

## Chapter 6

# Forest Chemicals

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**F**ew issues in contemporary forestry are as contentious as chemical use in management activities. Concerns over chemicals range from their effect on aquatic life, domestic water supplies on adjacent properties, and downstream community water supplies. Often, criticism of chemical use is conflated with opposition to clear-cutting and even-aged forest management.

Many forest managers believe chemicals provide an effective and safe tool to increase growth and yield, allowing forest lands to remain productive in difficult financial environments. Furthermore, chemicals — such as those used to treat root rot stumps, control problems like sudden oak death, or manage invasive species like the gypsy moth — can help maintain forest.

Competing perspectives associated with chemical use in forest management come into play when potable water sources may be affected. Given the range of land uses that can

occur on the watersheds supplying drinking water, understanding how chemicals are used in active forest management may assist in addressing concerns about their use.

Section one of this chapter will contextualize the use of chemicals in active forest management. We will describe the typical cycle of chemical applications in even-aged management in the Pacific Northwest. Then we will review four years of Oregon Department of Forestry Notifications of Operations (notifications) that involve chemical activities. Section two will describe the characteristics of chemicals typically used in forest management. Section three will assess scientific studies related to the effects of chemicals identified in the notifications, focusing on the water quality of streams adjacent to chemical applications that can transport chemicals downstream and potentially affect raw water intakes of community water supplies.

Section four will examine data from four case studies where water sampling was conducted to evaluate the effects of chemical applications in forest management. One of these studies, in the McKenzie River drainage, specifically focused on drinking water source protection. The other three focused on aquatic life effects, particularly on fish species on the federal list of endangered species. Section five will discuss studies that have identified pesticides at raw water intakes, as well as how these chemicals are treated in the water plant if their levels exceed EPA drinking water standards. The chapter will conclude with a summary and findings.

## 6.1. Background

Human activities, such as forestry or agriculture, alter the chemical and physical properties of water in many ways. One way is through the use of compounds such as pesticides and fertilizers. Forest pesticides, including herbicides, fungicides, insecticides and rodenticides, aid the reestablishment and management of forest tree species (Dent and Robben 2000). Insecticides are primarily used to control episodic infestations, such as bark beetles and defoliating insects. Fungicides are similarly used in isolated cases to control plant diseases. Many forest landowners use herbicides to control unwanted vegetation competing with tree seedlings. The broad view on herbicides is that they are the most cost-effective means of achieving reforestation objectives. Rodenticides are used during the initial stages of reforestation to control small mammals (mice, mountain beaver) that girdle seedlings; another category of reforestation chemicals are deer and elk repellents to reduce browse damage by large mammals such as deer, elk and bear. Some intensively managed plantation forests fertilize, with nitrogen or nitrogen plus phosphorus being the most popular (Binkley et al. 1999).

### 6.1.1. Typical sequence of forest chemical use

The *Pacific Northwest Weed Handbook*, Section M, is the standard reference for vegetation control on forestlands (Kelpsas and Landgren 2019), and includes various types of herbicide treatments and chemical mixtures. Figure 6-1 shows the typical sequence of chemical application used on even-aged forest management on private lands, and for some state forestlands (note: forest management activities are significantly different on federal lands). For intensive forest management as practiced on the Oregon Coast Range, treatment may begin prior to harvest by suppressing hardwoods, particularly bigleaf maple, in the understory that are likely to be released when the overstory is cut. This is usually done by “hack and squirt,” a method that introduces the herbicide into the plants by using spaced cuts made at a convenient height. Troublesome grass species such as false brome may be treated preharvest by ground-based backpack spray. Site preparation herbicide treatments are usually conducted after harvest, in the summer or early fall prior to seedling planting, usually through aerial application,

although sometimes ground-based equipment is used depending on terrain and local regulation. The intent of the site preparation applications is to reduce herbaceous plants (grass and forb) that compete with seedlings for moisture, and to eliminate brush and undesirable tree species that compete with desired trees for growing space.

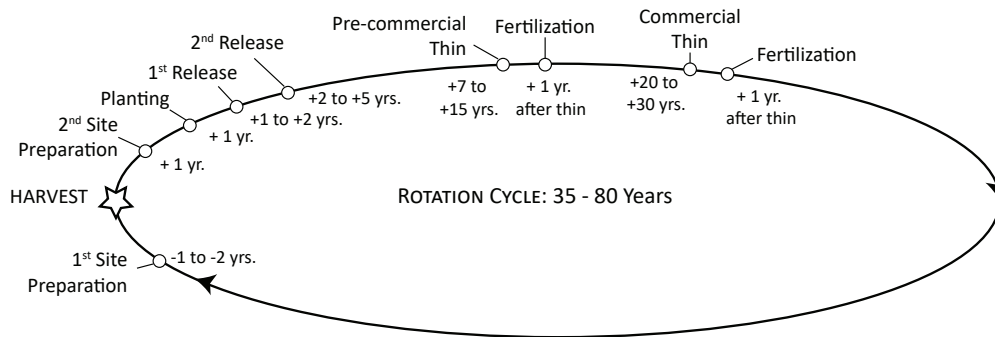


Figure 6-1. Typical even-aged harvest and revegetation cycle.

Once seedlings are planted, wildlife can girdle, bite off, browse or uproot them. Animal repellents and rodenticides are used to reduce these losses until the seedlings are “free to grow,” typically by age 5–7. After planting, especially if site preparation treatments were less than effective, a “spring release” herbicide treatment the first year targets grasses and forbs that compete with the seedlings for moisture. A second release spray two to five years after planting may be used if brush competition is still high. On the coast, additional glyphosate spot sprays may be used to control unwanted hardwoods. Most forest managers conduct one thinning operation, choosing between precommercial thins seven to 15 years after planting or a commercial thin from 20 to 30 years after planting, depending upon site quality and markets. Fertilization is typically used after thinning to accelerate canopy closure in the residual trees. Once these treatments are done, it is unlikely that further chemical applications will be made in the next 20–60 years until just before harvest when the cycle begins again.

### 6.1.2. Chemicals used in Oregon forestry

This section is based on an analysis of ODF Notifications of Operations (notifications) covering four calendar years from 2015 to 2018. The ODF provided notifications that involved the application of chemicals during this four-year period. This data provides an overview of how chemicals are used by forest managers on private and state land in Oregon. The types of chemicals used and the acreage covered can only be verified if an ODF stewardship forester inspects the process or if a complaint is received. Another limitation to this data is that some of the activities proposed in the notifications may not have occurred. What’s more, federal and most tribal land managers are not required to submit notifications to the state on their chemical operations. They follow their own management plans and Endangered Species Act biological opinions. **As such, the data provided here should be used as an indication of the types and extent of chemical uses, rather than exact amounts.**

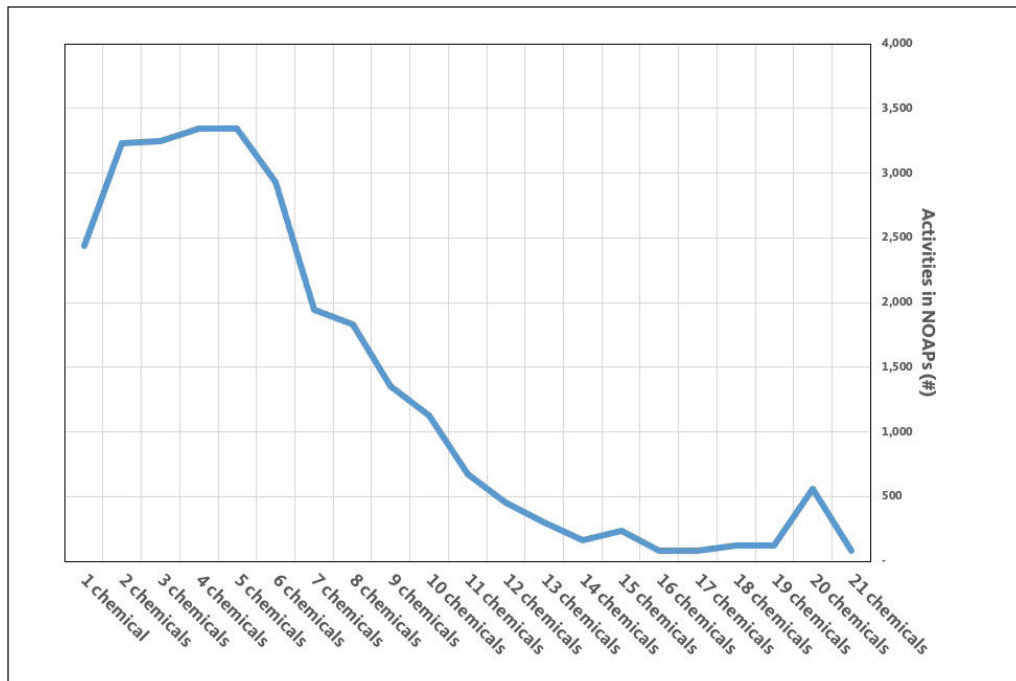


Figure 6-2. Number of chemicals “notified” in NOAP activities, 2015–2018.

From 2015–2018 there were 11,728 chemical application notifications covering 29,511 activities (usually an individual harvest unit or road) submitted through ODF’s FERNs. While 60% of the notifications covered a single activity—and 91% include three or fewer activities—in extreme cases there were hundreds of activities included in a single notification. The largest was 486. When chemical application is included in the activity, multiple chemicals are usually listed (Figure 6-2). For the 11,728 notifications involving 29,511 activities, there were 222 distinct chemicals in almost 160,000 mentions. These chemicals can include one or more herbicides (or mixtures) as well as “adjuvants” — additions to the herbicide formulation to improve its efficacy, application or both. About a third of the activities list up to three, two-thirds list six or fewer, and 75% list seven or fewer chemicals.

There are eight categories of chemical activities used in the FERNs system (Table 7-1). Forest chemicals are typically used in planting harvested areas and maintaining roads, but may also be used to treat infestations of insects, fungi or rodents. Of the notifications submitted during 2015–2018, almost 92% were revegetation related (animal repellent, fertilizer, herbicide [unit] and rodenticide). Road-related activities covered 5.6%, with only three notifications involving forest health (fungicide and insecticides) (Table 6-1). Of the revegetation notifications, 87% were for herbicide applications to previously harvested units, covering almost 4 million acres. However, as we’ll discuss below, there may be multiple chemical applications for the same unit within a single notification.

There are 91 different application methods listed in the notifications submitted during 2015-2018, many of which are duplicative. In general, they can be divided into aerial versus ground-based application. All animal repellents are delivered by ground-based spot applications, while about 98% of fertilizer application is done aerially, typically using a bucket suspended from a helicopter. The fungicides and insecticide treatments were notified as a ground-based spot applications, with only one rodenticide application (<0.1% of the total area) aerially. In the unit herbicide applications, about 28% were notified as aerial applications, with the remainder ground-based. Ground-based herbicide

**Table 6-1. Purposes and area for forest chemical applications 2015-2018.**

Purpose	Acres	% acres	Activities (#)	% activity
Animal repellent application	23,925	0.5%	180	0.6%
Fertilizer application	483,611	10.9%	853	2.9%
Fungicide application	218	0.0%	1	0.003%
Herbicide application*	-		1,100	3.7%
Herbicide application (road)	-		550	1.9%
Herbicide application (unit)	3,843,672	86.5%	26,041	88.2%
Insecticide application	161	0.0%	2	0.01%
Rodenticide application	92,632	2.1%	784	2.7%
<b>Total</b>	<b>4,444,219</b>		<b>29,511</b>	

\* Countywide roadside or spot treatment for noxious weeds.

applications range from stem injection, hack and squirt and backpack sprayers, to ATV- and truck-mounted pressurized sprayers (the last two applications are for roads maintenance). For the county-wide and road herbicide applications, only two out of 1,650 notifications were for aerial application (and these may have been mistakes in the notification). The remaining 82% were manual spot applications, with 16% pressurized broadcast.

The 29,511 activities identified in ODF notifications submitted from 2015 to 2018 mentioned the potential application of 222 different chemical formulations. As noted previously, a single activity often listed multiple chemicals that potentially could be applied (Figure 6-2), resulting in a total of 159,014 mentions in the dataset. **Not every chemical listed in a notification was applied; actual forestry use statistics are not routinely reported to any governmental agency but must be retained for three years and made available upon request by ODF or ODA.**

**Table 6-2. Top 10 active ingredients in ODF notifications, 2015–2018**

Herbicide	% of total*
Glyphosate	16.64%
Sulfometuron methyl	15.41%
Triclopyr	13.91%
Imazapir	12.72%
Metsulfuron methyl	12.10%
Clopyralid	9.32%
Hexazinone	8.81%
2,4-D	8.54%
Atrazine	5.80%
Aminopyralid	2.85%

\* Total percent exceeds 100% due to double counting in mixtures.

Our discussion will focus on two different classes of forest chemicals since they constitute the vast majority of those applied: herbicides (71%) and adjuvants (29%). Within the herbicides, there are 27 different active ingredients, with an additional 10 mixtures of two to three active ingredients. In terms of their frequency in the notifications, the top 10 herbicide active ingredients are shown in Table 6-2. The active ingredients in herbicides are sometimes mixed (about 11% of total mentions) to obtain synergistic effects, or broaden the range of target plants. Formulations may differ in the percent of the active ingredients, how it bonds with the target weeds (generally amine salt or ester), whether it contains additives that affect its efficacy or volatility, and variations in the composition of its inert compounds. (Martin et al. 2011). Tank mixes are a legal, accepted practice by EPA and ODA. Finally, the same manufacturer may market multiple formulations of the same active ingredient under different names targeted to different uses.

**Table 6-3. Adjuvant types found in ODF notifications, CY 2015–CY2018.**

Adjuvant type	# products	Frequency	% of total
Surfactant	46	26,494	57.65%
Carriers	6	8,221	17.89%
Deposition aid agents	3	7,662	16.67%
Spray indicator	5	1,994	4.34%
Anti-foaming agents	7	1,096	2.38%
Buffers	7	293	0.64%
Deodorizers	3	105	0.23%
Drift inhibitors	4	86	0.19%
Emulsifier	1	4	0.01%
Totals	82	45,955	

The other major category of chemicals applied in Oregon forests are adjuvants, or additions to the active ingredient (Jordan 2001; Curran and Lingenfelter 2009). Adjuvants represent 29% of the chemical applications mentioned in the notifications submitted from 2015 to 2018. There are nine basic types of adjuvants identified in the 45,955 mentions in the notifications. The nine types contain 82 different products or formulations (see Table 6-3). *Surfactants* are added to spray mixes to reduce surface tension for better contact with the plant surface, and are over half (58%) of the adjuvants mentioned in the notifications. The second most common adjuvants (18%) are *carriers*, used to transport the active ingredient to the target weed. *Deposition aid agents* (17%) increase the proportion of the spray that reaches the target weeds, and work similarly to *drift inhibitors* (0.19%). *Anti-foaming agents* (or defoamers) are added to suppress surface foam and air entrapment (Curran and Ligenfelter 2009); while *buffers* are added to alkaline (hard) water to avoid having the active ingredient bind with chemicals in the water rather than the target plant. *Deodorizers* are used to control odors in the spray formulation, while *emulsifiers* aid in the effective mixing of the spray batch.

## 6.2. Forest chemical descriptions

Applied pesticides can:

- Attach to solid matter such as soil or carbon particles.
- Dissolve into water.
- Vaporize.
- Be taken up by biota such as plants and animals (Ongley 1996).

The primary determinant for uptake is their behavior with water: *hydrophilic* pesticides form ionic bonds with water, while *hydrophobic* pesticides repel water molecules because they have no charge (i.e., nonpolar). Hydrophobic pesticides are more likely to attach to soil particles and can be transported as suspended sediments in water, while hydrophilic pesticides dissolved in water can move easily through soil and surface water (ExToxNet 1993). The amount of the pesticide that attaches to soil particles is dependent upon the size of the particle and the amount of organic carbon contained in the particle (Karickhoff 1981). Pesticides degrade through sunlight, water, other chemicals and microorganisms. How quickly a pesticide degrades, either in soil or water, is based on its partition coefficient and half-life (Hansen et al. 2015). Table 6-4 shows the modes of action; soil sorption coefficients ( $K_{oc}$ ); solubility in water; vapor pressure; degradation half-life in water (in the presence of light); and degradation in soil (aerobic conditions) for pesticides commonly used in Oregon forestry. The notes to Table 6-4 provide generally accepted thresholds for these attributes by chemical (Lewis et al. 2016). These rates reflect whether the chemical is likely to persist in soil or water or both; vaporize after application; and attach to sediment particles that could be transported downstream.

### 6.2.1. Insecticides

According to Dent and Robben (2000) and Sundaram and Szeto (1987), three chemically based pesticides are commonly applied in Oregon forests: carbaryl, diflubenzuron and chlorothalonil (chlorothalonil, a fungicide, is currently not registered for forestry use in Oregon). A natural, soilborne bacterium, *Bacillus thuringiensis* (Bt), is also used in the Pacific Northwest to control insects. As Table 7-1 shows, there were only two notifications for chemical activities involving insecticides (covering at most 146 acres) from 2015–2018.

**Carbaryl** (chemical formula  $C_{12}H_{11}NO_2$ ), commonly known under the brand name Sevin, is a 1-naphthyl methylcarbamate from the carbamate family. Carbaryl is solid, white in color, and is primarily used as an insecticide. It is toxic to insects but rapidly eliminated by vertebrates. The main species controlled by carbaryl are aphids, fire ants, fleas, ticks, and spiders. However, carbaryl kills not only the target species but also some beneficial species, such as honeybees or crustaceans (USDHHS 2007). Though toxic to humans, carbaryl is approved for use in U.S. The EPA has initially classified carbaryl as potential carcinogen (USEPA 2004a) and in 2016 as “not classifiable as to human carcinogenicity” (USEPA 2016), which could increase the risk for diabetes and metabolic disorders as well as impacting circadian rhythms (Popovska-Gorevski et al. 2017).

Table 6-4. Summary of pesticides encountered in Oregon forest management.

