ECOLOGICAL RISK ASSESSMENT: WILDLAND FIRE-FIGHTING CHEMICALS

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EXECUTIVE SUMMARY

The U.S. Department of Agriculture's Forest Service uses a variety of chemicals to aid in the suppression of fire in wildlands, including long-term retardants, foams, and water enhancers. This risk assessment examined the potential impacts of these fire-fighting chemicals on terrestrial wildlife and aquatic species. Exposures from both planned and accidental releases were considered, including on-target drops to terrestrial areas, accidental drops across water bodies, and accidental spills to a stream during aerial or ground transport.

Fire retardants were estimated to pose risks to non-sensitive small omnivores and songbirds from one retardant salt when applied at rates of 6 gallons per 100 square feet or higher. Water enhancers were associated with risks to non-sensitive small omnivores. Fire retardants were predicted to present risks from one retardant salt to sensitive small omnivores and sensitive songbirds, and, at higher rates, also for sensitive raptors and sensitive small herbivores. Water enhancers were predicted to pose risks to sensitive small omnivores, raptors, songbirds, and large herbivores. No risks were predicted from runoff for non-sensitive aquatic species. Risk to sensitive fish species from runoff into small streams in some ecoregions was associated with a surfactant in one foam product and a surfactant in one water enhancer. All retardant and foam products present risk to one or more aquatic species if applied across a small stream. (Water enhancers were not aerially applied by the Forest Service at the time this assessment was conducted; therefore, they were not evaluated in the accident scenarios.) In a large stream, sufficient dilution was achieved to decrease to negligible the risk from eight retardants and three foams. Risks remained for the other ten retardant and seven foam products. All concentrated and mixed retardant and foam products were associated with risk to one or more aquatic species if spilled into a small stream at the volumes assumed in risk assessment. In a large stream, sufficient dilution was achieved to decrease to negligible the risk from one foam product; risks remained for all other retardant and foam products.

In comparing these results to the limited field study data available, the assessment predicted risks from one retardant salt for which a previous field study had identified no adverse effects on terrestrial species. The inconsistency in these conclusions may be attributed to the conservative assumptions used in this risk assessment, particularly the assumption that the chemical was not attenuated by the environment prior to exposure of small mammals and the percent of diet assumed to be contaminated.

The results presented in this risk assessment depend on a number of factors, including the availability of pertinent scientific information, standard risk assessment practices, exposure assumptions, and toxicity dose-response assumptions. Whenever possible, this risk assessment integrated chemical- and species-specific scientific information on the response of aquatic and terrestrial organisms as well as the vegetative community. The approaches used to address these factors introduce minor to significant amounts of uncertainty into the risk assessment's conclusions. Overall, when assumptions were required, a conservative approach was taken, to provide risk results that are protective of the environment.

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ACRONYMS AND ABBREVIATIONS

BCF	bioconcentration factor
CAS	Chemical Abstracts Service (registry number)
cfs	cubic feet per second
DOI	U.S. Department of the Interior
EPA	U.S. Environmental Protection Agency
ft	foot; feet
g	gram(s)
gal	gallon(s)
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems (model)
gpc	gallons per 100 square feet
hr	hour(s)
in	inch(es)
K_{oc}	organic carbon partition coefficient
l	liter(s)
lb	pound(s)
LC_{50}	median lethal concentration
LC_{50}	median lethal dose
m	meter(s)
m^2	square meter(s)
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MTDC	Missoula Technology and Development Center
ND	no data available
NOEC	no-observed-effect concentration
ppm	parts per million
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UV	ultraviolet
YPS	yellow prussiate of soda; also known as sodium ferrocyanide

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1.0 INTRODUCTION

The U.S. Department of Agriculture (USDA) Forest Service uses a variety of chemicals to aid in the suppression of fire in wildlands, including long-term retardants, foams, and water enhancers. This report presents the methods and results of an ecological risk assessment of potential impacts of these fire-fighting chemicals on terrestrial wildlife and aquatic species.

Exposures from both planned and accidental releases are considered in this risk assessment. Releases may include on-target drops to terrestrial areas, drops across water bodies, and accidental spills during aerial or ground transport to a stream. A drop across a stream may be accidental, or it may be an inadvertent result of invoking an exception to the “300-foot guideline” intended to protect aquatic species.[1] This risk assessment evaluates each of these situations.

This report is organized into five major sections. Section 1.0 provides an introduction, background information, and an overview of the methodology. Section 2.0 presents the problem formulation. Section 3.0 provides the analysis. Section 4.0 presents the risk characterization, and Section 5.0 lists the references cited throughout this report.

1.1 Background Information

The potential ecological impacts of the fire-fighting chemical products in use in 1994 were assessed in a programmatic risk assessment prepared at that time (USDA 1995). Since then, new products have been qualified or approved, assumptions regarding exposure required updating, and additional information has become available addressing potential effects as well as areas of concern. Some minor revisions and additions to the 1994 risk assessment were prepared since its publication. However, this report represents an integrated re-assessment and complete update of the potential ecological impacts of the fire-fighting chemicals that were on the Qualified Products List of the Forest Service at the time this project was initiated (USDA 2002a), and serves as a single replacement for all of these previous ecological risk assessments.

This ecological risk assessment looks only at the biological risks of the wildland fire-fighting chemicals, should they be used. It does not evaluate alternatives to their use, nor does it discuss factors affecting management decisions on whether chemicals should be used in a particular situation.

[1] This guideline (USDA/DOI 2000) states that aerial application of retardant or foam is to be avoided within 300 feet of waterways. Exceptions can be made if alternative line construction tactics are not available, life or property is threatened, or potential damage to natural resources outweighs possible loss of aquatic life. The guideline is a joint policy of the U.S. Forest Service, Bureau of Land Management, National Park Service, and Fish and Wildlife Service.

1.2 Overview of Methodology

This ecological risk assessment follows the steps of problem formulation, analysis, and risk characterization, as described in the U.S. Environmental Protection Agency's (EPA's) *Guidelines for Ecological Risk Assessment* (EPA 1998). This risk assessment also identifies uncertainties that are associated with the conclusions of the risk characterization. The discussion that follows briefly describes these elements. A detailed description of ecological risk assessment methodology is contained in the EPA guidelines.

In problem formulation, the purpose of the assessment is provided, the problem is defined, and a plan for analyzing and characterizing risk is determined. The potential stressors (in this case, wildland fire-fighting chemicals), the ecological effects expected or observed, the receptors, and ecosystem(s) potentially affected are identified and characterized. Using this information, the three products of problem formulation are developed: (1) assessment endpoints that adequately reflect management goals and the ecosystem they represent, (2) conceptual models that describe key relationships between a stressor and assessment endpoint, and (3) an analysis plan that includes the design of the assessment, data needs, measures that will be used to evaluate risk hypotheses, and methods for conducting the analysis phase of the assessment.

Analysis is a process that examines the two primary components of risk—exposure and effects—and the relationships between each other and ecosystem characteristics. The assessment endpoints and conceptual models developed during problem formulation provide the focus and structure for the analysis. Exposure characterization describes potential or actual contact or co-occurrence of stressors with receptors, to produce a summary exposure profile that identifies the receptor, describes the exposure pathway, and describes the intensity and extent of contact or co-occurrence. Ecological effects characterization consists of evaluating ecological effects (including ecotoxicity) data on the stressor of interest, as related to the assessment endpoints and the conceptual models, and preparing a stressor-response profile.

Risk characterization (1) uses the results of the analysis phase to develop an estimate of the risks to ecological entities, (2) describes the significance and likelihood of any predicted adverse effects, and (3) identifies uncertainties, assumptions, and qualifiers in the risk assessment.

2.0 PROBLEM FORMULATION

This section presents the results of the problem formulation, in which the purpose of the ecological risk assessment is provided, the problem is defined, and a plan for analyzing and characterizing risk is determined.

2.1 Integration of Available Information

In this first step of problem formulation, the risk assessment identifies and characterizes the stressors, the ecological effects expected or observed, the receptors, and ecosystem potentially affected.

2.1.1 Stressors

In this ecological risk assessment, the potential stressors are the long-term retardants, foams, and water enhancers that may be used on wildlands to fight fires. The information in the following paragraphs was derived from the Forest Service's Wildland Fire Chemicals Systems information sheet on fire-fighting chemical products (USDA 2002b):

- *Long-term retardants* are the red liquids dropped from aircraft, often viewed in media coverage of wildland fire-fighting activities. These products are supplied as either wet or dry concentrates, and are mixed with water before they are dispersed over the target area. When the water is completely evaporated, the remaining chemical residue (primarily the same types of salts found in fertilizers) serves to decrease burning intensity and hence retard the fire’s spread, until it is removed by rain or erosion.

- *Foams* are supplied as liquid concentrates that are mixed with water. They contain foaming agents, which affect how the product clings to surfaces and how quickly the mix water drains out of the foam; and wetting agents, which increase the ability of the drained water to penetrate fuels.

- *Water enhancers* improve the ability of water to cling to vertical and smooth surfaces, and may consist of either elastomers (usually provided as liquid concentrates) or gels (usually provided as dry concentrates).

Foams and water enhancers all modify physical characteristics of water to aid in fire suppression, while long-term fire retardants leave a dried residue after the water evaporates that helps to reduce burning intensity.

Fire-fighting chemicals may be dropped from fixed-wing airplanes ("airtankers") or helicopters, or applied by ground crews from fire engines or using portable equipment; the application methods approved for each product are listed on the current Qualified Products List (USDA 2002a).

The fire-fighting chemical products addressed in this risk assessment are as follows:

Long-Term Fire Retardants
- Fire-Trol 300F
- Fire-Trol FTR
- Fire-Trol GTS-R
- Fire-Trol LCA-F
- Fire-Trol LCA-R
- Fire-Trol LCG-F
- Fire-Trol LCG-R
- Phos-Chek 259-F
- Phos-Chek 259-R
- Phos-Chek D75-F
- Phos-Chek D75-R
- Phos-Check G75-F
- Phos-Chek G75-W
- Phos-Chek HV-F
- Phos-Chek HV-R
- Phos-Chek LV-R
- Phos-Chek MV-R
- Phos-Chek MV-F

Foams
- 3M Light Water FT-1150
- Angus ForExpan S
- Ansul Silv-Ex
- Fire Choke
- Fire-Trol FireFoam 103
- Fire-Trol FireFoam 103B
- Fire-Trol FireFoam 104
- National Foam KnockDown
- Phos-Chek WD 881
- Pyrocap B-136

Water Enhancers
- FireOut ICE (Chemdal Aqua Shield)
- Stockhausen Firecape FP-47

The application rate for firefighting chemicals varies by situation. For long-term retardants, the type of fuel (vegetation) is a major factor in determining an application rate. The application rates used in this risk assessment for long-term retardants on various fuel types are included in Table 2-1 in Section 2.1.4. For foams and water enhancers, the analysis assumed an application rate of 4 gallons of mixed (diluted) product per 100 ft^2 (gallons per 100 ft^2 = gpc).

2.1.2 Ecological Effects

The ecological effects that may be associated with the fire-fighting chemicals are those associated with (1) direct toxicity to terrestrial wildlife and aquatic species that encounter the chemical, (2) phytotoxicity, and (3) effects on vegetation diversity. Permanent or persistent exposures through environmental pathways are not expected, since the application "footprint" of these chemicals is quite limited in terms of foraging areas and species habitat for any individual animal, and the ingredients generally degrade in the environment. Although bioaccumulation was evaluated in simple predator-prey scenarios, the potential for long-term biomagnification in the terrestrial food web was not evaluated for this same reason.

Fire is an integral component to and may have beneficial impacts on ecosystems. Adverse effects to an ecosystem could occur in terms of a decrease in fire-based beneficial effects. However, these effects are not directly related to risks from the chemicals specifically, but are tied to fire management and suppression decision-making regarding all methods of fire suppression. An analysis of these risks and benefits is outside the scope of this risk assessment, which focuses only on potential ecological risks from the fire-fighting chemicals, but related risk management considerations are addressed briefly in Section 4.5.

2.1.3 Receptors

The potential receptors in this ecological risk assessment were selected to represent a range of species present in wildlands. These receptors include mammals, birds, amphibians, fish, and aquatic invertebrates for which quantitative risk estimates can be made, based on the program description data in Section 2.0 and the environmental fate and transport predictions described in Section 3.0. Based on the results of this analysis, a qualitative assessment was conducted of risks to special status species—such as endangered, threatened, or other designated special status species, collectively referred to as "sensitive species" in this risk assessment —for whom the acceptable exposure threshold would be lower, to identify whether there could be risks to individual animals, as contrasted with protecting animal populations overall for non-sensitive species.

2.1.4 Ecosystems Potentially Affected

Fire-fighting chemicals could be applied wherever a wildfire occurs, and no one ecosystem can represent the variety of site conditions that are found in all areas where wildland fire is possible. Therefore, this risk assessment identified representative ecoregions to be analyzed (see Table 2-1), based on the classifications described by Bailey (1995) and considering areas of the U.S. where fire-fighting chemicals are more likely to be applied.

The occurrence of peak fire season within an ecoregion is an important consideration in assessing risk to wildlife species, since that is when chemical use is more likely to happen. If chemical application coincides with the presence of vulnerable life stages of a species, adverse impacts may be more likely. The peak fire season for each ecoregion is noted in Table 2-1.

Table 2-1. Representative Ecoregions

Description	Ecoregion[a]	Geographic Location	Retardant Coverage Level (gpc, or gal/100 ft^2)[b]	Peak Fire Season[c]
Annual and perennial western grasses	331: Great Plains-Palouse dry steppe	Rocky Mountain Piedmont, upper Missouri Basin Broken Lands, Palouse grassland of Washington and Idaho	1	Apr - Oct
Conifer with grass	M313: Arizona-New Mexico mountains–semidesert–open woodland–coniferous forest–alpine meadow	Arizona, New Mexico	2	May - Jul
	M331: Southern Rocky Mountain steppe–open woodland–coniferous forest–alpine meadow	Middle and southern Rocky Mountains	2	Jun - Sep
Shortneedle closed conifer	M332: Middle Rocky Mountain steppe–coniferous forest–alpine meadow	Blue Mountains, Salmon River Mountains, basins and ranges of southwestern Montana	2	Jun - Sep
	242: Pacific lowland mixed forest	Puget-Willamette lowland	2	Jul - Oct
Summer hardwood	234: Lower Mississippi riverine forest	Lower Mississippi River floodplain	2	Aug - May
Longneedle conifer	M212: Adirondack-New England mixed forest–coniferous forest–alpine meadow	Adirondack-New England highlands	2	Mar - Jun Oct - Nov
Fall hardwood	231: Southeastern mixed forest	Southeastern U.S.	2	Oct - Jun
Sagebrush with grass	342: Intermountain semi-desert	Columbia-Snake River plateaus, Wyoming basin	3	Jun - Oct
Intermediate brush (green)	315: Southwest plateau and plains dry steppe and shrub	Texas, eastern New Mexico	3	Oct - Jul
Shortneedle conifer (heavy dead litter)	212: Laurentian mixed forest	North-central lake-swamp-morainic plains, New England lowlands	4	May, Aug, Nov
	M242: Cascade mixed forest–coniferous forest–alpine meadow	Pacific northwest	4	Jul - Oct
Southern rough	232: Outer coastal plain mixed forest	Atlantic and gulf coastal plains, Florida	6	Sep - Jul
Alaska black spruce	131: Yukon intermontane plateaus taiga	Interior Alaska	6	Jun - Sep
California mixed chaparral	M262: California coastal range open woodland–shrub–coniferous forest–meadow	Southern California coastal range	>6	Aug - Oct

[a]Numbers and categories correspond to those described by Bailey (1995).
[b]Mixed (diluted) product.
[c]Source: NWCG 2003.

2.2 Assessment Endpoints

Assessment endpoints are selected based on three criteria: ecological relevance, susceptibility to stressors, and relevance to management goals (EPA 1998). For species that are endangered, threatened, or sensitive, the assessment endpoint selected is individual survival, growth, and reproduction. For non-sensitive species present in an area that was treated with fire-fighting chemicals, the assessment endpoint selected is the survival of populations.

Scenarios describing the potential impacts of fire-fighting chemical use on the assessment endpoints are developed in the conceptual model described in the next section. Table 2-2 summarizes the potential ecological effects and associated assessment endpoints for this risk assessment of fire-fighting chemicals.

Table 2-2. Assessment Endpoints

Ecological Effect	Assessment Endpoint
Direct toxicity to terrestrial wildlife and aquatic species	For species that are endangered, threatened, or sensitive, the assessment endpoint selected is survival, growth, and reproduction of each individual. For non-sensitive species, the assessment endpoint selected is the survival of a majority of individuals to sustain a local population.
Phytotoxicity	Individual plant growth for endangered, threatened, or sensitive species; survival of populations for non-sensitive species.
Effects on vegetation diversity	Changes in vegetation species/succession in an area

The occurrence of peak fire season within an ecoregion is an important consideration in assessing risk to wildlife species, since that is when chemical use is more likely to happen. If chemical application coincides with the presence of vulnerable life stages of a species, adverse impacts may be more likely. The peak fire season for each ecoregion is noted in Table 2-1.

