



Picloram (Tordon K and Tordon 22K) - FINAL REPORT

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Submitted to:

Leslie Rubin, COTR

Animal and Plant Health Inspection Service (APHIS)
Biotechnology, Biologics and Environmental Protection
Environmental Analysis and Documentation
United States Department of Agriculture
Suite 5A44, Unit 149
4700 River Road
Riverdale, MD 20737

Submitted by:

Syracuse Environmental Research Associates, Inc.

5100 Highbridge St., 42C
Fayetteville, New York 13066-0950
Telephone: (315) 637-9560
Fax: (315) 637-0445
Internet: SERA1@sprynet.com

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Picloram

Hexachlorobenzene

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

4A-TCP	2,3,5-trichloro-4-aminopyridine
a.e.	acid equivalents
a.i.	active ingredient
AEL	adverse-effect level
ACGIH	American Conference of Governmental Industrial Hygienists
ATSDR	Agency for Toxic Substances and Disease Registry
BCF	bioconcentration factor
bw	body weight
CBI	confidential business information
cm	centimeter
CNS	central nervous system
DAA	days after application
DAT	days after treatment
d.f.	degrees of freedom
EC _x	concentration causing X% inhibition of a process
EC ₅₀	concentration causing 50% inhibition of a process
F	female
F ₁	first filial generation
g	gram
HQ	hazard quotient
IRIS	Integrated Risk Information System
k _a	absorption coefficient
k _e	elimination coefficient
kg	kilogram
K _{o/c}	organic carbon partition coefficient
K _{o/w}	octanol-water partition coefficient
Kp	skin permeability coefficient
L	liter
lb	pound
LC ₅₀	lethal concentration, 50% kill
LD ₅₀	lethal dose, 50% kill
LOAEL	lowest-observed-adverse-effect level
m	meter
M	male
MCS	multiple chemical sensitivity
mg	milligram
mg/kg/day	milligrams of agent per kilogram of body weight per day
mL	milliliter
mM	millimole
MW	molecular weight
MOS	margin of safety
MSDS	material safety data sheet
NCI	National Cancer Institute
NIOSH	National Institute for Occupational Safety and Health

ACRONYMS, ABBREVIATIONS, AND SYMBOLS (*continued*)

NOAEL	no-observed-adverse-effect level
NOEL	no-observed-effect level
NOS	not otherwise specified
NRC	National Research Council
OM	organic matter
OPP	Office of Pesticide Programs
OPPTS	Office of Pesticide Planning and Toxic Substances
OSHA	Occupational Safety and Health Administration
ppm	parts per million
RBC	red blood cells
RfD	reference dose
RED	re-registration eligibility decision
UF	uncertainty factor
U.S.	United States
U.S. EPA	U.S. Environmental Protection Agency
WHO	World Health Organization
μ	micron
>	greater than
\geq	greater than or equal to
<	less than
\leq	less than or equal to
=	equal to
\approx	approximately equal to
\sim	approximately

COMMON UNIT CONVERSIONS AND ABBREVIATIONS

To convert ...	Into ...	Multiply by ...
acres	hectares (ha)	0.4047
acres	square meters (m ²)	4,047
atmospheres	millimeters of mercury	760
centigrade	Fahrenheit	1.8C° + 32
centimeters	inches	0.3937
cubic meters (m ³)	liters (L)	1,000
Fahrenheit	centigrade	0.556F° - 17.8
feet per second (ft/sec)	miles/hour (mi/hr)	0.6818
gallons (gal)	liters (L)	3.785
gallons per acre (gal/acre)	liters per hectare (L/ha)	9.34
grams (g)	ounces, (oz)	0.03527
grams (g)	pounds, (oz)	0.002205
hectares (ha)	acres	2.471
inches (in)	centimeters (cm)	2.540
kilograms (kg)	ounces, (oz)	35.274
kilograms (kg)	pounds, (lb)	2.2046
kilograms per hectare (kg/ha)	pounds per acre (lb/acre)	0.892
kilometers (km)	miles (mi)	0.6214
liters (L)	cubic centimeters (cm ³)	1,000
liters (L)	gallons (gal)	0.2642
liters (L)	ounces, fluid (oz)	33.814
miles (mi)	kilometers (km)	1.609
miles per hour (mi/hr)	cm/sec	44.70
milligrams (mg)	ounces (oz)	0.000035
meters (m)	feet	3.281
ounces (oz)	grams (g)	28.3495
ounces per acre (oz/acre)	grams per hectare (g/ha)	70.1
ounces per acre (oz/acre)	kilograms per hectare (kg/ha)	0.0701
ounces fluid	cubic centimeters (cm ³)	29.5735
pounds (lb)	grams (g)	453.6
pounds (lb)	kilograms (kg)	0.4536
pounds per acre (lb/acre)	kilograms per hectare (kg/ha)	1.121
pounds per acre (lb/acre)	mg/square meter (mg/m ²)	112.1
pounds per acre (lb/acre)	µg/square centimeter (µg/cm ²)	11.21
pounds per gallon (lb/gal)	grams per liter (g/L)	119.8
square centimeters (cm ²)	square inches (in ²)	0.155
square centimeters (cm ²)	square meters (m ²)	0.0001
square meters (m ²)	square centimeters (cm ²)	10,000
yards	meters	0.9144

