
1.3 Why Are We Interested in Dioxins/Furans?	4
2.0 Site Setting	5
2.1 Geography	5
2.2 Climate	6
2.3 Land Use	6
2.4 Demographics	7
3.0 Potential Sources of Dioxins/Furans	8
3.1 Pulp and Paper Mills and Related Industry	8
3.2 Medical Waste Incinerators	10
3.3 Crematories	11
3.4 Automobiles	11
3.5 Fires	12
3.6 Oil Furnace / Heating	12
4.0 Fate and Transport of Dioxins/Furans in the Environment	14
4.1 Physical Characteristics	14
4.2 Dioxins/Furans in Air	15
4.3 Dioxins/Furans on Land	16
4.4 Dioxins/Furans in Water	17
5.0 Dioxins/Furans in Soils	18
5.1 Factors Affecting Dioxins/Furans Concentrations in Soil	18
5.2 Assessment of Existing Dioxin/Furan Data	19
5.3 Dioxin/Furan Data for Port Angeles Soils	20
5.4 Dioxin/Furan Data for Washington State Soils	21
6.0 Methods for Source Identification	22
7.0 Summary	24
8.0 References	25

Acronyms/Abbreviations

AADT	Annual average daily traffic
ATSDR	Agency for Toxic Substances and Disease Registry
CLARC	Cleanup Levels and Risk Calculations
CSM	Conceptual site model
E & E	Ecology and Environment, Inc.
Ecology	Washington State Department of Ecology
EIM	environmental information management
EPA	U.S. Environmental Protection Agency
ESI	expanded site investigation
FWEC	Foster Wheeler Environmental Corporation
HpCDD	heptachlorodibenzo- <i>p</i> -dioxin
HpCDF	heptachlorodibenzofuran
HxCDD	hexachlorodibenzo- <i>p</i> -dioxin
HxCDF	hexachlorodibenzofuran
I-TEQ	toxic equivalence based on international accord
ITT	International Telephone and Telegraph
MCDD	monochlorodibenzo- <i>p</i> -dioxin
MCDF	monochlorodibenzofuran
MPE	Malcolm Pirnie Engineers
MTCA	Model Toxics Control Act
MWI	medical waste incinerators
NGVD	National Geodetic Vertical Datum
OCDD	octachlorodibenzo- <i>p</i> -dioxin
OCDF	octachlorodibenzofuran
ORCAA	Olympic Region Clean Air Agency
PeCDD	pentachlorodibenzo- <i>p</i> -dioxin
PeCDF	pentachlorodibenzofuran
POTW	publicly owned treatment works
TCDD	tetrachlorodibenzo- <i>p</i> -dioxin
TCDF	tetrachlorodibenzofuran
TEF	toxic equivalence factor
TEQ	toxic equivalence

1.0 Introduction

The Washington State Department of Ecology is investigating the presence of polychlorinated dibenzo-*p*-dioxins (dioxins) and polychlorinated dibenzofurans (furans) in Port Angeles soils. The study will focus on dioxins/furans present in soils in the vicinity of the former Rayonier Mill because pulp and paper mills are known to release these chemicals during operations, boiler testing confirmed the presence of dioxins/furans, and because dioxins/furans have been found in soils located on the Rayonier property.

This conceptual site model document summarizes the current understanding of potential sources of dioxins/furans in Port Angeles that could impact soils near the former Rayonier Mill. A description of how dioxins/furans may be transformed and transported in the environment also is provided in this document, followed by an introductory discussion of how we can evaluate dioxins/furans in soils surrounding the former Rayonier Mill in an attempt to determine if and where emissions may have impacted off-site soils.

1.1 What Are Dioxins/Furans?

Dioxins and furans are two classes of chemicals that are structurally similar in that they both contain two carbon ring structures. All dioxins include two oxygen atoms, while all furans include one oxygen atom. There are 210 unique dioxin/furan compounds, each called a “congener” (75 dioxin and 135 furan congeners), which differ from each other in the number of chlorine atoms on the benzene rings and in the position of the chlorine atoms.

Dioxin/furan congeners both contain one to eight chlorine atoms, either attached or substituted, resulting in eight homologue groups ranging from monochlorodibenzo-*p*-dioxins (MCDDs) and monochlorodibenzofurans (MCDFs) to octachlorodibenzo-*p*-dioxins (OCDDs) and octachlorodibenzofurans (OCDFs). Figure 1, shown below, shows the basic structure of dioxins/furans, with each numbered carbon atom corresponding to positions for chlorine substitution.

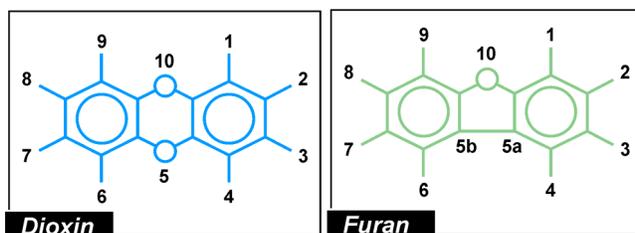


Figure 1. Structure and chlorine substitution locations for dioxins and furans.

Although there are 210 unique dioxin/furan congeners, only 17 of these are typically evaluated because they are considered by the U.S. Environmental Protection Agency (EPA) and the World Health Organization to be the most toxic. In this study, the terms “dioxins” and “furans” will be used to refer to the 17 congeners of primary interest,

presented in the following table. The question of whether additional congeners could help in source identification will be further addressed in the study design process.

Table 1. Dioxin/furan homologue groups and the 17 congeners of greatest concern, with chlorine substitutions in the 2, 3, 7, and 8 positions.

Dioxin/Furan Congeners	Abbreviation
<i>Dioxins</i>	
Tetrachlorodibenzo- <i>p</i> -dioxin	TCDD
2,3,7,8-tetrachlorodibenzo- <i>p</i> -dioxin	2,3,7,8-TCDD
Pentachlorodibenzo- <i>p</i> -dioxin	PeCDD
1,2,3,7,8-pentachlorodibenzo- <i>p</i> -dioxin	1,2,3,7,8-PeCDD
Hexachlorodibenzo- <i>p</i> -dioxin	HxCDD
1,2,3,4,7,8-hexachlorodibenzo- <i>p</i> -dioxin	1,2,3,4,7,8-HxCDD
1,2,3,6,7,8-hexachlorodibenzo- <i>p</i> -dioxin	1,2,3,6,7,8-HxCDD
1,2,3,7,8,9-hexachlorodibenzo- <i>p</i> -dioxin	1,2,3,7,8,9-HxCDD
Heptachlorodibenzo- <i>p</i> -dioxin	HpCDD
1,2,3,4,6,7,8-heptachlorodibenzo- <i>p</i> -dioxin	1,2,3,4,6,7,8-HpCDD
Octachlorodibenzo- <i>p</i> -dioxin	OCDD
<i>Furans</i>	
Tetrachlorodibenzofuran	TCDF
2,3,7,8-tetrachlorodibenzofuran	2,3,7,8-TCDF
Pentachlorodibenzofuran	PeCDF
1,2,3,7,8-pentachlorodibenzofuran	1,2,3,7,8-PeCDF
2,3,4,7,8-pentachlorodibenzofuran	2,3,4,7,8-PeCDF
Hexachlorodibenzofuran	HxCDF
1,2,3,4,7,8-hexachlorodibenzofuran	1,2,3,4,7,8-HxCDF
1,2,3,6,7,8-hexachlorodibenzofuran	1,2,3,6,7,8-HxCDF
1,2,3,7,8,9-hexachlorodibenzofuran	1,2,3,7,8,9-HxCDF
2,3,4,6,7,8-hexachlorodibenzofuran	2,3,4,6,7,8-HxCDF
Heptachlorodibenzofuran	HpCDF
1,2,3,4,6,7,8-heptachlorodibenzofuran	1,2,3,4,6,7,8-HpCDF
1,2,3,4,7,8,9-heptachlorodibenzofuran	1,2,3,4,7,8,9-HpCDF
Octachlorodibenzofuran	OCDF