Chemical	Mode of action	Absorption coefficient ( $K_{oc}$ ) <sup>1</sup>	Solubility water (mg/L) <sup>2</sup>	Vapor pressure (mPa) <sup>3</sup>	Water half-life (days) <sup>4</sup>	Soil half-life (days) <sup>5</sup>
2,4-D	Growth regulator	24	24,300	0.009	38	4.4
Aminopyralid	Growth regulator	8.3	2,480	$2.59 \times 10^{-09}$	0.6	35
Atrazine	Photosynthesis inhibitor	174	35	0.039	2.6	75
Carbaryl	Cholinesterase inhibitor	211	9.1	0.0416	10	16
Clopyralid	Growth regulator	5.0	7,850	$1.36 \times 10^{-09}$	271	23.2
Diflufenzuron	Insecticide: inhibits chitin synthesis	4,620	0.08	0.00012	80	3.0
Glufosinate-ammonium	Nitrogen metabolism	600	500,000	0.0031	Stable	7.4
Glyphosate	Amino acid synthesis inhibitor	16,331	10,500	0.0131	69	15
Hexazinone	Photosynthesis inhibitor	54	33,000	0.03	56	105
Imazapyr	Amino acid synthesis inhibitor	125	9,740	0.013	2.1	11
Metsulfuron methyl	Amino acid synthesis inhibitor	12	2,790	$1.40 \times 10^{-08}$	Stable	10
Sulfometuron methyl	Amino acid synthesis inhibitor	85	244	$7.3 \times 10^{-11}$	N/A	24
Triclopyr	Growth regulator	48	8,100	0.1	0.1	39

Sources: National Pesticide Information Center (NPIC). <http://npic.orst.edu/HPT/table.html>. Accessed 4/22/2019.  
*Pacific Northwest Weed Management Handbook*. <https://pnwhandbooks.org/weed/agrichemicals-properties>. Accessed 4/22/2019.  
 Lewis et al. 2016. Pesticide Properties DataBase. <https://sitem.herts.ac.uk/aeru/ppdb/en/Reports>. Accessed 4/22/2019.

Notes: Definitions and thresholds for herbicide characteristics (Lewis et al. 2016).  
 Freundlich ( $\log K_{oc}$ ) used if available in PPDB; otherwise linear  $K_{oc}$ . Values are in mL/g. < 15 = very mobile; 15 - 75 = mobile; 75 - 500 = moderately mobile; 500 - 4000 = slightly mobile; > 4000 = non-mobile.  
 Solubility in water at 20°C. < 50 = low; 50 - 500 = moderate; > 500 = highly soluble.  
 Vapor pressure at 25°C in mPa. < 5.0 = low volatility; 5.0 - 10.0 = moderately volatile; > 10 = highly volatile.  
 Aqueous photolysis (DT50) at pH7. Based on degradation in water exposed to light. < 1 = fast; 1 - 14 = moderately fast; 14 - 30 = slow; > 30 = stable.  
 Soil degradation (aerobic), DT50 (Typical) if available in PPDB. < 30 = non-persistent 30 - 100 = moderately persistent; 100 - 365 = persistent; > 365 = very persistent.



### 6.2.2. Herbicides

Herbicides are pesticides that target plant pests. Among all of the pesticides applied to the forest, herbicides are the most prevalent in the Pacific Northwest (Temple and Johnson 2011). Herbicides are produced in a variety of states, including liquids, granules and powders. In addition to active substances, pesticides include “inert” ingredients. These inert ingredients are not required to be identified but some are known to have toxic properties (Bernstein et al. 2013). To improve the performance of herbicides, other substances called adjuvants are added. We provide a brief description of each of the major herbicides used in Oregon forest management, including widely recognized trade names to aid understanding.

**2,4-D** (sold under various names, such as Crossbow, Weedone or Brushmaster) kills plants by stimulating uncontrolled growth, and is generally used on broadleaved weeds and woody plants. Some of the formulations are strictly confined to vegetation control in road maintenance. The effects of 2,4-D depend on the form (acid, ester or amine) and product (liquid, dust or granules) (<http://npic.orst.edu/factsheets/24Dgen.html>). Ester products perform better in early spring and on woody species (Kelpsas and Landgren 2019). It is highly soluble in water, volatile and has a low potential to leach to groundwater based on its chemical properties (Table 6-4). It is nonpersistent in soil but may persist in aquatic systems under certain conditions. It is moderately toxic to mammals but should not bioaccumulate (Lewis et al. 2016). 2,4-D was originally patented in 1942 in Great Britain and in the U.S. in 1945. Its original formulation patent expired in 1962, but other derivations remain patented.

**Aminopyralid** (Milestone) is a pyridine carboxylic acid herbicide for the long-term control of noxious and invasive broad-leaved weeds. Its mode of action is systemic, postemergent absorption by leaves and roots with some residual action. It is nonvolatile, soluble in water and has a high potential for leaching to groundwater. It is moderately persistent in soil, but has low volatility, high solubility in water (and thus high leachability). It degrades rapidly in surface waters (Lewis et al. 2016; NPIC 2019). Aminopyralid was originally registered in 2005 and is considered a low-risk pesticide (USEPA 2005).

**Atrazine** (Drexel Atrazine 5L) is the second most used herbicide in the U.S., only after glyphosate (Atwood and Paisley-Jones 2017). It is best used on germinating grasses and broadleaf weeds when they are small (Kelpsas and Landgren 2019). Atrazine is absorbed by plants through roots and foliage and accumulates in the new twigs and leaves, where it inhibits photosynthesis. However, in tolerant plants it can be metabolized. Atrazine is soil active, requiring rainfall for activation. It is a restricted-use chemical and can only be purchased and applied by licensed operators.

Atrazine is considered a potential risk to public health through drinking water, and was found to be the most common pesticide detected nationally in drinking water in 2001 (Gilliom et al. 2006). An ongoing national program begun in 2003 monitors approximately 150 community water systems on a weekly basis during seasons when applications are likely, and biweekly during the remainder of the year. The trigger for monitoring is 2.6 parts per billion (ppb) for finished water or 12.5 ppb for raw water over a 90-day rolling average. Continued exceedance can result in a ban on use of atrazine in the source watershed. About 100 community water systems have been determined to no longer require monitoring; however, another 30 have been added. No community water systems in Oregon are listed in either to 2003-2007 initial monitoring, or the latest 2017 list (<https://www.epa.gov/ingredients-used-pesticide-products/atrazine-background-and-updates#drinking-water>).

**Clopyralid** (Stinger, Transline) is a synthetic auxin, killing plants by stimulating uncontrolled growth. Clopyralid is used to control selected broadleaf weeds (including thistles) and elderberry (Kelpsas and Landgren 2019). It is highly soluble in water, volatile in air, and has a high risk of it leaching to groundwater (Table 6-4). It can be persistent in both soil and water systems depending upon conditions. It has a low mammalian toxicity and is not expected to bioaccumulate (Lewis et al. 2016).

**Glyphosate** (Roundup, and a wide variety of product names) is the most sold herbicide in the U.S. (Atwood and Paisley-Jones 2017). It is poorly absorbed by the digestive tract and is almost entirely eliminated unchanged through mammal excrements (Extension Toxicology Network 2019a). Minute amounts of glyphosate can be found in tissues 10 days after treatment. Numerous field and laboratory experiments on animals suggest that glyphosate has no impact on reproduction, which led to the assumption that the compound was unlikely to have any reproductive effects in humans (Extension Toxicology Network 2019a). Glyphosate went off U.S. patent in 2000, which has led to the development of several hundred products (<http://www.glyphosate.eu/history-glyphosate>; <http://npic.orst.edu/factsheets/glyphogen.html>).

A byproduct of glyphosate, aminomethylphosphonic acid, often abbreviated AMPA, is formed by the breakdown of glyphosate by microorganisms in soil and water, with one molecule of glyphosate creating one molecule of aminomethylphosphonic acid. Grandcoin et al. (2017) published a recent review of aminomethylphosphonic acid sources, behavior, and fate in natural waters. In addition to glyphosate as a source, aminomethylphosphonic acid is also formed from the breakdown of phosphonates, typically found in detergents and other industrial uses, and enter streams through wastewater treatment plants. Strongly adsorbed to soil particles, aminomethylphosphonic acid can persist in the soil and move into streams through erosion and sedimentation. While little is known about the toxicity of aminomethylphosphonic acid, it appears to be readily removed by most potable water treatment processes (Grandcoin et al. 2017).

**Hexazinone** (Velpar and others) is a broad-spectrum herbicide used to control grasses, broad-leaved weeds and woody plants by inhibiting photosynthesis (Kelpsas and Landgren 2019). It is active on contact and in the soil, absorbed through plant roots and foliage (Lewis et al. 2016). It can be long-lived in soil, rated as having high leachability, low volatility, and very soluble and moderately persistent in water (Table 6-4) (Lewis et al. 2016; NPIC 2019).

**Imazapyr** (Arsenal, Chopper, Habitat) is an herbicide used to control a broad range of annual and perennial weeds, as well as some woody species. Imazapyr went off U.S. patent in 2002, leading to the development of hundreds of new formulations. Imazapyr acts as a meristem inhibitor through inhibition of amino acid branched chain biosynthesis (NCBI 2020a). Imazapyr degrades in clear waters and is persistent and mobile in soil (Table 6-4). According to the EPA, there is little risk of toxicity to fish and aquatic invertebrates at maximum application rates. Imazapyr is categorized by the EPA as practically nontoxic to avian species, small mammals and honey bees. The EPA also concluded that based on available evidence, carcinogenicity of imazapyr to humans was not a concern (Durkin 2011). Research coordinated by the U.S. Forest Service suggests that imazapyr does not degrade quickly in soils (Durkin 2011), which is supported by the findings of Jarvis et al. (2006) who found an initial half-life of approximately 123 days and a terminal half-life of approximately 2,972 days.

**Metsulfuron Methyl** (Escort XP) is an acetolactate synthase (ALS) inhibitor that obstructs a key enzyme required for amino acid synthesis (UC-IPM 2019). It is readily

absorbed by both roots and foliage and translocated to leaves and stems. It is used to control ferns, and is especially effective on all *Rubus* (blackberry, salmonberry, etc.), as well as other herbaceous species (Kelpsas and Landgren 2019). Metsulfuron-methyl is moderately soluble in water, and unlikely to volatilize (Table 6-4) (NPIC 2019).

**Sulfometuron Methyl** (Oust) is a broad spectrum urea-based herbicide used in forestry to control woody tree species by inhibiting the synthesis of branched-chain amino acids, such as leucine and isoleucine. Microorganisms from soil and hydrolysis in water break down sulfometuron (NPIC 2020). Depending on water acidity, sulfometuron has a half-life between 10 days and eight weeks (NCBI 2020b; NPIC 2020). The compound is nontoxic to birds and slightly toxic to fish. The EPA detected no carcinogenic effects on humans from sulfometuron (NCBI 2020b).

**Triclopyr** (various product names) is a selective herbicide that controls woody and broadleaf plants. Triclopyr converts rapidly to a salt in natural soil and in aquatic environments. In water, breakdown by the action of sunlight is the main source of triclopyr degradation. The half-life in soil is from 30 to 90 days, while in water is less than one day (Table 6-4). Triclopyr is relatively toxic to birds, such as mallards, but not to bees, fish or aquatic invertebrates (NCBI 2020c). According to the EPA, triclopyr is “not classifiable as to human carcinogenicity” (USEPA 1998).

**Mixtures of herbicides.** Herbicides are commonly mixed with the intent to improve the control (Damalas 2004). This occurs in two ways: commercial products that contain multiple active ingredients; and “tank mixtures,” where the applicator determines the chemicals and their concentrations. Active ingredients are “tank mixed” to combine desirable properties, usually to widen the range of target species killed (Damalas 2004).

Damalas (2004) reviewed common interactions among herbicide tank mixtures. He determined that there were three times more cases where the mixes were antagonistic (i.e., reduced activity) as compared to those where the interactions were synergistic (i.e., increase activity). In general, herbicides from the same chemical group were more likely to be synergistic, while combinations from different groups may interact with each other and become deactivated, leading to antagonistic outcomes (Damalas 2004). Kelpsas and Landgren (2019) provide specific tank mix suggestions by target weed species found in forests of the Pacific Northwest.

### 6.2.3. Adjuvants, including surfactants

Adjuvants are defined as “a material added to a tank mix to aid or modify the action of an agrichemical, or the physical characteristics of the mixture” (ASTM 2016). The American Society of Testing and Materials (ASTM International, [www.astm.org](http://www.astm.org)) provides standard terminology and definitions related to adjuvants. Adjuvants can also be certified for their performance and applicator safety by the Council of Producers & Distributors of Agrotechnology (CPDA 2019). Adjuvants are commonly included in spray mixtures (Hartzler 2020). Adjuvants were developed to improve herbicide penetration into leaf cells, as well as aid in the spreading, wetting and adhesion of herbicides to leaves. Furthermore, some adjuvants serve to reduce herbicide drift, eliminate foaming problems in spray tank mixtures, or reduce alkaline hydrolysis (CPDA 2019). Penner (2000) categorizes adjuvants into three classes:

1. Activators that increase herbicide activity, absorption and spread and decrease photo-transformation of the herbicide.
2. Spray modifiers that alter the physical characteristics of the spray.
3. Utility modifiers that widen the conditions under which the herbicide is useful.

Activator adjuvants (e.g., surfactants, spreader-stickers, wetting agents or penetrants) are commonly used to improve the performance of postemergent herbicides by increasing herbicide retention or penetration on or into leaf surfaces, rainfastness, or to decrease photo-degradation of herbicides.

A wide array of adjuvants are available to enhance herbicide efficacy, including surfactants, oil concentrates, ammonium-N fertilizers, spreader-stickers, wetting agents, and penetrants (Curran et al. 1999; Hartzler 2020). Surfactants, particularly nonionic ones, are suitable as dispersing agents aimed at improving plant coverage and foliar penetration with low toxicity to the crop plants themselves. Oil concentrates usually improve penetrability of the herbicide into the leaves. Some fertilizers, such as liquid N fertilizer products, can act as adjuvants and improve the performance of some herbicides, particularly if the mix water is hard. Solutions of liquid N fertilizer are commonly encountered in combination with nonionic surfactants and oil concentrates. Adjuvants can be combined to provide multiple functions, such as ammonium sulfate, which is used to improve herbicide performance in drought conditions or in tank mixtures.

Some of the most popular adjuvants encountered in forestry applications in Oregon are listed in Table 6-5 (Bernstein *et al.*, 2013). The purpose of each adjuvant depends on the application method and intended use of the active ingredient of the herbicide according to the manufacturer's label.

**Table 6-5. Manufacturer-stated purpose for adjuvants in combination with herbicides.**

Adjuvants	Manufacturer stated purpose
Methylated seed oil	“Enhances the consistency or performance of certain post-emergence herbicides” and “improves leaf coverage and absorption.”
Foambuster	“Defoamer for use in aqueous solutions.”
Dyne-Amic	Serves as “nonionic surfactants.”
Grounded	Is “designed to enhance the deposition and absorption of both ground and aerial spray applications.”
Sta-put	“Improves deposition in the target swath and can retard, but not totally prevent drift.”
Syl-Tac	“Provides spreading, wetting and penetration on the leaf surface.”

#### 6.2.4. Fertilizers

The practice of using fertilizers in forest management is widespread in the southern region of the U.S., with more than 1.2 million acres treated annually with nitrogen or phosphorus (Fox et al. 2007), as well as in the Pacific Northwest (Binkley et al. 1999). About 125,000 acre of forestlands are fertilized annually in Oregon (Table 7.1). There is also increasing emphasis on the effects of fertilization on carbon sequestration and carbon and water fluxes. Nutrient dynamics are covered in Chapter 3, Section 3.3.1. In this chapter we will focus on the addition of fertilizers and their potential effects.

**Nitrogen/urea.** Nitrogen and urea are the most commonly used fertilizers. In the Pacific Northwest, tree growth is constrained by available nitrogen. Therefore, young plantations are sometimes fertilized with nitrogen, which is often delivered as pellets of

urea,  $(\text{NH}_2)_2\text{CO}$  and have a 46% content of N (Anderson 2002). The most common rate of application is approximately 200 lb N/ac (or 224 kg N/ha), an amount that balances tree growth with N-losses (Anderson 2002; Flint et al. 2008; Cornejo-Olviedo et al. 2017; Putney 2019). The EPA states that there is “inadequate information to assess the carcinogenic potential” of urea (Persad et al. 2011). Urea can produce skin irritation, but is more likely to do so when petroleum is part of the formulation (Persad et al. 2011).

### 6.2.5. Rodenticides

The usage of rodenticides in the Pacific Northwest is not as widespread as fertilization, with about 25,000 acres treated annually in Oregon (Table 7.1). Most applications are site-specific rather than broadcast. There are three general types of animals that damage seedlings and small trees: voles (*Microtus* spp.), pocket gophers (*Thomomys* spp.), and mountain beavers (*Aplodontia rufa*) (Arjo and Bryson 2007). Most rodenticides are applied underground in the target species' burrows. There are three different types of rodenticides registered for use in Oregon forest management (<https://ferns.odf.oregon.gov/E-Notification>):

**Zinc phosphide** (various product names) is commonly used for rodent and lagomorph (rabbit) control. For rodenticides, zinc phosphide is commonly applied as granules that are ingested. Zinc phosphide produces phosphine gas in the presence of moisture, which then disrupts mitochondrial respiration and blocks protein and enzyme synthesis (NPIC 2019). Zinc phosphide has low solubility in water, low volatility, and is considered nonpersistent in soil (Lewis et al. 2016).

**Chlorophacinone** (Rozol) is an anti-coagulant used for gopher and mice control. It acts by stopping the enzyme that produces vitamin K, needed for blood clotting (NPIC 2019). It requires multiple days of eating before it becomes effective (NPIC 2019). Chlorophacinone has low solubility in water, low volatility, low leachability, and is moderately persistent in soils (Lewis et al. 2016).

**Strychnine** (RCO Omega Gopher Grain Bait) is also used as a rodenticide, and has documented efficacy against pocket gophers (Evans et al. 1990). It works by causing cells in the spinal cord to fire rapidly, causing muscle spasms that can result in asphyxia and death (NPIC 2019). Strychnine is a restricted-use chemical, can only be formulated as less than 0.5% active ingredient, and must be applied only below ground (NPIC 2019).

### 6.2.6. Animal repellents

There are four types of animal repellents, including ones that:

1. Work on fear
2. Create a conditioned response due to prior consumption of the repellent
3. Cause instantaneous pain on contact
4. Taste bad (Trent et al. 2001).