Note: All references to pounds and ounces refer to avoirdupois weights unless otherwise specified.

CONVERSION OF SCIENTIFIC NOTATION

Scientific Notation	Decimal Equivalent	Verbal Expression
$1 \cdot 10^{-10}$	0.0000000001	One in ten billion
$1 \cdot 10^{-9}$	0.000000001	One in one billion
$1 \cdot 10^{-8}$	0.00000001	One in one hundred million
$1 \cdot 10^{-7}$	0.0000001	One in ten million
$1 \cdot 10^{-6}$	0.000001	One in one million
$1 \cdot 10^{-5}$	0.00001	One in one hundred thousand
$1 \cdot 10^{-4}$	0.0001	One in ten thousand
$1 \cdot 10^{-3}$	0.001	One in one thousand
$1 \cdot 10^{-2}$	0.01	One in one hundred
$1 \cdot 10^{-1}$	0.1	One in ten
$1 \cdot 10^0$	1	One
$1 \cdot 10^1$	10	Ten
$1 \cdot 10^2$	100	One hundred
$1 \cdot 10^3$	1,000	One thousand
$1 \cdot 10^4$	10,000	Ten thousand
$1 \cdot 10^5$	100,000	One hundred thousand
$1 \cdot 10^6$	1,000,000	One million
$1 \cdot 10^7$	10,000,000	Ten million
$1 \cdot 10^8$	100,000,000	One hundred million
$1 \cdot 10^9$	1,000,000,000	One billion
$1 \cdot 10^{10}$	10,000,000,000	Ten billion

EXECUTIVE SUMMARY

PROGRAM DESCRIPTION

Picloram is a herbicide used in the control a number of broadleaf weeds and undesirable brush. Picloram is used in Forest Service programs almost exclusively for the control of noxious weeds, particularly Kudzu. Very minor uses include rights-of-way management and wildlife habitat maintenance. Tordon K and Tordon 22K are the formulations of picloram currently available and used by the Forest Service. Both formulations are produced by Dow AgroSciences as a liquid containing the potassium salt of picloram (24.4% w/v). This is equivalent to a concentration of 2 lb a.e./gallon. The remaining 75.6% of the formulation consists of polyglycol 26-2. The U.S. EPA has placed polyglycol 26-2 on list 3 of the inerts that may be used in the formulation of pesticides. Very little additional information is available on this compound.

Although picloram is most often applied in Forest Service programs as the sole herbicide, it is also applied in combination with 2,4-D and less commonly with other herbicides. The most common methods of ground application for Tordon involve backpack (selective foliar) and boom spray (broadcast foliar) operations. Mist blower application of picloram is not permitted. The Forest Service does not typically use aerial applications for picloram. Nonetheless, Tordon is registered for aerial applications and aerial applications are included in this risk assessment in the event the Forest Service may wish to consider this application method. The labeled application rates for picloram range from 0.13 to 1.5 lb a.e./acre. Typically, the Forest Service uses rates in the lower part of this range - i.e., 0.3 to 0.56 lb a.e./acre. For this risk assessment, the typical rate of 0.5 lb a.e./acre with a lower range of 0.3 lb a.e./acre is used to reflect Forest Service practice. An upper range of 1.5 lb a.e./acre is used to assess the consequences of using the highest labeled rate should the Forest Service need to consider this option.

Technical grade picloram contains hexachlorobenzene as a contaminant. Currently, nominal or average concentrations of hexachlorobenzene are 8 ppm and the maximum concentration of hexachlorobenzene currently in technical grade picloram is 50 ppm (McMaster 1999). The impact of this contaminant is quantitatively considered in the human health risk assessment.