2.3 Conceptual Model

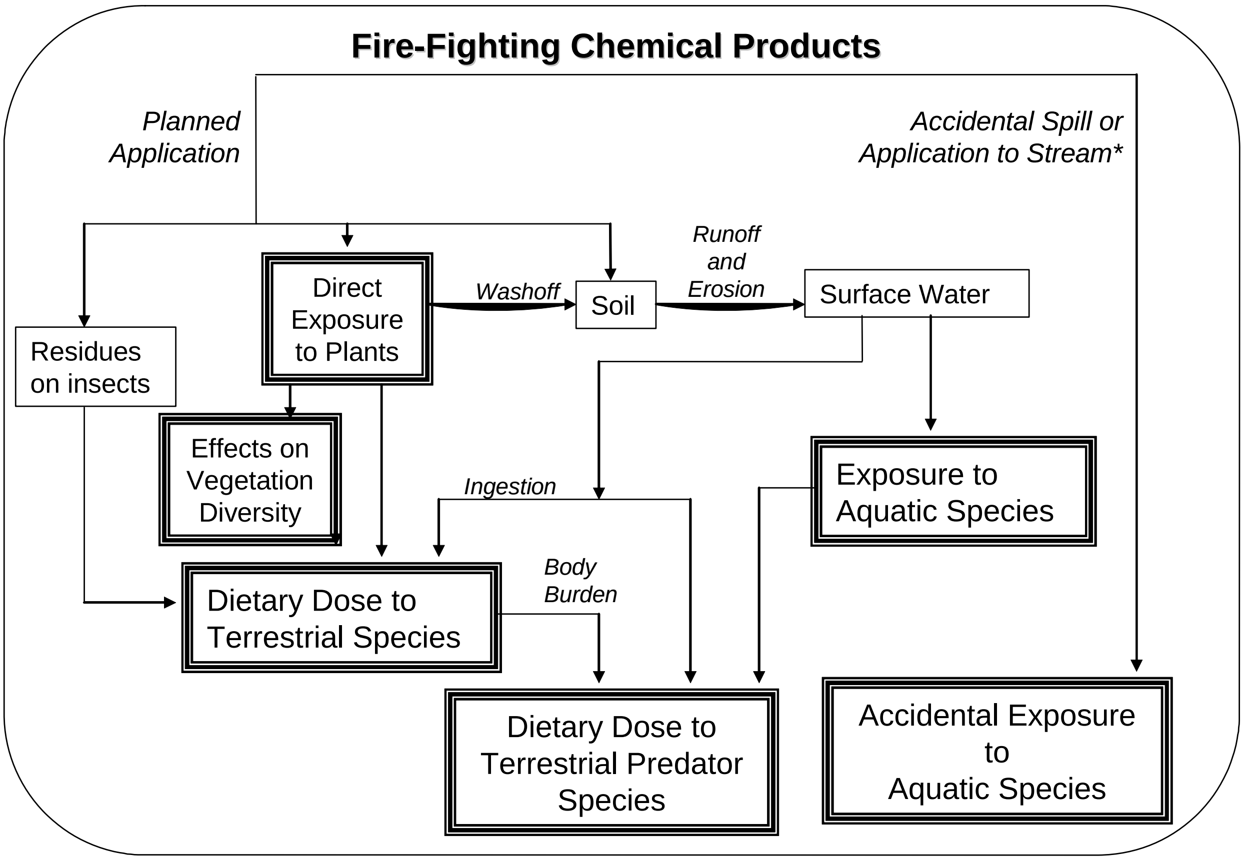
A conceptual model consists of a risk hypothesis that describes relationships between the stressor, exposure, and assessment endpoint response; and a diagram illustrating these relationships. For use of fire-fighting chemicals on wildlands in the U.S., the risk hypothesis is as follows:

Risk Hypothesis

Some ingredients in the fire-fighting products have demonstrated toxicity to terrestrial and aquatic wildlife and plant species, at varying levels, based on laboratory and field tests that have characterized exposure-response relationships. The associated hypothesis is that use of long-term retardants, foams, and water enhancers for wildland fire-fighting will cause chemical toxicity resulting in adverse effects to the individual's survival, growth, and reproduction for sensitive species, or to the survival of populations of non-sensitive species. Specifically, it is hypothesized that direct contact or soil-, water-, or diet-mediated exposure may occur at levels predicted to be associated with adverse individual or population-level effects.

To test this hypothesis, a conceptual model was developed to illustrate the relationships between stressors, exposure routes, and receptors. The conceptual model is presented in Figure 2-1.

Figure 2-1. Conceptual Model



*The "application to stream" scenario includes accidents as well as invoking an exception to the 300-foot aerial application waterway buffer.

2.4 Analysis Plan

Based on the conceptual model, scenarios were identified to evaluate risks to terrestrial and aquatic wildlife species from the identified assessment endpoints.

Direct Toxicity

1. Representative terrestrial and aquatic species and their characteristics were identified.

2. Each fire-fighting chemical formulation was screened for ingredients with high toxicity to wildlife, as determined by a mammalian oral median lethal dose (LD_{50}) <500 milligrams of

chemical per kilogram of body weight (mg/kg), or an acute aquatic species median lethal concentration (LC_{50}) <10 milligrams of chemical per liter of water (mg/L).[2]

3. Effects characterization: for chemicals with high toxicity (as determined in the screening step above), profiles were prepared summarizing toxicity, chemical and physical and properties, and environmental fate and transport.

4. Exposure characterization: environmental fate and exposure models were implemented, to estimate exposures in terms of dose (mg/kg) for terrestrial species or concentration (mg/L) for aquatic species.

5. The doses and concentrations identified in the exposure characterization were compared to the toxic properties identified in the effects characterization, using the guidelines developed by EPA for interpreting risk estimates to wildlife and aquatic species.

Phytotoxicity

Impacts on terrestrial plants from ingredients in the fire-fighting chemical formulations were evaluated. The exposure characterization for plants was based on the same application scenarios as the exposure characterization for wildlife species. Limited data were expected to be available for the effects characterization, so the risk characterization was planned to be quantitative where possible and qualitative where data were limited.

Vegetation Diversity

Positive and negative effects of chemicals on plant species' growth were considered qualitatively. A major focus of the analysis was the potential for enhancement of invasive species' spread and corresponding decline of native species.

[2] These screening thresholds were based on inclusion of chemicals defined by EPA, in terms of their acute toxicity, as moderately, highly, or very highly toxic (EPA 2007). EPA's categories are as follows:

Receptor	Parameter and Units	Toxicity Category				
		Very highly toxic	Highly toxic	Moderately toxic	Slightly toxic	Practically nontoxic
Birds and wild mammals	acute oral LD_{50} (mg/kg)	<10	10 - 50	51 - 500	501 – 2,000	>2,000
Aquatic organisms	acute LC_{50} (mg/L)	< 0.1	0.1 - 1	>1 - 10	>10 - 100	>100

3.0 ANALYSIS

3.1 Data and Models for Analysis

A combination of laboratory study data, field study data, and modeling outputs was used in the ecological risk assessment.

Quantitative dose-response information for a range of animal species has been generated for chemicals in laboratory studies conducted by researchers and manufacturers. These data were reviewed for use in this risk assessment. Sources include peer-reviewed scientific literature, manufacturers' material safety data sheets and information summaries, and government reports. These studies were reviewed to generate the LD_{50}s and LC_{50}s that are used in the ecological risk assessment.

Predicting the estimated environmental concentrations of the fire-fighting chemicals in this analysis relied primarily on mathematical modeling for the following reasons:

$ Little to no validated data are available from monitoring studies of fire chemical application, and the nationwide utility of data developed on environmental fate at individual sites would be limited, due to the significant influence of site-specific parameters (such as soil type, climate, slope, and other variables) on the potential for off-site transport; and

$ Sophisticated models have been validated in field tests, and are appropriate for application to this problem, which seeks to identify a representative range of exposure estimates for each ecoregion.

The EPA and other regulatory agencies recognize the value of modeling for predicting impacts.

Predicting environmental concentrations resulting from the use of fire-fighting chemicals is complicated by the wide range of chemical, environmental, and operational variables. To simplify the task, the modeler chooses a limited number of scenarios based on anticipated operations and circumstances. While the scenarios chosen in this study are intended for use in predicting expected conditions, a conservative bias was incorporated when assumptions were required. This is useful in overcoming the limitations and uncertainties that accompany modeling. If a model predicts that the less favorable circumstances produce acceptable results, then one can predict with greater confidence that the normal or more favorable circumstances will also produce acceptable results.

The computer-based Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model, described in detail in the following subsection, was used to estimate runoff of fire-fighting chemicals from treated areas into streams, possibly exposing aquatic species as well as terrestrial species (through drinking water). Point source loading was assumed for edge-of-field runoff into streams and for accidental spills into streams. Residue levels on foliage and other wildlife diet items were estimated using the results of field studies (see Section 3.2.1).

3.1.1 Modeling of Runoff Using GLEAMS

The GLEAMS model, developed by the USDA Agricultural Research Service (Leonard et al. 1987, Leonard et al. 1988), is a computerized mathematical model developed for field-sized areas to evaluate the movement and degradation of chemicals in soil within the plant root zone under various crop management systems. Version 3.0 of GLEAMS, a Microsoft Windows-based program used for this analysis, has undergone a number of improvements including improved handling of forested areas (Knisel and Davis 2000). The model has been tested and validated using a variety of data (see, for example, Leonard et al. 1987, Crawford et al. 1990). The following paragraphs briefly discuss the structure and function of the model.

Components

GLEAMS has four main components: hydrology, erosion, nutrients, and pesticides. The hydrology component of GLEAMS subdivides the soil within the rooting zone into as many as 12 computational layers. Soils data describing porosity, water retention characteristics, and organic matter content for the site-specific soil layers (horizons) are collected for model initialization. During a simulation, GLEAMS computes a continuous accounting of the water balance for each layer, including percolation, evaporation, and transpiration. Evaporation of chemicals from the soil surface is not represented, but evaporation of water can cause chemicals to move upward through the soil.

The erosion component of GLEAMS accounts for the basic soil particle size categories (sand, silt, and clay), and for small and large aggregates of soil particles. The program also accounts for the unequal distribution of organic matter between soil fractions, and uses this information and surface-area relationships to calculate an enrichment ratio that describes the greater concentration of chemicals in eroding soil compared with the concentration in surface soil.

The nutrient component of GLEAMS was used to model the retardant salts, which are the same chemicals that are used in the synthetic fertilizers that this component of the model was designed to evaluate. The model simulates the application of nitrogen and phosphorus, applied as fertilizers, animal wastes, or tillage. Over long periods of time without nutrient supplementation, the nitrogen and phosphorus concentrations will stabilize and remain relatively constant, as is the case in modeling forest scenarios.

The pesticide component of GLEAMS can represent chemical deposition directly on the soil, the interception of chemicals by foliage, and subsequent washoff. Although the fire-fighting chemicals are not pesticides, the GLEAMS model was determined to appropriately represent the use of the formulation components that are not retardant salts, since they are deliberately applied at known rates to defined wildland areas. Degradation rates are allowed to differ between plant surfaces and soil, and between soil horizons. Degradation calculations are performed on a daily time interval. Redistribution of chemicals because of hydrologic processes is also calculated on a daily time step. The distribution of a chemical between dissolved and sorbed states is described as a simple linear relationship, being directly proportional to the organic carbon partition coefficient (K_{oc})[3] and the organic matter content of the soil. The extraction of chemicals from the soil surface into runoff is calculated accounting for sorption (assumed to be relatively rapid) and using a related parameter describing the depth of the interaction of surface runoff and surface soil. Percolation of chemicals is calculated through each of the soil layers, and the amount that passes through the last soil layer is accumulated as the potential loading to the vadose zone[4] or groundwater. Input data required by the GLEAMS model consist of several separate files representing rainfall data, temperature data, hydrology parameters, erosion parameters, nutrient parameters, and chemical parameters.

Parameter Files

The rainfall data file contains the daily rainfall for the period of simulation. The temperature data file contains the daily or monthly mean temperature for the simulation period. The model determines rain and snow from the temperature data file.

Daily precipitation amounts and temperatures were input into the GLEAMS model. These values were simulated by a weather generator model, CLIGEN (USDA 2003). CLIGEN was initially developed by the USDA Agricultural Research Service, and has since undergone significant changes, including recoding to conform to the Water Erosion Prediction Project Fortran-77 Coding Convention. CLIGEN is a stochastic weather generator that produces daily time series estimates of precipitation, temperature, dewpoint, wind, and solar radiation for a single geographic point, based on average monthly measurements for the period of climatic record. The estimates for each parameter are generated independently of the others. CLIGEN version 5.104 was used in this effort. In addition to daily precipitation amounts and temperatures, wind velocity, dew point, and solar radiation were also obtained from the CLIGEN model.

The hydrology parameter file contains information on the size, shape, and topography of the area to which chemicals were applied, hydraulic conductivity, soil water storage, and leaf area indices. This file also contains the runoff curve number, which describes the tendency for water to run off the surface of the soil. Representative values for these parameters were identified from published soil surveys for each ecoregion.

The erosion parameter file contains information needed to calculate erosion, sediment yield, and particle composition of the sediment on a storm-by-storm basis. The input data can represent a number of optional configurations of fields, channels, and impoundments, but the representative scenarios for analysis in this study represented a single field for application of fire-fighting chemicals in each ecoregion.

Parameter files were prepared for all chemical ingredients, describing their water solubility, K_{oc}s, the tendency for the chemical to wash off plant surfaces, and the expected application rate and

[3] The K_{oc} indicates the extent to which a chemical partitions itself between the solid and solution phases of a water-saturated or unsaturated soil, or runoff water and sediment. It is the ratio of the amount of chemical adsorbed to soil per unit weight of organic carbon in the soil or sediment, to the concentration of the chemical in solution at equilibrium. Typical units are (µg adsorbed per g organic carbon) per (µg per mL solution). Values could range from 1 to 10 million.

[4] The partially saturated region between the ground surface and the water table.

schedule. For modeling purposes, it was assumed that there were no residues of the chemical on the site at the beginning of the simulation, and that no degradation occurred during the evaluation period.

Nutrient parameter files were prepared containing information on typical mineral content from county soil surveys for each ecoregion, average nitrogen concentrations in rainfall for a geographic area, and application information for retardant salts.

Model Setup

The objective of this simulation was to estimate chemical sorption to soil and loss in runoff following application of fire-fighting chemicals. Since an earlier risk assessment (USDA 1995) identified no likelihood that retardants and foams would leach below the rooting zone, the groundwater pathway was not evaluated in this assessment. The environmental input parameters were selected to represent the conditions in each ecoregion as realistically as possible.

Specific soil characteristics used in the model simulations are provided in Table 3-1. The soil characteristics are described to the modeled rooting depth of 24 to 60 inches (based on regional soil data), which can be interpreted as the depth from which water is actively taken up by the vegetation.

For each ecoregion, application of retardants, foams, and water enhancers was modeled using the application rates referenced in Section 2.1.1. Additional assumptions and inputs to the simulations included the following:

$ Daily rainfall data were generated for a three-year period using CLIGEN. Simulations were run for a three-year period following application of the fire-fighting chemical to allow for variability of runoff concentrations from year to year and to be able to make statistical estimates of the frequency of occurrence of a given level of runoff. No environmental degradation of the chemicals was assumed, to insert a conservative bias into the modeling results. In addition, to provide an additional measure of conservatism, a five-year, 24-hour storm event was inserted on the day following the chemical application, providing an upper bound estimate for potential concentrations in surface water runoff.

$ Temperature data were input as monthly average minimum and maximum, as simulated by CLIGEN.

$ The vegetative cover factor for erosion calculations (C) was estimated to be 0.004, representing good cover primarily with grasses.

A complete set of GLEAMS input and output tables was created for each combination of chemical and ecoregion.