1.2 Where Do Dioxins/Furans Come From?

Dioxins/furans make their way into the environment from a variety of sources. Except for small quantities used for research purposes, neither compound is created intentionally. Instead, dioxins/furans are unwanted by-products of chemical manufacturing and combustion or incineration processes involving chlorine compounds. For example, dioxins are most notorious for their presence as a contaminant in the herbicide, 2,4,5-T, and in Agent Orange. They can also be produced during incineration of wood, oil, and wastes. Major contributors of dioxins/furans to the environment include:

- Incineration of municipal solid waste and medical waste

- Secondary copper smelting
- Forest fires
- Land application of sewage sludge
- Cement kilns
- Coal fired power plants
- Residential wood burning
- Chlorine bleaching of wood pulp
- Backyard burning of household waste
- Byproducts and derivatives of chemical production (e.g., pentachlorophenol, 2,4,5-T)

Dioxins/furans are present at some level throughout the environment, in the air we breathe, the food we eat and water we drink, and in the soils and sediments beneath our feet. Dioxins/furans tend to be found in higher concentrations near industrial areas but are present in various concentrations throughout urban and rural areas and even in remote wilderness regions.

1.3 Why Are We Interested in Dioxins/Furans?

Federal and state environmental regulatory and health agencies are interested in dioxins/furans because they are toxic to humans and wildlife. The most toxic of the 210 dioxin/furan congeners is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD). Once released into the environment, dioxins/furans resist biodegradation, do not dissolve in water, and attach strongly to particles such as soil, dust, and sediment. This means that they are persistent and can bioaccumulate in people and animals. Despite their persistence and ubiquitous presence, however, levels of dioxins/furans in the environment have been declining since the 1970's due to improvements in air pollution control technologies for combustion and incineration facilities and to cleanup of dioxin-contaminated areas (U.S. EPA 2003).

The Department of Ecology is interested in dioxins/furans in eastern Port Angeles due to the potential for soil contamination resulting from decades of pulp and paper operations at the Rayonier Mill facility. This study seeks to evaluate dioxin/furan concentrations near the former Rayonier Mill recognizing there may be impacts from other nearby sources. The Rayonier Mill Off-Property study area is a developed urban landscape and as a result will be influenced by the general "urban plume" impacts documented in the literature in addition to impacts from the local pulp and paper industry. Therefore, the problem of source identification will address the issue of mixtures of source impacts. Multiple approaches to data evaluation will be combined in this study to achieve source identification and contribution allocations. Weight of evidence and consistency criteria will be used in combining various lines of evidence obtained from direct measurement, statistical and geospatial evaluation, chemometric analyses, and published data.

2.0 Site Setting

The study of dioxins/furans in eastern Port Angeles soils will focus on soils found in the vicinity of the former Rayonier Mill. The study area will be defined in the Soil Sampling Plan but is likely to be on the order of 5 to ten square miles in and adjacent to eastern Port Angeles; some samples in more distant locations may be included to provide comparative data. The following section briefly describes the physical setting for the approximate study area, including its geography, climate, land uses, and demographics.

2.1 Geography

The city of Port Angeles is located in Clallam County, along the northern coast of the Olympic Peninsula (Figure 2). The surrounding topography gently slopes from the foothills of the Olympic National Park to Port Angeles Bay, which opens on the Strait of Juan de Fuca.

The former Rayonier Mill, now a vacant property, is situated on the eastern edge of the Port Angeles Bay shoreline. The former Rayonier Mill is located in Section 11 of Township 30 north, Range 6 west, at a latitude of 48° 07' 00" north and longitude of 123° 24' 25" west. The property can be accessed from Highway 101 and Ennis Street, within one mile of the eastern city limit for Port Angeles.

The Rayonier property, which has been almost completely cleared of its mill facility and outbuildings, totals 80 acres. The majority of the property extends into Port Angeles Bay. The northern portion of the property is generally flat, with relatively steep bluffs rising rapidly to approximately 75 feet above National Geodetic Vertical Datum (NGVD) immediately to the southeast and southwest (HLA 1993). The terrain continues to rise to approximately 200, 265, and 150 feet above NGVD within approximately one mile southeast, south, and southwest of the property, respectively.

The general physical geography of the area to the south of the Rayonier property slopes upward for approximately one mile to the Peninsula Golf Course. White Creek and Ennis Creek converge on the former Rayonier mill property and discharge adjacent to the former mill. The North Coast Bluffs rise from the bay less than one mile southeast of the former mill. These bluffs slope upward for 100 feet and then gradually taper off, providing nearly a square mile of flat terrain that serves as a residential area southeast of the former mill. The mouth of Lees Creek is located nearly two miles to the east

West of the former Rayonier Mill, the terrain rises from sea level along the bay to 500 feet above NGVD south of the bay. The highest elevations within city limits, ranging from 400 to 500 feet above NGVD, occur at the southeastern border of the city. Several creek ravines cut through the city, running north from the foothills of the Olympic National Park to Port Angeles Bay, where they empty. Peabody Creek passes through the city center approximately one mile west of the former Rayonier Mill. Tumwater and Valley Creeks empty into Port Angeles Bay nearly two miles west of the former mill.

2.2 Climate

The average annual precipitation for Clallam County is consistently less than 30 inches per year (NOAA 2008). This is one of the lowest rates in the state, where precipitation ranges from greater than 240 inches per year to less than 25 inches per year.

Average maximum temperatures in this coastal zone range from 65° to 70° F during the summer months and 45° to 50° F during the winter months (NOAA 2008). Peak temperatures are rarely greater than 90° F in the summer or lower than 30° F in the winter. The coldest temperatures are typically associated with cold air blowing from the interior of Canada and down through the Puget Sound area. Freezing temperatures generally arrive in November.