HUMAN HEALTH RISK ASSESSMENT

Hazard Identification – The toxicity of picloram to experimental mammals has been very well-characterized. Most of the studies have been conducted in support of the registration of picloram and are summarized in the U.S. EPA re-registration eligibility decision (RED) document. Picloram has a low order of acute toxicity, with acute oral LD₅₀ values in the range of 3000 to 5000 mg/kg body weight. Picloram can cause irritation to the eyes. Although picloram is not a strong skin irritant, repeated dermal exposures may lead to skin sensitization.

The subchronic and chronic toxicity of picloram has been assayed in several mammalian species. The most sensitive end-point appears to changes in the liver, although the toxicologic significance of these changes is unclear. The highest NOAEL is 20 mg/kg/day with a corresponding LOAEL of 60 mg/kg/day. Picloram has been subject to several assays for reproductive toxicity,

mutagenicity, and carcinogenicity. As reviewed in the U.S. EPA RED, these endpoints do not appear to be associated with exposure to picloram.

Although technical grade picloram has been subject to several chronic bioassays for carcinogenicity and none of the bioassays have shown that picloram has carcinogenic potential, technical grade picloram does contain hexachlorobenzene, a compound that has shown carcinogenic activity in three mammalian species and has been classified as a potential human carcinogen by the U.S. EPA. Thus, this effect is considered both qualitatively and quantitatively in this risk assessment.

Exposure Assessment – A number of studies have been conducted on workers handling picloram that permit an estimate of worker exposure rates in terms of absorbed dose (mg/kg body weight per lb a.e. handled). These studies, along with studies on several other pesticides, have been used to develop exposure estimates for workers involved in directed and broadcast ground applications as well as broadcast aerial applications. For all three groups of workers, central estimates of exposure fall within a relatively narrow range: about 0.007 mg/kg/day to 0.01 mg/kg/day. The upper range of exposure is 0.04 mg/kg/day for aerial applications and ranges from 0.12 to 0.23 mg/kg/day for ground applications. Various accidental exposures are also considered for workers. Most of the accidental exposure scenarios result in dose estimates that are substantially below those based on general handling and application practices. The major exception is workers wearing contaminated gloves for one-hour. In this accidental scenario, the upper range of the estimated absorbed dose is about 0.4 mg/kg/day.

For the general public, most of the chronic or longer term exposure scenarios lead to central estimates of exposure that are below those for workers but upper ranges of exposure for the general public are close to the upper ranges for workers. Several accidental exposure scenarios lead to upper ranges of estimated exposures that are between 0.3 and 3 mg/kg/day, substantially higher than any of the exposure estimates for workers. While these accidental exposure scenarios may be considered extreme, they illustrate the importance of controlling exposures to the general public in the application of picloram.

Hexachlorobenzene is a persistent ubiquitous environmental pollutant. Estimates of hexachlorobenzene release to the environment associated with the production of chlorinated solvents range from 70,343 to 241,311 kg/year. Based on the amount of picloram currently used in Forest Service programs and the proportion of hexachlorobenzene in picloram, the amount of hexachlorobenzene released each year in Forest Service programs is about 0.09 kg or 3 ounces. Thus, Forest Service programs contribute very little to the background levels of hexachlorobenzene in the environment - i.e., about 1 part in 800,000 to 1 part in 2.5 million .

The Agency for Toxic Substances and Disease Registry (ATSDR) reports that general background contamination of the environment with hexachlorobenzene results in long-term daily national average doses of about 0.000001 mg/kg/day for the general public. The exposure assessments based on the use of picloram by the Forest Service result in long-term dose estimates for the general public that are below this amount by factors of about 1400 to about seven million.

Based on central estimates of exposure, workers will be exposed to greater amount of hexachlorobenzene than members of the general public. The central estimates of worker exposure under normal conditions to hexachlorobenzene are above the background levels of exposure by factors of about 7 to 10. Upper ranges of worker exposure are above background levels of exposure by factors of about 120 to 225. Thus, the use of picloram by the Forest Service could result in substantial increases above normal background levels of exposure to hexachlorobenzene for workers but not for members of the general public.