GLEAMS output provides edge-of-field chemical concentrations in runoff. To estimate surface water concentrations that may result from runoff events, calculations were applied assuming the application occurred in two different areas: a small (6,400-acre) drainage basin with a 12-cubic-

Table 3-1. Soil Characteristics within the Rooting Zone

Ecoregion	Soil Type	Runoff Curve No.	Hydraulic Slope (ft/ft)	Rooting Depth (in)	Saturated Conductivity (in/hr)*	Saturated Conductivity Below Root Zone (in/hr)	Organic Matter (%)*	Erodibility Factor
Great Plains-Palouse dry steppe	sandy clay loam	60	0.050	60	0.15 / 0.15 / 0.15	0.15	2.26 / 1.57 / 1.20	0.200
Arizona-New Mexico mountains–semidesert–open woodland–coniferous forest–alpine meadow	clay loam	60	0.150	60	0.50 / 0.15 / 0.15	0.15	1.68 / 1.35 / 1.14	0.350
Southern Rocky Mountain steppe–open woodland–coniferous forest–alpine meadow	sandy loam	60	0.120	60	1.5 / 1.5 / 1.5	0.15	3.49 / 2.17 / 1.27	0.200
Middle Rocky Mountain steppe–coniferous forest–alpine meadow	loam	60	0.150	60	0.75 / 0.50 / 0.35	0.15	6.49 / 4.39 / 1.15	0.350
Pacific lowland mixed forest	silty loam	60	0.200	60	1.3 / 1.3 / 1.3	0.15	10.0 / 4.2 / 0.8	0.258
Lower Mississippi riverine forest	silt	60	0.150	60	0.2 / 0.2 / 0.2	0.15	4.15 / 0.84 / 0.32	0.350

Table 3-1. Soil Characteristics within the Rooting Zone (continued)

Ecoregion	Soil Type	Runoff Curve No.	Hydraulic Slope (ft/ft)	Rooting Depth (in)	Saturated Conductivity (in/hr)*	Saturated Conductivity Below Root Zone (in/hr)	Organic Matter (%)*	Erodibility Factor
Adirondack-New England mixed forest–coniferous forest–alpine meadow	sandy loam	60	0.150	60	0.50 / 0.40 / 0.25	0.15	6.10 / 0.95 / 0.18	0.350
Southeastern mixed forest	sandy clay loam	60	0.150	60	4.0 / 0.8 / 2.0	0.15	1.0 / 1.0 / 1.0	0.326
Intermountain semi-desert	fine sandy loam	48	0.100	60	6.0 / 6.0 / 6.0	0.40	1.02 / 0.25 / 0.25	0.236
Southwest plateau and plains dry steppe and shrub	silty clay	60	0.100	60	0.5 / 0.3 / 0.3	0.15	2.91 / 2.12 / 1.80	0.250
Laurentian mixed forest	sandy loam	60	0.200	60	6.0 / 6.0 / 6.0	0.40	6.0 / 4.1 / 4.1	0.191
Cascade mixed forest–coniferous forest–alpine meadow	clay loam	60	0.120	60	1.3 / 1.2 / 0.4	0.15	3.68 / 3.46 / 1.40	0.296
Outer coastal plain mixed forest	loamy fine sand	60	0.030	60	6.0 / 6.0 / 6.0	0.30	4.7 / 4.7 / 4.7	0.100
Yukon intermontane plateaus taiga	silty loam	73	0.050	24	6.00 / 1.28 / 0.01	0.01	10.0 / 3.7 / 3.0	0.355
California coastal range open woodland–shrub–coniferous forest–meadow	sandy loam	60	0.250	36	1.84 / 0.88 / 0.03	0.03	5.06 / 3.43 / 1.96	0.182

*Multiple entries indicate the values used in the three different soil layers (horizons) that were modeled, in order of surface layer to deepest layer modeled.

feet-per-second (cfs) stream flowing through it, and a larger (147,200-acre) drainage basin with a 350-cfs stream flowing through it. The stream sizes were selected to span the range likely to be present in areas where fire-fighting chemicals are applied. The sizes of the respective drainage basins were estimated by reviewing the sizes of drainage basins typically associated with these stream sizes in watersheds across the U.S. (USGS 2003).

Accuracy and Limitations of GLEAMS Modeling Predictions

For a detailed discussion of the validation of GLEAMS, its sensitivity to errors in input parameters, and its expected accuracy, the reader should refer to the model documentation referenced at the beginning of this section. The GLEAMS computer model can provide a large amount of information without having to conduct expensive field studies and the subsequent chemical analysis. However, the model is sensitive to input parameters. Since the ecoregion conditions modeled were intended to be representative of conditions within a large and variable geographic area, the model results will not specifically predict environmental transport at any precise location, but provide an indication of the general chemical behavior that may be expected under typical conditions. The variation of the parameters used from those that exist at a specific location causes the majority of uncertainty in the model's output.

In the fate modeling, environmental degradation of the chemicals—in soil or in surface water—was not credited for reducing concentrations of any chemicals over time, since the length of time elapsing between application and exposure could vary greatly, and could possibly be very short. A study conducted by USGS (Little and Calfee 2002) indicated that the substrate on which the fire retardant is applied could have a significant effect on its persistence in the terrestrial environment and subsequent potential to contaminate adjacent aquatic systems at levels that could be toxic to fish. In containers, retardant (applied at a rate equivalent to 1 gpc) was weathered outdoors for 7 to 45 days on soils with a high (3.7%) or low (1.4%) organic matter content or on sand (0.2% organic matter), a volume of water was added to each test system, and then fathead minnows were placed in the water for 24 hours. Lethality to test fish increased as organic matter content decreased, with non-first order relationships observed between elapsed time and toxicity, indicating multiple factors affecting chemical speciation, availability, and resultant toxicity. These factors could include (1) degradation at different rates to both less and more toxic chemical species by various components of the retardant formulation; (2) chemical composition of soil influencing binding/mobility of various ingredients; and (3) possible additive or synergistic toxicity among the mixture of ingredients and degradation products that exists at a given time during the weathering process. Overall, the relationship between elapsed time and toxicity of retardant residues in runoff has not been quantitatively determined, therefore precluding modeling estimates in this predictive risk assessment. However, it can be concluded that the time-toxicity relationship is complex and will vary according to site-specific conditions. Clearly, any modeling estimates of chemical fate developed without a degradation factor will result in a conservative estimate.

3.1.2 Accidents

Average stream concentrations of chemicals were estimated one hour after a point-source accidental spill of a retardant or foam during transport to fire-fighting operations, to both large and small streams. The volume spilled was assumed as follows:

- three 2,000-lb bulk bags of powdered retardant concentrate
- a 2,000-gallon tank of wet retardant concentrate
- a 2,000-gallon tank of mixed, diluted retardant
- a 35-gallon spill of foam concentrate

Accidental retardant or foam application directly across a stream was also evaluated for both small and large streams at the application rates used in each ecoregion.

3.2 Characterization of Exposure

3.2.1 Direct Toxicity

Terrestrial Species

The terrestrial species exposure scenarios postulate that a variety of terrestrial wildlife species may encounter residues of fire-fighting chemicals when they re-enter areas after fire-fighting activities have subsided. The scenarios further postulate that these terrestrial species may be exposed to any applied chemicals through ingestion of contaminated food and water.

The list of representative terrestrial species is as follows:

<u>Mammals</u>
Deer (*Odocoileus* spp.) (large herbivore)
Coyote (*Canis latrans*) (carnivore)
Deer mouse (*Peromyscus maniculatus*) (omnivore, prey species)
Rabbit (*Sylvilagus* spp.) (small herbivore)
Cow (*Bos taurus*) (ruminant, evaluation of exposure to ammonia salts in retardant only)

<u>Birds</u>
American kestrel (*Falco sparverius*) (raptor)
Red-winged blackbird (*Agelaius phoeniceus*) (songbird)
Bobwhite quail (*Colinus virginianus*) (ground nester)

These particular wildlife species were selected because they represent a range of taxonomic classes, body sizes, foraging habitat, and diets for which parameters are generally available. For each species, characteristics were identified that were used in estimating doses of chemical ingredients in the fire-fighting products. These characteristics include body weight, dietary intake, composition of diet, and home range/foraging area. There were insufficient data available on the toxicity of the fire-fighting products and their ingredients to reptiles and terrestrial stages of amphibians to include representatives of these classes in the analysis.

For terrestrial wildlife, exposures were assumed to occur through ingestion of sprayed forbs, berries, insects, or seeds in a treated area, and, if relevant, ingestion of prey with residues or body burden. In addition, terrestrial species' drinking water was assumed to come from the small stream in each ecoregion using the corresponding retardant drop rate; where a retardant application rate was common to more than one ecoregion, the highest stream concentration associated with that rate was used in the calculation. In a screening-level risk assessment such as this one, emphasis on the dietary route of exposure is appropriate (EPA 2004).

Spray or drift residues on food items were estimated using the results of field studies by Hoerger and Kenaga (1972), as updated by Fletcher et al. (1994, as cited in Pfleeger et al. 1996). Table 3-2 lists the residue levels predicted.

Table 3-2. Residue Levels

Item	Residue (ppm per lb/acre) [a]
Grass	175[a]
Leaves	135
Forage	135
Small insects	135[b]
Fruits	15
Pod containing seeds	12
Large insects	12[b]

[a]ppm = parts per million; lb/acre = pounds per acre.
[b]Mean of short range grass and long grass.
[c]EPA's Office of Pesticide Programs groups small insects with broadleaf/forage plants and large insects with fruits, pods, and seeds (EPA 1999).

Predators that feed on other animals were assumed to receive the total body burden that each of the prey species received. Wildlife that feed on aquatic species were assumed to receive residue levels based on the chemical concentrations in water in a small stream and chemical-specific bioconcentration factors (BCFs) (the concentration of a chemical in aquatic organisms divided by the concentration in the surrounding water). In both cases, the appropriate prey body burden (appropriate to the prey's exposure as either another terrestrial species or an aquatic species) was incorporated into the "*RES*" term in the equation described in the next paragraph.

The doses for terrestrial wildlife from the food items comprising each species' diet were summed, as follows:

$$DOSE = \left[FRAC \times DIET \times \left(\sum_{i=1}^{n} RES_i \times INT_i \right) \right] \div BW$$

where:

DOSE	=	dose to wildlife species (mg/kg)
FRAC	=	fraction of diet assumed to be contaminated (0.5 if foraging range <1 acre, 0.1 if foraging range >1 acre; approach based on professional judgment)
DIET	=	mass of total daily dietary intake (kg)
RES_i	=	chemical residues on food item *i* (mg residues per kg food item)
INT_i	=	fraction of daily diet consisting of food item *i*
BW	=	body weight (kg)

To predict the total ingestion dose to terrestrial species, these food item doses were added to the estimated doses from drinking water from a small stream that received runoff. It was assumed that all of the animal's drinking water was obtained from a contaminated source, at a level equivalent to the highest estimated small stream concentration of the chemical that was estimated for any ecoregion. The species-specific parameters used in this analysis are summarized in Table 3-3.

Aquatic Species

The aquatic species exposure scenarios postulate that fish, tadpoles, and aquatic invertebrates in small and large streams may be exposed to chemical ingredients in wildland fire-fighting products through contaminated runoff coming off of areas to which the chemicals had been applied, or as a result of an accidental spill or drop into a stream.

For each chemical, risks were estimated for aquatic species for which ecotoxicity data are available. Representative aquatic species are as follows:

<u>Aquatic Species</u>
Rainbow trout (*Oncorhynchus mykiss*) (coldwater fish)
Water flea (*Daphnia* spp.*)* (aquatic invertebrate)
Tadpoles of frog or toad species, depending on data available (aquatic stages of amphibians)

In addition, a brief evaluation of risks from ammonia in the retardant products to freshwater mussels was conducted (see Section 4.1.2.2, *Risks to Freshwater Mussels from Ammonia*). A lack of toxicity data precluded quantification of risks to other benthic organisms.

The concentrations of the chemicals in streams were estimated using the environmental fate and transport modeling methodologies described in Section 3.1.

3.2.2 Phytotoxicity

The potential toxicity to plants of ingredients in the fire-fighting chemicals was evaluated semi-quantitatively, depending on the nature of the chemical-specific plant toxicity information that was available for each ingredient, if any.

Table 3-3. Exposure Assessment Parameters for Terrestrial Species

Parameter	Species							
	Deer	Coyote	Deer Mouse	Rabbit	Cow	Am Kestrel	RW Blackbird	BW Quail
Body weight (kg)	66.5	13	0.021	2.5	1102	0.11	0.052	0.18
Total diet (kg/day)	1.45635	0.68	0.00399	0.1	22.05	0.3	0.00849261	0.0144
Fraction of diet								
Grass	0.05	0	0.026	0.7	1	0	0.05	0
Leaves/forage/ small insects	0.95	0.03	0.14	0.3	0	0	0.9	0.003
Fruits	0	0	0.154	0	0	0	0	0.113
Pods/seeds/ legumes/large insects	0	0.01	0.68	0	0	0.361	0.05	0.884
Aquatic invertebrates	0	0	0	0	0	0	0	0
Mammals	0	0.785	0	0	0	0.336	0	0
Birds	0	0.175	0	0	0	0.303	0	0
Reptiles	0	0	0	0	0	0	0	0
Amphibians	0	0	0	0	0	0	0	0
Fish	0	0	0	0	0	0	0	0
Foraging range (acres)	704.235	7437.71	0.17297	44.478	5	370.65	1	4
Contaminated food fraction	0.1	0.1	0.5	0.1	0.1	0.1	0.1	0.1
Drinking water (L/kg-day)	0.104	0.0766	0.19	0	0.0491	0.15	0.157	0.115

3.2.3 Vegetation Diversity

This topic was evaluated qualitatively based on a literature review of the effects of fire suppression on the vegetative community. Available literature was limited and was both habitat- and chemical-specific.

3.3 Characterization of Ecological Effects: Ecological Response Analysis and Stressor-Response Profiles

3.3.1 Toxicity of Individual Ingredients

The chemical ingredients in the fire-fighting products were individually reviewed to identify their direct toxicity to terrestrial and aquatic wildlife species. The following screening process was applied to focus the analysis on chemicals with greater potential for effects to wildlife (see footnote in Section 2.4):

- Chemical ingredients were evaluated if the acute oral LD_{50} for terrestrial species was less than 500 mg/kg.

- Chemical ingredients were evaluated if the acute LC_{50} for aquatic species was less than 10 mg/L.

In addition, all of the retardant salts were retained in the analysis. Using this process, 25 individual chemicals were analyzed for ecological risks.

In all cases, the toxicity data indicating the greatest sensitivity to the chemical were used, regardless of life stage. A toxicity endpoint was sought for each of the representative species evaluated in this risk assessment; however, an LD_{50} for other species was used if no data were available for the species evaluated. For example, if no LD_{50} was found for Chemical "X" from a study using a coyote, an LD_{50} determined for another mammalian species, such as a rat, was used to derive the risk estimates for the coyote from Chemical "X." If no data were available at all for a class (for example, no data for any bird species), a mammalian value was substituted, which increased uncertainty but allowed the analysis of risk to that species to proceed.

For the other endpoints in this ecological risk assessment (phytotoxicity and vegetation diversity), the stressor-response descriptions are incorporated into the respective risk characterization discussions in Section 4.0.

3.3.2 Laboratory and Field Studies Using Formulated Products

In addition to the laboratory study data for targeted ingredients, the results of laboratory and field studies using formulated products were reviewed. In Section 4.1.2, these data are discussed qualitatively in terms of the results of the quantitative risk assessment that used the individual ingredient data. Because the formulated products are mixtures of several ingredients, each of which behaves differently in the environment, it is more appropriate for this risk assessment to evaluate the individual ingredients' risks to terrestrial and aquatic species,[5] since their exposure to the chemicals is mediated by each ingredient's properties during weathering, transport, or solution/suspension in surface water. Appendix A lists the formulated product toxicity data that were identified.

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[5] Including the summation of risks from the ingredient mixtures (that is, products), assuming additivity in accordance with EPA guidance; see approach to assessing risks from mixtures in Section 4.1.1.

Acute toxicity to bird species was greater than 1,000 mg/kg for all formulated products tested, indicating slight toxicity. Acute toxicity to rats and mice was greater than 500 mg/kg for all products, indicating slight toxicity to practically nontoxic, with most formulations having LD_{50}s greater than 2,000 mg/kg (practically nontoxic). Dermal LD_{50}s in rats and rabbits were greater than 2,000 mg/kg for all products, indicating low toxicity. Toxicity to earthworms was assessed for five products, with LD_{50}s greater than 1,000 mg/kg in all cases, indicating low toxicity.

For aquatic species, the toxicity of formulated products varies widely, depending on product, species, temperature, light conditions, and water hardness. Toxicity in fish species ranges from moderately toxic down to practically nontoxic, with reported LC_{50}s varying from 3 to >10,000 mg/L for salmonids, and from 8 to >10,000 mg/L for bluegill, fathead minnows, and largemouth bass. For aquatic invertebrates, identified LC_{50}s range from 7 to >1,000 mg/L. For tadpoles, LC_{50}s ranged from 22 to 293 mg/L for the products tested.

Field studies conducted by Vyas et al. (1997) were also reviewed. In the first of two experiments, the application of the retardant Phos-Chek G75-F or the foam Ansul Silv-Ex had no effect on small mammal populations in a mixed-grass prairie ecosystem in North Dakota. In the second experiment, the same products were applied to a Great Basin sagebrush/riparian ecosystem in Nevada, again resulting in no detectible effect on small mammal abundance, survival, recruitment, and movement, or on biochemical indices from tissue and blood samples. The application rates in the Nevada test were 3 gpc for the Phos-Chek retardant, and 0.33 gallons (gal) per 100 square meters (m^2) (approximately 0.03 gpc) for both 0.5 and 1% Silv-Ex foam solutions.

4.0 RISK CHARACTERIZATION

Risk characterization is the last step in the ecological risk assessment process. The exposure profile is compared to the stressor-response profile, to estimate the likelihood of adverse effects.

4.1 Direct Toxicity

4.1.1 Methodology for Estimating Ingredient Risks

By comparing the exposure profile data (estimated dose or water concentration) to the stressor-response profile data (LD_{50}s, LC_{50}s), an estimate of the possibility of adverse effects can be made. The potential risks were characterized following the quotient methodology used by EPA's Office of Pesticide Programs (EPA 2006). The quotient is the ratio of the exposure level to the hazard level. For acute exposures, the levels of concern at which a quotient is concluded to reflect risk to wildlife species are as follows (EPA 2006):

- Terrestrial species (non-sensitive): 0.5, where dose equals one-half the LD_{50}.

- Sensitive terrestrial species (endangered, threatened, other special status): 0.1, where dose equals one-tenth the LD_{50}.

- Aquatic species (non-sensitive): 0.5, where water concentration equals one-half the LC_{50}.

- Sensitive aquatic species (endangered, threatened, other special status): 0.05, where water concentration equals one-twentieth the LC_{50}.