A wind rose based on data from Ecology's air monitoring station (No. 53009) located at the base of Ediz Hook for the year 2006 is provided in Figure 3, below. Prevailing winds recorded at this station blow from the west and west-southwest and the average wind speed was 6.5 knots. Average wind speeds are lowest between March and November and are strongest from November to late February (NOAA 2008). Data collected from this station in 2001 were used by Rayonier to generate an air deposition model for the former mill but are not considered ideally representative of conditions at the Rayonier property, in part due to differences in topography at Ediz Hook and the Rayonier property (Integral 2006a).

An additional meteorology station was located on the bluff south of the Rayonier property during the mill demolition phase, between 1997 and 1999 (see Integral 2006a, Appendix I for wind rose). Winds were predominantly from the northwest during this period. Although these data were collected from an elevation consistent with the top of the former Rayonier Mill stack, it was not selected for past air modeling efforts due to data gaps during the monitoring period and lack of validation by ORCAA or Ecology (Integral 2006a; Wilson 2008, Personal Communication). The average wind speed recorded at the Rayonier station was reported to be approximately 2 to 3 knots, two times less than the average wind speed recorded at the Ediz Hook station (Integral 2006a, Appendix I).

2.3 Land Use

The greater Port Angeles area has a long history of inhabitation and mixed land uses. Native Americans from the Lower Elwha Klallam Tribe were the first humans to settle in and around Port Angeles, primarily near the mouth of Ennis Creek. Two former Klallam villages, I'e'nis and Tse-whit-zen, once stood where Port Angeles is today.

Spanish explorers en route to exploring Vancouver Island named the town's natural harbor Puerto de Nuestra Señora de Los Angeles (History Link 2008). From 1887 to 1904, the property now occupied by Rayonier was utilized by the Puget Sound Cooperative Colony (Integral 2006a). In 1890, the city of Port Angeles became incorporated. During the early part of the twentieth century, the establishment of lumber, pulp, paper, and plywood mills along the harbor boosted the local economy (History Link 2008). The immediate harbor surroundings are diversified in their use, ranging from commercial to residential.

Within the city limits of Port Angeles, zoning today includes mixed industrial, commercial, recreational, and residential. In addition to mixed residential and commercial structures, the city of Port Angeles contains publicly owned treatment works (POTW), the Olympic Memorial Hospital, and schools of elementary through senior high levels. Zones adjacent to the Rayonier property include commercial arterial, public buildings, public parks, a hospital, the POTW, and single family homes (Port Angeles 2008.)

2.4 Demographics

Clallam County has seen higher growth rates than the state average over the past eight years. The census data demonstrate a 9.7 percent population growth rate, which is higher than the state's average annual growth rate of 8.5 percent. The 2006 population estimate for Clallam County was 70,400 persons, and the county contained 33,517 housing units at the end of 2006. The most recent census of 2000 indicated 3,692 units currently occupied in the city of Port Angeles. The census also reported a total of 30,683 housing units for all of Clallam County, 11 percent of which were located in Port Angeles.

The total area of Clallam County is 1,739.45 square miles, with an average of 37.1 occupants per square mile, according to the 2000 census. The census also reported an average of 2.31 persons per household and a median household income of \$40,391 per person. The per capita income in 1999 was \$19,517. Persons who fell below the poverty level as defined by the federal government totaled 12.3 percent of the county's population (Census 2008).

3.0 Potential Sources of Dioxins/Furans

The EPA (2003), Ecology (1998), and the ATSDR (1998) have identified a number of environmental sources of dioxins/furans. These include combustion, metal smelting and refining, chemical manufacturing and processing, and natural sources. In the past, chlorinated chemical manufacturing and use were the primary contributors of dioxins/furans to the environment. Today, however, thanks to reduced production and use of chlorinated compounds, the main sources of these pollutants are incineration and combustion activities (ATSDR 1998).

According to the EPA (2003), air emissions from combustion are the largest source of dioxins/furans in the environment. The EPA (2003) reports that the contribution of dioxins/furans from air emissions is at least one order of magnitude greater than all other quantified source categories combined. Municipal waste incinerators, backyard burn barrels, and medical waste incinerators represent 71 percent of the total quantified air emission sources nationwide (U.S. EPA 2003).

Combustion and incineration sources known to emit dioxins/furans include medical waste, municipal solid waste, hazardous waste, and sewage sludge waste incineration; industrial burners (wood, coal, oil); metal smelting; cement kilns; diesel fuel combustion; and residential burning (wood, oil, waste). An inventory of these sources can be obtained from the EPA in *An Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States for the Years 1987, 1995, and 2000* (2006) and from a downloadable database of source emission data (U.S. EPA 2001).

The following section identifies specific pulp and paper facilities, crematories, medical waste incinerators, and other potential sources of dioxins/furans in the Port Angeles area. When possible, the location of these sources has been identified on Figure 4. Solid or municipal waste and hazardous waste incinerators also are potential sources of dioxin/furan emissions but no such incinerators are located in Port Angeles (Wilson 2008, Personal Communication).

Estimates of dioxin/furan emissions are provided when available. Most often, these are estimates generated by the EPA based on a survey of published data, and they are expressed as a mass of chemical as a toxic equivalence (TEQ) per mass of media (e.g., 1.5 grams TEQ/kg of wood). Values listed as a TEQ are based on toxic equivalence factors (TEFs) established by the World Health Organization in 1998 (Van den Berg et al. 1998). In some cases, TEQs are based on older TEFs adopted by international convention in 1989 and are referred to as I-TEQs (U.S. EPA 1989).

3.1 Pulp and Paper Mills and Related Industry

A study conducted by the EPA and the pulp and paper industry in 1990 documented the presence of dioxins/furans in bleached pulp, wastewater sludge, and wastewater effluent (U.S. EPA 1990). Concentrations of dioxins/furans in pulp, sludges, and wastes decreased significantly after 1988 as improved technologies and operations practices

reduced dioxin/furan formation (ATSDR 1998). Dioxins/furans are also formed during incineration of wastes, particularly salt-laden wood wastes, in onsite boilers.

Three major pulp and paper mills have been constructed in Port Angeles, only one of which, Nippon Paper Industries, is still operating today. Former and current pulp and paper mills in Port Angeles include the following:

- The Crescent Boxboard Company was built in 1918 and later was renamed Fibreboard. Fibreboard produced cartons and paper packaging until its close in 1970. No emissions data were found for the Fibreboard Company.
- Zellerbach built a mill next to the Fibreboard mill in 1921, at the base of Ediz Hook. The newsprint and paper producing mill first operated under the name of Washington Pulp and Paper Corporation, and later changed its name to Crown Zellerbach. The mill was then purchased by Daishowa America and is currently owned and operated by Nippon Paper Industries. Nippon burns hog fuel (bark wood waste), cardboard, sludges, and residual oil #6 in its onsite boiler (Ecology 1998). No data regarding Nippon Paper Industries' dioxin/furan emissions were available from the Olympic Region Clean Air Agency (ORCAA).
- The Olympics Forest Products Company constructed a pulp mill along the waterfront in 1930. The mill later merged with two independent companies to become Rayonier, Inc. In 1968, International Telephone and Telegraph (ITT) Corporation purchased Rayonier, Inc., renaming the mill ITT Rayonier. The mill operated under ITT Corporation until 1994, when the mill was spun off from ITT Corporation and resumed operating under the name Rayonier, Inc. until its closure in 1997. Rayonier used wood chips, including salt-laden wood, in the onsite hog burner (Integral 2006a).