Accidental exposure scenarios for both workers and members of the general public do result in short term exposures to hexachlorobenzene that are above the background dose of 0.000001 mg/kg/day. The highest dose estimate is about 0.02 mg/kg, the upper range of exposure for a worker wearing contaminated gloves for one-hour. For members of the general public, the highest dose estimate is about 0.006 mg/kg and is associated with the short term consumption of contaminated fish. As with the exposure scenarios for picloram, all of the accidental exposure scenarios for hexachlorobenzene involve relatively brief periods of exposure and most should be regarded as extreme.

Dose-Response Assessment – The Office of Pesticide Programs of the U.S. EPA has derived an RfD of 0.2 mg/kg/day for picloram. This RfD is based on a chronic rat NOAEL of 20 mg/kg/day and an uncertainty factor of 100. In the same study, the LOAEL was 60 mg/kg/day and the effect noted was a change in the staining properties of liver cells. No frank signs of toxicity were seen at this or higher dose levels. This NOAEL for chronic toxic effects is below the NOAELs for reproductive effects. Thus, doses at or below the RfD will be at or below the level of concern for reproductive effects. An earlier RfD of 0.07 mg/kg/day is listed on IRIS. This RfD was based on a subchronic rather than chronic study.

The contamination of technical grade picloram with hexachlorobenzene can be quantitatively considered to a limited extent. The U.S. EPA has derived an RfD and cancer potency parameter for hexachlorobenzene. Based on the levels of contamination of technical grade picloram with these compounds and the relative potencies of these compounds to picloram, this contamination is not significant in terms of potential systemic toxic effects. This assessment, however, does not impact the potential carcinogenicity associated with hexachlorobenzene.

Risk Characterization – Based on the estimated levels of exposure and the criteria for acute exposures by ATSDR and for chronic exposures by the U.S. EPA, there is no evidence that typical exposures to picloram will lead to dose levels that exceed the level of concern. For workers, only one accidental exposure scenario, wearing contaminated gloves for 1-hour, results in estimates of absorbed doses that exceeds the RfD by a modest amount. As discussed by U.S. EPA, picloram has a very low acute toxicity. The consequences of this modest short-term excursion above the chronic RfD are not likely to be substantial.

For members of the general public, the upper limits for hazard quotients are below a level of concern and the risk characterization is relatively unambiguous: based on the available information and under the foreseeable conditions of application, there is no route of exposure or scenario

suggesting that the general public will be at any substantial risk from longer-term exposure to picloram. For the acute/accidental scenarios, none of the central estimates representing typical exposure conditions exceed the RfD. For several scenarios, however, estimates of the upper limits of exposure exceed a level of concern by margins greater than those for workers. While these exposure scenarios do not suggest that adverse effects would be likely, these and the other acute scenarios help to identify the types of scenarios that are of greatest concern and may warrant the greatest steps to mitigate. For picloram, such scenarios involve both oral (contaminated water) and dermal (spills or accidental spray) exposures.

Irritation and damage to the eyes can result from exposure to relatively high levels of picloram - i.e., placement of picloram directly onto the eye - and repeated exposures to picloram can lead to skin sensitization. From a practical perspective, eye irritation and skin sensitization are likely to be the only overt effects as a consequence of mishandling picloram. These effects can be minimized or avoided by prudent industrial hygiene practices during the handling and application of picloram.

Based on the standard assumptions used in this and other Forest Service risk assessments, the contamination of picloram with hexachlorobenzene does not appear to present any substantial cancer risk based on central and in most cases upper range estimates of exposure. Administratively, the Forest Service has adopted a cancer risk level of one in one-million (1÷1,000,000) as a trigger that would require special steps to mitigate exposure or restrict and possibly eliminate use.

Based on relatively conservative exposure assumptions and at the typical application rate of 0.5 lb a.e. picloram/acre, the risk levels estimated for members of the general public are below this trigger level. The highest risk level for the general public is estimated at about 6 in 10 million ($5.63e-07$ or about 0.0000006) at an application rate of 0.5 lb a.e./acre. This is only a factor of about two below the level of concern. At an application rate of 1.5 lb a.e. picloram/acre, however, the resulting risk would be about 1.6 in one-million, slightly above the Forest Service trigger level of one in one-million. Based on central rather than upper estimates of exposure, the highest cancer risk is about one in one-billion.. The exposure scenario associated with this risk level involves the upper limit of exposure from the consumption of contaminated fish by subsistence populations - i.e., groups that consume relatively large amounts of fish. The consumption of fish contaminated with hexachlorobenzene is a primary exposure scenario of concern because of the tendency of hexachlorobenzene to bioconcentrate from water into fish. This is also consistent with the general observation that exposure to hexachlorobenzene occurs primarily through the consumption of contaminated food.