The fear-based repellents usually contain sulfurous compounds such as urine from predators, meat proteins (and blood meal), garlic or putrescent egg solids. Conditioned response repellents are designed to make the animal ill so that they will avoid the treated plant in the future. Thiram (tetramethylthiuram disulfide) is the chemical most used for this. It's registered by EPA as both an animal repellent and fungicide, but doesn't show up on the FERNS list of chemicals. The EPA doesn't consider it a potential threat to drinking water quality, but its use is restricted to commercial applicators. Contact repellents mostly rely on capsaicin (chili) or ammonia to immediately irritate the throat or nostrils

of the animal. Taste repellents are usually bitter: bitrex (denatonium benzoate) has the Guinness Book of Records for the most bitter substance and is widely used to prevent children from ingesting products such as antifreeze, detergents, cleaners and scented markers. Denatonium benzoate is considered to have toxicological concern, but little risk, due to its usage pattern (Lewis et al. 2016).

#### 6.2.7. Formulation used in forestry applications

The pesticides commonly encountered in forestry applications are combinations of chemicals — called formulations — that effectively control the pest. A pesticide formulation is a mixture of active and inactive ingredients: the former prevents, kills or repels a pest to act on a plant, and the latter enhances the effectiveness of the active ingredient or ensures an easier and safer manipulation or application. The presence of many formulations is driven by three factors: variations in solubility of the active ingredient, ability to control the pest, and easiness to handle and transport.

The formulations are delivered in two states: fluid or solid. Liquid formulations are when chemicals are generally mixed with water. However, there are formulations when crop oil, diesel fuel or kerosene are present (Fishel, 2013). The liquid formulation can be separated in several categories, based on the combination of chemical components: emulsifiable concentrates, ready-to-use solutions, ultra-low volume, invert emulsions, aerosols and liquid baits.

The solid formulations can be grouped in ready to use and concentrates, which requires further mixture with a fluid (usually water). The solid formulations are encountered under the following forms, depending on the size of the particle: dusts, granules and pellets. Some authors include the soluble or wettable powders and water-dissolvable granules as solid formulations, but they are a combination of liquid and solids. According to Perry and Randall (2000), the main formulations encountered in forestry applications are solutions (i.e., substances soluble in water or other solvents, such as fuel oil), emulsions (i.e., two unlike liquids mixed together), wettable powders (i.e., finely divided solid particles that can be dispersed in a liquid), and granules (i.e., crystals of the effective chemical bound together with an inert carrier).

### 6.3. Science review of the effects of forest chemicals on source water quality

This study is based on 116 articles and reports, of which 96 were published following peer review. Because the impact of forest activities on the chemical composition of water is a major topic of interest, several major review papers were written in the last two decades (Binkley et al. 1999; Anderson 2002; Michael 2004; Tatum et al. 2017). Among these, two — Binkley et al. (1999) and Anderson (2002) — focused on fertilizers, and two — Michael (2004) and Tatum et al. (2017) — focused on herbicides.

#### 6.3.1. Forest chemicals and changes to the composition of water

Many issues of concern associated with the application of herbicides and fertilizers to manage vegetation involve the unintended collateral effects on other plants, animals, water and air (Lautenschlager and Sullivan 2004; Tatum 2004; Louch et al. 2017). Because the objective of this report is to assess the impact of chemicals on drinking water quality, we will limit the discourse only to herbicides and fertilizers that may affect raw drinking water quality. Since there were only two notifications over the four-year period (covering a maximum of 161 acres), insecticides will not be

covered. It is important to note, however, that their application could have adverse effects on water quality.

**Fate and movement of forest chemicals.** The movement of herbicides through the soil profile depends on a variety of degradative and dilution processes. Biological and chemical processes play a large role in impeding herbicide movement through soil profiles by destroying the herbicide molecule (Michael 2004). The residence time of chemicals is measured with the half-life, which is the time needed for dissipation of half of the amount applied (Michael and Neary 1993). Half-life is measured in days, and for most herbicides commonly used in silvicultural applications, is less than 90 days (Wauchope et al. 1992). Some, such as 2,4-D or sulfometuron, are as low as 10 or 20 days (NCBI 2020b, 2020d).

A vast array of mechanisms impact the fate and toxicity of herbicides, which can be grouped in biotic and abiotic processes (Fenner et al., 2013). The main abiotic mechanisms (i.e., without involving organisms) occurring in the forested environment are hydrolysis and photolysis (Büyüksönmez et al., 1999). *Hydrolysis*, which is the major transformation process for organophosphate and carbamate pesticides, cleaves chemical bonds by the addition of water. *Photolysis* is a transformation of a molecule when excited by ultraviolet light, which can transform carbaryl, for example, into 1-naphthol and methyl isocyanate (MIC), which is highly toxic. However, Büyüksönmez et al. (1999) argued that photolysis does not play an important role in actual degradation, except in limited cases, because usually “only a small portion of the substrate is exposed to light. Biotic mechanisms that transform the herbicides are processes occurring in the presence of microorganisms. The biological transformations breakdown the pesticides when the chemical compound is bioavailable and is compatible with enzymes produced by the microorganisms.

In general, herbicide movement through soil is slow and most forest herbicides have not been detected deep into the soil (Vasilakoglou et al. 2001; Beulke et al. 2004; Weber et al. 2007). Glyphosate, almost immobile in soil, has not been found below 15 centimeters (USEPA 1993). Triclopyr has been found to a depth up to 30 centimeters (Lee et al. 1985, Stephenson et al. 1990), whereas hexazinone has been detected as deep as 75 centimeters (Roy et al. 1989; Feng and Navratil 1990; Allender 1991; Michael et al. 1999). Imazapyr is rarely found below 50 centimeters, but has been detected under 30 centimeters in several soil types (Rahman et al. 1993). Similarly, sulfometuron and metsulfuron move up to 50 centimeters, but are not commonly found below 70 centimeters (Walker and Welch 1989; Lym and Swenson 1991).

An important role in the biological degradation of herbicides is advective dispersion, which slows the movement of herbicide through the soil profile. In advective dispersion, the solute front is partially slowed by interaction with the soil. This advective slowing acts on two directions. First, it dilutes the front; second, it retains the herbicide in the root zone for a longer period of time, during which degradation can occur. Soils with with a high percentage of organic matter and clay have superior advective dispersion of nonpolar pesticides. Advective dispersion and the lack of significant movement through the soil profile impede groundwater contamination by forestry herbicides (Michael 2003). Weber et al. (2007) found that atrazine mobility depends on the type of soil and water solubility of the chemicals. They also found that the amount of herbicide present in soil after four months is a function of the amount of organic matter and is inversely related with soil pH and soil leaching potential. However, their findings are not robust, as a repeated analysis was used in interpretation of the data, which is sensitive to violation of assumptions. Because the authors did not provide any evidence that the assumptions were met, the

interpretation is not necessarily expandable to other areas or chemicals; however, they do provide a perspective on the physicochemical properties of soils on herbicide mobility.

Michael (2004) argued that “the maximum concentrations of herbicide observed in streams is related to the method of application,” particularly if applied to ephemeral or intermittent streams. Broadcast applications are generally associated with the highest concentration observed during the day of application because control on where the herbicide will land is more limited. If application occurs when the ephemeral or intermittent channels contain water, then the herbicides may reach perennial streams. Several studies suggest that on the application day, aerial broadcast applications may result in concentrations of herbicide in streams that are twice as large as concentrations resulting from overland flow during a first storm in the absence of buffer areas (Michael et al. 2006; McBroom et al. 2013; Scarbrough et al. 2015; Louch et al. 2017). Baseflow between storms contains herbicide with concentrations near or below analytical detection limits (Michael and Neary 1993, Michael et al. 1999; Michael 2003). Storms after herbicide application may contaminate the stream until, at most, the fifth storm, when herbicides are typically no longer detected in streams (Louch et al. 2017). Nevertheless, irrespective of the recording time of the application timing, the maximum concentrations observed in streams last from a few minutes to a few hours (Louch et al. 2017). The largest concentrations occur during storm runoff and seldom last longer than 30 minutes, but even these highest concentrations rarely exceed drinking water quality standards (Michael 2004).

Downslope movement of herbicides occurs principally in the form of overland flow or macropore flow (Bastardie et al. 2002; Buttle and McDonald 2002). Overland flow, when occurring immediately after herbicide application, can contain high concentrations of herbicide that could reach streams (Michael 2004). Overland flow depends on the antecedent soil moisture conditions, precipitation rate, infiltration rates and drainage capacity. However, overland flows almost always occur when the instantaneous precipitation rate exceeds the infiltration rate, which in Pacific Northwest rarely corresponds to spraying periods. Current modeling approaches of water movement in the Pacific Northwest mention Hortonian overland flow, but there is no specific term representing it numerically, which suggests that overland flow is a rare occurrence (Wu et al. 2012). For low antecedent soil moisture and high infiltration rates, almost no downslope movement occurs. Alternatively, for high antecedent soil moisture and saturated soil, the infiltration rates may be exceeded, which results in overland flow. Overland flow will almost always appear on poorly drained soils compared with the well-drained soils, given similar slope, precipitation intensity and duration. Fast movement of the overland flow leads to higher contamination levels of streams than when herbicides reach streams through baseflow by leaching through the soil (Michael et al. 1999; Michael 2003). Besides overland flow, the macropore flow can also contribute to downslope movement of herbicides (Shipitalo et al. 2000).

**Herbicide active ingredients used in forestry.** In this study we will review the fate and toxicity of most commonly used herbicides (Clark et al. 2009; Dinger and Rose 2010; and Bernstein et al. 2013), namely 2,4-D, atrazine, glyphosate, hexazinone, imazapyr, sulfometuron and triclopyr.

- **2,4-D** is a phenoxyacetic acid compound that controls broadleaf weeds. The Oregon Department of Forestry monitored several herbicide applications (Dent and Robben 2000) and found that aerial broadcasts of 2,4-D — as the formulation Low Vol 6 (Loveland Products), at a rate of 38.4 and 56.8 ounces per acre and a concentration less than 90% — resulted in insignificant surface water values compared with the water criteria for human health (i.e., 0.14 parts per billion measured vs. 300 parts per billion threshold).



- **Aminopyralid** is a pyridine carboxylic acid herbicide aiming at management of rangeland, pastures and natural areas (wildlife management areas, natural recreation areas, campgrounds, trailheads and trails). Aminopyralid controls broadly the systemic postemergence of a number of noxious and invasive species (USEPA 2005). A benefit of applying aminopyralid is its residual weed control, which limits reinfestations and reduces the subsequent retreatment (USEPA 2005). The EPA found that aminopyralid is practically nontoxic to nontarget animals and is not likely to impact terrestrial and aquatic plants (USEPA 2005).
- **Atrazine** is a triazine chemical used for controlling broadleaf and grassy weeds. When a 10-meter buffer is used, stream management zones have been effective at reducing the amount of atrazine reaching the stream by at least 25% for slopes less than 22% (Matos et al. 2008; Pinho et al. 2008). Atrazine can contaminate surface water and groundwater by runoff from row crops (NCBI 2020d). Atrazine was found to be slightly to moderately toxic to humans through oral, dermal and inhalation exposure; only slightly toxic to birds and fish; and practically nontoxic to bees (NCBI 2020d).
- **Clopyralid**, which contains hexachlorobenzene and pentachlorobenzene as active ingredients, is an herbicide targeting primarily broadleaf weeds (Durkin and Follansbee 2004). Typical application of clopyralid is through backpacks, even though aerial broadcastings may also be used. The toxicity of clopyralid is relatively well-studied for mammals. Those studies suggest that the cancer risk for humans is low (Durkin and Follansbee 2004). Clopyralid is expected to have high mobility in soil and is not expected to be adsorbed by the suspended solids and sediment from stream water. Clopyralid exhibits low toxicity to fish, and is relatively nontoxic to birds, bees and spiders (Durkin and Follansbee, 2004).
- **Glyphosate** is an aminophosphonic analogue of the natural amino acid glycine that inhibits the enzymes used to metabolize amino acids, thus regulating plant growth. It is the most sold herbicide in the U.S. (Atwood and Paisley-Jones 2017). Glyphosate is poorly absorbed by the digestive tract and is almost entirely eliminated unchanged through mammal excrements (NCBI 2020e). Minute amounts of glyphosate can be found in tissues 10 days after treatment. Numerous field and laboratory experiments on animals suggest that glyphosate has no impact on reproduction, which led to the assumption that the compound was unlikely to have any reproductive effects in humans (Extension Toxicology Network 2019a). Glyphosate, measured in a stream as pulses defined by the storm events, does not seem to be short lived. Louch et al. (2017) in the Alsea Watershed Study found that glyphosate is present in water after almost one month and six rain events. In contrast, Caldwell and Courtner (2020) didn't find glyphosate in stream water after application. Both the Louch et al. (2017) and Caldwell and Courtner (2020) studies will be reviewed in detail below.
- **Hexazinone** is a triazine herbicide used against a series of weeds and some woody plants (Tu et al. 2001). Hexazinone is a systemic herbicide that inhibits photosynthesis of the targeted plants. The National Center for Biotechnology Information says hexazinone is "unlikely to be carcinogenic to humans under normal circumstances." Furthermore, hexazinone is considered slightly to nontoxic for birds and bees but slightly toxic to fish and other freshwater organisms.
- **Imazapyr**, which is member of the imidazolinone class of herbicide, is used extensively in both the southern U.S. and Pacific Northwest. As with other herbicides, there are many formulations of imazapyr, the most popular one being

Arsenal, which is produced by BASF. In several experiments reported by the EPA in its registration review (USEPA 2014), imazapyr in its isopropylamine salt form, more so than its acid form, is likely to damage aquatic macrophytes (i.e., aquatic plants growing in or near water), as well as some species of algae. Both forms are considered to be toxic to terrestrial plants (USEPA 2014). The EPA considers imazapyr as “practically nontoxic to mammals, birds, honeybees and fish.” It can be inferred that it poses little risk to humans or other species of animals (USEPA 2014). Tatum (2004) notes that similar to glyphosate, imazapyr poses insignificant risk to invertebrates when exposed to environmentally relevant concentrations. The exposures to imazapyr based on recommended dosages within the best management practices framework raise only minimal concern for animals, except for reptiles and amphibians (Trumbo and Waligora 2009), for which there is a lack of data (Durkin 2011; Tatum et al. 2017).

- **Metsulfuron methyl** is a sulfonylurea compound used as a herbicide for broadleaf weeds and some grasses (NCBI 2020g). Metsulfuron methyl acts by inhibiting cellular division of the shoots and roots. Metsulfuron-methyl has low toxicity for birds, aquatic organisms and honey bees. The EPA classifies metsulfuron-methyl as toxicity class III, being unlikely “to be carcinogenic to humans,” considering that tests on rats did not exhibit an increase in the number of tumors (NCBI 2020g).
- **Sulfometuron methyl**, a benzoate ester that is the methyl ester of the benzoic acid, is active at very low concentrations and is broadcast on forest sites at rates of as low as 26 grams per hectare (Paranjape et al. 2015). Sulfometuron has relatively low soluble in water and increasing pH (10 milligrams per liter at 25°C and pH 5.5) according to the manufacturer (NCBI 2020b). In pine plantations, Michael (2003) found that the type of application has a significantly different impact on water composition. Sprayed sulfometuron leads to only 12.5% of the water samples with quantifiable residues of sulfometuron, whereas the pelleted application, even at lower rates, delivered higher concentrations in more than 70% of the samples. Considering that the sulfometuron applications were combined with a BMP of a 15-meter untreated stream management zone, Michael (2003) concluded that “adverse impacts on watersheds in the southern USA are unlikely.” Due to the assumptions in the Michael (2003) study, this finding cannot necessarily be extrapolated to the Pacific Northwest.
- **Triclopyr**, a monocarboxylic acid, is a selective systemic herbicide used for control of woody and broadleaf (NCBI 2020c). Triclopyr is slightly to practically nontoxic to birds, fish and bees (USEPA 1998). The EPA classified triclopyr as a “Group D chemical (not classifiable as to human carcinogenicity),” based on studies executed on rats (USEPA 1998).

**Changes to water quality due to herbicides.** Besides these review papers, three studies focused on the impact on water quality of herbicides used in silvicultural practices. Studies by Thistle et al. (2009), Louch et al. (2017), and Caldwell and Courter (2020) are relevant to the Pacific Northwest. We will go into greater detail reviewing the last two papers since their results are directly applicable to the most commonly used chemicals and application techniques (aerial spraying) in the Pacific Northwest.

Thistle et al. (2009) evaluated the efficacy of riparian buffers to reduce spray drift into live streams. Conducted in the Coast Range west of Corvallis, Oregon, with stream buffers representing Forest Practices Act-required widths for medium (70-foot) and small (50-foot) fish-bearing streams, the study used fine droplets of water containing sulfoflavine fluorescent dye as a proxy for aerially applied herbicides. Using fine droplets allowed for more precise evaluation of drift since they become entrained in airflows

traveling towards the riparian buffer. Thistle et al. (2009) showed that the riparian buffers captured or deflected approximately 90% of fine spray drift, with evidence that the wider buffers captured more fine spray droplets. Intermediate-density buffers (not clearly defined in the paper) appear to capture a greater fraction of fine droplets compared to open buffers (where there is little interception by vegetation) and dense buffers (where air flows are diverted above and over the riparian area). These findings are consistent with a review of stream management zones and herbicide applications in the U.S. and New Zealand (Tatum et al. 2017).

Louch et al. (2017) carried out an extensive study of the impact of aerially applied herbicides in Oregon's Coast Range using the Needle Branch watershed that was part of the Alsea Revisited paired watershed study (<http://www.watershedsresearch.org/watershed-studies>). An earlier, and much more extensive, reporting of the sample results is found in National Council for Air and Stream Improvement (2013). Glyphosate, imazapyr, sulfometuron methyl, and metsulfuron methyl, and the glyphosate breakdown chemical, aminomethylphosphonic acid, were evaluated in a single herbicide application to the 91-acre unit on Aug. 22, 2010. Three stream-gaging stations had been established as part of the larger Alsea Revisited paired watershed study, and sampling for herbicides in stream water was conducted at these three sites. The upper portion of the unit (above the HIGH gaging station at the boundary between the nonfish and fish-bearing stream segments) is classified as a small nonfish stream under the Forest Practices Act, and as such, it does not require a riparian buffer (although there is a statutory 10-foot setback from spraying open-water areas). The MID site was at the bottom of the harvest unit containing the Small Fish stream segment where a 50-foot buffer was required. The LOW sampling site was approximately 1 kilometer downstream from the spraying.