Where risks are identified, they can be interpreted to mean that the identified exposure level could be associated with loss of at least half of a local population of non-sensitive species or puts individual animals of sensitive species at risk of mortality. The levels of concern identified above are used by EPA as a policy tool to interpret the risk quotient and to analyze potential risk to terrestrial and aquatic organisms (EPA 2006). For determining the presence of chronic risks, EPA lists the level of concern as the point at which the estimated environmental concentration is less than the "no-observed-effect concentration" (NOEC) from a laboratory or field study. Since (1) NOECs were not consistently available for the fire-fighting chemicals and (2) most exposures are expected to be short-term, intermittent, or one-time events, a chronic analysis for all the products was not conducted as part of this risk assessment. However, possible sublethal effects (including those from longer-term exposures) from the ingredients in approved products is an area of ongoing inquiry within the Forest Service.

Because the fire-fighting chemical products are mixtures of ingredients, terrestrial or aquatic wildlife could be exposed to more than one of the individual ingredients at a time. In accordance with current EPA guidance on assessing the risks from chemical mixtures (EPA 1986), an additive approach (in the absence of any data indicating synergistic or antagonistic interactions) was used in these cases, in which the quotients of multiple targeted ingredients in a single product were summed, providing an additive quotient indicating the risk from the product as a whole. The additive quotient is interpreted in the same manner as a quotient for a single ingredient; that is, risk is presumed to exist if the additive quotient exceeds the thresholds listed in the bulleted list above.

4.1.2 Estimated Risks of Ingredients and Products

4.1.2.1 Terrestrial Species Risks

In long-term retardant formulations, only one ingredient, a retardant salt, was associated with risks to terrestrial species. This retardant salt's risk is attributed to the combination of its low LD_{50} and significant proportion in several products formulated by both current retardant manufacturers. Foams were not predicted to pose any risk to terrestrial species. Two ingredients in one water enhancer were associated with risks, although it is unlikely these ingredients would still be present when terrestrial animals re-enter and browse in an area where fire-fighting activity had occurred (see further discussion below). The ingredient types and associated products with predicted risks for terrestrial wildlife are summarized in Table 4-1.

Individual ingredients in long-term retardant products were not associated with any risks to terrestrial animals when applied at a rate of 1 gpc.

At a rate of 2 gpc, sensitive omnivores (based on risks to the deer mouse) were predicted to be at risk from one retardant salt in Fire-Trol 300F, Fire-Trol GTS-R, Phos-Chek D75-F, and Phos-Chek D75-R. In addition, the Phos-Chek G75-F and G75-W formulations as a whole were predicted to pose a risk to sensitive omnivores when risks from the ingredients analyzed were added together, even though none of the individual ingredients was associated with a risk on its own. Sensitive songbirds (based on risks to the red-winged blackbird) were also predicted to be at risk from the same retardant salt in the Fire-Trol 300F and Fire-Trol GTS-R products.

At a rate of 3 gpc, sensitive omnivores (based on risks predicted for the deer mouse) were predicted to be at risk from one retardant salt in Fire-Trol 300F, Fire-Trol GTS-R, Phos-Chek D75-F, Phos-Chek D75-R, Phos-Chek G75-F, and Phos-Chek G75-W. Sensitive songbirds (based on risks estimated for the red-winged blackbird) were also predicted to be at risk from the same retardant salt in the Fire-Trol 300F, Fire-Trol GTS-R, Phos-Chek D75-F, and Phos-Chek D75-R products. In addition, the Phos-Chek G75-F and G75-W formulations as a whole were predicted to pose a risk to sensitive songbirds when risks from the ingredients analyzed were added together, even though none of the individual ingredients was associated with a risk on its own.

At a rate of 4 gpc, sensitive omnivores (based on risks to the deer mouse) were predicted to be at risk from one retardant salt in Fire-Trol 300F, Fire-Trol GTS-R, Phos-Chek D75-F, Phos-Chek D75-R, Phos-Chek G75-F, Phos-Chek G75-W, Phos-Chek HV-F, Phos-Chek HV-R, Phos-Chek LV-R, and Phos-Chek MV-R. In addition, the Phos-Chek MV-F formulation as a whole was predicted to pose a risk to sensitive omnivores when risks from the ingredients analyzed were added together, even though none of the individual ingredients was associated with a risk on its own. Sensitive raptors (based on estimated risks for the American kestrel) were predicted to be at risk from one retardant salt in Fire-Trol 300-F and Fire-Trol GTS-R. Sensitive songbirds (based on risks predicted for the red-winged blackbird) were also predicted to be at risk from the same

Table 4-1. Products with Estimated Risks to Terrestrial Wildlife Species

Ingredient Type	Applied Rate (gpc product)[a]	Product	Repre-sentative Species	Ingredient Risk Range[b]	Product Risk Range[b]
Retardant salt	2	Fire-Trol 300F, GTS-R Phos-Chek D75-F, D75-R	Deer mouse	0.102 - 0.180	0.102 - 0.181
		Fire-Trol 300F, GTS-R	Red-winged blackbird	0.119	0.120
	3	Fire-Trol 300F, GTS-R Phos-Chek D75-F, D75-R, G75-F, G75-W	Deer mouse	0.147 - 0.270	0.153 - 0.272
		Fire-Trol 300F, GTS-R Phos-Chek D75-F, D75-R	Red-winged blackbird	0.101 - 0.179	0.105 - 0.180
	4	Fire-Trol 300F, GTS-R Phos-Chek D75-F, D75-R, G75-F, G75-W, HV-F, HV-R, LV-R, MV-R	Deer mouse	0.105 - 0.360	0.109 - 0.362
		Fire-Trol 300-F, GTS-R	American kestrel	0.132	0.133
		Fire-Trol 300F, GTS-R Phos-Chek D75-F, D75-R, G75-F, G75-W	Red-winged blackbird	0.130 - 0.239	0.135 - 0.240
	6	Fire-Trol 300F, GTS-R Phos-Chek D75-F, D75-R, G75-F, G75-W, HV-F, HV-R, LV-R, MV-R, MV-F	Deer mouse	0.149 - 0.540	0.155 - 0.544
		Fire-Trol 300F, GTS-R	Rabbit	0.109	0.110
		Fire-Trol 300F, GTS-R Phos-Chek D75-F, D75-R, G75-F, G75-W	American kestrel	0.108 - 0.198	0.112 - 0.199
		Fire-Trol 300F, GTS-R Phos-Chek D75-F, D75-R, G75-F, G75-W, HV-F, HV-R, LV-R, MV-R	Red-winged blackbird	0.105 - 0.358	0.109 - 0.361
Reactant	4	Stockhausen Firecape FP-47	Deer mouse	0.452	1.09
			American kestrel	0.166	0.397
			Red-winged blackbird	0.299	0.719
pH adjuster	4		Deer mouse	0.622	1.09
			American kestrel	0.228	0.397
			Red-winged blackbird	0.413	0.719
NA[c]	2	Phos-Chek G75-F, G75-W	Deer mouse	NA	0.102 - 0.103
	3		Red-winged blackbird		0.101 - 0.103
	4	Phos-Chek MV-F	Deer mouse		0.103
	6		Red-winged blackbird		0.103
	4	Stockhausen Firecape FP-47	Deer		0.101

[a]gpc = gallons per 100 ft^2.

[b]Risks are presented in terms of quotient values for that exceed 0.1, the threshold for risk to sensitive species, as described in Section 4.1.1. Risks are also present for non-sensitive species if the quotient exceeds 0.5.

[c]No risk from individual ingredients, but the additive risk from all ingredients exceeded the risk threshold of 0.1.

retardant salt in Fire-Trol 300F, Fire-Trol GTS-R, Phos-Chek D75-F, Phos-Chek D75-R, Phos-Chek G75-F, and Phos-Chek G75-W.

At a rate of 6 gpc, sensitive omnivores (based on risks to the deer mouse) were predicted to be at risk from one retardant salt in Fire-Trol 300F, Fire-Trol GTS-R, Phos-Chek D75-F, Phos-Chek D75-R, Phos-Chek G75-F, Phos-Chek G75-W, Phos-Chek HV-F, Phos-Chek HV-R, Phos-Chek LV-R, Phos-Chek MV-R, and Phos-Chek MV-F. Sensitive small herbivores (based on risks to the rabbit) were predicted to be at risk from the same retardant salt in Fire-Trol 300F and Fire-Trol GTS-R. Sensitive raptors (based on risks to the American kestrel) were predicted to be at risk from the same retardant salt in Fire-Trol 300F, Fire-Trol GTS-R, Phos-Chek D75-F, Phos-Chek D75-R, Phos-Chek G75-F, and Phos-Chek G75-W. Sensitive songbirds (based on risks predicted for the red-winged blackbird) were also predicted to be at risk from the same retardant salt in the Fire-Trol 300F, Fire-Trol GTS-R, Phos-Chek D75-F, Phos-Chek D75-R, Phos-Chek G75-F, Phos-Chek G75-W, Phos-Chek HV-F, Phos-Chek HV-R, Phos-Chek LV-R, and Phos-Chek MV-R products. In addition, the Phos-Chek MV-F formulation as a whole was predicted to pose a risk to sensitive songbirds when risks from the ingredients analyzed were added together, even though none of the individual ingredients was associated with a risk on its own. Non-sensitive omnivorous mammals (represented by the deer mouse) were also predicted to be at risk from one retardant salt in the Fire-Trol 300F and GTS-R products.

No terrestrial species risks were predicted from foams.

The water enhancer Stockhausen Firecape FP-47 was associated with risks to some terrestrial species from two of its ingredients: a reactant and a pH adjuster. Risks were predicted for sensitive omnivores (based on risks to the deer mouse), raptors (based on risks to the American kestrel), and songbirds (based on risks to the red-winged blackbird). In addition, risks were predicted for sensitive large herbivores (based on risks to deer) from the product as a whole, due to the high quotients predicted for these two ingredients. Non-sensitive species risks were predicted for omnivores (represented by the deer mouse) from the pH adjuster in the product; and to non-sensitive songbirds (represented by red-winged blackbirds) based on additive risks from all product ingredients analyzed. However, the mobility and quick degradation / neutralization of the reactant and the pH adjuster in outdoor conditions would make it extremely unlikely that they would be present at any toxicologically significant level by the time terrestrial species in search of food re-entered an area that was treated with this product during fire-fighting activities.

Summary of Quantitative Terrestrial Species Risk Assessment

The quantitative risk assessment for terrestrial wildlife from individual ingredients in the fire-fighting chemical products predicted the following:

- Non-sensitive species: Fire retardants were estimated to pose risks to small omnivores from one retardant salt when applied at rates of 6 gpc or more. Water enhancers were associated with risks to small omnivores and songbirds.

- Sensitive species: Fire retardants were predicted to present risks from one retardant salt to small omnivores and songbirds, and, at higher rates, also for raptors (≥4 gpc) and small herbivores (≥6 gpc). Water enhancers were predicted to pose risks to small omnivores, raptors, songbirds, and large herbivores.

The toxicity data for the formulated products were also compared to exposure estimates, using the same methodology as for individual ingredients. However, in many cases, toxicity data results for formulated products have been recorded to be "greater than" the highest value tested, with no specific result identified. When these "minimum" results were excluded from the risk estimates, the only risks identified using the whole-product toxicity data were for sensitive omnivores and sensitive songbirds from three retardant formulations at drop rates ranging from 2 to 6 gpc, and to sensitive large herbivores from one water enhancer. All of these products were captured in the risk conclusions for the individual ingredients (see Table 4-1) at the same or higher application rates. In most cases, toxicity data for the individual ingredients were identified as a discrete value in the available literature instead of as a range (in which case the minimum value was used in this risk assessment), providing a more sensitive and accurate basis for the ingredient-specific analysis than is possible for a whole-product assessment.

In the field studies conducted by Vyas et al. (1997) (see Section 3.3.2), no detectible effects on small mammals were found after application of Phos-Chek G75-F at a rate of 3 gpc. In this risk assessment, all retardant formulations with high proportions (greater than 50% composition) of the retardant salt in that product were predicted to pose risks to sensitive small omnivores (as represented by the deer mouse). The inconsistency in these conclusions can be attributed to the conservative assumptions for this risk assessment, particularly the assumption that the retardant salt was not attenuated by the environment prior to exposure of small mammals. Also, the risk assessment included arbitrary assumptions about the percent of diet contaminated (50% for this category), which ignores the potential for food avoidance by animals if residues are detected by taste or odor.

4.1.2.2 Aquatic Species Risks

Risks from Runoff

Two individual ingredients in the approved products were predicted to pose risks to aquatic species from runoff containing residues of fire-fighting chemicals: a surfactant in National Foam KnockDown, and a different surfactant in Stockhausen Firecape FP-47. Table 4-2 summarizes the ingredient types, products, and scenarios for which risks were identified from runoff.

The runoff exposure scenario is intended to predict risks to aquatic species from non-accidental use; that is, when all application guidelines are followed and no spills or oversprays of streams occur. Table 4-3 ranks the risks from the various fire-fighting chemical products in runoff, in order of the greatest-to-least risk to rainbow trout, which is generally the more sensitive of the species evaluated in this assessment. Risks presented for each product are the additive risks from the more highly toxic chemical ingredients that were evaluated quantitatively in this analysis.

Table 4-2. Products with Estimated Risks to Aquatic Species from Runoff

Ingredient Type	Ecoregion	Product	Repre-sentative Species	Ingredient Risk Range[a]	Product Risk Range[a]
Surfactant	Small streams in Southern Rocky Mountain steppe-open woodland-coniferous forest-alpine meadow	National Foam KnockDown	Rainbow trout	0.211	0.211
	Small streams in Lower Mississippi riverine forest			0.0664	0.0664
	Small streams in southwest plateau and plains dry steppe and shrub			0.141	0.141
Surfactant	Small streams in southeastern mixed forest	Stockhausen Firecape FP-47	Rainbow trout	0.0723	0.0729
			Tadpoles	0.0737	0.0737
	Small streams in southwest plateau and plains dry steppe and shrub		Rainbow trout	0.0536	0.0544
			Tadpoles	0.0546	0.0546
	Small streams in outer coastal plain mixed forest		Rainbow trout	0.0580	0.0586
			Tadpoles	0.0591	0.0591

[a]Risks are presented in terms of quotient values that exceed 0.05, the threshold for risk to sensitive species, as described in Section 4.1.1. Risks are also present for non-sensitive species if the quotient exceeds 0.5.

Table 4-3. Risks to Aquatic Species from Wildland Fire-Fighting Products in Runoff

	Estimated Risks*					
	Small Stream			Large Stream		
Product	**RT**	**DM**	**TP**	**RT**	**DM**	**TP**
Retardants						
Phos-Chek D75-F	3.63E-02	6.64E-03	2.12E-03	1.25E-03	2.29E-04	7.61E-05
Fire-Trol LCG-R	2.50E-02	7.30E-06	1.59E-03	8.94E-04	2.61E-07	5.71E-05
Fire-Trol LCG-F	2.47E-02	7.25E-06	1.58E-03	8.86E-04	2.60E-07	5.66E-05
Fire-Trol LCA-R	2.37E-02	6.91E-06	1.51E-03	8.50E-04	2.48E-07	5.43E-05
Fire-Trol LCA-F	2.33E-02	6.84E-06	1.49E-03	8.36E-04	2.45E-07	5.34E-05
Phos-Chek 259-F	2.18E-02	3.99E-03	ND	7.53E-04	1.38E-04	ND
Phos-Chek D75-R	1.43E-02	2.62E-03	2.13E-03	4.95E-04	9.05E-05	7.63E-05
Phos-Chek G75-W	1.38E-02	2.52E-03	2.09E-03	4.77E-04	8.73E-05	7.47E-05
Phos-Chek G75-F	1.38E-02	2.52E-03	2.36E-04	4.77E-04	8.73E-05	8.44E-06
Fire-Trol FTR	1.07E-02	7.13E-06	6.82E-04	3.82E-04	2.56E-07	2.44E-05
Fire-Trol 300F	8.07E-03	6.16E-06	4.83E-04	2.89E-04	2.62E-07	1.73E-05
Fire-Trol GTS-R	7.43E-03	1.81E-05	4.90E-04	2.66E-04	6.50E-07	1.75E-05
Phos-Chek 259-R	6.34E-04	ND	ND	2.27E-05	ND	ND
Phos-Chek HV-F	1.87E-04	3.19E-05	2.97E-04	6.71E-06	1.14E-06	1.06E-05
Phos-Chek LV-R	1.87E-04	3.19E-05	2.97E-04	6.71E-06	1.14E-06	1.06E-05
Phos-Chek HV-R	1.86E-04	3.12E-05	2.90E-04	6.65E-06	1.12E-06	1.04E-05
Phos-Chek MV-R	1.86E-04	3.12E-05	2.90E-04	6.65E-06	1.12E-06	1.04E-05
Phos-Chek MV-F	1.64E-04	2.17E-05	2.02E-04	5.86E-06	7.77E-07	7.22E-06
Foams						
National Foam KnockDown	2.11E-01	1.06E-05	7.98E-06	8.76E-03	3.80E-07	2.86E-07
Fire-Trol FireFoam 103B	4.30E-02	4.57E-02	ND	1.48E-03	1.58E-03	ND
Fire-Trol FireFoam 104	4.30E-02	4.57E-02	ND	1.48E-03	1.58E-03	ND
Fire-Trol FireFoam 103	4.25E-02	4.56E-02	ND	1.47E-03	1.57E-03	ND
Phos-Chek WD 881	2.10E-02	2.06E-02	ND	7.37E-04	7.23E-04	ND
Fire Choke	6.53E-03	1.30E-03	2.72E-03	2.34E-04	4.65E-05	9.74E-05
3M Light Water FT-1150	2.81E-03	3.02E-03	ND	1.06E-04	1.13E-04	ND
Pyrocap B-136	2.24E-03	ND	ND	9.49E-05	ND	ND
Ansul Silv-Ex	4.20E-05	0.00E+00	ND	1.50E-06	0.00E+00	ND
Angus ForExpan S	0.00E+00	0.00E+00	ND	0.00E+00	0.00E+00	ND
Water Enhancers						
FireOut ICE	—	—	—	—	—	—
Stockhausen Firecape FP-47	7.29E-02	2.80E-02	7.37E-02	2.52E-03	9.68E-04	2.55E-03

Note: RT=rainbow trout DM=Daphnia magna TP=tadpole species

*A risk is predicted for sensitive species if the quotient value exceeds 0.05 (indicated by shaded quotient), and for non-sensitive species if it exceeds 0.5 (indicated by boldface + shaded quotient).