The cancer risk assessment for workers consistently leads to estimates of risk that are far below the Forest Service trigger level. It is worth noting, however, that the U.S. EPA's cancer risk assessment for workers resulted in much higher risk estimates in the range of 1.07×10^{-7} to 4.19×10^{-5} . The upper end of this range, about four in one-hundred thousand, is above the Forest Service trigger level by a factor of about 40. In the calculation of cancer risk, some of the assumptions used by the U.S. EPA differ substantially from those used in the current risk

assessment. The U.S. EPA assumed 100% dermal absorption of hexachlorobenzene and appears to have assumed that hexachlorobenzene is present at the maximum allowed concentration cited in the RED, 100 ppm.

ECOLOGICAL RISK ASSESSMENT

Hazard Identification – The toxicity of picloram is relatively well characterized in experimental mammals but few wildlife species have been assayed relative to the large number of non-target species that might be potentially affected by the use of picloram. Within this admittedly substantial reservation, picloram appears to be relatively non-toxic to terrestrial animals but is moderately toxic to aquatic animals, particularly fish.

The assessment of the toxicity of picloram to non-target terrestrial animals is based almost exclusively on toxicity studies using experimental mammals - i.e., the same studies used in the human health risk assessment. Acute oral LD₅₀ values for picloram are in the range of 3000 to 5000 mg/kg body weight and highest NOAEL from a chronic study is 20 mg/kg/day. Some additional studies are available on birds, bees, and snails that generally support the characterization of picloram as relatively non-toxic to terrestrial animals. This assessment is supported by one recent field study that reported no detectable effects on mammalian or avian diversity after the application of picloram.

Picloram is a pyridine herbicide that acts as a plant growth regulator. This is to say that picloram mimics naturally occurring plant auxins or hormones in a manner that leads to uncontrolled and abnormal growth. These effects can in turn lead to gross signs of toxicity or death. The toxicity of picloram to terrestrial plants has been assayed in relatively standardized studies of seed emergence, seed germination, and post-emergence applications that have been submitted to the U.S. EPA to support the registration of picloram. Picloram is more toxic to broadleaf plants than grains or grasses. The lowest reported adverse effect (the EC₂₅ for the inhibition of seed emergence in soybeans) for the potassium salt of picloram is 0.000014 kg or about 0.000012 lb a.e./acre. This is a factor of about 40,000 below the typical application rate of 0.5 lb a.e./acre. The highest reported NOAEL in any of the terrestrial plant bioassays is 70 g a.e./ha [equivalent to 0.07 kg/ha or 0.062 lb a.e./acre] for post-emergent application in wheat and seed germination in barley.

The acute and chronic toxicity of picloram to aquatic animals has been assayed in various species of trout and *Daphnia magna*, a small aquatic invertebrate. Acute (96-hour) LC₅₀ values for trout range from about 5 mg/L to about 20 mg/L. In *Daphnia*, the reported acute (48-hours) LC₅₀ value is 68.3 (63-75) mg/L. Chronic studies using reproductive or developmental parameters for trout and daphnia report no-effect levels of 0.55 mg/L (trout) and 11.8 mg/L (*Daphnia*) and adverse effect levels of 0.88 mg/L (trout) and 18.1 mg/L (*Daphnia*). Thus, it appears that fish, or at least trout, are more sensitive than daphnids to both the acute and chronic effects of picloram. Based on standard bioassay in aquatic algae, the lowest effect level for the potassium salt of picloram (EC₂₅ for growth inhibition *S. capricornutum*) is 52.6 mg/L with a corresponding NOAEL of 13.1 mg/L. Thus, based on comparable toxicologic endpoints, it appears that trout are more sensitive to the toxicity of picloram than algae or aquatic invertebrates.