Samples were automatically collected hourly from just before the application and continuing 24 hours at the three sites. Automatic sampling was manually triggered when storms were predicted, with collection intervals ranging from hourly to every six hours. Subsequently, grab samples were taken approximately weekly during base flows between storms. Two methods were used to analyze the glyphosate and aminomethylphosphonic acid samples: high performance liquid chromatography coupled with fluorescence for all the samples; and, liquid chromatography-tandem mass spectrometry for a smaller subset of the samples. The subset of samples analyzed by liquid chromatography-tandem mass spectrometry are more precise but less sensitive than liquid chromatography-fluorescence, and only about 7% of samples collected were analyzed by liquid chromatography-tandem mass spectrometry, and then only for glyphosate and aminomethylphosphonic acid (NCASI 2013).

Table 6-6 shows the highest herbicide concentrations found in Needle Branch Creek during and after the spray application. Unfortunately, a background "interferent" of unknown composition appeared to vary from sample to sample for glyphosate and aminomethylphosphonic acid, and affected the imazapyr analyzes as well, leading the authors to contend that the liquid chromatography-fluorescence results are "high biased" by unknown amounts (NCASI 2013). Imazapyr, sulfometuron methyl and metsulfuron methyl concentrations were below the method detection limits so they were not analyzed with liquid chromatography-tandem mass spectrometry. "Thus, the absolute bias in the liquid chromatography-fluorescence result for any given sample is unknown" (Louch et al. 2017, 400).

They found that glyphosate was present in water above the regulatory thresholds in nonfish stream locations close to the application sites where no riparian buffer was required. No glyphosate samples were available during and after herbicide application at the fish-bearing sample site due to equipment failure. The other four herbicides

had concentrations so low that the researchers did not expect impacts on any other organisms, other than aquatic plants. Furthermore, the concentrations were so minute that even pulses of any exposure could be mitigated (Table 6-6).

**Table 6-6. Highest herbicide concentrations ( $\mu\text{g/L}$ ) in Needle Branch samples (Louch 2013).**

Sample site	Chemical	Glyphosate	AMPA	MSS	SMM	Imazapyr
	Formulation	Accord XRT II	n/a	Sulfomet Extra	Sulfomet Extra	Chopper Gen II
High	Application	0.062	0.007	Equip. fail	Equip. fail	Equip. fail
	Baseline (after)	0.030	0.007	<1.000	<0.500	0.200
	1st storm	0.084	0.010	<1.000	<0.500	0.400
	2nd storm	0.062	0.009	No analysis	No analysis	No analysis
	3rd storm	0.021	0.004	No analysis	No analysis	No analysis
	4th storm	0.041	No analysis	No analysis	No analysis	No analysis
	5th storm	No analysis	No analysis	No analysis	No analysis	No analysis
Middle	Application	Equip. fail	0.007	<1.000	<0.500	0.200
	Baseline (after)	0.019	0.007	<1.000	<0.500	0.200
	1st storm	0.149	0.008	<1.000	<0.500	0.400
	2nd storm	0.036	0.005	No analysis	No analysis	No analysis
	3rd storm	No analysis	No analysis	No analysis	No analysis	No analysis
	4th storm	0.045	0.004	No analysis	No analysis	No analysis
	5th storm	0.029	<0.004	No analysis	No analysis	No analysis
Low	Application	<0.018	<0.004	No analysis	No analysis	No analysis
	Baseline (after)	0.034	0.008	<1.000	<0.500	<0.200
	1st storm	0.058	0.012	No analysis	No analysis	Equip. fail
	2nd storm	0.040	0.007	No analysis	No analysis	No analysis
	3rd storm	Equip. fail	No analysis	No analysis	No analysis	No analysis
	4th storm	0.042	0.006	No analysis	No analysis	No analysis
	5th storm	No analysis	No analysis	No analysis	No analysis	No analysis
Blank control	MDL	0.018	0.004	1.000	0.500	0.200
	LCL	0.015	0.015	0.625	0.625	0.625

Source: NCASI 2013, Appendices D, E, F, and H. MDL = Method detection level; LCL = Lower calibration level. AMPA = amino-methylphosphonic acid (a breakdown product of glyphosate); MSS = sulfometuron methyl; and MSM = metsulfuron methyl.

To summarize, Louch et al. (2017) concluded that:

- Glyphosate had no impact on site-specific aquatic organisms (in water) and little risk to the Needle Branch aquatic community (in suspended sediment)
- Aminomethylphosphonic acid most likely had “no effect.”
- Imazapyr most likely had “no effect.”
- Sulfometuron methyl was well below the levels shown to have adverse effects on fish, amphibians or invertebrates.

- Metsulfuron methyl was well below the levels shown to have adverse effects on fish, amphibians or invertebrates.

As in many field-based evaluations, there were problems in Louch et al (2017) that likely affected their results:

1. Auto-sampler for glyphosate and aminomethylphosphonic acid failed at MID during application that precludes evaluating the effects of a riparian buffer on in-stream concentrations. There were pulses of glyphosate at HIGH where there was no buffer (other than a 3-meter aerial spray boom turned off on the stream side). Because of sampler failures, it's not possible to determine if there were pulses at MID immediately after application, with or without the contribution from the unbuffered upper reach, and one significant non-fish-bearing tributary that enters Needle Branch.
2. Auto-sampler for Imazapyr, sulfometuron methyl, and Metsulfuron methyl failed at HIGH during application. This precludes understanding impacts of potential drift on these three chemicals when no stream buffer is present. Non-detect at MID during application may not have captured what had happened above due to time-of-travel from the unbuffered upper reach. No analysis was conducted of samples during the application period at LOW since the MID samples were considered Nondetect.
3. Disturbing difference in results based on two different techniques run by different organizations. The liquid chromatography/fluorescence results run by the National Council for Air and Stream Improvement Inc. were approximately twice the concentrations of the liquid chromatography/tandem mass-spectrometer. Justification for this approach is in two NCASI internal reports.
4. The authors discount a liquid chromatography-flouescence glyphosate pulse at LOW during the first storm due to a "background interferent to be present in samples" (pg. 400). They compare this to a liquid chromatography-tandem mass spectrometry sample collected two hours earlier that was Non-Detect. This previous liquid chromatography-tandem mass spectrometry result was used to justify stating that glyphosate did not move the 1 kilometer between MID and LOW. However, the Supplementary material explanation says that the concentrations of this "interferent" were variable, and unpredictable, over the course of the study, and the liquid chromatography-tandem mass spectrometry split samples were only conducted on about 7% of the samples.
5. In the Supplemental file, it appears that the Louch (2017) study used spray buffers on the order of 15–18 meters. Based on Bladon et al (2016), there was a roughly 15-meter buffer left on this section of Needle Branch. Needle Branch is a Small Non fish-bearing stream in the upper reaches (above LOW), then becomes a Small Fish-bearing stream at the site of the LOW stream gauge.

Similar to Louch et al. (2017), Caldwell and Courter (2020) evaluated four chemicals applied in 2016 and 2017 for silvicultural applications on the northwest Oregon Coast. Active ingredients applied were glyphosate, clopyralid, sulfometuron methyl and metsulfuron methyl. These herbicides were evaluated in three harvest units, and one control, on Stimson Lumber Company property in the Tillamook region of Oregon's north coast (including two harvest units within the City of Tillamook's source watershed). Caldwell and Courter (2019) do not specify the Forest Practices Act classification for the streams in these units. The ODF FERNS notifications and written plans for the harvests and chemical applications were reviewed for the three harvest sites. We also obtained

the spray specifications and GPS-based flight line maps for the herbicide applications from Wilbur-Ellis Company (Napavine, Washington). A spreadsheet of the sample analyses supplementary to the journal article was also used.

The 63-acre Powerline unit (2015-511-12269C and 2016-511-05927) has a small fish stream in the lower end of the unit, with six other drainages classified as small nonfish. The small fish stream has a 3.4-acre buffer that also encompasses the lower portions of three small nonfish streams. Above the buffer, it appears there was a 75- to 150-foot no spray zone along the small nonfish stream at the bottom of the unit, but that other small nonfish streams in the unit were sprayed because they did not contain water at the time of application on July 28, 2016. Glyphosate 5.4 (Alligare) and SFM Extra™ (Alligare) were applied at an elevation of approximately 6 meters above the vegetation at a target rate of 4.7 liters per hectare and 280 gallons per hectare, respectively. The adjuvants Crosshair (Wilbur-Ellis) for drift and deposition control, and Syl-Tac (Wilbur-Ellis) as a surfactant were included in the application at 290 milliliters per hectare and 440 milliliters per hectare, respectively (Caldwell and Courter 2019). Water samples were collected at the Powerline unit at a site just below the treated unit (Upstream), and at a second site 3 kilometers downstream (Downstream).

The 42-acre Crowbar (Crow) Unit (NOAP 2017-511-07450) has a medium fish stream, Killam Creek, that also is classified as domestic water use, as well as an unnamed small fish stream, both at the bottom of the unit. There are five additional small nonfish streams draining the interior of the unit. The written plan indicates that no spraying will be conducted within 60 feet of any fish or domestic-use stream. Review of the flight lines on the spray map shows a spray buffer of about 100 feet from any fish or domestic-use stream; all small nonfish streams within the interior of the unit were sprayed. On July 13, 2017 Oust XP (Bayer) and Transline (Dow Agro) were applied by helicopter at between 9 meters and 15 meters above the canopy at a rate of 200 milliliters per hectare and 4.7 liters per hectare, respectively. Oust XP's active ingredient is sulfometuron methyl, while Transline's is clopyralid. Crosshair was also added to the tank mix at a rate of 290 milliliters per hectare. Water samples were collected at Crowbar Creek at the bottom of the unit just above the tributary's confluence with Killam Creek (Treatment), and at a site 1.6 kilometers below the treatment area on Killam Creek (Downstream).

The 82-acre 120 Wasp unit (NOAP 2016-511-13178C) contains small fish streams on its east and west sides (along with a small fish tributary into the interior from the west), and nine small nonfish or unknown status SU streams throughout the interior of the harvest unit. The fish streams contain a 50-foot riparian buffer along a total of 5,280 feet of length. The chemical application plan for 120 Wasp (NOAP 2017-511-06271) specifies a no-spray buffer of 60 feet from fish-bearing streams if the wind is less than 5 mph blowing away from the buffer, and 100 feet if it is less than 2 mph and blowing towards the buffer. The unit was sprayed on July 17, 2017 by helicopter from an elevation of 9–15 meters with a mixture of Oust Extra (Bayer) and Glyphosate 5.4 at a rate of 290 milliliters per hectare and 4.7 liters per hectare, respectively. Oust Extra's active ingredients are sulfometuron methyl and metsulfuron methyl, while Glyphosate 5.4's is glyphosate. Water samples were taken approximately 300 meters from the bottom of the unit (Upstream), and at a second site 1.9 kilometers downstream (Downstream).

The sampling design for the study was that water samples would be collected prior to the spray applications (grab samples), during and subsequent to the application (automated samplers), post application monthly grab samples, and automated sampling during the first two (2016) and three (2017) storms that were predicted to

have greater than 0.5 inches of rain during 24 hours. The auto-samplers for the 2016 Powerline treatment were programmed to collect five samples at varying intervals after spray application (0, 6, 12, 24, and 32 hours); however, due to equipment malfunction, only one sample was collected after application. Grab samples were collected monthly after the spray application during baseflow conditions. Storm event samples for the 2016 treatment were taken at 0, 6, 12, 24, 48 and 72 hours after initiation. The auto-sampling interval changed in 2017 for the Crowbar and 120 Wasp treatments to collect samples hourly for a 12-hour period after the unit was sprayed. During the three storm events, samples were taken at two-hour intervals (24 samples) for the first storm; five-hour intervals (22 samples) for the second storm (storm “2b”); and two-hour intervals (24 samples) for the third storm (Caldwell and Courter 2020, Supplementary Data File).

Caldwell and Courter (2020) referenced contact with the Louch et al. (2017) group in designing their study and analytical methodology. Sample retrieval and storage followed standard practices. They used the liquid chromatography-tandem mass spectrometry sample analysis method for metsulfuron methyl and sulfometuron methyl; gas chromatography-tandem mass spectrometry (GC/MS/MS) for clopyralid and triclopyr, and high-performance liquid chromatography (HPLC) for glyphosate and aminomethylphosphonic acid. Practical quantification levels, i.e., the lowest equipment calibration levels, were 0.1 micrograms per liter ( $\mu\text{g}/\text{L}$ ) for clopyralid, 5  $\mu\text{g}/\text{L}$  for glyphosate and aminomethylphosphonic acid, and 0.01  $\mu\text{g}/\text{L}$  for sulfometuron methyl and metsulfuron methyl. Note that the practical quantification level is different from the minimum detection level: for glyphosate, the minimum detection level was 1  $\mu\text{g}/\text{L}$ . Samples were analyzed by Anatek Labs, Inc. of Moscow, Idaho. Table 6-6 summarizes the results from this study showing the highest concentrations of the active ingredients at the three sites during application, baseline samples and the first three storms.

Caldwell and Courter (2020) report that, “Additionally, glyphosate and aminomethylphosphonic acid were not detected in any surface water samples from pre-application through post-storm grab samples in both study years” (page 6). More accurately, no glyphosate was detected above the 5  $\mu\text{g}/\text{L}$  practical quantification level in the Powerline unit, and none was found at or above the minimum detection level of 1  $\mu\text{g}/\text{L}$  in the 120 Wasp unit in 2017 (L. Courter, personal communication, 4/2/2020). “If glyphosate were mobilized, however, this likely occurred during the first or second storm event when total suspended solids (TSS) concentrations ranged approximately 350 to 500 mg/mL, indicating substantial surface soil runoff” (Caldwell and Courter 2020, page 14).

**Table 6-7. Highest herbicide concentrations ( $\mu\text{g/L}$ ) after silvicultural applications on the northern Oregon Coast (Caldwell & Courter 2019).**

Site and chemical	Formulation	Upstream sample site					Downstream sample site				
		Appli- cation	Base- flow	1st Storm	2nd Storm	3rd Storm	Appli- cation	Base- flow	1st Storm	2nd Storm	3rd Storm
<b>Powerline*</b>											
Glyphosate	Glyphosate 5.4	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	n/a
SMM	SFM Extra	0.03	0.07	0.08	0.03	n/a	<0.01	0.03	<0.01	<0.01	n/a
MSM	SFM Extra	0.01	0.01	0.07	0.01	n/a	<0.01	0.00	<0.01	<0.01	n/a
<b>Crowbar</b>											
SMM	Oust XP	0.32	<0.01	0.10	0.01	<0.01	0.07	0.00	0.17	0.00	n/a
Clopyralid	Transline	1.41	<0.1	0.80	<0.1	<0.1	0.35	0.00	0.98	0.00	<0.01
<b>120 Wasp*</b>											
Glyphosate	Glyphosate 5.4	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
SMM	Oust Extra	0.04	0.01	0.15	0.08	0.01	0.01	<0.01	0.03	0.03	0.01
MSM	Oust Extra	0.02	0.00	0.01	0.01	0.00	0.01	<0.01	0.01	0.01	<0.01

\*All results from Caldwell & Courter (2020) data from Supplementary Data, ieam4196-sup-0001-ieam-2019-029-suppdata\_anon.xlsx, "Detection Data" sheet. Storm sampling reported for the highest recorded value at either upstream or downstream; same with baseline. Practical quantification levels are 0.1  $\mu\text{g/L}$  for clopyralid and triclopyr, 5  $\mu\text{g/L}$  for glyphosate and AMPA, and 0.01  $\mu\text{g/L}$  for SMM and MSM. Minimum detection level for glyphosate at 120Wasp as 1  $\mu\text{g/L}$ .

Sulfometuron methyl was applied at all three sites, and was detected in water samples above the practical quantification level at all three sites. For the Powerline unit, sulfometuron methyl began to be detected at the proximal sampling site 32 hours after application, but then the auto-sampler stopped. Sulfometuron methyl continued to be present at low concentrations throughout the remainder of the study period at the Upstream sampling site. However, sulfometuron methyl was found only in two grab samples at the distal sample site (Downstream), 69 and 76 days after application. At the Upstream site on the 120 Wasp unit, sulfometuron methyl began to be detected five hours after the application began, and peaked at seven hours (Table 6-7). Compared to the application concentrations, sulfometuron methyl was found at four times higher concentrations during the first storm (and at the last sample collected during the storm), twice as high during the second storm, and only a third as high during the third storm.

The pattern at the 120 Wasp Downstream showed two detections during the application period, the first three hours after the start of spraying and the second at seven hours; with trace amounts during the first storm, but concentrations at levels approximately half those of the Upstream site during the second storm, returning to trace levels during the third storm. At Crowbar, sulfometuron methyl concentrations at the site proximal to the application were approximately eight to 10 times those at Powerline or 120 Wasp, with the highest concentration beginning immediately after (or even during) the application. The first flush of sulfometuron methyl at the Downstream site was about five hours after application began, again with the first positive reading being the highest.

Metasulfuron methyl was detected at both the Powerline and 120 Wasp units after application. After spraying at Powerline, trace concentrations were detected at the Upstream site about 12 hours after application during the last collection at the auto-sampler. Metasulfuron methyl was again detected in trace amounts during all baseflow grab samples, then peaked approximately 24 hours into the first storm.