Eighteen of the 30 products were estimated to pose their greatest rainbow trout risk in the Yukon intermontane plateaus taiga ecoregion. The ecoregions associated with the greatest estimated risks to rainbow trout from each of the other 12 products were as follows:

- Southeastern mixed forest ecoregion: Phos-Chek 259F and Stockhausen Firecape FP-47
- Outer coastal plain: Phos-Chek D75-F, D75-R, G75-F, and G75-W
- Lower Mississippi riverine forest: 3M Light Water FT-1150
- Southwest plateau and plains dry steppe and shrub: Fire-Trol FireFoam 103, 103B, and 104; and Phos-Chek WD 881
- Great Plains-Palouse dry steppe: Pyrocap B-136

The prediction of higher risk in the Yukon ecoregion compared to the other studied ecoregions may be tempered by the results of a recent USGS study. Soils in these Alaskan areas contain a high proportion of organic matter; 10, 3.7, and 3.0% in the upper, middle, and lower horizons were the values used in this risk assessment. Little and Calfee (2002) studied the environmental persistence of fire retardants, and concluded that:

> ...soil composition appears to be a critical variable when evaluating the environmental hazards of these fire-retardant chemicals. Even though applications are quite high relative to LC50 concentrations for fish, the weathering of these materials on soils having 3 to 5 percent organic matter would rapidly diminish toxicity of short-term exposures.

As previously noted, degradation was not taken into account in the modeling for this risk assessment, since no “expected” length of time can be identified between application and precipitation. Therefore, the selected approach errs on the conservative side to avoid underestimating potential exposures if the actual interim period was brief, which would allow only minimal (if any) degradation to occur. This precautionary note is equally relevant to other soils with high organic matter content.

Risks from Accidental Application Across Stream

Table 4-4 summarizes the ingredient types, products, and scenarios for which aquatic species were predicted to be at risk from accidental application across a stream.

Tables 4-5 and 4-6 rank the risks from the various fire-fighting chemical products in order of the greatest-to-least risk to rainbow trout found for the maximum end of the risk range (across ecoregions) from accidental application to small and large streams, respectively. Risks presented for each product are the additive risks from the more highly toxic chemical ingredients that were evaluated quantitatively in this analysis.

Table 4-4. Product Ingredients with Estimated Risks to Aquatic Species from Accidental Application Across Stream

Ingredient Type	Stream size	Product	Repre-sentative Species	Ingredient Risk Range[a]	Product Risk Range[a]
Corrosion inhibitor	Small streams in any ecoregion	Fire-Trol 300F, FTR, GTS-R, LCA-F, LCA-R, LCG-F, LCG-R	Rainbow trout	0.755 - 4.85	0.372 - 161
			Tadpole	<0.05[b] - 0.310	<0.05[b]- 0.331
	Large streams in any ecoregion	Fire-Trol 300F, FTR, GRS-R, LCA-F, LCA-R, LCG-F, LCG-R	Rainbow trout	<0.05[b] - 0.677	0.0518 - 22.5
Retardant salt	Small streams in any ecoregion	Fire-Trol 300F, GTS-R Phos-Chek D75-F, D75-R, G75-F, G75-W, HV-F, HV-R, LV-R, MV-R, MV-R	Rainbow trout	<0.05[b] - 0.296	<0.05[b] - 1.78
		Fire-Trol 300F, GTS-R Phos-Chek D75-F, D75-R, G75-F, G75-W, HV-F, HV-R, LV-R, MV-R, MV-R	Tadpole	<0.05[b] - 0.239	<0.05[b] - 0.330
Retardant salt	Small streams in any ecoregion except Great Plains-Palouse dry steppe	Fire-Trol FTR, LCA-F, LCA-R, LCG-F, LCG-R	Rainbow trout	<0.05[b] - 0.163	0.372 - 5.02
			Daphnia magna	<0.05[b] - 0.163	<0.05[b] - 0.163
Retardant salt	Small streams in any ecoregion	Phos-Chek 259F, 259R	Rainbow trout	0.0510 - 0.313	0.0522 - 0.341
Fungicide	Small streams in Laurentian, Cascade, outer coastal plain, Yukon, and California coast	Phos-Chek D75-F	Rainbow trout	0.0616 - 0.0924	61.9 - 92.8
Surfactant	Small streams in any ecoregion	3M Light Water FT-1150 Fire-Trol FireFoam 103, 103B, 104 Phos-Chek WD 881	Rainbow trout	0.652 - 1.66	1.54 - 1.77
			Daphnia magna	0.699 - 1.78	1.65 - 1.89
	Large streams in any ecoregion		Rainbow trout	0.0910 - 0.231	0.215 - 0.247
			Daphnia magna	0.0975 - 0.248	0.230 - 0.263
Surfactant	Small streams in any ecoregion	Angus ForExpan S Ansul Silv-Ex Phos-Chek WD 881	Rainbow trout	0.274 - 0.722	0.274 - 1.77
			Daphnia magna	0.307 - 0.810	0.307 - 1.89
	Large streams in any ecoregion	Ansul Silv-Ex Phos-Chek WD 881	Rainbow trout	0.0913 - 0.101	0.232 - 0.247
			Daphnia magna	0.102 - 0.113	0.113 - 0.263

Table 4-4. Product Ingredients with Estimated Risks to Aquatic Species from Accidental Application Across Stream (continued)

Surfactant	Small streams in any ecoregion	Ansul Silv-Ex	Rainbow trout	0.940	1.66
	Large streams in any ecoregion			0.131	0.232
Surfactant	Small streams in any ecoregion	Fire Choke	Rainbow trout	0.415	0.523
			Daphnia magna	0.227	0.252
	Large streams in any ecoregion		Rainbow trout	0.0579	0.0730
Surfactant	Small streams in any ecoregion	Fire Choke	Rainbow trout	0.0662	0.523
			Tadpoles	0.0674	0.0676
Surfactant	Small streams in any ecoregion	National Foam KnockDown	Rainbow trout	0.194	0.195
Solvent	Small streams in any ecoregion	Phos-Chek WD 881	Rainbow trout	0.465	1.77
			Daphnia magna	0.453	1.89
	Large streams in any ecoregion		Rainbow trout	0.0648	0.247
			Daphnia magna	0.0631	0.263
Surfactant	Small streams in any ecoregion	Pyrocap B-136	Rainbow trout	0.0544	0.0544

[a]Risks are presented in terms of quotient values that exceed 0.05, the threshold for risk to sensitive species, as described in Section 4.1.1. Risks are also present for non-sensitive species if the quotient exceeds 0.5.
[b] "<0.05" indicates that estimated concentrations from some of the named products in some ecoregions are below the level associated with risk to this aquatic species.

Table 4-5. Risks to Aquatic Species from Wildland Fire-Fighting Products Accidentally Applied Across a Small Stream

	Range of Estimated Risks Across Ecoregions*					
	Rainbow Trout		*Daphnia magna*		Tadpole	
Product	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Fire-Trol LCG-R	**8.36E-01**	**5.02E+00**	2.72E-02	1.63E-01	5.17E-02	3.10E-01
Fire-Trol LCG-F	**8.27E-01**	**4.96E+00**	2.71E-02	1.62E-01	5.11E-02	3.07E-01
Fire-Trol LCA-R	**7.94E-01**	**4.76E+00**	2.58E-02	1.55E-01	4.91E-02	2.94E-01
Fire-Trol LCA-F	**7.80E-01**	**4.68E+00**	2.55E-02	1.53E-01	4.82E-02	2.89E-01
Fire-Trol FTR	3.72E-01	**2.23E+00**	2.66E-02	1.60E-01	2.21E-02	1.32E-01
Phos-Chek WD 881	**1.77E+00**	**1.77E+00**	**1.89E+00**	**1.89E+00**	0.00E+00	0.00E+00
Ansul Silv-Ex	**1.66E+00**	**1.66E+00**	**8.10E-01**	**8.10E-01**	0.00E+00	0.00E+00
3M Light Water FT-1150	**1.66E+00**	**1.66E+00**	**1.78E+00**	**1.78E+00**	0.00E+00	0.00E+00
Fire-Trol FireFoam 103	**1.66E+00**	**1.66E+00**	**1.78E+00**	**1.78E+00**	0.00E+00	0.00E+00
Fire-Trol FireFoam 103B	**1.66E+00**	**1.66E+00**	**1.78E+00**	**1.78E+00**	0.00E+00	0.00E+00
Fire-Trol 300F	2.58E-01	**1.55E+00**	4.26E-03	2.56E-02	5.51E-02	3.31E-01
Fire-Trol FireFoam 104	**1.54E+00**	**1.54E+00**	**1.65E+00**	**1.65E+00**	0.00E+00	0.00E+00
Fire-Trol GTS-R	2.55E-01	**1.53E+00**	7.60E-03	4.56E-02	5.49E-02	3.30E-01
Fire Choke	**5.23E-01**	**5.23E-01**	2.52E-01	2.52E-01	6.76E-02	6.76E-02
Phos-Chek 259-F	5.70E-02	3.42E-01	1.09E-03	6.55E-03	0.00E+00	0.00E+00
Phos-Chek 259-R	5.22E-02	3.13E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Angus ForExpan S	2.74E-01	2.74E-01	3.07E-01	3.07E-01	0.00E+00	0.00E+00
National Foam KnockDown	1.95E-01	1.95E-01	3.24E-05	3.24E-05	2.44E-05	2.44E-05
Phos-Chek D75-F	2.70E-02	1.62E-01	5.34E-03	3.20E-02	2.31E-02	1.38E-01
Phos-Chek D75-R	1.76E-02	1.06E-01	3.63E-03	2.18E-02	2.31E-02	1.39E-01
Phos-Chek G75-W	1.54E-02	9.25E-02	3.51E-03	2.11E-02	2.27E-02	1.36E-01
Phos-Chek HV-F	1.41E-02	8.48E-02	2.47E-03	1.48E-02	2.30E-02	1.38E-01
Phos-Chek LV-R	1.41E-02	8.48E-02	2.47E-03	1.48E-02	2.30E-02	1.38E-01
Phos-Chek HV-R	1.41E-02	8.47E-02	2.47E-03	1.48E-02	2.29E-02	1.38E-01
Phos-Chek MV-R	1.41E-02	8.47E-02	2.47E-03	1.48E-02	2.29E-02	1.38E-01
Phos-Chek MV-F	1.40E-02	8.37E-02	2.36E-03	1.42E-02	2.20E-02	1.32E-01
Phos-Chek G75-F	1.39E-02	8.34E-02	3.47E-03	2.08E-02	2.23E-02	1.34E-01
Pyrocap B-136	5.44E-02	5.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

*A risk is predicted for sensitive species if the quotient value exceeds 0.05 (indicated by shaded quotient) and for sensitive and non-sensitive species if it exceeds 0.5 (indicated by boldface + shaded quotient).

Table 4-6. Risks to Aquatic Species from Wildland Fire-Fighting Products Accidentally Applied Across a Large Stream

	Range of Estimated Risks Across Ecoregions*					
	Rainbow Trout		*Daphnia magna*		Tadpole	
Product	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Fire-Trol LCG-R	1.17E-01	**6.99E-01**	3.80E-03	2.28E-02	7.20E-03	4.32E-02
Fire-Trol LCG-F	1.15E-01	**6.92E-01**	3.77E-03	2.26E-02	7.13E-03	4.28E-02
Fire-Trol LCA-R	1.11E-01	**6.64E-01**	3.60E-03	2.16E-02	6.84E-03	4.10E-02
Fire-Trol LCA-F	1.09E-01	**6.53E-01**	3.56E-03	2.14E-02	6.72E-03	4.03E-02
Fire-Trol FTR	5.18E-02	3.11E-01	3.71E-03	2.23E-02	3.07E-03	1.84E-02
Phos-Chek WD 881	2.47E-01	2.47E-01	2.63E-01	2.63E-01	0.00E+00	0.00E+00
Ansul Silv-Ex	2.32E-01	2.32E-01	1.13E-01	1.13E-01	0.00E+00	0.00E+00
3M Light Water FT-1150	2.31E-01	2.31E-01	2.48E-01	2.48E-01	0.00E+00	0.00E+00
Fire-Trol FireFoam 103	2.31E-01	2.31E-01	2.48E-01	2.48E-01	0.00E+00	0.00E+00
Fire-Trol FireFoam 103B	2.31E-01	2.31E-01	2.48E-01	2.48E-01	0.00E+00	0.00E+00
Fire-Trol 300F	3.60E-02	2.16E-01	5.94E-04	3.56E-03	7.68E-03	4.61E-02
Fire-Trol FireFoam 104	2.15E-01	2.15E-01	2.30E-01	2.30E-01	0.00E+00	0.00E+00
Fire-Trol GTS-R	3.55E-02	2.13E-01	1.06E-03	6.36E-03	7.66E-03	4.60E-02
Fire Choke	7.30E-02	7.30E-02	3.52E-02	3.52E-02	9.42E-03	9.42E-03
Phos-Chek 259-F	7.94E-03	4.77E-02	1.52E-04	9.13E-04	0.00E+00	0.00E+00
Phos-Chek 259-R	7.28E-03	4.37E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Angus ForExpan S	3.82E-02	3.82E-02	4.29E-02	4.29E-02	0.00E+00	0.00E+00
National Foam KnockDown	2.72E-02	2.72E-02	4.52E-06	4.52E-06	3.40E-06	3.40E-06
Phos-Chek D75-F	3.76E-03	2.25E-02	7.44E-04	4.46E-03	3.22E-03	1.93E-02
Phos-Chek D75-R	2.45E-03	1.47E-02	5.06E-04	3.04E-03	3.23E-03	1.94E-02
Phos-Chek G75-W	2.15E-03	1.29E-02	4.89E-04	2.93E-03	3.16E-03	1.90E-02
Phos-Chek HV-F	1.97E-03	1.18E-02	3.45E-04	2.07E-03	3.21E-03	1.92E-02
Phos-Chek LV-R	1.97E-03	1.18E-02	3.45E-04	2.07E-03	3.21E-03	1.92E-02
Phos-Chek HV-R	1.97E-03	1.18E-02	3.44E-04	2.06E-03	3.20E-03	1.92E-02
Phos-Chek MV-R	1.97E-03	1.18E-02	3.44E-04	2.06E-03	3.20E-03	1.92E-02
Phos-Chek MV-F	1.95E-03	1.17E-02	3.29E-04	1.98E-03	3.06E-03	1.84E-02
Phos-Chek G75-F	1.94E-03	1.16E-02	4.84E-04	2.90E-03	3.11E-03	1.87E-02
Pyrocap B-136	7.59E-03	7.59E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00

*A risk is predicted for sensitive species if the quotient value exceeds 0.05 (indicated by shaded quotient) and for sensitive and non-sensitive species if it exceeds 0.5 (indicated by boldface + shaded quotient).

Risks from Accidental Spill to Stream

All concentrated and mixed retardant and foam products present a significant risk to one or more aquatic species when spilled into a small stream at the volumes assumed in this risk assessment. As stream size increases, risks to aquatic species decrease due to dilution of the chemical contaminant by the larger water volume. For the representative large stream evaluated in this risk assessment, sufficient dilution was achieved to remove National Foam KnockDown from the list of products with predicted aquatic species risks in the case of an accidental spill; risks remained for all other retardant and foam formulations.

Risks to Freshwater Mussels from Ammonia

Augspurger et al. (2003) evaluated available data on the toxicity of ammonia to genera of freshwater mussels, and developed a recommendation for a water quality criterion of 0.3 to 1.0

mg/L total ammonia (as nitrogen) at pH 8 to protect these species. Evaluating the estimated water concentrations of the ammonium-containing compounds (see Appendix A) against these criteria, including the very conservative simplifying assumption that *all* nitrogen is present as ammonia, runoff from retardant-treated areas is not expected to result in water concentrations that would pose a risk to freshwater mussels. However, as with other aquatic species, an accidental spill (particularly in a small stream) would likely result in mortality to mussels.

Summary of Quantitative Aquatic Species Risk Assessment

The quantitative risk assessment for aquatic species from individual ingredients in the fire-fighting chemical products predicted the following:

- Runoff: No risks were predicted for non-sensitive species. Risks to sensitive fish species in small streams in some ecoregions were associated with a surfactant in one foam product. Risks to sensitive fish and aquatic stages of amphibians in small streams in some ecoregions were predicted from a surfactant in one water enhancer.