Exposure Assessment – Terrestrial animals might be exposed to any applied herbicide from direct spray, the ingestion of contaminated media (vegetation, prey species, or water), grooming activities, or indirect contact with contaminated vegetation. In acute exposure scenarios, the highest exposures for small terrestrial vertebrates will occur after a direct spray and could reach up to about 12 mg/kg under typical exposure conditions and up to about 40 mg/kg under more extreme conditions. Somewhat lower doses are anticipated from the consumption of contaminated vegetation: about 3 mg/kg under typical conditions with an upper range of 30 mg/kg. The consumption of contaminated water will generally lead to much lower levels of exposure. A similar pattern is seen for chronic exposures. Estimated daily doses for the a small vertebrate from the consumption of contaminated vegetation are in the range of 0.6 to 10 mg/kg/day and far exceed doses that are anticipated from the consumption of contaminated water, 0.00075 mg/kg/day to 0.023 mg/kg/day. Based on general relationships of body size to body volume, larger vertebrates will be exposed to lower doses and smaller animals, such as insects, to much higher doses than small vertebrates under comparable exposure conditions. Because of the apparently low toxicity of picloram to animals, the rather substantial variations in the different exposure assessments have little impact on the assessment of risk to terrestrial animals.

For terrestrial plants, five exposure scenarios are considered quantitatively: direct spray, spray drift, runoff, wind erosion and the use of contaminated irrigation water. Unintended direct spray is expressed simply as the application rates considered in this risk assessment, 0.5 lb a.e./acre with a range of 0.3 lb a.e./acre to 1.5 lb a.e./acre, and should be regarded as an extreme/accidental form of exposure that is not likely to occur in most Forest Service applications. Estimates for the other routes of exposure are much less, ranging from 0.000003 lb a.e./acre (the lower range for wind erosion) to 0.03 lb a.e./acre (the upper range for spray drift). All of these exposure scenarios are dominated by situational variability because the levels of exposure are highly dependent on site-specific conditions. Thus, the exposure estimates are intended to represent conservative but plausible ranges that could occur but these ranges may over-estimate or under-estimate actual exposures in some cases.

Exposures to aquatic plants and animals is based on essentially the same information used to assess the exposure to terrestrial species from contaminated water. The estimated rate of contamination of ambient water associated with the normal application of picloram is 0.025 (0.01 to 0.06) mg a.e./L at an application rate of 1 lb a.e./acre. For acute exposure scenarios, the highest estimated concentration of picloram in water after an accidental spill is about 0.8 mg a.e./L with a range of about 0.27 to 27 mg a.e./L.

Dose-Response Assessment – For terrestrial mammals, the dose-response assessment is based on the same data used to derive the RfD in the human health risk assessment: a NOAEL of 20 mg/kg/day from a 2-year rat feeding study. The data on other terrestrial animals, both birds and invertebrates, is not as detailed as the available information on experimental mammals. Fewer toxicologic endpoints have been examined and no lifetime studies are available. This is a very common state of affairs for many pesticides and reflects the more rigorous requirements for the testing of potential human health effects relative to effects in non-target wildlife species. Within

this limitation, the available information does not suggest that birds or terrestrial invertebrates are likely to be more sensitive to picloram than experimental mammals.

The most sensitive non-target plant species appears to be soybeans, with an EC₂₅ for seed emergence 0.000014 kg a.e./ha or about 0.000012 lb a.e./acre. Exposures that are likely to cause effects in tolerant plant species is taken as 0.04 lb a.e./acre, the approximate level associated with an inhibition of seed emergence in wheat - i.e., an EC₂₅ of 0.0388 kg a.e./ha with a NOAEL of 0.0175 kg a.e./ha. While it is apparent that broadleaf plants are more sensitive to picloram than grains or grasses, all plant species on which data are available are likely to be affected by picloram at application rates used in the field - i.e. 0.3 to 1.5 lb a.e./acre.

Bioassays on the toxicity of picloram to aquatic animals is limited to studies on trout and *Daphnia magna*. Based on these studies, fish appear to be somewhat more sensitive to picloram than aquatic invertebrates in both acute and chronic studies. The lowest reported no-effect level for fish is 0.55 mg/L. Concentrations of 0.88 mg/L were associated with decreased growth of trout fry. Concentrations of picloram in water causing fifty percent mortality in some species of trout has been estimated at about 5 mg/L. Comparable estimates in *Daphnia* are about 70 mg/L. Standard bioassays of aquatic plant species submitted to support the registration of picloram have yielded EC₅₀ values for growth inhibition in the range of 20 mg/L to over 50 mg/L. Based on these studies, aquatic plants would appear to be less sensitive to picloram than fish. Some more recent and non-standard field studies, however, have noted inhibition of flowering in aquatic macrophytes at concentrations as low as 0.1 mg/L.