Concentrations during the second storm were about one-tenth for first; no analysis was conducted during the third storm. No metsulfuron methyl was ever detected at the Downstream sampling site at the Powerline unit. At the 120 Wasp site, metsulfuron methyl began being detected at the Upstream site five hours after spraying began, and peaked at seven hours. No metsulfuron methyl was detected during Baseflow sampling at either the Upstream or Downstream sampling sites. During the first storm, metsulfuron methyl at the proximal site began to be detected nine hours after initiation, and peaked at 11 hours at the Upstream site; at the Downstream site, metsulfuron methyl was only detected at the last auto-sample collection 50 hours after the storm began. In contrast, during the second storm at the 120 Wasp unit, metsulfuron methyl was detected at the Upstream site immediately (i.e., potentially remobilized from sediments) and throughout for the 115 hours, and at the Downstream site a similar pattern was seen, although the concentrations were a third to half those at the Upstream site, and the duration was 75 hours. By the third storm, metsulfuron methyl had apparently washed through the system as no detections above the practical quantification levels were seen at either the Upstream or Downstream sample sites. Caldwell and Courter (2020) concluded that both sulfometuron methyl and metsulfuron methyl, as a result of their high sorption factor, primarily moved through the Powerline and 120 Wasp sites with the first storm event. The highest concentrations found during application at Crowbar are likely to result from the drainage pattern and steep stream gradient.

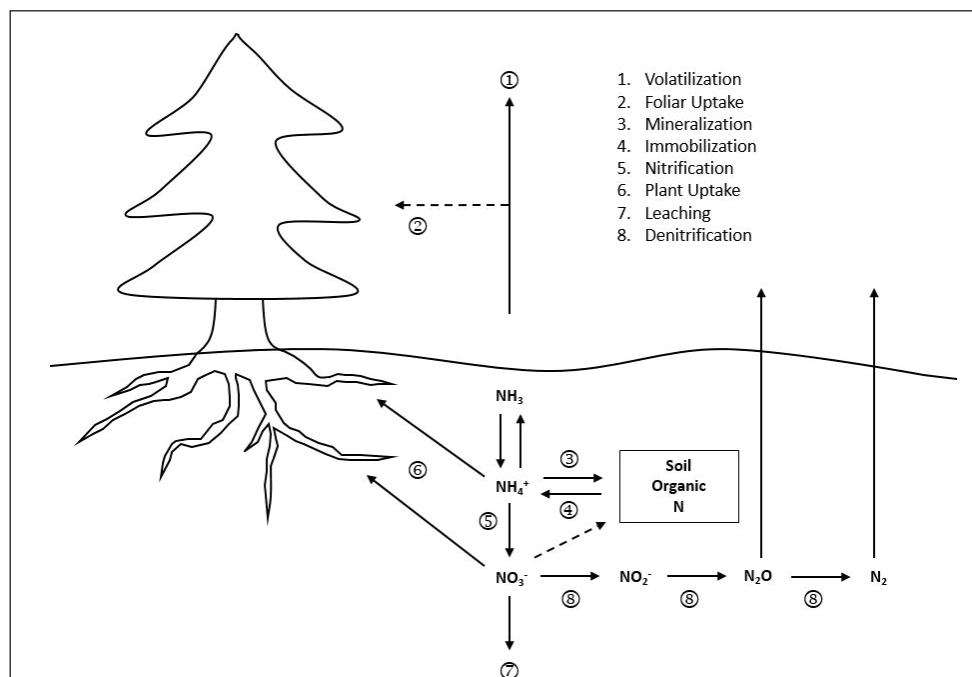
Crowbar was the only unit where clopyralid was applied. Similar to sulfometuron methyl, clopyralid was detected at the Upstream site almost immediately after application began at 10:10 a.m. and by 11:30 a.m. the concentration was 1.41 µg/L, receding during the next seven hours. At the Downstream site, clopyralid detections began about 3.5 hours after spraying started, peaking at 4.5 hours, and continuing for the remaining 21 hours of sample collection. No clopyralid was found at any time in the baseflow samples at either Upstream or Downstream Crowbar sample sites. During the first storm at the Crowbar unit, clopyralid detections began at the Upstream site four hours after initiation, peaked at 16 hours (with a secondary peak at 32 hours), and continued through the remainder of the 44-hour sample collection. Clopyralid detections at the Downstream Crowbar sample site began four hours after the first storm began, peaked at 16 hours, and continued intermittently through the remainder of the 44-hour sample collection. No clopyralid was detected above the practical quantification levels during the second storm at either the Crowbar Upstream or Downstream sample locations. No clopyralid was detected at the Upstream sample location during the third storm. However, at the Downstream site, trace amounts (0.002 µg/L) were detected at the beginning of the storm and lasting for 14 hours until going below practical quantification levels. Caldwell and Courter (2020) theorize that due to its low sorption potential clopyralid mobilized during the first storm event, and thus was not detected during subsequent storm events.

Caldwell and Courter (2020) conclude that while herbicides (possibly with the exception of glyphosate) were found at all sites during application and early season storms, “maximum herbicide concentrations in our study were four orders of magnitude below [human health] benchmarks” (pg. 12). While not noted in the study, it’s quite likely based on early detections during application at the Crowbar site, along with its high stream network density, that overspraying occurred in live nonfish seasonal streams. The data indicate that those herbicides (again possibly with the exception of glyphosate) that are highly sorptive onto sediment particles are remobilized during storm events (i.e., the Downstream sampling sites quickly detecting concentrations at the beginning of storms).

### 6.3.2. Fertilizers

Figure 6-3 shows nitrogen cycling in a typical PNW forest environment (Nason & Myhold 1992). In Figure 6-3, N is elemental nitrogen, having three unpaired electrons that result in large electrostatic attractions;  $N_2$  is dinitrogen, a gas that forms 78% of the Earth's atmosphere;  $N_2O$  is nitrite, commonly converted from ammonium by bacteria through nitrification;  $NO_2$  is nitrogen dioxide;  $NO_3^-$  is nitrate, the base for nitric acid and commonly forms water soluble salts;  $NH_3$  is ammonia, an uncharged molecule, and a gas at room temperature; and  $NH_4^+$  is ammonium, a positively charged molecule that is most frequently found as crystallized salt compounds.

An artificial source of nitrogen comes from fertilization with urea that reaches water either through runoff or thru direct application to the streams (Flint et al. 2008). Besides the peak levels that occur soon after urea applications, prolonged higher nitrogen levels are present for months after the broadcast, which suggests the existence of other pathways for nitrogen, such as lateral movement or leaching into the groundwater (Flint et al. 2008). To study the movement of nitrogen and nitrogen-derived products thru the soil towards the streams is commonly studied with lysimeters (Perakis and Sinkhorn 2011; Devine et al. 2012). Even imperfect, as they provide a punctual representation of a continuous environment (Kitanidis 1997), lysimeters supply a process-based picture of nitrogen movement through the soil matrix. Flint et al. (2008) suggest that approximately 2% of total applied nitrogen leached beyond the rooting zone as nitrate nitrogen ( $NO_3^-$ -N) and ammonium nitrogen ( $NH_4^+$ -N). They found that more than half of the administered nitrogen was accounted for, with 26% in the overstory and 27% in the soil. The distribution of nitrogen among various ecosystem components was measured six months after urea broadcasting, which suggests a long-term impact on stream water. Nevertheless, the results are not necessarily convincing, as the significance was slightly below the commonly stated level of 0.05 (i.e., p-value = 0.03), and the assumptions



Source: Nason & Myhold 1992.

Figure 6-3. Nitrogen cycling in a PNW forest environment.

needed for analysis were not verified, particularly homogeneity of the variance (i.e., heteroskedasticity), which could change the significance (Neter et al. 1996).

The current studies revealed that forest fertilization increases nutrient concentrations in stream water. Binkley et al. (1999) mentioned three main sources for an increase in nutrient concentration:

- Application of fertilizer directly into streams.
- The use of ammonium nitrate forms of fertilizer instead of urea.
- The application of higher dosages by either larger rates or by repeated doses.

Nevertheless, the perspective of Binkley et al. (1999) is that even when higher concentrations of nutrients are achieved, the impact could be minimal with respect to degradation of water quality.

It is argued that the current criteria for stream nutrient concentrations are insufficient to evaluate fertilization's effects, particularly in the Cascade streams of the Pacific Northwest where the supply of nitrogen limits primary production (Bothwell 1992; Anderson 2002). Nitrate concentrations resulting from forest fertilization very rarely exceed EPA standards. Ammonia concentrations beyond prescribed limits have rarely been observed (Binkley et al. 1999). These standards are focused on protection of drinking water for human health, and they are not intended to prevent ecosystem degradation.

There are no drinking water standards for urea-N, as the compound is not toxic and does not represent a threat to human health (Binkley et al. 1999). However, there are standards for urea breakdown products, such as nitrate nitrogen ( $\text{NO}_3\text{-N}$ ) and nitrite nitrogen ( $\text{NO}_2\text{-N}$ ). Nitrate in drinking water can be a direct human health hazard when transformed to nitrite in the digestive system in quantities sufficient to reduce the oxygen-carrying capacity of red blood cells. This is mainly a concern for infants, pregnant women and nursing mothers. The EPA uses the 10 milligram per liter standard as the maximum contaminant level for nitrate-N and 1 milligram per liter for nitrite-N for regulated public water systems (WQA 2013). Phosphorus in drinking water generally does not pose a serious or direct human health risks (Scatena 2000). Phosphorus is often added to municipal drinking water to reduce corrosion and leaching of lead and other toxins from water pipes. However, high phosphorous and nitrogen runoff can also create harmful algal blooms (Gatz, 2018) as toxic blue-green algae called cyanobacteria (included in the Contaminant Candidate List [CCL]) (USEPA 2015).

In summary, while elevated N export often occurs after clear-cut harvests and forest fertilization may increase dissolved N in some waterways, available scientific evidence suggests that these increases are usually temporary and do not seriously degrade drinking water quality in most cases. To date, nitrates have not been found to accumulate in drinking water as a sole result of forestry activities in quantities that exceed drinking water standards (Bisson et al. 1992; Binkley et al. 1999, Anderson 2002; Binkley et al. 2004). Perhaps of greater concern from a drinking water perspective are the cascading and cumulative ecological effects that elevated levels of nitrates and phosphates can have in lakes and rivers. This emerging issue is discussed in the following section.

**Changes to water quality due to nutrients.** Flint et al. (2008) and Poor and McDonnell (2007) conducted studies about fertilizers in the Pacific Northwest. Both studies pointed to changes in nutrient concentrations, with the largest contributor being the nonforest activities. Flint et al. (2008) suggested that human sewage is the main source of N, whereas Poor and McDonnell (2007) argued that agricultural catchments

supplied N-concentrations larger than residential catchments. Both studies indicated that the smallest source of stream nitrogen associated with human activities is related to forest management. Nevertheless, the two studies used simple statistical analyses that did not provide evidence that the assumptions needed for valid inference were tested, which does not support generalization of their findings. Furthermore, Flint et al. (2008) hypothesized that “if fertilizer is applied on steeper slopes where surface flow is present, impacts on surface water quality could be greater.” They did not provide any experimental evidence to support this perspective, however.

In addition to these studies, a large body of research has been dedicated to the leakage of nutrients — mainly nitrogen and phosphorus — from the forest following harvesting operations. Almost all studies pointed to a change in water chemistry, sometimes even without the presence of a nearby harvest (Greathouse et al. 2014).

Several studies (i.e., Gravelle et al. (2009), Slesak et al. (2009), and Devine et al. (2012)) focused on nutrient dynamics were also of interest for the Pacific Northwest, even when no fertilization occurred. Gravelle et al. (2009) studied nutrient concentration dynamics before and after timber harvest in the Mica Creek Experimental Watershed in Idaho. Their study revealed a significant increase only in  $\text{NO}_3 + \text{NO}_2$ , but no change in total phosphorus, orthophosphate and total nitrogen. These findings could be influenced by the possible inclusion of outliers in the analysis, clearly identified in Figure 9 without a formal assessment of their impact. They also used an analytical framework not necessarily suitable for repeated measures, as the comparisons were executed using Student’s t-test.

Other studies developed models predicting nutrient concentrations from environmental variables — such as flow, temperature or time of travel for a reach — for management or scientific decisions (Sigleo et al. 2010; Johnson et al. 2011; Wise and Johnson 2011; Devine et al. 2012). However, the absence of a formal and complete model development framework (Neter et al. 1996; Kitanidis 1997) suggests that the models are in essence a different perspective on hypothesis testing rather than an analytical tool. Without any assessment of the confidence in the results, some of these studies, such as Wise and Johnson (2011) or Johnson et al. (2011) serve predominantly an intuitional role rather than a decisional one.

The most common fertilizer used in the Pacific Northwest is urea. Binkley et al. (1999) argued that even though there were no detectable effects of forest fertilization on the composition and productivity of stream communities, more research was needed — “especially in relation to P fertilization.” The main effect of nitrogen and phosphorus is eutrophication, increased growth of plants that can deplete dissolved oxygen in water and ultimately suffocate aquatic organisms. However, as evidence suggests, since BMPs became standard practice in forest management, the impact of forest fertilization on the addition of nitrogen to surface water is negligible in contrast with agriculture and residential activities (Binkley et al. 1999; Poor and McDonnell 2007; Flint et al. 2008). Therefore, assuming a proportional impact on eutrophication, one can infer that the main sources of eutrophication are related to actions occurring outside the managed forest. A similar conclusion was reached by Anderson (2002), which states that “biological responses may be minimal in small streams nearest to application because of light limitation, but may be elevated downstream where light is sufficient to allow algal growth.” He continues by saying that “algal response could be greatest in downstream reaches.”

### 6.3.3. Best management practices

Best management practices, or BMPs, are a set of practices, often voluntary, that reduce nonpoint pollution to standards compatible with water quality goals (Robben and Dent 2002). Riparian buffers are an example of a BMP. In a comprehensive study of the impact of the most common herbicides used in the BMP practices — namely 2,4-D, glyphosate, hexazinone, imazapyr, metsulfuron, sulfometuron and triclopyr — Michael (2004) concluded that single-stem injection and soil spot application with a 10-meter buffer will lead to stream contamination of very small amounts, up to 0.04 milligrams per liter. While small, that amount could represent “a level of contamination that cannot be eliminated by current methods of stream protection,” according to Michael (2004).

Current trends in water quality protection are focused on the effects of an increase in the riparian management area width. Several studies revealed that herbicide application on ephemeral and intermittent streams without riparian management areas resulted in high level of stream contamination, sometimes up to 0.6 milligrams per liter on the day of application (Michael et al. 1999; Michael 2004). Michael (2004) argued that the increase of the buffer zone to protect the perennial streams have a beneficial effect on water quality, but a riparian management area beyond a 10-meter width will not lead to significantly different impacts on stream contamination with herbicides. Overall, the current results suggest that silvicultural herbicide applications implemented with contemporary BMPs are unlikely to result in chronic exposure of aquatic biota, and applications according to the BMP practices are unlikely to degrade surface waters (McBroom et al. 2013).

Current BMPs focus on keeping fertilizer applications well away from drinking water sources to reduce the chances of fertilizer being mistakenly applied directly into them. This is usually done by specifying retention of a buffer strip of vegetation adjacent to streams and water bodies (a streamside management zone) where fertilizer preparation and use is not allowed. These vegetated buffers serve to help filter nutrients mobilized by harvesting and site preparation from subsurface flows before they enter waterways. Filtering effectiveness generally increases with increase in buffer width (Pike et al. 2010). Feller (2009) suggests that buffers greater than 100 meters remove essentially all excess nutrients, although effectiveness varies by watershed and with soil properties, topography, subsurface hydrology, vegetation type and other factors.

If properly implemented, BMPs to minimize nutrient flushing after forestry activities and the potential for fertilizers to get into waterways are generally considered to be effective (Cristan et al. 2016; Stednick 2008). However, rigorous studies of BMP effectiveness are still limited (Edwards et al. 2016) and most industrial forest owners apply fertilizers by helicopter (Hanley et al. 2006) which can be imprecise. Also, risks of dissolved nutrients in runoff affecting drinking water may be locally higher where the source watershed is smaller, steeper and closer to the municipal water intake, contains a significant percentage of commercial timberland, or where tree plantations within the source watershed are fertilized multiple times.

## **6.4. Prevalence of chemicals found in streams related to forest management activities**

This section will describe the results of four monitoring studies conducted in watersheds that have active forest management as their primary land use. We will begin by providing EPA standards and criteria for evaluating the presence of pesticides in drinking water, particularly their fates from application to breakdown.

### 6.4.1 Standards, health advisory and human benchmarks for forest chemicals

The EPA under the Safe Drinking Water Act (see Chapter 2) determines water quality standards for treated water through its National Primary Drinking Water Regulations (CFR Part 141). In addition to required water quality standards, the EPA also provides states pesticide guidance to consider incorporating in their own regulations. Table 6-8 shows these different standards, and their relevant levels for chemicals commonly used in forest management. Because these standards and guides are for finished (i.e., treated) water, any levels exceeding them in raw water would require treatment.

**Table 6-8. U.S. EPA 2018 Drinking Water Standards, Health Advisories and Human Health Benchmarks for pesticides and nutrients (fertilizers).**

Chemical	Trade names	MCL (mg/L)	MCL	Health Advisory Level (HAL) (mg/L)	Human Health Benchmark (HHBM) (µg/L)
2-4DP-p salts & esters	Hi-Dep; Weedar 64; Weed RHAP; Amine 4; AquaKleen (Amines)	0.07	Goal		230
Atrazine	Aatrex; Atratul; Fogard; Gesaprim; Griffex; Mebazine; Primatol A; Vectal	0.003	0.07	N/A	N/A
Aminopyralid	Milestone; Capstone; Opensight		0.003		3,000
Carbaryl	Sevin; Prokoz			1.0	N/A
Clopyralid	Stringer; Curtail; Transline; Redeem				960
Diflufenzuron	Dimilin				100
Glufosinate-ammonium	Liberty, Cheetah, Scout, others				40
Glyphosate	Roundup; Rodeo; Accord; Glyphomate	0.7		N/A	N/A
Hexazinone	Velpar; Pronone; 10G		0.7	3/2	N/A
Imazapyr	Arsenal; Chopper				16,000
Metsulfuron methyl	Opensight; Escort; Ally				1,600
Sulfometuron methyl	Oust				1,760
Triclopyr	Garlon 3A; Capstone; Redeem; Remedy				300
Nitrate (NO <sub>3</sub> -) Nitrogen	Urea fertilizers	10		N/A	N/A
Nitrite (NO <sub>2</sub> -) Nitrogen	Urea fertilizers	1	10	N/A	N/A

Sources: HHBM: <https://iaspub.epa.gov/apex/pesticides/f?p=HHBP:home>

HAL (1-day, 10-day child exposure): <https://www.epa.gov/sites/production/files/2018-03/documents/dwtable2018.pdf>

MCL/MCL Goal: <https://www.epa.gov/sites/production/files/2018-03/documents/dwtable2018.pdf>

Trade names: <http://pmep.cce.cornell.edu/profiles/extoxnet/TIB/tradename-index.html>

Trade names: [https://www.fs.usda.gov/Internet/FSE\\_DOCUMENTS/fseprd496996.pdf](https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd496996.pdf)

*Maximum Contaminant Levels* are federally enforceable standards for finished (i.e., treated) drinking water allowed under the Safe Drinking Water Act and developed under EPA's regulatory authority (40 CFR §141.2). The determination on whether to regulate is based on three criteria:

1. The contaminant may have an adverse effect on the health of persons.
2. The contaminant is known to occur or there is a high chance that the contaminant will occur in public water systems often enough and at levels of public health concern.
3. Regulation of the contaminant presents a meaningful opportunity for health risk reductions for persons served by public water systems (<https://www.epa.gov/dwregdev/how-epa-regulates-drinking-water-contaminants>).