In addition, a plywood manufacturing company is located on the Port Angeles harbor. A cooperative worker group built the Peninsula Plywood Company in 1941. This company was later purchased by an Alaskan Native village corporation, Klukwan, Inc. Klukwan, Inc. operated under the name K Ply through February 2008. K-Ply used a boilers fueled with wood-only waste produced onsite, supplemented with some purchased wood waste fuel (K-Ply 2004). Some logs were rafted at the mill prior to processing, resulting in the use of some salt-laden wood waste in the hog fuel burner (K-Ply 2004).

Due to the location of each mill on Port Angeles Bay and the abundance of wood as a source of fuel for onsite burners, the mills likely burned wood chips and wood wastes coming from logs floated in Port Angeles Bay and other nearby bodies of water. Use of salt-laden wood in hogged fuel burners can result in significantly higher emissions of dioxins/furans than facilities burning salt-free wood (Duo and Leclerc 2004; Lavric et al. 2004; Luthe et al. 1997; Luthe et al. 1998; Pandompatam et al. 1997; Preto et al. 2005; Uloth et al. 2005).

Emission tests conducted at four Canadian and one U.S. facility using salt-laden wood-fueled boilers demonstrated a range in dioxin/furan emission factors (1.4 to 27.6 ng I-TEQ/kg of wood waste burned), with an average emission factor of 13.2 ng I-TEQ/kg of wood waste burned (U.S. EPA 2003). The amount of dioxins/furans emitted from wood burners is highly variable and depends on the specific waste feed characteristics, the rate of incineration, the percentage of oxygen present in the furnace, furnace and stack temperature, and the amount of time the waste feed was present in the furnace (i.e., residence time).

The former Rayonier mill went through various regulatory and structural changes over the history of its operations. Under normal operating conditions, air emissions were released from numerous sources on site, including the recovery and hog fuel boiler stacks, the chlorine dioxide generator, and vents in the bleach plant, acid plant, and blowpits. Rayonier reportedly emitted approximately 1.5 million pounds of chemicals into the air in 1993, including chloroform, nitric oxide, nitrogen dioxide, sulfuric acid, chlorine, and sulfur dioxide (U.S. EPA 1993). A single source test was performed in 1995, yielding a load of 0.17 mg TEQ/day (FWEC 1997).

Limited testing was performed in hog fuel boiler #6 at the former Rayonier Mill, including bag house ash (1,310 ng/kg TEQ) and washed ash (170 ng/kg TEQ) in 1988 (FWEC 1997). The presence of dioxins/furans has been confirmed in further sampling performed in the hog fuel boiler. Samples from the hogged fuel boiler were obtained in 1989, with resulting total dioxin and total furan concentrations of 2,700 ng/kg and 19,000 ng/kg in boiler ash and 22,000 ng/kg and 22,000 ng/kg in filter ash, respectively (FWEC 1997).

Additional samples of bag house fly ash (total TCDD 160,000 ng/kg; total TCDF 64,000 ng/kg) and filter ash (total TCDD 380,000 ng/kg and total TCDF 33,000 ng/kg) were collected in 1991 and 1993. In 1996, concentrations of 2,3,7,8-TCDD (110 ng/kg) and 2,3,7,8-TCDF (350 ng/kg) were detected in vacuum filter ash (FWEC 1997). Generally, dioxin/furan loading is associated with fly ash as opposed to grate or filter ash (Ecology 1998). A complete description of these sample results is provided by Foster Wheeler Environmental Corporation (1997) and Integral Consulting Inc. (2006a).

3.2 Medical Waste Incinerators

Medical waste incinerators (MWIs) burn solid wastes produced by hospitals, medical research facilities, and veterinary clinics. Medical wastes are incinerated to reduce the volume of waste prior to landfill disposal and to sterilize any infectious materials. Over 95 percent of MWIs constructed in the United States are modular furnaces using controlled air (U.S. EPA 2003). The formation of dioxins/furans during incineration varies greatly depending on the type of MWI, waste feed composition, temperature of incineration, and the length of time the compounds are exposed to elevated temperatures.

EPA (2003) indicates that total dioxin/furan concentrations will vary depending on the residence time of the waste in the incineration chamber. For MWIs operating both intermittently and continuously, the EPA estimates total I-TEQ emission factors of 7.44 x

10^{-11} and 9.09×10^{-10} kg I-TEQ/kg waste for residence times of 2 and 1 second, respectively (U.S. EPA 2003). Identical emission rates were estimated for batch feed MWIs. The average amount of waste incinerated at MWIs nationwide in 1995 was estimated to be 461 g I-TEQ/year (U.S. EPA 2003).

An incinerator was operated at the Olympic Memorial Hospital, which was founded in 1951 at 939 Caroline Street in Port Angeles. Records of the dates of operation, mode of operation (batch, continuous, intermittent), activity level, and waste feed type are not available from ORCAA (Wilson 2008, Personal Communication) or the Olympic Memorial Hospital. It is possible that this incinerator burned medical waste and/or solid waste. No MWI is currently in operation in Port Angeles (Wilson 2008, Personal Communication). Because so little information is available for this facility, no assumptions can be made regarding emission rates of dioxins/furans specific to this incinerator.

3.3 Crematories

Limited dioxin/furan emission testing has been performed at crematories, with reported emission rates of less than 1 μg I-TEQ/body to 80 μg I-TEQ/body. The EPA (2003) reports an average emission rate of 0.50 μg I-TEQ/body from one U.S. crematory. The average emission rate for all tested facilities (including European facilities) is 17 μg I-TEQ/body.

Two crematories currently operate in Port Angeles, the Drennan & Ford Funeral Home and Crematory and the Mt. Angeles Crematorium, both located on Monroe Road. No dioxin/furan emissions data are available for these facilities.

3.4 Automobiles

Incomplete combustion of gasoline and diesel fuel results in the formation of dioxins/furans when a chlorine source is present. Chlorine can come from fuel or oil additives (e.g., dichloroethane). Measurements of dioxins/furans in tailpipe emissions, used oil, and heavily used tunnels have shown that emissions vary based on the type of fuel (leaded, unleaded, diesel), engine temperature, weight or class of the vehicle, and terrain or required engine effort. The congener profiles observed in both tailpipe emissions and used oil samples were found to be similar to the dioxin/furan congener pattern seen in municipal waste incinerator emissions (U.S. EPA 2003).