- Accidental application across stream: All retardant and foam products present risk to one or more aquatic species if applied across a small stream. In a large stream, sufficient dilution was achieved to decrease to negligible the risk from eight retardants and three foams. Risks remained for the other ten retardant and seven foam products.

- Accidental spill: All concentrated and mixed retardant and foam products present risk to one or more aquatic species if spilled into a small stream at the volumes assumed in risk assessment: three 2,000-lb bulk bags of powdered retardant concentrate; a 2,000-gal tank of wet retardant concentrate; a 2,000-gal tank of mixed, diluted retardant; or a 35-gal spill of foam concentrate. In a large stream, sufficient dilution was achieved to decrease to negligible the risk from one foam product; risks remained for all other retardant and foam products.

No whole-product analysis was attempted for the runoff scenario, since each ingredient's environmental behavior (for example, adsorption to soil and solubility in runoff water) would be influenced, if not wholly determined, by that chemical's specific chemical and physical properties, and not by the product's characteristics. As in the ingredient-based assessment, accidental applications or spills into water bodies would be expected to result in adverse effects.

4.2 Sodium Ferrocyanide

Sodium ferrocyanide is used as a corrosion inhibitor and has been an ingredient in long-term fire retardants since the 1970s. Also referred to as yellow prussiate of soda (YPS or YP soda), sodium ferrocyanide in the aquatic environment reacts in the presence of ultraviolet (UV) light to release free cyanide ions that are toxic to aquatic organisms. In early scientific literature, Burdick and Lipschuetz (1950) reported that dilute concentrations of sodium ferrocyanide solutions became toxic to fish when exposed to sunlight. Recent studies under laboratory conditions have demonstrated an increase in toxicity to fish and amphibians exposed to fire retardant products containing sodium ferrocyanide in the presence of UV light. Calfee and Little (2003) exposed rainbow trout and southern leopard frog tadpoles to six fire retardant formulations with and without sodium ferrocyanide and to sodium ferrocyanide alone under three different UV light treatments. Mortality of trout and tadpoles exposed to Fire-Trol GTS-R, Fire-Trol 300-F, Fire-Trol LCA-R, and Fire-Trol LCA-F was significantly increased in the presence of UV radiation when sodium ferrocyanide was present in the mixture. Mortality commonly occurred within the first few hours of exposure. Free cyanide concentrations increased as UV intensities increased. For all tests with rainbow trout, total and un-ionized ammonia did not reach toxic levels. In tests with tadpoles, ammonia remained below toxic thresholds with the exception of one test with Fire-Trol LCA-R where un-ionized ammonia exceeded the lower threshold value for effects on amphibians by 0.02 mg/L. For this risk assessment, LC_{50} values derived in the Little and Calfee (2003) study for rainbow trout and tadpoles exposed to YPS and UV radiation were used to estimate risk to aquatic species in Table 4-3.

The ability of organisms to detect and avoid chemical contaminants is of major toxicological significance because avoidance of contamination reduces both exposure and resulting injury to an organism. Avoidance of rainbow trout was evaluated in laboratory exposures to two fire retardant products: Fire-Trol GTS-R and Phos-Chek D75-R. Fire-Trol GTS-R was also tested (1) without sodium ferrocyanide and without ferrous oxide colorant, and (2) with sodium ferrocyanide and without ferrous oxide colorant. Sodium ferrocyanide was also tested independently (Wells et al. 2004). Studies were conducted in countercurrent avoidance chambers in a flow-through design engineered to create a distinct boundary between treated water and reference water. Rainbow trout consistently avoided water treated with retardants at all concentrations tested; the response was not dose-dependent, but rather was an all or none response. Tests with different chemical formulations demonstrated that the absence of sodium ferrocyanide or ferrous oxide did not diminish the avoidance response. These tests suggested that rainbow trout were able to detect and avoid concentrations of less than 10% of the GTS-R LC_{50} that had been established for rainbow trout by Calfee and Little (2003). In tests with sodium ferrocyanide alone, fish avoided the treated water but to a lesser extent than they avoided the Fire-Trol GTS-R product.

Fish sensory systems have been shown to be highly sensitive to salts (Kleerekoper 1976); thus, fish in this study may have responded to salinity associated with the fire retardant product's constituents. However, other environmental variables including ammonia, pH, water quality, and temperature may influence an organism's response in the natural environment. In evaluating and interpreting risk information, the importance of an avoidance response must be considered. Although the avoidance of fire retardant chemicals can be advantageous to aquatic organisms, long-term avoidance may reduce or eliminate critical habitat and result in selection of less optimal habitat in terms of food, shelter, and reproduction for fish species (Atchison et al. 1987). However, the ability to sense and avoid the presence of retardants at concentrations significantly below lethal concentrations can provide protection for a species and allow for the recovery of that species after the threat of chemical exposure has passed, if areas of refuge are available.

In addition to application of fire retardant on the landscape, burning of biomass, such as during a wildland fire, releases a complex mixture of hundreds of chemicals, varying by type of vegetation and nature of the fire. These compounds may become airborne in smoke, or may remain on the ground in partially burnt fuels and ash. Cyanide compounds may be among those produced during a wildland fire, and to which aquatic species may be exposed (Barber et al. 2003, Crouch et al. 2006). Depending on the chemical species present and their site-specific environmental behavior, biomass-derived cyanide compounds could contribute to a cumulative effect (with cyanide from a sodium ferrocyanide source) on aquatic species.

4.3 Phytotoxicity

Bradstock et al. (1987) reported dramatic short-term effects (widespread leaf death in tree, shrub, and ground cover species) in an Australian eucalyptus forest that was sprayed with a mixture of ammonium sulfate and a thickener. The fire retardant mixture contained 20 grams (g)/L (0.17 lb/gal) of ammonium sulfate and 1 g/L (0.009 lb/gal) of kelzan, an organic polysaccharide thickener. The mixture was dropped from a fixed-wing aircraft about 40 m (132 ft) above ground to a plot 15 m x 70 m (49 ft x 230 ft) in a eucalyptus forest near Sydney. The drop rate was not reported, but the ground level coverage ranged from zero to 2 L/m^2, with un unknown amount having been intercepted by vegetation. Leaf death occurred within a week of treatment and continued for many months in both the overstory and understory. While the overstory recovered rapidly, decreased cover in many understory species persisted at one year post-application. The results of associated greenhouse experiments reported in this study indicated that the ammonium sulfate component was the retardant ingredient responsible for foliar damage, and that foliar washing did not minimize the adverse effect.

A field study (Larson and Newton 1996) examined the effect of Phos-Chek G75-F retardant (applied at a rate of 1 gpc) and Silv-Ex foam (189 L/100 m^2 of 0.5% solution, or about 4.6 gpc) application on vegetation in a North Dakota mixed grass prairie. In each test area, four plots were evaluated: a control, application of product only, application of product + burn, and burn only. Phos-Chek G75-F retardant application produced a notable increase in herbaceous biomass for the first growing season only, regardless of whether the plot was also burned, and caused no effects on shoot, leaf, or stem growth characteristics. Silv-Ex foam had subtle effects on vegetation characteristics in one species: increased consumption of plant leaves by herbivorous insects (“herbivory”), enhanced leaf growth, and depressed shoot growth. However, no effect on herbaceous biomass accumulation was noted, indicating little effect on average plant growth as a result of foam application. This study’s observations regarding species diversity effects are discussed in the following section.

A follow-up study (Larson et al. 1999) evaluated the same retardant and foam product when applied to Great Basin shrub steppe vegetation, in northern Nevada. Growth, resprouting, flowering, and incidence of galling insects were not affected by treatment with Phos-Chek G75-F retardant applied at a rate of 3 gpc, or by treatment with 0.5 and 1.0% Silv-Ex foam applied at a rate of 1,410 L per hectare (about 0.35 gpc). This study’s observations regarding species diversity effects are discussed in the following section.

Shoot and whole plant death on individual plants were recorded following experimental application of Phos-Chek D75-R to plots on an Australian heathland (Bell 2003, Bell et al. 2005). Adverse effects varied by species, and increased with increasing application rate (from 0.5 to 1.5 L mixed retardant per m^2, or 1.2 to 3.7 gpc). However, there was little change in visual estimates of percent foliar cover between treated and untreated areas.

Hartskeerl et al. (2004) studied the effects of firefighting foams on Australian native plants. Angus ForExpan, at concentrations from 0.1 to 1.0%, was applied to seedlings of seven species. No growth response attributable to the foam treatment was detected.

Few studies have evaluated the potential effects of fire retardants and foams on terrestrial vegetation. Overall, they indicate the possibility of phytotoxic effects to individual plants of more sensitive species at the application rates typically used, but generate no expectation of widespread or enduring impacts. Visible browning of leaves—possibly related to chemical burn caused by direct application of an ammonium-based product as well as dehydration of the leaf surface from exposure to the elevated salt content of the fire retardant—has been documented in field studies by Larson and Newton (1996); however, regeneration of leaf material was recorded later in the same growing season and herbivory was not affected.

Some surfactants—which, as a class, comprise active ingredients in the foam and some water enhancer products—have been demonstrated to adversely affect seed germination, inhibit seedling growth, and otherwise indicate toxicity to some higher plants (Talmage 1994). The concentrations at which effects have been observed vary widely and differ among plant species, with some studies showing no adverse effects at all. Since only limited areas are treated with these products, and the vegetation would otherwise be severely affected by the fire itself in the absence of these products' use, it is concluded that foams and some water enhancers may have adverse effects on individual plants or localized areas of vegetation, and that further exhaustive or quantitative analysis is not warranted.

4.4 Vegetation Diversity

Information on the effects of fire retardant chemicals on vegetation diversity is extremely limited. Larson et al. (1999) suggested that many effects of ammonium-based retardants can be anticipated based on studies with fertilizers. Similar to the effects of fertilizers, fire retardants may encourage growth of some plant species and giving them a competitive advantage over others, thus resulting in changes in community composition and species diversity (Tilman 1987, Wilson and Shay 1990). Bell et al. (2005) recorded enhanced weed invasion in an Australian heathland ecosystem, particularly in areas receiving high concentrations of Phos-Chek D75R.

The effects of Phos-Chek D75-F and Silv-Ex application on species diversity were also evaluated in a North Dakota grassland community (Larson and Newton 1996) and in a shrub steppe area in the Great Basin in Nevada (Larson et al. 1999). The researchers measured community characteristics, including species richness, evenness, diversity, and number of stems of woody and herbaceous plants.

- In the North Dakota prairie ecosystem, species richness was reduced in plots exposed to both retardant and foam regardless of whether the plot was burned or unburned. All plots were dominated by *Poa pratensis*, which clearly gained a competitive advantage from retardant application and crowded out other species.

- Investigations in the Great Basin shrub steppe ecosystem also showed that plots treated with fire chemicals experienced initial declines in species richness; however, differences among plots were undetectable after a year. Depression of species richness was most pronounced in the riparian corridor.

Overall, vegetative community response to burning was more dramatic than was the response to chemical application. In both studies, the authors note that each study was short-term, and that long-term ecological responses should be measured over several growing seasons. However, they did recommend that managers intending to use these chemicals to control prescribed burns should consider the effects on species richness or on individual species of concern (invasive species) when they evaluate management objectives on a landscape scale.

In an evaluation of the application of Phos-Chek XA fire retardant that was applied to a California grassland during the course of fighting a wildland fire, Larson and Duncan (1982) studied the effects on vegetative productivity. The two-year study reported that application of the retardant produced almost twice the yield of forage in the first year after application in both burned and unburned areas; this relative increase continued into the second year for the unburned treated plot. In the second year, there was no statistically significant increase in forage production in either the treated or untreated burned plots compared to the unburned, untreated control area. The authors reported that, although forbs usually increase in annual grassland after a fire, nitrogen fertilizer favors grasses, which dominated the first year after the fire. Forbs dominated the second year.

Although the phytotoxic effects and vegetation diversity endpoints in this analysis have underlying links related to mechanisms of toxicity (for example, varying susceptibility to effects on seed germination among plant species), further exhaustive or quantitative analysis of the topic is not warranted, since only limited areas are treated with these products and the vegetation would otherwise be severely affected by the fire itself in the absence of their use.

4.5 Risk Management Considerations

The type, severity, and likelihood of potential risks from use of chemical products to fight wildland fires are discussed in the previous sections of this chapter. The *probability* of their use to suppress a specific wildland fire depends on (1) whether the fire will be suppressed, and, if it will be suppressed, (2) whether chemical products are appropriate to the situation.

Suppression Decision-Making

The 2003 *Interagency Strategy for the Implementation of Wildland Fire Management Policy* listed three types of wildland fire (that is, any non-structure fire that occurs in wildland) (USDA / DOI 2003):

- Wildfire – An unplanned and unwanted wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out.

- Wildland Fire Use – The application of the Appropriate Management Response to naturally-ignited wildland fires to accomplish specific resource management objectives in predefined designated areas outlined in Fire Management Plans (FMPs). Operational management is described in the Implementation Plan (Wildland Fire Implementation Plan (WFIP)).

- Prescribed Fire – Any fire ignited by management actions to meet specific objectives.

The resource management objectives targeted in the second and third type of wildland fire encompass the broad range of beneficial impacts that fire offers, particularly to fire-dependent wildlands.

> Many of America's wildlands are characterized as fire-dependent. That is, they require periodic fire in order to maintain a healthy, resilient condition. Within these ecosystems, certain kinds of fire are beneficial; conversely, in the absence of fire adverse impacts occur. Today, after a century of attempted fire exclusion, extensive areas of the country are at risk from intense, severe wildfires that threaten nearby communities and cause significant damage to soil and other key ecological components. The most dangerous, most damaging, and most costly wildfires in recent history are often in fire-dependent wildlands where conditions are altered, and wildlands that are no longer healthy or resilient, because several fire cycles have been missed. (USDA / DOI 2003)

In determining the response to a wildland fire, one discrete policy articulated in the 2001 Federal fire management policy (DOI et al. 2001) states that "Fire, as a critical natural process, will be integrated into land and resource management plans and activities on a landscape scale, and across agency boundaries. Response to wildland fires is based on ecological, social, and legal consequences of the fire. The circumstances under which a fire occurs, and the likely consequences on firefighter and public safety and welfare, natural and cultural resources, and, values to be protected, dictate the appropriate response to the fire." The 2003 strategy clarifies that "Agency mission will influence the response to wildland fire. In sum total, fire is a critical natural process, even though at smaller scales fire may not be a critical natural process. The L/RMP [land / resource management plan] will define and identify fire's role in the ecosystem. The corresponding response to an ignition (Appropriate Management Response) is guided by the strategies and objectives outlined for FMU's [fire management units] in the FMP. Values are defined in the FMP. Initial attack is planned and specified in FMPs."

Use of Chemical Products in Fire Suppression Actions

Use of chemical products to fight a wildland fire is determined on a case-by-case basis, by the responsible official for that particular incident. Environmental considerations are included in the decision-making process: environmental guidelines for use of suppression chemicals are integrated into Chapter 12 of *Interagency Standards for Fire and Aviation Operations*, also known as the "Red Book" (NIFC 2005).

4.6 Uncertainties

Analysis of the uncertainty in an ecological risk assessment is an integral part of analyses conducted under EPA's guidelines (EPA 1998). The results presented in this risk assessment depend on a number of factors, including the availability of pertinent scientific information, standard risk assessment practices, exposure assumptions, and toxicity assumptions. Uncertainties are introduced into a risk assessment because a range of values could be used for each assumption. In general, most assumptions were selected to be representative of typical conditions, while a certain few assumptions (such as no environmental degradation to less toxic chemicals) were selected to avoid underestimating risks. Uncertainty is introduced the ecological risk assessment process in both the problem formulation and analysis stages.

Uncertainties in problem formulation are manifested in the quality of conceptual models (EPA 1998). During problem formulation, the original development of the conceptual model could neglect risks that do exist but are not recognized, or could overemphasize risks that are relatively minor. The lack of available data with which to consistently evaluate sublethal effects for all ingredients/products is one example. (However, known areas of concern, such as the possibility for some surfactant ingredients to affect the endocrine systems of certain species, are included among ongoing areas of inquiry by the Forest Service.) In contrast, the conceptual model's characterization of environmental transport pathways and potential routes of fire-fighting chemical exposure to wildlife and aquatic species are reasonably unambiguous, as depicted in Figure 2-1.

In the analysis phase, several sources of uncertainty arise, including selection of receptors; exposure of receptors; data variability regarding the toxicity of the products, their ingredients, and the toxicity of the resulting mixture; and the assumptions made in defining the ecoregion characteristics. The sources of uncertainty and their effect on the risk conclusions are summarized below:

- In terms of the utility of the risk assessment conclusions for nationwide decision-making, the selection of the representative species that were evaluated introduces significant uncertainty into the conclusions. The species that were evaluated were carefully selected with this issue in mind, to provide a basic level of risk information for a wide range of wildlife, including mammals and bird species with a range of dietary/foraging characteristics and body sizes, fish, aquatic invertebrates, and amphibian tadpoles. Risks to other animals such as reptiles and terrestrial stages of amphibians were not assessed, since there were little to no toxicity data available for many of the ingredients in the fire-fighting chemical products for them. The resulting set of risk conclusions provides a general perspective on potential risks to wildlife, with the uncertainty in actual risk to a species growing with decreasing similarity to the species that were evaluated as representative species in the analysis.