The list of contaminants subject to regulation with maximum contaminant levels are listed in the Code of Federal Regulations (40 CFR §141.61) for both organic contaminants (§141.61(a) and synthetic organic contaminants (§141.61(c)). Nitrate and nitrite nitrogen are addressed in §141.62(b)(7) and (8). When contaminant levels are above the maximum contaminant level, water utilities must apply additional measures to reduce their levels using “best available technology” (40 CFR §). For organic contaminants, best available technologies are determined for each contaminant from within three types: granular activated carbon; packed tower aeration; or oxidation, Depending upon the contaminant, there may be more than one acceptable treatment type (§141.61(b)). For inorganic contaminants (nitrate and nitrite nitrogen), best available technologies include ion exchange, reverse osmosis and electro dialysis (nitrate only)(§141.62(c)).

*Maximum Contaminant Level Goal* is the maximum level of a contaminant in drinking water that has no human health effects, with the addition of a margin of safety to incorporate uncertainty. The maximum contaminant level goals are nonenforceable criteria (40 CFR §141.2).

*Health Advisory Levels* are informal technical guidance for contaminants without enforceable standards but that may have human health effects (USEPA 2018). However, they may be used by states to set their own standards. Five health advisory levels are provided:

- One-day health advisory (child consuming 1 liter of water for one day).
- Ten-day health advisory (up to 10 days of exposure, with child consuming 1 liter of water per day).
- Lifetime health advisory (adult drinking 2 liters of water per day)
- Reference Dose that is likely to be without an appreciable risk during a lifetime, incorporating an order of magnitude of uncertainty and based on a person's weight (milligrams per kilogram per day).
- Drinking Water Equivalent Level (DWEL) that is derived by multiplying the reference dose by body weight and dividing this figure by daily water consumption.

These health advisory levels are based on noncarcinogenic effects. A sixth health advisory criteria is the level of the contaminant in water that would entail a lifetime cancer risk of 1 in 10,000 (USEPA 2018). In Table 6-8, we have reported the health advisory levels using the both the 1-Day and 10-Day child exposure criteria for illustrative purposes; a complete list of contaminants and all standards and advisories can be found with EPA (2018).

*Human Health Benchmarks* are defined as levels of pesticides “at or below which adverse health effects are not anticipated from one-day or lifetime exposures” (USEPA 2017). The human health benchmarks were developed for those chemicals that the EPA has not set health advisory levels or an enforceable federal drinking water standard (USEPA 2017). The human health benchmarks can be found at: <https://iaspub.epa.gov/apex/pesticides/f?p=HHBP:home>

*Health-Based Screening Levels* are developed by the U.S. Geological Survey for contaminants that do not have EPA maximum contaminant levels or human health benchmarks for pesticides (Norman et al. 2018). These can be found at <https://water.usgs.gov/water-resources/hbsl>.

#### 6.4.2. Pesticide monitoring techniques

Studies of pesticides in water typically rely on two types of sampling: passive sampling where the equipment remains in the stream for a certain duration and is then taken to the laboratory for analysis; and grab samples, which are taken at one time, stabilized, and analyzed in the laboratory. The benefit of passive samplers is that they integrate pesticide concentrations in the water column over a longer period of time, and are thus more likely to discover contaminants that are transitory or present in relation to rainfall or flow events. Two types of passive sampling equipment are used: polar organic chemical integrative sampler and semipermeable membrane device, often together since they target different classes of compounds. Alvarez (2010) reviews both polar organic chemical integrative sampler and semipermeable membrane devices. Both polar organic chemical integrative samplers and semipermeable membrane devices can provide concentration and load determinations if adequate streamflow data is available. The National Environmental Methods Index, a program of EPA and USGS, provides specific information on available analysis techniques for contaminants through a searchable database (<https://www.nemi.gov/home/>).

**Polar Organic Chemical Integrative Samplers** are designed to sample water-soluble (polar or hydrophilic) organic chemicals from aqueous environments. The polar organic chemical integrative sampler provides time-weighted average concentrations of chemicals over deployment periods ranging from weeks to months. It consists of a solid material (sorbent) contained between two microporous polyethersulfone membranes. The membranes allow water and dissolved chemicals to pass through to the sorbent where chemicals are trapped. The polar organic chemical integrative sampler extracts are then analyzed by various instrumental techniques, including high-performance liquid chromatography (HPLC), gas chromatography (GC), gas chromatography mass spectrometry (GC/MS) and liquid chromatography mass spectrometry (LC/MS) (NEMI 2020a). Polar organic chemical integrative samples are designed for more water soluble organic chemicals that are represented by the relative hydrophilic versus hydrophobic characteristic logarithm of the octanol/water partition coefficient ( $\log K_{ow}$ ) of less than 3. This includes most pharmaceuticals, illicit drugs, polar pesticides (such as glyphosate, AMPA, glufosinate), phosphate flame retardants, surfactants, metabolites and degradation products (Alvarez 2010). The pesticide-polar organic chemical integrative sampler uses a triphasic admixture of Isolute ENV+ and Ambersorb 1500 or 572 carbon dispersed on S-X3 BioBeads (Alvarez 2010).

**Semipermeable Membrane Devices** are generally used for sampling neutral organic chemicals with a log octanol-water partition coefficient ( $K_{ow}$ ) greater than 3. Polycyclic aromatic hydrocarbons, polychlorinated biphenyls, chlorinated pesticides,



polybrominated diphenyl ethers, dioxins, and furans are all commonly measured using semipermeable membrane devices (Alvarez 2010). Of particular importance is that quality control samples should represent 20– 50% of the sample set and include semipermeable membrane devices -fabrication blanks, semipermeable membrane devices -process blanks, reagent blanks, field-blank semipermeable membrane devices, permeability reference compound samples, semipermeable membrane devices spikes and procedural spikes (NEMI 2020b).

#### 6.4.3. Levels of forest chemicals found in streams draining Pacific Northwest forestlands

Along with the studies used in the science review, we identified are four additional locations where water quality sampling has been (and is) conducted to determine pesticide levels likely related to forest management activities. These are:

1. The Hood River watershed which is not used as surface source water.
2. The South Yamhill River, the water supply for Sheridan, Oregon.
3. The McKenzie River, the source for Eugene's water supply.
4. The Hoh River watershed in Washington state.

South Yamhill and Hood River are part of the interagency network of Pesticide Stewardship Partnerships; while the Hoh River serves a similar function in Washington. The Eugene Water and Electric Board has a long history of studies related to water quality and land use in their source watershed, the McKenzie River. Other than EWEB's studies on the McKenzie, all the other studies were focused on evaluating the effects of pesticides on aquatic organisms. However, in none of these studies were the actual amounts of pesticides, their time of application or location known. As a result, these studies are best characterized as reconnaissance-level assessments of the prevalence of pesticides in streams draining forest lands.

**Hood River Pesticide Stewardship Partnership.** The Hood River watershed has been the site of extensive pesticide monitoring since the late 1990s. The Hood River Pesticide Stewardship Partnership was founded in 2000 to support this sampling through outreach to users. The Oregon Department of Environmental Quality began sampling for pesticides in the Hood River basin in 1999 (Temple and Johnson 2011). Chlorpyrifos and azinphos-methyl were studied in 2002 and 2003 by Jenkins (2004), and USGS supplemented the DEQ sampling in 2011-2012 (Hapke et al. 2016). The DEQ produced two reports on their grab samples and polar organic chemical integrative sampler/ semipermeable membrane device sampling in 2014 (Masterson and Crown 2015, Crown et al. 2015).

While the primary focus for sampling was pesticide use in orchards and effluent from fruit-packing operations, there were seven grab sample sites that had more than 85% forest and less than 5% agriculture or orchard land uses. (Temple and Johnson 2011, Appendix A). These sites are Dog (n = 41; 2001–2004); Hood, Middle Fork (n = 17; 1999–2000); Hood, West Fork, Mouth (n = 21; 2008–2009); Hood, West Fork, RM 2.5 (n = 6; 2008 – 2009); Hood, West Fork, RM 4.7 (n = 20; 1999–2001); Neal Upper, Above Diversion (n = 113; 2001–2007) and Neal, Upper, Below Diversion (n = 97; 2003–2009). Most sampling took place during the months from March to June, with additional small numbers of samples in September and October depending upon the year and site (Temple and Johnson 2011, Appendix B). The range of pesticides included in the grab sampling changed over the period, with additional ones added in 2007, 2009 and 2010

(these latter ones were not included in Temple and Johnson, 2011). In addition to the grab samples, during 2011 and 2012 year-round monitoring of pesticides was conducted using polar organic chemical integrative sampler and semipermeable membrane device passive samplers (Hapke et al. 2016). In both these studies, the focus was on effects of pesticides on aquatic life, particularly endangered Species Act-listed salmon.

The results from grab samples from 1999 to 2009 are reported in Temple and Johnson (2011). No detections were found for atrazine in 295 samples at the seven sites. There was one detection of the insecticide chlorpyrifos in 2008 at the upper Neal Creek below the diversion; the exact concentration was not reported, but it may have exceeded the 0.041 µg/L of the lowest aquatic life water quality standard. One detection of fluometuron, an herbicide only registered for cotton, was found in upper Neal Creek in April 2009, but at a concentration four orders of magnitude below EPA benchmarks. Finally, there were occurrences in 2009 of hexazinone at all sites in Neal Creek, likely as a result of forest operations; concentrations of between 0.04 and 0.10 µg/L were found in March through June, along with other occurrences at 0.04 µg/L in September and October. These concentrations of hexazinone are five to six orders of magnitude less than water quality benchmarks for aquatic life. Temple and Johnson (2011) also report detections of imazapyr in 2010 at sites below forest land uses, although this data is not incorporated into their analyses.

The USGS continuously monitored pesticides in the Hood River watershed from March 2011 to March 2012 using polar organic chemical integrative sampler and semipermeable membrane device samplers to determine time-weighted average water concentrations over each two-month deployment period (Hapke et al. 2016). Four sites were sampled: the mouth of Neal Creek (also sampled by DEQ); Rogers Creek (a tributary to the Middle Fork Hood River); Green Point Creek at its mouth; and the West Fork (W.F.) Hood River at its mouth. Based on the land use descriptions in Hapke et al. (2016), the Neal Creek site receives “pesticide-laden fruit processing facility wastewater discharge” (page 3); Rogers Creek has only 9% forest land use (compared to 14% agriculture with the remaining bare rock); while both the W. F. Hood River (DEQ sample location) and Green Point Creek (a tributary to the WF Hood River) deployments in the upper watershed were intentionally sited in cooperation with ODF because they would be harvested and sprayed during the deployment period in the fall of 2011.

The polar organic chemical integrative samplers detected four forestry-use herbicides at both the Green Point Creek and W.F. Hood River sites during their late August through October 2011 deployment (Hapke et al 2016). These chemicals, and their concentrations at Green Point Creek and WF Hood River, respectively, were: triclopyr (0.170 µg/L., 0.250 µg/L); 2,4-D (0.170 µg/L, 0.250 µg/L); chlorsulfuron (0.027 µg/L, 0.026 µg/L); and at W.F. Hood River only, metsulfuron methyl (0.070 µg/L). Pyrethroids and chlorpyrifos were not detected at either site. Legacy pesticides, such as hexachlorobenzene (a fungicide) were found at Green Point Creek (0.000015 µg/L) and W.F. Hood River (0.000013 µg/L), and *o,p'* and *p,p'*-DDT at the W.F. Hood River site (0.000007 µg/L for each). None of these levels were sufficiently high to merit discussion.

In 2014 the DEQ collected grab samples and installed polar organic chemical integrative sampler/semipermeable membrane devices in the Hood River basin (Masterson and Crown 2015, Crown et al. 2015). One sample site, Upper Neal Creek downstream from the irrigation diversion, is the same site reported in the Temple and Johnson (2011) study. Low levels of hexazinone (Velpar) were found in four samples at the Upper Neal site; imazapyr was also found in four grab samples at this site in March and October at around 0.050 µg/L or lower. Both imazapyr and hexazinone concentrations were significantly lower in 2013 and 2014 than they were observed in 2009–2012 (Masterson

and Crown 2015a). Diuron, an herbicide used to control annual and perennial broadleaf and grassy weeds in noncrop areas and fruits (NCBI 2020h), was found once in March, twice in April, once in May and once in October 2014 at the Upper Neal Creek site at concentrations of 0.0111 µg/L., 0.0227 µg/L, 0.0402 µg/L, 0.0121 µg/L, and 0.0904 µg/L, respectively, much below its maximum residue limit (MRL) in food and agriculture products when pesticides are applied correctly of 4.29 µg/L. Propiconazole, a systematic foliar fungicide (ExToxNet 1993), was detected once in April and again in October, 2014 grab samples at concentrations of 0.0681 µg/L and 0.042 µg/L, again much below its MRL of 21.5 µg/L. Neither diuron nor propiconazole is currently approved for use in forestry. None of the polar organic chemical integrative sampler/semipermeable membrane device or sediment sample sites corresponded to a location having the majority of upstream land use in forestry (Crown et al 2015).

**South Yamhill River Pesticide Stewardship Partnership.** The second Pesticide Stewardship Partnership site that provides information on the effects of forest management on residues in stream water is a subset of the larger Yamhill PSP using three sites on tributaries to the South Fork Yamhill River in the Grand Ronde area (Cook et al. 2018). The South Fork Yamhill River is used as a surface water source for the City of Sheridan, especially during periods of high demand (MSA 2002). Forest land uses comprise 32% of the source watershed area for Sheridan (DEQ 2018). The pesticide sample sites were at the mouths of Agency Creek, Gold Creek and Rogue River; with about 54 grab samples collected from October 2010 through October 2016. In addition, a polar organic chemical integrative sampler was installed at the Rogue River site for 28 days in October 2010. Other than standard ODF notifications for chemical activities, no additional detailed information on the timing, location or amounts of pesticides applied during the study were available. Pesticide loadings into receiving streams were not determined because stream discharge data was not available.

Land use in Agency Creek above the sampling site is 96.4% forest, with 1.5% urban and 2.1% other. There is no agriculture in the basin. For Gold Creek, 94.7% of land above the sample site is forest, with 3.3% urban and 1.8% other. Only 0.2% is classified as agriculture. The Rogue River subwatershed is more urban (8.6%), with other representing 4.4%, and agriculture 0.2%. The remaining 86.8% of the land in the Rogue River subwatershed is forest. Agricultural uses include grass and hay for livestock consumption, and small Christmas tree farms. The predominant herbicide active ingredients used by forest managers in the course of the study were glyphosate, imazapyr, atrazine, metsulfuron-methyl, sulfometuron methyl and hexazinone. In addition to these chemicals, there were two degradates, aminomethylphosphonic acid from glyphosate and desethylatrazine from atrazine. Generally, herbicides were used during the spring (March 1 to May 30) and fall (Sept. 1 through Oct. 31), based on ODF Notification start months (Cook et al. 2018). Table 6-9 shows a summary of the results compared to EPA aquatic life benchmarks.

As with Hood River, the primary focus for pesticide monitoring in the South Yamhill PSP study was the potential effects of pesticides on fish and other aquatic life. Of the herbicides, only imazapyr was detected in Agency Creek (0.126 µg/L in October 2010); while hexazinone (once), metsulfuron-methyl (twice), sulfometuron methyl (four times), and the glyphosate degradant aminomethylphosphonic acid (once) at the Rogue River sampling location. The vast majority of pesticide detections were found in Gold Creek (note: Table 9 in Cook et al. [2018] incorrectly labels this as “Agency Creek”). Atrazine (seven times in 2011 and 2012, along with another seven times for its degradate desethylatrazine in 2012) and hexazinone (twice in 2012) were found in Gold Creek. The aquatic herbicide fluridone, detected at Gold Creek in both April 2012

and 2013; however, it is not labelled for forestry use and it is unknown where and why it was used. DEET (N,N-Diethyl-meta-toluamide) is an insect repellent that was detected twice in Gold Creek in September 2012 and April 2014, and once in Agency Creek in August 2016. There is no evidence that the detection of DEET was related to a forest management activity. The 2010 polar organic chemical integrative sampler deployment for 28 days in the Rogue River (at Highway 18) detected the presence of atrazine, hexazinone, and triclopyr in low levels; a grab sample taken once at the same site detected no herbicides.

The results from the South Yamhill study are similar to those found at Hood River. There are detections of herbicides typically used in forest management activities, but at levels significantly below those that are likely to cause harm to humans in either acute or chronic exposures (Cook et al. 2018). However, one limitation of the South Yamhill study is the lack of sampling after the onset of rains in the fall which is when other studies have shown pesticide runoff.

**Table 6-9. Water quality sampling results from South Yamhill PSP, 2010–2016.**

Herbicide	Samples (#)	Detections (#)	Detection frequency (%)	Aquatic life benchmark (µg/L)	Benchmark exceedences (#)
Atrazine	183	6	3.3%	1	0
AMPA	63	1	1.6%	249,500	0
DEET	168	3	1.8%	37,500	0
Desethylatrazine	153	8	5.2%	N/A	N/A
Fluridone	168	1	0.6%	480	0
Hexazinone	168	3	1.8%	7	0
Imazapyr	157	1	0.6%	24	0
Metsulfuron-methyl	57	2	3.5%	0.36	0
Sulfometuron methyl	153	4	2.6%	0.45	0

Source: Cook et al. 2018, Table 5.