Since 1950, the Washington State Department of Transportation has gathered information on the annual average daily traffic (AADT), which includes data for both cargo trucks and passenger vehicles. These data are gathered from the Urban Station Couplet of Highway 101, where traffic feeds through the Port Angeles city limits. At mile marker 249.63, where traffic flows in both directions (less than half a mile from the former Rayonier Mill), the AADT was 34,000 vehicles in 1995, 31,000 in 2000, and 34,000 in 2005. The most recent report for traffic data from 2006 shows no significant increase in AADT at mile marker 249.63. AADT data obtained from three stations (each within a one mile radius of mile marker 248.75,) from 1995 until the end of 2006 revealed a 0.7 percent annual increase in AADT within the Port Angeles city limits during this time.

The EPA (2003) estimates the mean emission factor for automobiles using unleaded gasoline (with catalytic converters) to be 14.9 pg I-TEQ/liter of fuel consumed.

Truck data for Highway 101 was recorded at a weigh station within five miles of the former Rayonier Mill. By examining data collected at the weigh station, it is possible to deduce the number of trucks likely to enter Port Angeles at a given time. In 2006, 23,000 vehicles entered Port Angeles, of which 9 percent (2,070 daily units) were cargo trucks. The percentage of trucks passing westbound into the city varied from 8 percent in 1995 (1,280 trucks daily), to 10 percent in 2000 (1,500 trucks daily), and 9 percent in 2006 (2,070 daily trucks). The mean emission factor for diesel fueled trucks is 1,290 pg I-TEQ/liter of fuel consumed (U.S. EPA 2003).

3.5 Fires

While soil dioxins/furans are believed to be primarily the result of anthropogenic sources, the literature also addresses their possible formation naturally as a result of forest fires (Gullett and Touati 2003) and in forest soils in the absence of fires (Hoekstra et al. 1999). Nevertheless, these sources are considered to be relatively minor compared to the anthropogenic combustion sources discussed above. Other human-generated causes of dioxin/furan emissions related to fires include the use of wood fuel, barbecues, and burn barrels. Accidental fires within the built environment also may contribute to dioxins/furan emissions (Ecology 1998).

The EPA (2003) reports that in the United States in 1995, 25 percent of wood burning was related to the residential sector, and 72 percent was related to the industrial sector. Moreover, wood fuel was the primary energy source in 2.6 percent of homes, and wood fuel is the primary heat source in more rural, low-income homes than in other populations (U.S. EPA 2003). ORCAA (2005) reports 3,958 homes that use wood fuel for heating. In Port Angeles, approximately seven percent of homes burn wood as a primary source of heat (City Data 2008).

Studies of flue gas, chimney soot, and the bottom ash found in chimneys and wood stoves have shown measurable concentrations of dioxins/furans. The EPA (2003) estimates an emission rate of 2 ng I-TEQ/kg of wood burned. Dioxin/furan emissions were shown to be greater when building materials, garbage, and treated wood were burned (U.S. EPA 2003).

3.6 Oil Furnace / Heating

The use of heating oil in commercial and residential settings can result in the emission of dioxin/furan compounds. The EPA (2003) reports that no testing for dioxins/furans in air emissions from furnaces was available at the time of writing but found that dioxins/furans had been detected in soot samples collected from the interior of oil-fired furnaces. Therefore, no dioxin/furan emissions estimates are recommended for use. It is important to note the likelihood that some residential and commercial properties in Port Angeles rely on oil for heating, and these furnaces may contribute to dioxins/furans in the environment. For example, a diesel boiler and propane boiler are in use at Monroe

Elementary and Dry Creek Elementary Schools, respectively (Duce 2008, Personal Communication). A boiler also is located at the county courthouse.

4.0 Fate and Transport of Dioxins/Furans in the Environment

Dioxins/furans are released into the environment via a variety of mechanisms, depending on the means of their production and in the source medium in which they are found. The general release mechanisms, transport processes, and transformation and uptake mechanisms are presented in the Conceptual Site Model, Figure 5. Factors affecting concentrations of dioxins/furans in soil (from the air emissions, transport, and deposition pathway) are depicted in Figure 6.

Dioxins/furans generated during the production and use of chlorinated chemicals may be released with waste effluents during the chemical manufacturing process or later during product use. These chemicals then may find their way into ambient air, surface and subsurface soils, groundwater, and surface water. Dioxins/furans generated during combustion or incineration processes may be released into ambient air then may be eventually deposited on surrounding surfaces.

This section draws upon information presented by the ATSDR (1998) and the EPA (2003) to summarize the physical characteristics of dioxins/furans, as well as their release mechanisms, transport, and transformation in the environment.

4.1 Physical Characteristics

As mentioned briefly in Section 1, dioxins/furans consist of two chlorinated carbon ring structures. As chlorine substitution (i.e. the number of chlorine atoms per congener) increases, both the water solubility and vapor pressure decrease. This translates to an enrichment of TCDD/TCDF and PeCDD/PeCDF (low chlorine substituted tetra- and penta- homologue groups) in the gas and dissolved phases in air and water and an enrichment of HpCDD/HpCDF and OCDD/OCDF (high chlorine substituted hepta- and octa- homologue groups) in the particle-bound phases in air and water.

The low solubility and vapor pressure of dioxins/furans are reflected in their Henry's Law constants, which are low and decrease further with increasing chlorine substitution. This indicates that their volatilization from water is a slow process and that more highly substituted congeners will be the least likely to volatilize from water. The volatilization half-life (amount of time required for one-half of a substance to volatilize) for 2,3,7,8-TCDD in lakes and ponds is 32 days, while the half-life for rivers is 16 days (ATSDR 1998).

Dioxins/furans are highly lipophilic, meaning they adsorb strongly to organic matter in soil and sediment, and the higher the carbon content, the more strongly they bind to such materials. As a class of chemicals, they are generally not reactive, and they are resistant to microbial activity (ATSDR 1998).

4.2 Dioxins/Furans in Air

A number of combustion and incineration sources within the categories shown on the Conceptual Site Model (Figure 5) can be identified in Port Angeles. These sources may now release, or have historically released, dioxins/furans to the environment. Formation occurs during incineration of plastics, vegetation treated with chlorinated herbicides, paper and wood treated with chlorophenols, and pesticide-treated wastes. As a result of typical human activities and in the absence of any notable point source of air emissions, urban areas have been shown through ambient air sampling to behave as area-wide sources of dioxins/furans to surrounding areas (Cleverly et al. 2003). This is consistent with the generally higher soil concentrations for dioxins/furans in urban versus rural/remote areas (see Section 5 below).

Dioxins/furans released into the air via combustion and incineration processes are found in both gaseous and particle-bound phases; however, most dioxins/furans adsorb to particles due to their low vapor pressure. Gas phase dioxins/furans are removed from the atmosphere via reactions with hydroxyl radicals and other reactive oxygen species, resulting in half-lives ranging from 0.5 to 9.6 days, depending on the level of chlorine substitution (ATSDR 1998). The half-life of particle-bound dioxins/furans is approximately 10 days, based on wet and dry deposition of the particles (ATSDR 1998). For lighter, less substituted congeners, some photolysis may occur.