Risk Characterization – Picloram is a herbicide and the most likely damage to non-target species will involve terrestrial plants. As is the case with any herbicide, the likelihood of damage to non-target plant species is related directly to the difference between the sensitivity of target species—which dictates the application rate—and the sensitivity of the potential non-target species. Although picloram is more toxic to broadleaf plants than grains or grasses, direct spray at application rates between 0.3 and 1.5 lb a.e./acre are likely to damage all groups of terrestrial plants although the most severe damage would probably be apparent in broadleaf plants. With picloram, both broadleaf and non-broadleaf plants could be adversely affected by off-site drift over a relatively narrow band - i.e., about 100 feet. Some sensitive broadleaf species could be affected by off-site drift at a much greater distances. The scenarios for runoff, wind erosion, and irrigation water are dominated by situational variability. This variability, nonetheless, has only a minor impact the characterization of risk to relatively tolerant plant species. Except for the upper limit associated with spray drift, there is little basis for asserting that substantial or detectable evidence of damage would be noted in tolerant plant species. The situational variability in the exposure assessments for runoff, wind erosion, and irrigation water does have a substantial impact on the characterization of risk for sensitive nontarget plant species. All of these scenarios may overestimate or underestimate risk under certain conditions. The simple verbal interpretation for this quantitative risk characterization is that sensitive plant species could be adversely affected by the off-site transport of picloram under a variety of different scenarios depending on local site-specific conditions that cannot be generically modeled. If picloram is applied in the proximity of sensitive crops or other desirable sensitive plant species, site-specific

conditions and anticipated weather patterns will need to be considered if unintended damage is to be avoided. More tolerant plant species are not likely to be affected unless they are directly sprayed or subject to substantial drift.

The potential for adverse effects on other terrestrial nontarget animal species appears to be remote. The weight of evidence suggests that no adverse effects in terrestrial animals are plausible using typical or even very conservative worst case exposure assumptions.

Information on aquatic animals and plants are limited. Picloram appears to be more toxic to trout than to an aquatic invertebrate, *Daphnia magna*, a commonly used test species in toxicity studies. Based on a standard set of assumptions used in constructing accidental spill scenarios, some fish mortality would be expected and could be substantial if picloram were spilled into a relatively small body of water with a low water turnover rate. This characterization of risk, however, is dominated by arbitrary or situational uncertainty.

Longer term water concentrations associated with the normal application of picloram at an application rate of 1 lb a.e./acre are likely to be in the range of 0.01 to 0.06 mg/L in areas with substantial rainfall or as the result of applications in which some initial incidental contamination of water occurs. All of these concentrations are substantially below concentrations that have been shown to impact aquatic plants or animals. At the highest plausible application rate, the upper estimate of the range of longer-term water concentrations would be very close to the concentration of 0.1 mg/L that causes inhibition of flowering in two aquatic plant species. Even at the highest estimated concentrations, however, no effects would be anticipated in aquatic animals and substantial mortality would not be anticipated in aquatic plants.

The risk characterization for both terrestrial and aquatic species is limited by the relatively few animal and plant species on which data are available compared to the large number of species that could potentially be exposed. This limitation and consequent uncertainty is common to most if not all ecological risk assessments.

1. INTRODUCTION

The USDA Forest Service uses the herbicide, picloram, in its vegetation management programs. Two commercial formulations are used by the Forest Service, Tordon K and Tordon 22K. The USDA Forest Service has conducted risk assessments on picloram as part of previous environmental impact statements (USDA 1989a,b,c) and has prepared a herbicide background statement on picloram (USDA 1989d). The present document provides updated risk assessments for human health effects and ecological effects to support an assessment of the environmental consequences of using picloram in future Forest Service programs.

This document has four chapters, including the introduction, program description, risk assessment for human health effects, and risk assessment for ecological effects or effects on wildlife species. Each of the two risk assessment chapters has four major sections, including an identification of the hazards associated with picloram and its commercial formulation, an assessment of potential exposure to the product, an assessment of the dose-response relationships, and a characterization of the risks associated with plausible levels of exposure. These are the basic steps recommended by the National Research Council of the National Academy of Sciences (NRC 1983) for conducting and organizing risk assessments.

Although this is a technical support document and addresses some specialized technical areas, an effort was made to ensure that the document can be understood by individuals who do not have specialized training in the chemical and biological sciences. Certain technical concepts, methods, and terms common to all parts of the risk assessment are described in plain language in a separate document (SERA 1998). Furthermore, the technical terms are defined in the glossary to this risk assessment. Some of the more complicated terms and concepts are defined, as necessary, in the text.