**EWEB McKenzie River Project.** Forested lands represent 88% of the McKenzie watershed (Morgenstern et al. 2017). Over half the McKenzie watershed is managed by the Willamette National Forest. The BLM manages a sixth, and the remaining third is a variety of industrial and nonindustrial timberland owners. Most of these private owners are concentrated in the Mohawk, Gate Creek, Mill Creek and Quartz Creek basins. EWEB owns the 900-acre Leaburg Forest, a patchwork of properties bordering the Leaburg Power Canal and Hydroelectric Plant. While one purpose of the forest is to generate revenue, improving forest condition will also improve water quality and increase habitat benefitting EWEB's Federal Energy Regulatory Commission (FERC) license requirements (EWEB 2017). Trout Mountain Forestry created a Stewardship Plan in 2016 intended to demonstrate best forest management practices to protect water quality and improve forest health; and the first thinnings in the forest were conducted in 2017 (Morgenstern 2017).

The first drinking water source protection plan for EWEB was published in 2000 (Blair 2000). Forestry is identified as a potential source risk in the 2000 plan, but most concern is related to sediment from forest roads and changes in peak flows from harvest activities. A new 10-Year Strategic Plan (2018-2028) following the American Water Works Association G-300 standards for implementing source water protection programs was finalized in 2017 (EWEB 2017). This plan emphasizes monitoring of storm

events during first flush winter and spring storms. It also formalizes the “Pure Water Partnership” ([www.purewaterpartners.org](http://www.purewaterpartners.org)) to provide landowner incentives to protect source water quality. “Healthy Forests Clean Water” focuses in the middle and upper watershed to reduce wildfire risk, protect water quality, increase fish and wildlife habitat, and generate revenues through stewardship contracts on Willamette National Forest lands. Private industrial forestry activities are identified as a general focus area for the Middle McKenzie region of the watershed.

The EWEB conducted a baseline source water protection study from 2000–2009 (Morgenstern et al. 2011). One part of this project included an EWEB and USGS storm event monitoring program, begun in 2002 and extending to 2010, that focused on pesticides and other dissolved organic compounds. Industrial forestry was one of three primary land uses evaluated for the study; the others were urban runoff and agriculture (Kelly et al. 2012). Subbasins likely to experience high amounts of chemical application were identified by ODF notifications. Sampling was conducted based on ODF notifications; however, there was no information on pesticide application rates, the exact chemical or the volume applied. Grab samples were collected twice-yearly at 28 tributary and mainstem sites, resulting in 117 samples during 16 sampling events during storm runoff in the fall and spring. Fifteen of the sample sites were characterized as “forestry” with a total of 33 samples collected during the study. Of the 51 pesticide detections at the forestry sites, almost two-thirds occurred during spring storms (31), with the most of the others (18) occurring during fall storms, and none during nonstorm sampling. There was a statistically significant relationship ( $r=0.68$ ;  $p<0.0001$ ) between pesticide detections and rainfall at the forestry sites. A total of 14 pesticide compounds were detected at forest sites, although using a minimum reporting level of  $0.1 \mu\text{g/L}$  reduced this number to three compounds, of which two were unique to the forestry sites (imazapyr and nicosulfuron, with one detection each). Only one compound, triclopyr, exceeded  $1.0 \mu\text{g/L}$  at a forestry site, but on further investigation was determined to be a recent homeowner application.

In addition, USGS began using polar organic chemical integrative sampler/semipermeable membrane device passive samplers in September and October 2007 at three sites, and then expanding to six sites between March and October 2010 (McCarthy et al. 2009). Results from the passive samplers are reported in McCarthy et al. (2012 [data] and 2014 [analyses]). Only one sampling site (E310, Camp Creek at Camp Creek Road) potentially shows the influence of active forest management. This site is 85% industrial forest, 13.5% agriculture (pasture, Christmas trees, livestock, blueberries, etc.) and 1.5% rural residential land use. (Note, however, that Kelly et al. [2012] characterize this site as a “mixed” land use). During the 2007 polar organic chemical integrative sampler sampling at Camp Creek, although 21 pesticides were detected, none were found at levels greater than the method detection level, generally less than one nanogram per liter (ng/L). In the 2007 semipermeable membrane device sampling, diethyl phthalate, benzophenone, phenanthrene, flouranthene, and pyrene were detected at levels between the method detection level and the method quantitation limit (McCarthy et al. 2012). During the sampling at Camp Creek from May 25 to June 23, 2010, hexachlorobenzene, lindane, o,p'-DDD, endosulfan-II, endosulfan sulfate and trans-permethrin were all found at, or greater than, the method quantification level (McCarthy et al. 2012, Appendix 2, Table 4). In the 2011 sampling from April 20 to May 18 and Aug. 24 to Sept. 22, hexachlorobenzene and pentachloroanisole found at levels above the method detection level. None of these chemicals are typically used in forest management, although o,p'-DDD (Mitotane) may be present as a degradant of historic DDT applications. It's also used as a pharmaceutical to treat adrenocortical carcinoma and Cushing's syndrome in humans.

The EWEB Strategic Plan (Technical Appendix) and other communications are clear that EWEB believes that forested lands produce higher quality water than any other potential surface water source. EWEB recognizes that forest management use of pesticides is a potential risk, but through their tracking and monitoring, they consider it a comparatively low risk (Morgenstern et al. 2017). “The water quality data from samples collected downstream of industrial forest land uses indicates various pesticides being detected at low levels during significant rainfall events. Even though this data indicates forestry activities are a lower-priority threat, EWEB continues to monitor water quality and work with forestry stakeholders to prevent and reduce wildfires, mitigate roads, increase riparian forest buffers and reduce chemical use” (Morgenstern et al. 2017, 25). This perspective is shared by the USGS researchers who conducted the reconnaissance level monitoring: “... even though the data are limited, these results indicate that effects of forestry pesticide use are negligible at these locations in the river system ... .” (Kelly et al. 2012, 30). “Although forest land use is predominant in the basin, and forestry pesticide use can be detected in small tributaries draining forested lands following application, these compounds were rarely were detectable in the McKenzie River. Forestry pesticide use, therefore, probably is not a potential threat to drinking-water quality at the present time.” (Kelly et al. 2012, 32). “... the majority of compounds that present a documented threat to drinking water quality, in terms of water-quality regulations or suspected endocrine disruption, are associated with agricultural and urban land use applications rather than forestry.” (Kelly et al. 2012, 34)

**Hoh River study.** Similarly to the South Yamhill study in Oregon, the Washington State Department of Agriculture partnered with the Hoh Indian Tribe to evaluate pesticide occurrence in areas managed for commercial timber production on the Olympic Peninsula (Handcock 2018). For a pilot study, the agriculture department chose four tributary streams to the Hoh River that were expected to have timber harvests and reforestation activities during the study period. These streams are Elk Creek (3.74 square miles, 77% Washington Department of Natural Resources land, 23% private timber and 0.4% nonprofit); Winfield Creek (10.74 square miles; 54% state natural resource department land, 41% private timber, 5% nonprofit); Lost Creek (2.11 square miles; 67% private timber, 2% state, 31% nonprofit); and Nolan Creek (9.69 square miles; 49% state, 35% private timber; 17% nonprofit). The nonprofit lands are owned by The Nature Conservancy and the Hoh River Trust and are intended to create a 10,000 acre, 32-mile conservation corridor from Olympic National Park to the Pacific Ocean (TNC 2017). They have few timber harvests (Handcock 2018).

Each site was grab sampled six times during the summer of 2017: a mid-July background sample, and then weekly from Aug. 9 through Sept. 5. Seven herbicides commonly used in forestry were analyzed: glyphosate, glufosinate-ammonia, aminomethylphosphonic acid, imazapyr; triclopyr, metsulfuron methyl and sulfometuron methyl. Sample collection, storage and analyses followed the state agriculture department’s standard operating procedures. Quality assurance methods for the pesticide analyzes included field replicates, field blanks, matrix spikes and matrix spike duplicates. Laboratory quality control included laboratory control samples, laboratory control sample duplicates, surrogate spikes and method blanks.

No herbicides were detected at any of the four sites during the background sampling on July 17, or during the first sample event on Aug. 16. Nor were detections ever made during any sampling event in Winfield Creek. Herbicides were found at the other three sites sampled, with 13 positive detections found at these sites: glyphosate (four detections), glufosinate-ammonium (seven detections), and aminomethylphosphonic acid (two detections) (Table 6-10). The most detections occurred on Aug. 23 with

five detections, and the only herbicide ever found in Lost Creek was glufosinate-ammonium on that date. At Nolan Creek, glufosinate-ammonium was found on three out of the four sample dates, glyphosate and its degradant aminomethylphosphonic acid on two occasions. At Elk Creek, glufosinate-ammonium was detected in the last three sample dates; as was glyphosate on Aug. 23 and Aug. 29, with its degradant aminomethylphosphonic acid on the last two sample dates. In no case were concentrations of herbicides detected above EPA aquatic health benchmarks (Handcock 2018).

**Table 6-10. Herbicide detections in the 2017 WSDA Hoh River study.**

Date	Location	Herbicide	Concentration (µg/L)
8/9/2017	Nolan Creek	Glufosinate-ammonium	0.008
	Nolan Creek	Glyphosate	0.010
8/23/2017	Nolan Creek	Glufosinate-ammonium	0.058
	Nolan Creek	Glyphosate	0.032
	Lost Creek	Glufosinate-ammonium	0.008
	Elk Creek	Glufosinate-ammonium	0.010
	Elk Creek	Glyphosate	0.266
8/29/2017	Elk Creek	AMPA	0.015
	Elk Creek	Glufosinate-ammonium	0.003
	Elk Creek	Glyphosate	0.027
9/6/2017	Nolan Creek	Glufosinate-ammonium	0.008
	Elk Creek	AMPA	0.008
	Elk Creek	Glufosinate-ammonium	0.008

Similar with the other studies discussed in this section, the exact timing, location and formulation of herbicides in the tributary watersheds were unknown for this pilot study. It is possible that some of the detections may have resulted from activities other than forest management, such as vegetation control along roadsides. Specifically, during sampling at Elk Creek on Aug. 23, an aquatic noxious weed control spray team was working in the vicinity of the sample location.

#### 6.4.4. Pesticide fate modeling approaches

The EPA has a number of modeling approaches to evaluate contaminant risk. The Pesticide in Water Calculator models both surface and groundwater pesticide concentrations based on percent cropped area in a watershed (<https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#PWC>). Additional EPA models can be found at: <https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment>. The USDA Soil and Water Assessment Tool (SWAT) (<https://swat.tamu.edu/>) has been used in over 3,000 journal publications worldwide to model a wide range of pollutants. The uncalibrated model is based on a standard set of parameters, including digital elevation models; stream layers, in the U.S. typically the National Hydrographic Dataset (NHDPlus); landuse, generally the Cropland Data Layer (CDL) in the U.S.; soils, usually the Soil Survey Geographic (SURRGO) database; and weather (daily temperatures and precipitation). The Soil and Water Assessment Tool has

been used to evaluate pesticide fates in the Coulonge drinking water catchment area of southwest France (Vernier et al. 2017), and also for spatiotemporal modeling of pesticide fates in agriculture (Wang 2019). However, no references of it being used in forestry were found (Source: Iowa State University SWAT literature database for peer-reviewed journal articles, [https://www.card.iastate.edu/swat\\_articles/](https://www.card.iastate.edu/swat_articles/)).

We could find only one example of pesticide fate modeling conducted in Oregon. A recent journal article presents the initial results of SWAT modeling in Zollner Creek in the Pudding River subwatershed of the Molalla River that is 91% agriculture (Janney and Jenkins 2019). Atrazine was the focus of the Zollner Creek monitoring, similar to other SWAT pesticide modeling (Winchell et al. 2018). Janney and Jenkins used five different parameter optimization scenarios to evaluate modeling biases, considering  $\pm 25\%$  of estimated stream discharges and atrazine concentration levels to be an acceptable model outcome. These scenarios sequentially added local knowledge and spatially explicit data to the standard SWAT model formulation. Scenarios that reduced bias were: (a) adding better precipitation data using NEXRAD, although some overestimate of flows remained; and (b) adding an estimated amount of tile drainage, which improved the model outcomes to “very good” using the Nash-Sutcliffe modeling efficiency coefficient, a satisfactory percentage bias and the best fit for the mean daily streamflow. Of the 29 parameters likely to influence the hydrologic simulation, streamflow was considered the most important (Janney and Jenkins 2019). However, according to the authors, the study was limited due to the lack of streamflow monitoring, information on the extent of tile drains, amounts and locations of atrazine applications, and the relative infrequency of pesticide sample collection (12 times).

In contrast to the Janney and Jenkins (2019) SWAT modeling where atrazine applications were unknown, Winchell et al. (2018) studied 27 watersheds in Illinois, Indiana, Ohio and Texas, 25 of these as part of the Atrazine Ecological Monitoring Program (funded by Sygenta, an atrazine manufacturer) with the remaining two in Ohio in the Heidelberg University National Center for Water Quality Monitoring program. Atrazine data was provided through surveys at the crop reporting district. The data included total mass of atrazine applied, total area treated and total crop area over several years. Temporal applications of atrazine within a probability distribution were estimated based on planting timing. Grab water samples were collected on an average of once every four days, as well as some rainfall-driven event-driven sampling to represent runoff. In general, Winchell et al. (2018) found that the uncalibrated model slightly overpredicted atrazine concentrations but that the mean bias (observed/simulated) was less than one part per billion (0.93 ppb), and generally less than a factor of 2 in the concentration.

As an evolution of SWAT, the EPA has developed a web-based, interactive pesticide fate model (<https://epahawqs.tamu.edu/>) at the 12-digit hydrologic unit code (HUC) scale that uses SWAT as its foundation (Yen et al. 2016). There seems to be potential to conduct these types of modeling exercises for primarily forested watersheds under active management to obtain better, and site-specific, pesticide fate information for community water supply watersheds.

## 6.5. Chemicals in raw water supplies

As we’ve seen above, pesticides used in forest management find their way into streams, typically in very low concentrations and during either the application or first few storms in the winter. Yet, forest management is one of many activities where pesticides are applied. Various organizations sample to identify the types and amounts of pesticides



in surface waters. Table 6-11 shows the results of sampling conducted statewide from 1995 to 2020 by the DEQ, ODA, EPA and USGS for those pesticides labelled for forest use (there were no results identified for diflufenican and glufosinate-ammonium). Almost 42,000 water sample results were available for these nine pesticides, and the table divides these into three categories for when the chemical: (a) wasn't detected; (b) was detected, but at concentrations below the ability of an instrument to quantify; and (c) was in concentrations that were sufficient to quantify. In cases where a pesticide was found in surface waters, the concentrations were sufficiently low in about 88% of the samples that the level could not be quantified. In cases where it could be quantified, most were below water quality standards — in many cases by orders of magnitude. This is consistent with the results of studies that Oregon DEQ has done on toxics, both statewide (DEQ 2015) and specifically for the North Coast (DEQ 2019).

The Safe Drinking Water Act requires public water suppliers to periodically test for toxic chemicals in both their raw water intakes and distribution systems. The Oregon Health Authority (OHA) reports these results as “Alerts” in their “Drinking Water Data Online” system. An alert is issued if a water sample shows contaminant concentrations above one-half the maximum contaminant level for inorganic chemicals, and any detected value for synthetics and volatile organic groups. We queried this database for the same period as that covered by the results in Table 6-11, specifically looking for those drinking water systems that had alerts for chemicals commonly used in forest management. From 1995 to April 2020, there were 2,293 alerts for 26 organic chemicals found in drinking water. The data provided the sample location, which was either the entry point into the treatment plant, or from the distribution system. Many utilities have multiple sources for their raw water, and we were only interested in those from surface water, or groundwater under the influence of surface water.

**Table 6-11. Numbers of samples and detections in Oregon streams of pesticides used in forestry, 1995–2020.**

Pesticide	Non-detect	Quantifiable	% Detect	Total samples
2,4-D	4,074	341	7.7%	4,415
Atrazine	7,730	2,553	24.8%	10,283
Carbaryl	5,445	442	7.5%	5,887
Glyphosate	802	421	34.4%	1,223
Hexazinone	4,620	152	3.2%	4,772
Imazapyr	4,869	219	4.3%	5,088
Metsulfuron-methyl	2,827	238	7.8%	3,065
Sulfometuron methyl	4,085	698	14.6%	4,783
Triclopyr	2,343	124	5.0%	2,467

Source: DEQ, AWQMS Water Quality Monitoring Data, 1/1/1995 to 4/6/2020 for surface water samples collected by DEQ, ODA, USEPA and USGS (accessed 4/8/2020).

Examining the records, we were able to cross-reference those entry points that were surface water from those from well water, ultimately finding 254 alerts for 74 public water supplies resulting from organic contaminants in surface waters at their raw water intakes. Of these 254 alerts, only two are for chemicals used in forest management: 2,4-D and atrazine. There were four alerts for 2,4-D, two each for Salem and Lake Oswego. The Salem alerts occurred in August 2016 and April 2017 with concentrations

of 0.12 µg/L and 0.11 µg/L, respectively, from its North Santiam River raw water intake. The two Lake Oswego alerts occurred in late September 2007 and June 2013 with concentrations of 0.63 µg/L and 0.13 µg/L, respectively, from its Clackamas River raw water intake. The maximum contaminant level for 2,4-D is 3.0 µg/L, so the levels of 2,4-D contamination found in these two systems ranged from one-fifth to one-three hundredth of the drinking water standard. The only other organic contaminant found at raw surface water intakes was atrazine, more commonly used in agriculture than forestry. It was found in the Canby Utility intake in February 2015 at a concentration of 0.17 µg/L at its Mollala River source. Atrazine also has a 3.0 µg/L maximum contaminant level, so the concentration found was one-twentieth of the standard.

## 6.6. Pesticide application violations

Pesticide use in Oregon is regulated by the State Pesticide Control Act (ORS Ch. 634) and enforced by the Oregon Department of Agriculture under administrative rules (OAR Ch. 603, Div. 57 Pesticide Control). To be used in Oregon, pesticides are required to be registered with ODA, and as part of this regulation appropriate uses and controls are identified. The statute also preempts local pesticide regulations except on their own (i.e., local government) lands (ORS 634.057). Pesticide applicators must be licensed (ORS 634.122), and aerial applicators require an additional certificate (ORS 634.128). There are 22 categories of prohibited acts (ORS 634.372). The act also established the Pesticide Analytical and Response Center to receive and coordinate responses to pesticide incidents among state agencies (ORS 634.550). Figure 6-4 shows the process used to receive complaints through state agencies, investigate and report findings (PARC 2018). The Oregon Department of Forestry has procedures for receiving pesticide-related complaints and working with ODA and others on investigations (PARC 2018).