Once airborne, dioxins/furans may be widely transported. The presence of dioxins/furans in sediments of water bodies located far from industrial sources demonstrates the wide-ranging transport of these chemicals in the atmosphere (ATSDR 1998). Factors affecting chemical transport include wind speed, physical characteristics of the surrounding environment, the elevation at which they are released, and temperature, as shown in Figure 6.

Particles entrained in wind may eventually be deposited on soils, water surfaces, and vegetation. Particles in air are deposited through settling (e.g., gravity) or by being literally washed out of the air by precipitation. Dioxins/furans as gases may adsorb to plant surfaces (ATSDR 1998). Dioxin/furan particles deposited on vegetation (e.g., trees, grass) may eventually be rinsed into underlying soils. Tree cover has been found to result in a “scrubbing” of ambient atmospheric dioxins/furans, resulting in an enrichment of concentrations in forest soils compared to other locations (Horstmann et al. 1997; McLachlan and Horstmann 1998; Rogowski et al. 1999).

Particulates deposited on land surfaces may be re-entrained by wind and carried to other areas, where they may bind to organic matter in soil or be further transported by overland flow of storm water. Erosion of soil by surface water runoff may ultimately transport dioxins/furans to rivers, streams, estuaries, lakes, and other surface water bodies via storm sewer systems. Wind-blown particulates also may be deposited directly onto water surfaces, where they will partition to bed sediment and, to a lesser extent, adsorb to suspended sediment particles within the water column.

Due to their low vapor pressure and low solubility, dioxins/furans released via air emissions will ultimately be bound to organic matter found in surface soil and bed sediment. The higher the organic content of the soil, the less mobile the dioxins/furans are and the less likely they will be to migrate to subsurface soils and groundwater. Measurements of ambient air dioxin/furan concentrations in relation to ambient temperatures (daytime/nighttime variations) are consistent with the hypothesis that soils act as a reservoir source through volatilization for lower chlorinated congeners (Cleverly et al. 1999).

4.3 Dioxins/Furans on Land

As mentioned in the previous section, the most likely form of transport for dioxins/furans in soil is erosion via wind and storm water runoff. The high lipophilicity of dioxins/furans combined with low vapor pressure and low water solubility indicates that dioxins/furans in soil do not leach well into subsurface soil and groundwater during rain events. The higher the organic carbon content in soil, the less mobile the compounds will be. Due to their lack of mobility, dioxins/furans are most often found in the upper several centimeters of surface soil (ATSDR 1998). In cases where they have been found in subsurface soil and groundwater, it means that transport has been facilitated by mechanical disturbance or by the presence of organic solvents. If the soil's organic content is low and/or higher concentrations of dioxins/furans are present, the lack of binding sites in the soil can also cause their vertical migration to subsurface soils.

Dioxins/furans deposited on soil are not likely to be taken up by plant roots and translocated to the plant shoots because they are hydrophobic and bind strongly to soil. Generally, there is minimal uptake of dioxins/furans via plant roots except for plants from the *Cucurbitaceas* family (e.g., cucumbers, melons, and gourds), which are able to translocate dioxins/furans from the roots to the rest of the plant (ATSDR 1998). Gas and dry particle deposition on plant foliage is the primary uptake route for plants; although loss through photodegradation and volatilization from foliage may occur (ATSDR 1998).

Co-occurrence of dioxins/furans in soil with solvents not only increases the potential for vertical migration, but also may facilitate photolysis, which otherwise is not a reliable method of dioxin/furan degradation. The ATSDR (1998) reports that photolysis of OCDD can occur, resulting in the production of more toxic 2,3,7,8-substituted homologues TCDD, PeCDD, HxCDDs, and HpCDD. Nevertheless, degradation of dioxins/furans in surface soil is generally negligible. Researchers in Times Beach, Missouri found that concentrations of these compounds in surface and subsurface soil samples remained essentially unchanged in core samples collected over a span of four years (ATSDR 1998). The half-life of dioxins/furans in surface soils is estimated to range from 9 to 15 years, while their half-life in subsurface soils may range from 25 to 100 years (ATSDR 1998). Similarly, EPA (2003) provides a half-life of dioxins/furans in soil ranging from 10 to 12 years.

Although some biotic degradation of dioxins/furans may occur, fungi (*Trichoderma viride*, *Phanerochaete chrysosporium*) and bacteria (*Pseudomonas putida*, *Pseudomonas testosteroni*) exhibited limited ability to degrade 2,3,7,8-TCDD in laboratory and field

studies (ATSDR 1998). Nevertheless, biological degradation is not reported to be a significant transformation mechanism for dioxin/furan removal (ATSDR 1998).

4.4 Dioxins/Furans in Water

Dioxins/furans may be released into water through direct discharge of contaminated industrial effluents, discharges from storm drains, and aerial deposition of particles. Although migration of dioxin/furan emissions from the former Rayonier Mill and other Port Angeles sources is outside the scope of the current study, a brief summary of dioxin/furan transport in water is presented for completeness.

Because they are hydrophobic and have low volatility, only a small portion will evaporate to ambient air, and most dioxins/furans will settle out and partition to bottom sediments. A very small amount will partition to particles suspended within the water column. As with soil, dioxins/furans adsorbed to sediment are not mobile, but disturbance of sediment causing resuspension of particles in the water column may increase both transport of dioxin/furan-bound particles and uptake of dioxin/furan-bound particles by biota.

Benthic organisms may accumulate dioxins/furans and other lipophilic chemicals through uptake of interstitial water (water found between sediment particles), ingestion of phytoplankton and zooplankton, and ingestion of suspended sediment. Of these three main uptake pathways, minimal uptake of dioxins/furans occurs via intake of suspended sediment and water (ATSDR 1998). Ingestion of benthic organisms by foraging fish, and their subsequent ingestion by predacious and piscivorous fish results in dioxin/furan transfer within the aquatic food web. Significant transformation of dioxins/furans occurs in aquatic organisms; however, discussion of these processes is beyond the scope of this study.

Photolysis is the dominant loss mechanism for dioxins/furans in water, although this transformation mechanism is reduced for more highly substituted congeners (ATSDR 1998). ATSDR (1998) reports 2,3,7,8-TCDD half-lives for dissolved dioxins/furans ranging from 118 hours in the winter to 21 hours in the summer. The majority of dioxins/furans in aquatic systems are found in the sediments, and their lipophilicity and low reactivity make them resistant to biotic degradation (ATSDR 1998). As with soil, biotic degradation of dioxins/furans in sediments is not reported to be a significant method of dioxin/furan removal (ATSDR 1998).