- The actual exposure of any particular animal to the chemicals could, and likely will, vary from the exposures assumed in this assessment:

  - For terrestrial species, dietary and drinking water doses could vary from (a) none, if an animal's ingestion in an unevenly contaminated area resulted in chance or deliberate avoidance of food and water sources containing residues; to (b) 100%, which would result in estimated doses and risks as much as 2 or 10 times higher for animals with wide or limited foraging ranges, respectively. (Current dose estimates reflect assumptions about the fraction of an animal's diet that was assumed to be contaminated; see Section 3.2.1).

- This uncertainty is further complicated by actual variation in residue levels in or on contaminated food items and water. The levels were estimated based on well-validated models, but necessarily assumed uniform application rate of the chemicals over the drop area, which is not consistent with actual use, but will average out over larger areas. The impact of this issue on the total uncertainty is likely minimal. Additional sources of ingestion exposure that were not considered in this assessment could also occur, including incidental soil ingestion (such as from preening / grooming behavior) and ingestion of contaminated sediment entrained in aquatic prey species.

- For aquatic species, the length of exposure to a chemical concentration in water will significantly affect the toxicity associated with that exposure. Generally, if the time period of exposure is longer, the concentration that can be tolerated is lower, and vice versa. In this analysis, the most conservative short-term LC_{50} was selected for each chemical, regardless of actual duration of the toxicity test. Thus, the LC_{50}s that were used are based on exposure durations that range from 1 hour to more than 10 days. To estimate risks, these LC_{50}s were compared to water concentrations of generally short duration. The risks were based on the initial, instantaneous water concentrations in streams, which would quickly decrease as a result of longitudinal dispersion and possible sediment sorption and degradation. In addition, no scenarios for the potential for aquatic organisms to avoid exposure were introduced into the calculation of risk. This could lead to a generally minimal to moderate overestimate in the predicted risk.

- When more than one toxicity data source was identified, the most conservative value (the value associated with the greatest toxicity) was selected for use in the risk assessment. This could lead to overestimates in the predicted risk.

- The interactions of the various ingredients in a product could enhance or decrease the toxicity of any one ingredient. In accordance with EPA guidance, additive toxicity was assumed in the absence of the data to the contrary. The estimated additive toxicity of the ingredient combinations in the products was compared to the toxicity data reported in tests on the product mixtures (see Section 4.1.2); this comparison was made for terrestrial species, and for direct drop and spill scenarios for aquatic species. Consistent results indicated that the additivity assumption has resulted in minimal uncertainty in the risk conclusions.

- Fire-fighting chemicals can be used anywhere that a wildland fire occurs. The physical, chemical, and biological attributes of the natural system in which the chemicals are deposited will have a great impact on the environmental transport and fate of chemicals in that system, including the concentration of chemicals in water, soil, or as residues on terrestrial species diet items. Fifteen representative ecoregions were modeled in the analysis; actual areas into which fire-fighting chemicals are deposited will differ in some or all of these details. This introduces a significant level of uncertainty into the risk conclusions, which may be associated with either an underestimate or an overestimate of risk at a real-world location.

- For all scenarios, the analysis assumed no degradation of the chemicals to less toxic forms. This assumption was made since no minimum timeframe could be assured between chemical use and ecological exposure, and also since studies of retardant degradation on various substrates have shown that the relationship between toxicity to aquatic species and elapsed time is complex, indicating that multiple factors affect the resulting toxicity. This assumption of no degradation, for purposes of the analysis, may be associated with overestimates of risk to terrestrial and aquatic species, and also with further uncertainty regarding the potential for enhancement of invasive species' spread and corresponding decline in native species.

Table 4-7 summarizes these key sources of uncertainty and their potential significance for the risk conclusions presented in this assessment.

Table 4-7. Summary of Key Uncertainties

Source of Uncertainty	Direction[a,b]	Magnitude[b,c]	Comment
Risk exists but is not assessed.	+/–	2	The availability of toxicity data limits the ability to evaluate issues (such as sublethal effects) for all ingredients/products.
Other significant environmental and/or exposure pathways exist but were not assessed.	+/–	0	Pathways of exposure are relatively unambiguous.
Use of representative species as receptors.	+/–	2	Data availability and model simplification required this approach.
Terrestrial species food item contamination frequency.	+/–	2	Could vary from 0 to 10 times the modeled amount.
Chemical residues in/on terrestrial species food and water.	+/–	1	Models used are well-validated, but actual chemical coverage is not uniform.
Duration of aquatic species' exposure compared to duration of toxicity testing.	+	2	In most cases, exposure duration would be far less than the test duration.
Initial water concentrations were used instead of a time-weighted average or other downward adjustment (such as decrease due to sorption, dispersion).	+	2	Initial concentrations were used since exposure could occur at any time after application.
Most conservative toxicity value used for each chemical.	+	1	This avoided underestimating toxicity.
Additive toxicity was assumed for ingredient mixtures.	+/–	0	Risks from ingredient-specific vs. whole-product toxicity data were consistent.
Use of representative ecoregions.	+/–	3	Attributes of natural systems where chemicals are used will likely differ in one or more respects from those that were modeled.
Environmental degradation to less toxic forms of ingredients was not included in the model.	+	2	Exposure could occur at any time after application.

[a]Direction of effect on risk calculations: "+" may result in risks that are overly conservative; "–" may result in risks that are underestimated.
[b]Direction and magnitude values based on professional judgment.
[c]Magnitude of effect on risk calculations: 0 = negligible, 1 = small, 2 = medium, 3 = large.

4.7 Ecological Risk Summary and Discussion

The quantitative risk assessment for terrestrial wildlife from individual ingredients in the fire-fighting chemical products predicted the following:

- Non-sensitive species: Fire retardants were estimated to pose risks to survival of populations of small omnivores from one retardant salt when applied at rates of 6 gpc or more. Water enhancers were associated with risks to survival of populations of small omnivores and songbirds.

- Sensitive species: Fire retardants were predicted to present risks from one retardant salt to survival of individual small omnivores and songbirds, and, at higher rates, also for individual raptors (≥4 gpc) and small herbivores (≥6 gpc). Water enhancers were predicted to pose risks to survival of individual small omnivores, raptors, songbirds, and large herbivores.

The quantitative risk assessment for aquatic species from individual ingredients in the fire-fighting chemical products predicted the following:

- Runoff: No risks were predicted for survival of populations of non-sensitive species. Risks to survival of individuals of sensitive fish species in small streams in some ecoregions were associated with a surfactant in one foam product. Risks to survival of individuals of sensitive fish and aquatic stages of amphibians in small streams in some ecoregions were predicted from a surfactant in one water enhancer.

- Accidental application across stream: All retardant and foam products present risk to survival of populations or individuals of one or more aquatic species if applied across a small stream. In a large stream, sufficient dilution was achieved to decrease to negligible the risk from eight retardants and three foams. Risks remained for the other ten retardant and seven foam products.

- Accidental spill: All concentrated and mixed retardant and foam products present risk to one or more aquatic species if spilled into a small stream at the volumes assumed in risk assessment: three 2,000-lb bulk bags of powdered retardant concentrate; a 2,000-gal tank of wet retardant concentrate; a 2,000-gal tank of mixed, diluted retardant; or a 35-gal spill of foam concentrate. In a large stream, sufficient dilution was achieved to decrease to negligible the risk from one foam product; risks remained for all other retardant and foam products.

The toxicity data for the formulated products were also compared to exposure estimates for terrestrial species exposures and for accidental exposures to aquatic species, with results consistent with the ingredient analysis. No whole-product analysis was attempted for the runoff scenario, since each ingredient’s environmental behavior (and thus likelihood to run off) would be determined by that chemical’s specific chemical and physical properties, and not by the product’s characteristics.

In comparing these results to the limited field study data available, the assessment predicted risks from one retardant salt for which a 1997 field study identified no adverse effects on terrestrial species. The inconsistency in these conclusions can be attributed to the conservative assumptions used in this risk assessment, particularly the assumptions that the chemical was not attenuated by the environment prior to exposure of small mammals, along with assumptions about the percent of diet contaminated.

In the fate modeling, environmental degradation of the chemicals was not credited for reducing concentrations of any chemicals over time, since the length of time elapsing between application and exposure could vary greatly, and could possibly be very short. A 2002 study indicated that the substrate on which the fire retardant is applied could have a significant effect on its persistence in the terrestrial environment and subsequent potential to contaminate adjacent aquatic systems at levels that could be toxic to fish. Lethality to test fish increased as organic matter content decreased, with non-first order relationships observed between elapsed time and toxicity, indicating multiple factors affecting chemical speciation, availability, and resultant toxicity. The relationship between elapsed time and toxicity of retardant residues in runoff has not been quantitatively determined, therefore precluding modeling estimates in this predictive risk assessment. However, it can be concluded that the time-toxicity relationship is complex and will vary according to site-specific conditions, and that any modeling estimates of chemical fate developed without a degradation factor, as is the case in this analysis, will result in a conservative estimate.

For the vegetative community, field studies suggest that the overall effect of burning was more dramatic than effects resulting from chemical application. However, all authors suggested that studies should be conducted over a series of several years to determine the relevance of chemical application to ecological recovery after fires. In addition, they cautioned that land managers should be aware of the competitive advantage that the ammonium-based chemicals might provide to invasive species.

The results presented in this risk assessment depend on a number of factors, including the availability of pertinent scientific information, standard risk assessment practices, exposure assumptions, and toxicity assumptions. The approaches used to address these factors introduce minor to significant amounts of uncertainty into the risk assessment's conclusions. Generally, when assumptions were required, a conservative approach was taken, to provide risk results that are more protective of the environment.

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APPENDIX A

TOXICITY DATA ON FIRE-FIGHTING CHEMICAL FORMULATED PRODUCTS

Terrestrial Species Toxicity Data for Fire-Fighting Chemical Products

Product	Species	Endpoint	Result	Reference
3M Light Water FT-1150	Rat	LD_{50}	>5,050	Stillmeadow 1987
Ansul Silv-Ex	Earthworm	LD_{50}	>1,000 mg/kg	Vyas et al. 1997
Ansul Silv-Ex	Northern bobwhite	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Ansul Silv-Ex	Rat	LD_{50}	>5,050 mg/kg	Stillmeadow 1986
Ansul Silv-Ex	Red-winged blackbird	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Ansul Silv-Ex	White-footed mouse	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Fire Choke	Rat	LD_{50}	>5,050 mg/kg	Stillmeadow 1993
FireOut ICE	Rat	LD_{50}	>5,050 mg/kg	Stillmeadow 1997
Fire-Trol FireFoam 103/103B	Rat	LD_{50} (oral)	>5,050 mg/kg	Fire-Trol Holdings 2000a
	Rabbit	LD_{50} (dermal)	>2,010 mg/kg	
Fire-Trol FireFoam 104	Rat	LD_{50} (oral)	>5,050 mg/kg	Fire-Trol Holdings 2000b
	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	
Fire-Trol 300F	Rat	LD_{50} (oral)	4,063 mg/kg	Stillmeadow 2002
Fire-Trol 300F	Rat	LD_{50} (oral)	>500 mg/kg	Fire-Trol Holdings 1999a
	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	
Fire-Trol FTR	Rat	LD_{50} (oral)	>5,050 mg/kg	Stillmeadow 1997
Fire-Trol FTR	Rat	LD_{50} (oral)	>5,010 mg/kg	Fire-Trol Holdings 2001
	Rabbit	LD_{50} (dermal)	>2,010 mg/kg	
Fire-Trol GTS-R	Earthworm	LD_{50}	>1,000 mg/kg	Vyas et al. 1997
Fire-Trol GTS-R	Northern bobwhite	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Fire-Trol GTS-R	Rat	LD_{50} (oral)	3,850 mg/kg	Fire-Trol Holdings 1999b
	Rabbit	LD_{50} (dermal)	>2,010 mg/kg	
Fire-Trol GTS-R	Rat	LD_{50} (oral)	2,850 mg/kg	Stillmeadow 2002
Fire-Trol GTS-R	Red-winged blackbird	LD_{50}	2,197 mg/kg	Vyas et al. 1997
Fire-Trol GTS-R	White-footed mouse	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Fire-Trol LCA-F	Rat	LD_{50} (oral)	>5,000 mg/kg	Fire-Trol Holdings 1999c
	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	

Terrestrial Species Toxicity Data for Fire-Fighting Chemical Products

Product	Species	Endpoint	Result	Reference
Fire-Trol LCA-R	Rat	LD_{50} (oral)	5,050 mg/kg	Stillmeadow 2002
Fire-Trol LCA-R	Rat	LD_{50} (oral)	>505 mg/kg <5,050 mg/kg	Fire-Trol Holdings 1999d
	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	
Fire-Trol LCG-F	Rat	LD_{50} (oral)	>5,000 mg/kg	Fire-Trol Holdings 1999e
	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	
Fire-Trol LCG-R	American kestrel	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Fire-Trol LCG-R	Earthworm	LD_{50}	>1,000 mg/kg	Vyas et al. 1997
Fire-Trol LCG-R	Northern bobwhite	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Fire-Trol LCG-R	Rat	LD_{50} (oral)	>5,050 mg/kg	Fire-Trol Holdings 1999f
	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	
Fire-Trol LCG-R	Red-winged blackbird	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Fire-Trol LCG-R	White-footed mouse	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Forexpan S	Rat	LD_{50} (oral)	4,767 mg/kg	Stillmeadow 1994
Forexpan S	Rat	LD_{50} (oral)	>5,000 mg/kg	Angus Fire 2001
		LD_{50} (dermal)	>2,020 mg/kg	
National Foam KnockDown	Rat	LD_{50} (oral)	>5,000 mg/kg	National Foam 2000
		LD_{50} (dermal)	>2,000 mg/kg	
Phos-Chek 259-F	Rat	LD_{50} (oral)	3,100 mg/kg	Astaris 2003a
Phos-Chek 259-R	Rat	LD_{50} (oral)	>5,050 mg/kg	Stillmeadow 2002
Phos-Chek D75-F	Rat	LD_{50} (oral)	4,722 mg/kg	Stillmeadow 2002
Phos-Chek D75-F	Earthworm	LD_{50}	>1,000 mg/kg	Vyas et al. 1997
Phos-Chek D75-F	Northern bobwhite	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Phos-Chek D75-F	Red-winged blackbird	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Phos-Chek D75-F	White-footed mouse	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Phos-Chek D75-R	Rat	LD_{50} (oral)	3,967 mg/kg	Stillmeadow 2002
Phos-Chek D75-R	Rat	LD_{50} (oral)	>4,249 mg/kg	Astaris 2003b
	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	

Terrestrial Species Toxicity Data for Fire-Fighting Chemical Products

Product	Species	Endpoint	Result	Reference
Phos-Chek G75-F	Rat	LD_{50} (oral)	4,278 mg/kg	Astaris 2003c
Phos-Chek G75-W	Rat	LD_{50} (oral)	>505 mg/kg <5,050 mg/kg	Astaris 2003c
	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	
Phos-Chek HV-F	Rat	LD_{50} (oral)	>5,050 mg/kg	Astaris 2001a
Phos-Chek HV-R	Rat	LD_{50} (oral)	>5,050 mg/kg	Astaris 2001a
	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	
Phos-Chek LV-R	Rat	LD_{50} (oral)	>5,050 mg/kg	Astaris 2001b
	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	
Phos-Chek MV-F	Rat	LD_{50} (oral)	>5,050 mg/kg	Stillmeadow 1991
Phos-Chek MV-R	Rat	LD_{50} (oral)	>5,050 mg/kg	Stillmeadow 2002
Phos-Chek MV-R	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	Astaris 2001b
Phos-Chek WD-881	Earthworm	LD_{50}	>1,000 mg/kg	Vyas et al. 1997
Phos-Chek WD-881	Northern bobwhite	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Phos-Chek WD 881	Rat	LD_{50} (oral)	>5,000 mg/kg	Astaris 2001c
	Rabbit	LD_{50} (dermal)	>2,000 mg/kg	
Phos-Chek WD-881	Red-winged blackbird	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Phos-Chek WD-881	White-footed mouse	LD_{50}	>2,000 mg/kg	Vyas et al. 1997
Pyrocap B-136	Rat	LD_{50} (oral)	>5,050 mg/kg	Pyrocap 1997
	Rabbit	LD_{50} (dermal)	>2,020 mg/kg	
Stockhausen Firecape FP-47	Rat	LD_{50}	>5,000 mg/kg	Stillmeadow 2001