Pesticide incident reports are retained for five years (C. Higby, PARC, personal communication 2/24/2020). A query of ODA's Pesticide Program database on 2/21/2020 found 4,149 pesticide-related incidents from July 2013 to August 2019, of which 140 (3.4%) were related to forest use. In addition to a spreadsheet with summary data, each incident's Case Detail report was also reviewed. Figure 6-5 shows the number of reported incidents annually from 2013 through 2019. Note, however, that a single pesticide-related incident may have multiple complainants. Of the 140 incidents, almost 74% (104) are related to aerial applications of herbicides; 14% (19) are for ground applications in forest units; 5% (seven) are for right-of-way spraying in forested areas; 4% (six) are applicator records and licensing reviews; and 3% (four) are general concerns not attributable to a specific application type. From the 140 incidents, there were six incidents where violations were found; and, in three cases, "Letters of Advisement" were sent as warnings.

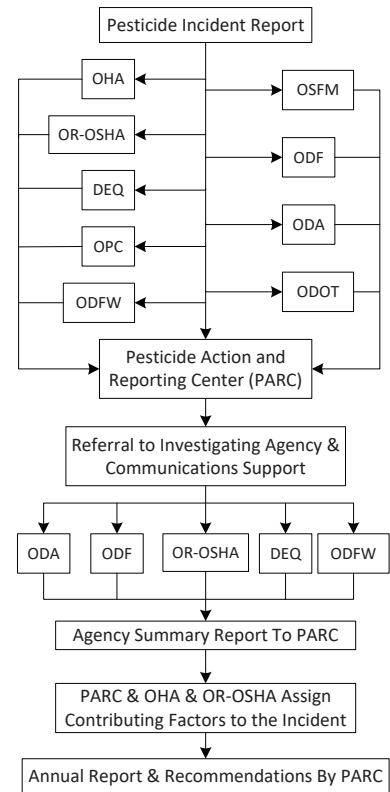
The ODA classifies pesticide-related incidents into six different categories (Figure 6-6):

1. Agriculture Use Observation (AUO).
2. Agriculture Use Follow-up (AUF).
3. Nonagricultural Use Observation.
4. Nonagricultural Use Follow-up.
5. Applicator Records Inspection (ARI).
6. Tracking.

Observations are when an ODA pesticide investigator is on-site during an application, commonly accompanied by an ODF stewardship forester. As part of the observation, the ODA pesticide investigator will also inspect the labels for all chemicals applied, determine whether the applicators are appropriately licensed and in some cases return after a period of time to evaluate vegetation to determine if there are signs of drift. Typically, observations are requested by landowners (timber companies) when they are conducting applications in sensitive areas such as adjacent to lakes and state parks, where there are known concerns in the community (e.g., Triangle Lake), or history with neighbors. Of the 61 observations (out of 140 incidents) during our analysis period, 87% were for aerial spraying, and 92% of those were at the request of the landowner. A similar proportion of ground application observations are initiated by landowners. Based on the case notes, ODA often encourages landowners to avail themselves of observations as a mechanism to reduce disputes. ODA identified a violation in four out of the 57 cases initiated by landowners, three times for aerial applications and once for ground.

The other major category of pesticide incidents are complaints, comprising 38% (64) out of the 140 cases. These are classified by ODA as “follow-ups” from either agricultural applications (i.e., forestry for our dataset); or nonagricultural use, which in our analysis corresponds to spray applications to rights-of-way in forested areas. Complaints generally result in an investigation by ODA (again, usually in conjunction with ODF stewardship foresters) that includes a site visit and discussion

with the complainant, the applicator and the landowner. If a violation is suspected, samples of vegetation and/or soil may be taken for ODA laboratory analysis. A detailed case record of the incident in the form of an affidavit is prepared by the ODA pesticide investigator. Almost all of the forestry complaints regarding aerial applications are the result of concerns over drift. There were five cases of violations in the 41 (12%) cases where investigations led to a finding, mostly of ORS 634.372(4) for carelessness and negligence, and in one case ORS 634.372(9) for failure to follow label requirements. In



Source: PARC 2018.  
Figure 6-4. Pesticide complaint process.

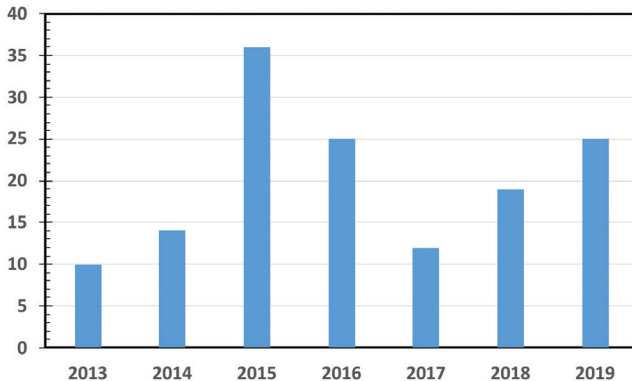


Figure 6-5. Annual pesticide-related incidents report to ODA.

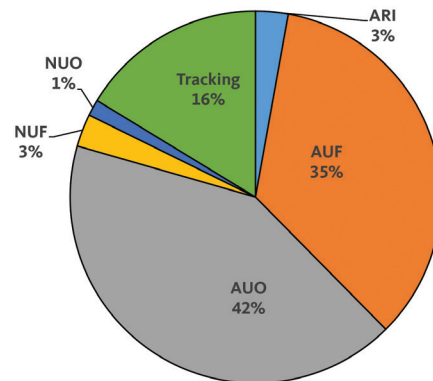


Figure 6-6. Types of pesticide-related incidents reported from July 2013 to August 2019.

one case, Cedar Valley near Gold Beach on the south coast, the aerial applicators license was revoked, although his \$20,000 fine was suspended; and in another case, Applebee Aviation had two violations (one of which resulted from spraying crew members) that resulted in their license suspended for a year and a total of \$55,436 in fines. Complaints regarding ground-based applications and particularly rights-of-way generally involve spraying into live water, especially streams; or spraying onto adjacent properties (again, mostly for rights of way applications). There were nine complaints over ground-applications. Four were unresolved, usually due to either the operation hadn't yet been conducted or the complainant failed to cooperate, and four other cases were investigated and found not to be violations. In one case, the violation was due to drift over a fence line to an adjacent property.

The third type of pesticide-related incidents involve ODA reviewing applicator records, i.e., Record Reviews. Whenever an observation or complaint is filed, the ODA pesticide investigator checks to determine whether the pesticide is appropriately labelled for forestry (or rights of way) use and whether the concentration applied is within the label limits for that use. At the same time, the licenses of the operator and all applicators are confirmed, particularly whether they have the appropriate endorsements for forestry, rights of way, and rotary-wing aerial (if applied by helicopter). For aerial operations, the GPS tracking records are also requested and reviewed. Beyond these standard operating procedures for observations and complaints, ODA may request three years of application records from operators and sample specific jobs to determine whether the paperwork contains the required elements (OAR 503-057-130). Pesticide dealers have similar record-keeping requirements (OAR 603-057-0140). There were six of these records inspections over the 2013–2019 period for operators involved in forestry applications. In two of these, it was determined that the operator was not involved in applications at that time. In three cases, the record keeping was determined inadequate and the operator received a Letter of Advisement (warning) to improve their practices. And, in one case the operator was a Letter of Advisement due to lacking appropriate licenses and endorsements for roadside spraying without a right-of-way endorsement.

The fourth type of pesticide-related incidents are designated as “Tracking,” which is a catch-all category. Tracking is used when there is too little information to initiate an investigation, a complainant fails to cooperate with the investigation, ODA (PARC) is contacted about a forthcoming application or another agency is taking the lead on an investigation.

The ODA, often through the Pesticide Analytical and Response Center, receives about 700 pesticide-related referrals annually. Of these, about 3.5% are related to forestry. For the forestry incidents, about 75% are concerned with aerial application of pesticides. Half these aerial-related referrals are requests by landowners for ODA to observe spraying; with the other half complaints about past or future applications. There are three “hotbeds” for complaints: the Triangle Lake/Noti area of the central Coast Range; Gold Beach on the south coast; and the Rogue/Applegate valley in southern Oregon. On average, there are only slightly over three pesticide-application violations of all types (application, record-keeping, licensing) per year in the forestry sector. In two cases, these violations resulted in the suspension or revocation of aerial application licenses. In context, according to ODF's FERNS notification system, there were likely around 7,000 applications per year over this period (Table 6-1), involving 454 applicators with Forestry license endorsements, including 115 applicators and operators with the aerial (helicopter) endorsement (Kachadoorian 2019).

## 6.7. Summary and recommendations

The use of forest chemicals is a complex admixture of physics, biology and social science. We addressed this by evaluating the extent and types of chemical uses and their effects on water quality, with a particular emphasis on effects at the raw water intake. We reviewed published, peer-reviewed articles on the effects of herbicide treatment, and evaluated a number of additional studies conducted by agencies. We analyzed water quality data, both for streams as well as conditions at raw water intakes for community water supplies. Finally, we examined four years of forestry-related pesticide incidents to assist in understanding controversies related to forest chemical use. We will conclude the chapter by summarizing the findings from the information presented, and provide a set of recommendations for future efforts based on our analyses.

### 6.7.1. Summary

Chemicals play an integral role in the management of Oregon's forests. Based on an analysis of ODF's FERNS data, there are over 7,400 activities that involve chemical applications on potentially 1 million acres of Oregon forest land annually, with the vast majority of these herbicides being applied to harvested units (Table 6-1). Applications include herbicide spraying for:

- Site preparation prior to replanting.
- Competing vegetation control afterwards.
- Animal and rodent repellants to protect seedlings.
- Fertilization to increase growth rates after thinning.
- Maintenance of rights-of-way for both travel and utility corridors.

With the exception of rights-of-way, a defining characteristic of these chemical applications is that they occur infrequently over the 30- to 80-year typical harvest cycle (Figure 6-1). And while the public perception of chemical use in forests is often critical, pesticides applied to forest land represent only from 2.8% (2007) to 4.2% (2008) of those used statewide, according to the Oregon Pesticide Use Reporting System that was defunded in 2009 (ODA 2008, 2009). ODA data show that 3.5% of pesticide-related incidents involve forestry use of pesticides.

In comparison to other sectors of Oregon's economy that use pesticides, chemicals typically applied in forestry (Table 6-2) are less toxic to humans, move fairly rapidly through soil and water, and don't accumulate (Table 6-4). Most of these are herbicides that are not strongly absorbed (attached) to soil particles, are water soluble, have low volatility (i.e., evaporation and resuspension), and decay rapidly in both water and soil. This means that these herbicides do not tend to build up in the soil or bio-accumulate.

Contemporary best management practices, with a couple of additions, have the potential to protect areas off-site if followed. Extensive research (and accompanying models) have allowed a better understanding of the importance of droplet size distributions on reducing on pesticide drift, as have the development of adjuvants specifically tailored to mitigate drift. Helicopters have precise GPS and nozzle flow data loggers that accurately position the ship both in space and chemical delivery; some models can be preprogrammed to include flight plans that automatically buffer streams and sensitive areas. There is also substantial research from the agriculture community, and one paper reported here from forestry, on the value of wooded buffers to prevent drift into streams. Additions to the Forest Practice Act rules recently proposed through

an industry-environmental collaborative process would extend buffers along non-fish streams, but to be effective at preventing drift these buffers should be forested.

This examination demonstrates that while pesticides are commonly detected in surface waters, in almost all cases they are found in concentrations below levels that can be accurately measured. When quantifiable detections are found, as we've seen from the forestry use studies, they tend to be transient and most likely to occur either during application or in early season storms. In particular, unless live water is directly sprayed (a label violation for herbicides used in forest silviculture), most herbicide runoff occurs during the first winter storms. In one report (Morgenstern 2014) this constituted 70% to 90% of the pesticide loadings, a finding that was confirmed by the Louch et al. (2017) and Caldwell and Courter (2019). The impact of chemicals used in forest management on downstream raw source water supplies depends on the size of the contributing watershed, the proportion annually subject to chemical applications, and other land uses in the basin.

### 6.7.2. Recommendations

1. **Pesticide use data needs to be reported.** It is difficult for stakeholders and the affected public to understand the impacts, positive and negative, of forest chemicals without good reporting data. This is part of a larger concern over pesticide use relating to air and water quality in Oregon. At present, data on pesticide and chemical use is not routinely reported, even at the aggregate level. While ODF FERNS provides information on where and possibly when forest chemicals will be used, it allows multiple chemicals to be listed over long periods of time, with no subsequent reporting on what was actually applied unless a complaint was filed. In 1999 the Oregon Legislature created the Pesticide Use Reporting System (PURS), but it was never adequately funded and implemented. When its sunset provision was proposed for renewal during the 2019 Legislative Session in HB2980, there was broad support from across the political spectrum (Oregonians for Food and Shelter to the Farmworkers Union) for PURS to be extended and funded. This bill died in the Ways and Means Committee as the Legislature adjourned. A bill more specific to forestry was also introduced, HB4168, that implements the aerial application procedures and reporting requirements identified in the Memorandum of Understanding for the "Oregon Strategy" drafted by the timber industry and the conservation community (Governor's Office 2020). This bill, too, died prior to passage in the House with adjournment. (Note: This was passed subsequently to the completion of the original report). The Board of Forestry and ODF could by administrative rule change its notification system to require reporting and disclose chemicals used in management operations.
2. **Current water quality sampling efforts are insufficient.** A corollary to the lack of pesticide use information is the sparseness of data on potential pesticide loadings in surface waters, particularly at the raw water intakes for public water supplies. Most current sampling at raw water intakes is not correlated with times of likely chemical pulses, i.e., the early winter storms. Moreover, it is clear from the silvicultural herbicide applications studies that detections and concentrations in receiving waters are highly variable even within a storm event. There is a similar constraint in the grab samples and automatic samplers that are commonly used: they provide detection and concentration information at point(s) of time, but not loads (i.e., the total mass of the substance transported in water over a given period of time) since stream discharge is usually not measured during the sampling (Meals et al. 2013). Sampling and analysis techniques developed and applied by the USGS,

such as polar organic chemical integrative sampler and semipermeable membrane device (see Section 6.4.2) have the capability to accurately integrate pesticide concentrations over longer periods; and in conjunction with streamflow, the ability to estimate loads. These devices could be particularly beneficial at raw water intakes where there is concern over pesticide loadings and the quantity of water flowing into the intake is known.

3. **Study designs need improvement.** The majority of studies focused on assessing the impact of pesticides on water quality can be loosely characterized as “reconnaissance” or “case studies” because of their study design and limited replicability. Most of the pesticide/herbicide peer-reviewed studies in the Pacific Northwest, and other areas of the U.S. were conducted by industry or industry-supported organizations (the National Council for Air and Stream Improvement) and tend to be short-term and locally focused (Louch et al. 2017; Caldwell and Courter 2020). They have the advantage of knowing exactly when and what was applied and have more site-specific sampling. But they are limited because the applicators know that they are being studied and that fact may affect their behavior. In contrast, the Pesticide Stewardship Partnership and USGS studies sampled over a longer period, but the partnership studies did not have the exact amounts and timing of application and may have missed storm events. The USGS used a sampling method that integrated pesticide concentrations over time, but that method was still limited because of unknown application amounts and timing. Improved study designs would incorporate random, applicator- and landowner-blind sampling of pesticide applications. This approach is critical for developing replicable scientific results.
4. **Pesticide fate modeling is a critical need.** Inference based on downstream measurements includes complex interactions between pesticide and environment, as well as assumptions on their spatial and temporal distribution, which still require significant research. A useful tool to answer many management questions is modeling. Complex hydrological models, such as the Soil and Water Assessment Tool (Wang 2019) could assist practitioners and regulators to understand the fate of silvicultural forest chemicals. The SWAT has been used for over 50 pesticide fate studies worldwide for agricultural practices, but not for pesticide fates in forest applications. While such process-based models have their limitations, they can provide a structured approach to evaluating herbicide movements at the watershed scale.
5. **Pesticide Stewardship Partnerships.** The partnerships are good outreach tools, but do not produce replicable science. The PSP doesn’t collect pesticide application data and locations in its “partnerships,” and its sampling regimes aren’t designed and implemented to catch episodic events (application, early winter storms) generally recognized to be when the highest concentrations are likely to be found. Additionally, the lack of streamflow data in these studies limits their ability to evaluate “loads” versus point concentrations. By involving landowners, applicators and agency personnel, partnerships’ benefits could be further enhanced by better knowledge of pesticides applied, the timing of those applications, and better monitoring procedures as outline above.
6. **OSU research cooperatives provide a framework to support future studies.** Creating credible science in an arena as complex as forest chemical use requires long-term and intensive studies across the ownership landscape. One model to achieve this is the research cooperatives in the College of Forestry at Oregon State

University. Since 1982 there has been an industry-agency-university cooperative studying forest revegetation that has a substantial record of accomplishments over its almost 40-year history, presently called the Vegetation Management Research Cooperative (<http://vmrc.forestry.oregonstate.edu/>). The cooperative has the partners needed to successfully conduct the type of herbicide transport and fate studies and modeling described here.

7. **Wooded buffers prevent or reduce spray drift.** Both the Louch et al. (2017) and Caldwell and Courter (2020) studies demonstrated that nonbuffered, small non-fish streams received spray during application. In contrast, the Thistle et al. (2009) study demonstrated the efficacy of wooded buffers in capturing or deflecting fine spray drift. This finding is consistent with a number of studies on agricultural spray drift. The extension of wooded buffers to small non-fish streams under the Forest Practices Act and its rules would protect these streams from drift, and reduce potential loadings downstream. Extension of spray exclusion zones along small non-fish streams is one of the proposals in the “Oregon Strategy” of the state, timber industry and conservation groups (Governor’s Office 2020); it is clear from the science that the effectiveness of these buffers would be improved if they were wooded.

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