5.0 Dioxins/Furans in Soils

This study will focus on collecting dioxin/furan data for one environmental medium: surficial soils. The identification of variables that influence the dioxin/furan concentrations in soils is an important component of the conceptual site model. Such variables will be important considerations in selecting sampling locations, developing sampling and sample handling protocols, and interpreting the sampling and analysis results. For an example of a soil sampling plan for dioxin/furan characterization, see U.S. EPA 2007, Appendix C. The available data from previous studies of soils in and near Port Angeles will also provide a starting point for developing a sampling design, and are briefly noted here.

5.1 Factors Affecting Dioxins/Furans Concentrations in Soil

Figure 6 provides a schematic illustration of some of the factors potentially affecting dioxin/furan concentrations at any selected soil sampling location for the air emissions/transport/deposition pathway, which has been noted as a dominant pathway affecting soils apart from direct land applications of materials containing dioxins/furans. The factors listed on Figure 6 relate to the mass emissions over time from sources, air transport factors, the characteristics of the sampling location, and properties of the soils at that location. Detailed application of these factors will guide study design.

The stack emissions from the Rayonier facility occurred in a near-shore environment. The differential heating over land versus over water in a near-shore environment can result in a turbulent boundary layer over land, resulting in plume mixing down to ground level and increasing deposition of particulates to local soils. In reference to Figure 6, the first factor influencing emissions deposition is the magnitude (volume, mass) and duration (operating years) of the emissions from the source. The second factor, height of the stack and temperature of the emissions, affect the behavior of the emissions as they exit the stack, such as how high the plume will rise. The third factor, distance and direction from the source, takes into consideration the emissions behavior and meteorological conditions. Factors two and three affecting plume height, distance, and direction also influence the fourth factor, the elevation of soils potentially impacted by stack emissions.

The ultimate concentrations of dioxins/furans found in local soils are further influenced by factors five, six, and seven: presence or absence of ground cover that can scrub dioxins/furans from air; ground surface slope and potential for flooding that can affect erosion or washing out of soils containing dioxins/furans; and soil disturbance. Disturbances include a number of actions, including tilling, landscaping, cuts related to construction, filling, and amendments to soil (ash, fertilizer, pesticides, etc), among other actions.

The eighth factor listed on Figure 6, depth in soil column, refers to the chemical characteristics of dioxins/furans influencing their fate in soil. As discussed in Section 4, dioxins/furans are highly hydrophobic and are not readily leached into subsurface soils by percolating rainwater. Factor nine, organic carbon content, refers to the chemical

characteristics of the soil on which the dioxins/furans are deposited. The higher the organic matter content in the soils, the more likely the dioxins/furans are to bind to soils and less likely they are to leach into subsurface soils.

Consideration of these factors will be incorporated into the soil sampling design, informing where soil samples will be located to capture the most likely areas of emissions deposition. These factors also will guide the evaluation of the representativeness of local “background” soil samples collected during previous investigations.

5.2 Assessment of Existing Dioxin/Furan Data

Any evaluations of soil dioxin/furan data, and especially any comparisons across studies, need to consider the characteristics of the data and what they do and do not represent. Different studies often reflect different choices on various factors affecting dioxin/furan measurements and interpretations. Reviews of previously collected soil dioxin/furan data for the Port Angeles area have already raised questions regarding the representativeness and usefulness of some results based on how the sampling design and sampling protocols addressed factors such as those listed on Figure 6. In addition to the factors shown on Figure 6, data interpretations and comparisons need to consider additional characteristics, including the following:

- Results reported as bulk versus TEQ values.
- Results reported as total organic carbon-normalized values.
- For TEQ results, consideration of which set of TEFs were used.
- Whether the results include or omit co-planar, dioxin-like PCBs.
- Treatment of not-detected congeners in TEQ calculations (e.g., uniform substitution at zero, one-half, or the full reporting limit, or selective non-zero substitution only for not-detected congener results that are detected and quantified in at least one sample, or other statistical treatment). It is a common finding for some of the 2,3,7,8-substituted congeners to be reported as not-detected in soil samples. How these not-detected results are evaluated can affect calculated TEQ values and complicate the assessment of congener patterns, especially when the overall dioxin/furan levels are only modestly elevated.
- For summary measures, what type of statistic is used (e.g., mean versus median, or arithmetic versus geometric mean).
- Results reported on a dry weight versus a wet weight (rarely used) basis.
- The number of samples collected and analyzed (characterization of variability).
- Whether single grab or composite samples are analyzed (local variability).
- Sieving of the bulk soil sample before lab analyses or other sample handling/preparation steps.
- Analytical methods, reporting limits, and data reporting conventions (e.g., adjusted for recovery).
- Year of sampling (time trends).
- Presence of known dioxin/furan sources near the sample location.

While the literature on levels of soil dioxins/furans is growing, the available information base – for example, general surveys of typical urban soil levels, absent major point sources – is in many respects still relatively small. Compilations and reviews of this literature are available in several reports (U.S. EPA 2003; U.S. EPA 2007; Muller et al. 2004). Recent surveys that include urban areas are available for the Colorado Front Range, Davis County, Utah, and Australia. These reports indicate that dioxins/furans have been detected at measurable, albeit low, concentrations even at remote sampling locations. Their ubiquitous distribution is the result of long-range transport from sources. The general pattern of dioxin/furan concentrations can be characterized as a gradient from remote/rural to urban to near-source areas as follows:

Remote/rural areas < Urban areas < Near-source areas

Where:

- Concentrations in remote and rural areas generally range from less than 1 ppt TEQ up to several ppt TEQ in surface soils;
- Concentrations in urban areas not in the vicinity of notable, large sources (i.e., reflecting general “urban plume” impacts from diffuse or area sources) increase up to a few tens of ppt TEQ; and
- Concentrations in areas close to notable, large emissions sources can increase up to hundreds or even thousands of ppt TEQ.

The distance from dioxin/furan emission sources at which their “signal” can be detected in soils has not been well-characterized. In general, a relatively small fraction of total emissions may deposit locally, even within the first 100 km (Lohman and Seigneur 2001), with the bulk of emitted dioxins/furans being subject to relatively long-range transport.

5.3 Dioxin/Furan Data for Port Angeles Soils

Soils on the former Rayonier Mill property are characterized by sampling results from both EPA’s Expanded Site Investigation (ESI; E & E 1998a) and Rayonier’s remedial investigation (Integral 2006a). A query of Ecology’s Environmental Information Management (EIM) database did not yield dioxin/furan analytical data for soils in Port Angeles; although, several investigations are known to have evaluated dioxin/furan in soils in or near Port Angeles, outside Rayonier properties. Five data sets have been identified that provide data for off-site soils:

- ESI (E & E 1998a) – The site investigation included the collection of 20 off-site soil samples from 14 locations and three background soil samples.
- Rayonier 13th & M Street Landfill (E & E 1998b) – Four surface soil samples were collected at nearby residences and at one residence defined as a “background” location.
- Mt. Pleasant Landfill (E & E 1998c) – Off-site soil samples were collected from six locations of concern to area residents, including gardens and play areas. The

report notes that dioxins/furans were elevated in one “background” sample, which was likely due to a house fire on that property.