Aquatic Species Toxicity Data for Fire-Fighting Chemical Products

Product	Species	Endpoint	Result	Reference
Ansul Silv-Ex	Chinook salmon	LC_{50} (48 hr) LC_{50} (96 hr)	14 - >130 mg/L[c] 11 - 39 mg/L[c]	Buhl and Hamilton 1998
Ansul Silv-Ex	*Daphnia magna*	EC_{50} (24 hr) EC_{50} (48 hr)	7 - 10 mg/L[c] 7 mg/L	McDonald et al. 1996
Ansul Silv-Ex	*Daphnia magna*	LC_{50} (48 hr)	17 mg/L	McDonald et al. 1996
Ansul Silv-Ex	Fathead minnow	LC_{50} (4 hr) LC_{50} (48 hr) LC_{50} (96 hr)	22 mg/L 17 mg/L 8 mg/L	Gaikowski et al. 1996a
Ansul Silv-Ex	Fathead minnow	LC_{50} (48 hr) LC_{50} (96 hr)	19 - 36 mg/L[c] 19 - 32 mg/L[c]	Gaikowski et al. 1996a
Ansul Silv-Ex	*Hyalella azteca*	EC_{50} (24 hr) EC_{50} (48 hr) EC_{50} (72 hr) EC_{50} (96 hr)	35 - 36 mg/L[c] 31 - 36 mg/L[c] 26 - 29 mg/L[c] 24 - 27 mg/L[c]	McDonald et al. 1997
Ansul Silv-Ex	Lahontan cutthroat trout	LC_{50} (4 hr)	29 mg/L	Poulton 1997
Ansul Silv-Ex	Mayfly	LC_{50} (4 hr) EC_{50} (2 hr)	25 mg/L 27 mg/L	Poulton 1997
Ansul Silv-Ex	Rainbow trout	LC_{50} (4 hr) EC_{50} (4 hr)	68 mg/L 29 mg/L	Gaikowski et al. 1996b
Ansul Silv-Ex	Rainbow trout	LC_{50} (48 hr) LC_{50} (96 hr)	14 - >78 mg/L[c] 11 - >78 mg/L[c]	Gaikowski et al. 1996b
Ansul Silv-Ex	Stonefly	EC_{50} (4 hr)	689 mg/L	Poulton 1997
Fire-Trol FireFoam 103	Rainbow trout (juvenile)	LC_{50} (96 hr)	30 mg/L	Fire-Trol Holdings 2000a
Fire-Trol FireFoam 103B	Rainbow trout (juvenile)	LC_{50} (96 hr)	41.1 mg/L	Fire-Trol Holdings 2000a
Fire-Trol FireFoam 104	Rainbow trout (juvenile)	LC_{50} (96 hr)	34.6 mg/L	Fire-Trol Holdings 2000b
Fire-Trol 300-F	Rainbow trout (juvenile)	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	72 mg/L 43 mg/L 12 mg/L	Calfee and Little 2003

Aquatic Species Toxicity Data for Fire-Fighting Chemical Products

Product	Species	Endpoint	Result	Reference
Fire-Trol 300-F	Southern leopard frog tadpole	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	55 mg/L 33 mg/L 24 mg/L	Calfee and Little 2003
Fire-Trol FTR	Bluegill	LC_{50} (24 hr) LC_{50} (96 hr)	>1,500 mg/L >1,500 mg/L	Johnson and Sanders 1977
Fire-Trol FTR	Coho salmon (yearling)	LC_{50} (24 hr) LC_{50} (48 hr) LC_{50} (96 hr)	506 mg/L 506 mg/L 495 mg/L	Blahm et al. 1972
Fire-Trol FTR	Coho salmon (sub-yearling)	LC_{50} (24 hr) LC_{50} (48 hr) LC_{50} (96 hr)	935 mg/L 803 mg/L 781 mg/L	Blahm et al. 1972
Fire-Trol FTR	Coho salmon (yolk-sac fry)	LC_{50} (24 hr) LC_{50} (96 hr)	>500 mg/L 580 mg/L	Johnson and Sanders 1977
Fire-Trol FTR	Coho salmon (swim-up fry)	LC_{50} (24 hr) LC_{50} (96 hr)	1,050 mg/L 930 mg/L	Johnson and Sanders 1977
Fire-Trol FTR	Coho salmon (fingerling)	LC_{50} (24 hr) LC_{50} (96 hr)	1,050 - >1,500 mg/L[c] 1,000 mg/L	Johnson and Sanders 1977
Fire-Trol FTR	Fathead minnow	LC_{50} (24 hr) LC_{50} (96 hr)	>1,500 mg/L >1,500 mg/L	Johnson and Sanders 1977
Fire-Trol FTR	Largemouth bass	LC_{50} (24 hr) LC_{50} (96 hr)	>1,500 mg/L >1,500 mg/L	Johnson and Sanders 1977
Fire-Trol FTR	Rainbow trout (yearling)	LC_{50} (24 hr) LC_{50} (48 hr) LC_{50} (96 hr)	572 mg/L 550 mg/L 440 mg/L	Blahm et al. 1972
Fire-Trol FTR	Rainbow trout (sub-yearling)	LC_{50} (24 hr) LC_{50} (48 hr) LC_{50} (96 hr)	836 mg/L 627 mg/L 517 mg/L	Blahm et al. 1972
Fire-Trol FTR	Rainbow trout (yolk-sac fry)	LC_{50} (24 hr) LC_{50} (96 hr)	>500 mg/L 700 mg/L	Johnson and Sanders 1977
Fire-Trol FTR	Rainbow trout (swim-up fry)	LC_{50} (24 hr) LC_{50} (96 hr)	800 mg/L 790 mg/L	Johnson and Sanders 1977
Fire-Trol FTR	Rainbow trout (fingerling)	LC_{50} (24 hr) LC_{50} (96 hr)	>1,000 mg/L 940 - >1,000 mg/L[c]	Johnson and Sanders 1977

Aquatic Species Toxicity Data for Fire-Fighting Chemical Products

Product	Species	Endpoint	Result	Reference
Fire-Trol FTR	Scud	LC_{50} (24 hr) LC_{50} (96 hr)	>100 mg/L 55 mg/L	Johnson and Sanders 1977
Fire-Trol GTS-R	Chinook salmon	LC_{50} (48 hr) LC_{50} (96 hr)	234 - >6,000 mg/L[a] 218 - >6,000 mg/L[a]	Hamilton and Buhl 1997
Fire-Trol GTS-R	*Daphnia magna*	EC_{50} (24 hr) EC_{50} (48 hr)	780 - >780 mg/L[a] 257 - 339 mg/L[a]	Hamilton and Buhl 1997
Fire-Trol GTS-R	Fathead minnow (juvenile); outdoor test stream under clear skies	100% mortality (3 hr)	128 mg/L	Little and Calfee 2002a
		59% mortality (6 hr)	64 mg/L	
		no mortality (6 hr)	32 mg/L	
	Fathead minnow (juvenile); outdoor test stream under heavy cloud cover	no mortality (6 hr)	128 mg/L (HCT[b])	
Fire-Trol GTS-R	Fathead minnow	LC_{50} (24 hr) (high UV light, no sediment) LC_{50} (24 hr) (low UV light, no sediment) LC_{50} (24 hr) (high UV light, sediment present) LC_{50} (24 hr) (low UV light, sediment present)	34.8 mg/L 98.7 mg/L 40.6 mg/L 226 mg/L	Little and Calfee 2002b
Fire-Trol GTS-R	Fathead minnow	LC_{50} (48 hr) LC_{50} (96 hr)	193 - >2,463 mg/L[a] 135 - 787 mg/L[a]	Gaikowski et al. 1996a
Fire-Trol GTS-R	*Hyalella azteca*	EC_{50} (24 hr) EC_{50} (48 hr) EC_{50} (72 hr) EC_{50} (96 hr)	385 - 813 mg/L[a] 314 - 635 mg/L[a] 192 - 441 mg/L[a] 127 - 363 mg/L[a]	McDonald et al. 1997
Fire-Trol GTS-R	Rainbow trout	LC_{50} (48 hr) LC_{50} (96 hr)	218 - >6,000 mg/L[a] 207 - >10,000 mg/L[a]	Gaikowski et al. 1996b
Fire-Trol GTS-R	Rainbow trout (juvenile)	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	34 mg/L 33 mg/L 6 mg/L	Calfee and Little 2003

Aquatic Species Toxicity Data for Fire-Fighting Chemical Products

Product	Species	Endpoint	Result	Reference
Fire-Trol GTS-R	Southern leopard frog tadpole	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	78 mg/L 40 mg/L 22 mg/L	Calfee and Little 2003
Fire-Trol LCA-F	Rainbow trout (juvenile)	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	34 mg/L 14 mg/L 3 mg/L	Calfee and Little 2003
Fire-Trol LCA-F	Southern leopard frog tadpole	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	>50 mg/L 49 mg/L 29 mg/L	Calfee and Little 2003
Fire-Trol LCA-R	Rainbow trout (juvenile)	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	21 mg/L 17 mg/L 3.19 mg/L	Calfee and Little 2003
Fire-Trol LCA-R	Southern leopard frog tadpole	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	201 mg/L 141 mg/L 25 mg/L	Calfee and Little 2003
Fire-Trol LCG-R	Chinook salmon	LC_{50} (48 hr) LC_{50} (96 hr)	1,007 - >10,000 mg/L[a] 1,007 - >10,000 mg/L[a]	Buhl and Hamilton 1998
Fire-Trol LCG-R	*Daphnia magna*	EC_{50} (24 hr) EC_{50} (48 hr)	1,007 - 1,676 mg/L[a] 813 - 848 mg/L[a]	McDonald et al. 1996
Fire-Trol LCG-R	Fathead minnow	LC_{50} (48 hr) LC_{50} (96 hr)	1,394 - >10,000 mg/L[a] 519 - >7,037 mg/L[a]	Gaikowski et al. 1996a
Fire-Trol LCG-R	*Hyalella azteca*	EC_{50} (24 hr) EC_{50} (48 hr) EC_{50} (72 hr) EC_{50} (96 hr)	417 - 961 mg/L[a] 182 - 685 mg/L[a] 93 - 606 mg/L[a] 73 - 535 mg/L[a]	McDonald et al. 1997
Fire-Trol LCG-R	Rainbow trout	LC_{50} (48 hr) LC_{50} (96 hr)	954 - >10,000 mg/L[a] 872 - >10,000 mg/L[a]	Gaikowski et al. 1996b
Forexpan S	Rainbow trout	LC_{50} (96 hr)	10.4 mg/L	Angus Fire 2001
Phos-Chek 259	Bluegill	LC_{50} (24 hr) LC_{50} (96 hr)	600 mg/L 350 mg/L	Johnson and Sanders 1977
Phos-Chek 259	Coho salmon (yearling)	LC_{50} (24 hr) LC_{50} (48 hr) LC_{50} (96 hr)	160 mg/L 150 mg/L 143 mg/L	Blahm et al. 1972

Aquatic Species Toxicity Data for Fire-Fighting Chemical Products

Product	Species	Endpoint	Result	Reference
Phos-Chek 259	Coho salmon (sub-yearling)	LC_{50} (24 hr) LC_{50} (48 hr) LC_{50} (96 hr)	160 mg/L 158 mg/L 128 mg/L	Blahm et al. 1972
Phos-Chek 259	Coho salmon (yolk-sac fry)	LC_{50} (24 hr) LC_{50} (96 hr)	>200 mg/L 145 mg/L	Johnson and Sanders 1977
Phos-Chek 259	Coho salmon (swim-up fry)	LC_{50} (24 hr) LC_{50} (96 hr)	175 mg/L 170 mg/L	Johnson and Sanders 1977
Phos-Chek 259	Coho salmon (fingerling)	LC_{50} (24 hr) LC_{50} (96 hr)	245 - 250 mg/L[c] 245 - 250 mg/L[c]	Johnson and Sanders 1977
Phos-Chek 259	Fathead minnow	LC_{50} (24 hr) LC_{50} (96 hr)	470 mg/L 300 mg/L	Johnson and Sanders 1977
Phos-Chek 259	Largemouth bass	LC_{50} (24 hr) LC_{50} (96 hr)	720 mg/L 450 mg/L	Johnson and Sanders 1977
Phos-Chek 259	Rainbow trout (yearling)	LC_{50} (24 hr) LC_{50} (48 hr) LC_{50} (96 hr)	128 mg/L 128 mg/L 128 mg/L	Blahm et al. 1972
Phos-Chek 259	Rainbow trout (sub-yearling)	LC_{50} (24 hr) LC_{50} (48 hr) LC_{50} (96 hr)	148 mg/L 148 mg/L 148 mg/L	Blahm et al. 1972
Phos-Chek 259	Rainbow trout (yolk-sac fry)	LC_{50} (24 hr) LC_{50} (96 hr)	>200 mg/L 115 mg/L	Johnson and Sanders 1977
Phos-Chek 259	Rainbow trout (swim-up fry)	LC_{50} (24 hr) LC_{50} (96 hr)	102 mg/L 94 mg/L	Johnson and Sanders 1977
Phos-Chek 259	Rainbow trout (fingerling)	LC_{50} (24 hr) LC_{50} (96 hr)	170 - 175 mg/L[c] 160 - 165 mg/L[c]	Johnson and Sanders 1977
Phos-Chek 259	Scud	LC_{50} (24 hr) LC_{50} (96 hr)	>100 mg/L 40 mg/L	Johnson and Sanders 1977
Phos-Chek D75-F	Chinook salmon	LC_{50} (48 hr) LC_{50} (96 hr)	218 - >3,600 mg/L[a] 218 - >3,600 mg/L[a]	Buhl and Hamilton 1998
Phos-Chek D75-F	*Daphnia magna*	EC_{50} (24 hr) EC_{50} (48 hr)	188 - 280 mg/L[a] 140 - 280 mg/L[a]	McDonald et al. 1996
Phos-Chek D75-F	*Daphnia magna*	LC_{50} (48 hr)	76 mg/L	McDonald et al. 1996

Aquatic Species Toxicity Data for Fire-Fighting Chemical Products

Product	Species	Endpoint	Result	Reference
Phos-Chek D75-F	Fathead minnow	LC_{50} (4 hr) LC_{50} (48 hr) LC_{50} (96 hr)	1,047 mg/L 312 mg/L 127 mg/L	Gaikowski et al. 1996a
Phos-Chek D75-F	Fathead minnow	LC_{50} (48 hr) LC_{50} (96 hr)	262 - >2,789 mg/L[a] 168 - >2,250 mg/L[a]	Gaikowski et al. 1996a
Phos-Chek D75-F	*Hyalella azteca*	EC_{50} (24 hr) EC_{50} (48 hr) EC_{50} (72 hr) EC_{50} (96 hr)	421 - 974 mg/L[a] 94 - 450 mg/L[a] 74 - 421 mg/L[a] 53 - 394 mg/L[a]	McDonald et al. 1997
Phos-Chek D75-F	Lahontan cutthroat trout	LC_{50} (4 hr) EC_{50} (4 hr)	434 mg/L 233 mg/L	Poulton 1997
Phos-Chek D75-F	Mayfly	LC_{50} (4 hr) EC_{50} (4 hr)	1,051 mg/L 798 mg/L	Poulton 1997
Phos-Chek D75-F	Rainbow trout	LC_{50} (4 hr) EC_{50} (4 hr)	237 mg/L 233 mg/L	Gaikowski et al. 1996b
Phos-Chek D75-F	Rainbow trout	LC_{50} (48 hr) LC_{50} (96 hr)	218 - >3,600 mg/L[a] 218 - >3,600 mg/L[a]	Gaikowski et al. 1996b
Phos-Chek D75-F	Rainbow trout (juvenile)	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	495 mg/L 351 mg/L 227 mg/L	Calfee and Little 2003
Phos-Chek D75-F	Southern leopard frog tadpole	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	293 mg/L 269 mg/L 269 mg/L	Calfee and Little 2003
Phos-Chek D75-F	Stonefly	LC_{50} (4 hr) EC_{50} (4 hr)	1,545 mg/L 767 mg/L	Poulton 1997
Phos-Chek D75-R	Fathead minnow (juvenile); outdoor test stream under clear skies	no mortality (6 hr)	240 mg/L (HCT)	Little and Calfee 2002a
Phos-Chek D75-R	Rainbow trout (juvenile)	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	168 mg/L 168 mg/L 168 mg/L	Calfee and Little 2003

Aquatic Species Toxicity Data for Fire-Fighting Chemical Products

Product	Species	Endpoint	Result	Reference
Phos-Chek D75-R	Southern leopard frog tadpole	LC_{50} (96 hr, dark) LC_{50} (96 hr, light control) LC_{50} (96 hr, UV)	189 mg/L 178 mg/L 155 mg/L	Calfee and Little 2003
Phos-Chek WD-881	Chinook salmon	LC_{50} (48 hr) LC_{50} (96 hr)	12 - >47 mg/L[a] 7 - 47 mg/L[a]	Buhl and Hamilton 1998
Phos-Chek WD-881	*Daphnia magna*	EC_{50} (24 hr) EC_{50} (48 hr)	8 - 15 mg/L[a] 4 - 11 mg/L[a]	McDonald et al. 1997
Phos-Chek WD-881	Fathead minnow	LC_{50} (48 hr) LC_{50} (96 hr)	13 - 36 mg/L[a] 13 - 32 mg/L[a]	Gaikowski et al. 1996a
Phos-Chek WD-881	*Hyalella azteca*	EC_{50} (24 hr) EC_{50} (48 hr) EC_{50} (72 hr) EC_{50} (96 hr)	45 - 46 mg/L[a] 35 - 36 mg/L[a] 28 - 30 mg/L[a] 10 - 22 mg/L[a]	McDonald et al. 1997
Phos-Chek WD 881	Rainbow trout	LC_{50} (96 hr)	22 mg/L	Astaris 2001c
Phos-Chek WD-881	Rainbow trout	LC_{50} (48 hr) LC_{50} (96 hr)	11 - >47 mg/L[a] 10 - 44 mg/L[a]	Gaikowski et al. 1996b
Stockhausen Firecape FP-47	Rainbow trout (juvenile)	LC_{50} [d]	28 mg/L	Stockhausen 2002

[a]Varied with water hardness (and life stage, for fish species).
[b]HCT = highest concentration tested
[c]Varied with temperature
[d]Duration not specified

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