- Rayonier Remedial Investigation (Integral 2006a) – As part of the “Ecological Sampling” effort, 15 soil samples were collected in the vicinity of the former mill.
- Gale’s Addition – Collection of eight samples at a parcel undergoing development in the Gale’s Addition neighborhood of Port Angeles, including four surface and two subsurface soil samples and two soil stockpile samples. Additional samples have been collected for this location. These data have not yet been released.

Results from the first three of these data sets have been evaluated in Rayonier’s remedial investigation report (Integral 2006a) and various stakeholder groups. Further evaluation of these data will need to consider multiple factors affecting the measured soil concentrations and their representativeness for this study.

5.4 Dioxin/Furan Data for Washington State Soils

Additional data on soil dioxin/furan concentrations in Washington State are available from Ecology’s EIM system and other sources and will be reviewed for applicability to this study:

- The Oeser Company Superfund Site, Whatcom County (E & E 2002) – Dioxin/furan data collected from residential yards surrounding a wood treating facility to support a human health risk assessment.
- Little Squalicum Park, Whatcom County (E & E 2002; Integral 2006b) – In association with the Oeser Company investigation, additional soil samples were collected near Little Squalicum Creek.
- BNSF Skykomish, King County (RETEC 2005) – Soil samples were collected to support a remedial investigation of a former maintenance and fueling facility.
- Ecology (Rogowski et al. 1999) – State survey of dioxins/furans in soil including data from forest, open, urban, and agricultural areas.
- EPA (2007) – A recent national pilot survey of rural soils included one sample at Lake Ozette on the Olympic Peninsula.
- Cobb et al. (1993) – Soils in the Skagit Valley were collected and analyzed before construction of a proposed municipal waste incinerator to provide an understanding of baseline conditions.

These Washington State data, as well as the compiled national and worldwide data sets (U.S. EPA 2003; U.S. EPA 2007; Muller et al. 2004), will provide an additional context within which to interpret the Port Angeles study results.

6.0 Methods for Source Identification

One of the primary and direct evaluations of the soils dioxin/furan data to be collected in this study will be a comparison of total TEQ values to risk-based cleanup levels under the Model Toxics Control Act (MTCA). The (default) risk-based values are derived from the MTCA exposure and risk equations in Chapter 173-340 WAC and are documented in Ecology's online database of cleanup levels and risk calculations (CLARC). The soil risk-based cleanup level for dioxins/furans has recently been revised as a result of a rule amendment process.

The data also will be evaluated in comparison to other soils data that may represent reference or "background" values, if available, taking account of the differences by land use category. Comparisons to other available Washington State data sets, and compiled national and worldwide results, will provide additional context for the Port Angeles data evaluations.

A major objective of this study is also to evaluate the soil dioxin/furan results with respect to source(s). There have been previous attempts to evaluate possible sources for previously sampled off-site residential soils (MPE 2006). The Rayonier Mill Off-Property study area is a developed urban landscape and as a result will be influenced by the general "urban plume" impacts documented in the literature. The problem of source identification will therefore unavoidably have to address the issue of mixtures of source impacts. Given the mechanisms for air transport and deposition, the relative contributions from general urban sources versus specific sources are expected to change as a function of sampling location; that is, the mixture ratios will be variable rather than constant across the data set. Non-air pathway sources (e.g., direct land application sources) may also contribute, although efforts will be made through the study design process to minimize their influence.

Different dioxin/furan sources have been characterized by their chemical profiles for the seventeen 2,3,7,8-substituted congeners (Cleverly et al. 1997 and Pandompattam et al. 1997). A "profile-matching" approach comparing the source (e.g., emission) profiles to sampled soil profiles, using various statistical approaches, is one idea often suggested for evaluating source identification.¹ It relies on the initial finding that source profiles for different candidate sources are sufficiently distinct to be classified and discriminated in evaluating the soils data set. If source-specific congener profiles are not available (e.g., for the previously operated Port Angeles medical waste incinerator), a general profile for the source category must be used. This is a source of uncertainty for the analysis. Moreover, transformation and fate processes during air transport and after deposition can alter the congener profile, affecting the effectiveness and representativeness of a "profile-matching" analysis. For this study, the soils data may be initially evaluated using a "profile-matching" approach, although it is deemed likely that there will be significant limitations to this approach.

¹ This is sometimes referred to as fingerprint analysis. EPA's Fingerprint Analysis of Contaminant Data (FALCON) guidance uses normalized profile data and regression analysis for this type of evaluation (Plumb 2004).

The question of source identification is from one perspective a classic pattern recognition problem. It may be useful to obtain a data set that provides a wide array of patterns to help identify or classify patterns more clearly and provide a more reliable basis for discriminating source influences. The study design process will consider this question and whether it will be potentially useful to collect additional samples well outside of the likely area of influence of identified Port Angeles dioxin/furan emission sources.

Multiple approaches to data evaluation will be combined in this study to support conclusions regarding potential source identification and contribution allocations. Weight of evidence and consistency criteria will be used in combining the various lines of evidence. Data evaluation approaches, in addition to possible profile-matching, will generally include the following:

- Evaluations of spatial patterns in the soils data set. These may include cluster or gradient analyses based on total dioxin/furan concentrations, TEQ values, or congener profiles. Data mapping to evaluate basic distance - direction patterns will also be performed.
- Chemometric (statistical) evaluations. The soils data set, which will provide multivariate data for at least the 2,3,7,8-substituted dioxin/furan congeners, can be analyzed using a variety of multivariate statistical methods. A general overview of such multivariate methods can be found in several environmental forensics texts (Murphy and Morrison 2001 and Morrison and Murphy 2005). A literature review identifies a number of applications of these multivariate analysis approaches. These statistical analysis approaches can work “backwards” from the soils data set to identify the number of potential (significant) sources of dioxins/furans and their contributions to individual samples. Thus, source profiles are not required. If any additional tracer chemicals are identified that may be particularly useful for tracking the influence of individual sources and discriminating among them, the chemometric evaluations will also take such tracer chemical results into consideration.
- Plausibility evaluations. Any interpretations of the data with respect to potential source(s) based on profile matching, spatial, or chemometric evaluations will also be evaluated for reasonableness on the basis of source-pathway relationships. Information such as the likely magnitude of dioxin/furan emissions, wind rose data, deposition modeling results, validated odor complaint mapping (as reported in the TRC odor study for the Rayonier Mill), comparable results from studies at other sites (e.g., distance from source), and other relevant information can be considered as part of the plausibility analysis.

7.0 Summary

This Conceptual Site Model will be revised as additional information is obtained. Ultimately, the Conceptual Site Model will inform the development of the Soil Sampling Plan, which will describe the study design and methods for data analysis.

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