The human health and ecological risk assessments presented in this document are not, and are not intended to be, comprehensive summaries of all of the available information. There is a very large body of literature on the environmental fate and toxicology of picloram. In addition to the herbicide background statement on picloram (USDA 1989d), the toxicology and environmental fate of picloram have been reviewed recently by the U.S. EPA (U.S. EPA 1992a,b; U.S. EPA 1994; U.S. EPA 1995a,b; U.S. EPA 1998a; U.S. EPA 1999) as well as the USDA (USDA 1995; ExToxNet 1996a). An additional review on picloram has recently been published by Cox (1998). The U.S. EPA (1995a) re-registration eligibility decision (RED) document also includes a summary of the product chemistry, mammalian toxicology, and ecotoxicology studies that were submitted by industry to the U.S. EPA as part of the registration process for this compound. Full-text copies of some of these studies were obtained for this review to clarify certain points not fully detailed in the RED (i.e., Baker 1989a,b,c,d,e,f; Bidlack 1980a,b; Murphy 1993) but, for the most part, the RED was used as the source of information for the CBI studies.

In the interest of economy and because of the availability of recent and detailed reviews on picloram, an updated chemical background statement has not been prepared with the current risk assessment. While this document discusses the key studies required to support the risk

assessments, it makes no attempt to re-summarize all of the information cited in the existing reviews.

For the most part, the risk assessment methods used in this document are similar to those used in risk assessments previously conducted for the Forest Service as well as risk assessments conducted by other government agencies. Details regarding the specific methods used to prepare the human health risk assessment are provided in SERA (1998), while detailed explanations of specific methods used in estimating occupational exposure are provided in Rubin et al. (1998). Similar documentation for methods used in assessing dermal absorption are provided in Durkin et al. (1998).

Risk assessments are usually expressed with numbers; however, the numbers are far from exact. *Variability* and *uncertainty* may be dominant factors in any risk assessment, and these factors should be expressed. Within the context of a risk assessment, the terms *variability* and *uncertainty* signify different conditions.

The term *variability* is used to indicate knowledge or assumptions of how things may change. Variability may take several forms. For this risk assessment, three types of variability are distinguished: *statistical*, *situational*, and *arbitrary*. *Statistical variability* reflects apparently random patterns in data. For example, various types of estimates used in this risk assessment involve relationships of certain physical properties to certain biological properties. In such cases, best or maximum likelihood estimates can be calculated as well as upper and lower confidence intervals that reflect the statistical variability in the relationships. *Situational variability* describes variations depending on known circumstances. For example, the application rate or the applied concentration of a herbicide will vary according to local conditions and goals. As discussed in the following section, the limits on this variability are known and there is some information to indicate what the variations are. In other words, *situational variability* is not random. *Arbitrary variability*, as the name implies, represents an attempt to describe changes that cannot be characterized statistically or by a set of conditions that are well defined. This type of variability dominates some spill scenarios involving either a spill of a chemical on to the surface of the skin or a spill of a chemical into water. In either case, exposure depends on the amount of chemical spilled and the area of skin or volume of water that is contaminated.

While the term *variability* is used to reflect a knowledge or at least an explicit assumption about how things may change, the term *uncertainty* is used to reflect a lack of knowledge. For example, the focus of the human health dose-response assessment is an estimation of an “acceptable” dose that will not be associated with adverse human health effects. For picloram and for most other chemicals, however, this estimation regarding human health must be based on data from experimental animal studies, which cover only a limited number of effects. Generally, judgmental methods such as the application of uncertainty factors are the basis for estimating such a no effect levels in humans. Although the judgments may reflect a consensus (i.e., be used by many groups in a reasonably consistent manner), the resulting estimations of risk cannot be proven analytically. In other words, the estimates regarding risk involve uncertainty. The primary functional

distinction between variability and uncertainty is that variability is expressed quantitatively, while uncertainty is generally expressed qualitatively.

In considering different forms of variability, almost no risk estimate presented in this document is given as a single number. Usually, risk is expressed as a central estimate and a range, which is sometimes very large. Because of the need to encompass many different types of exposure as well as the need to express the uncertainties in the assessment, this risk assessment involves numerous calculations.

Most of the calculations are relatively simple, and the very simple calculations are included in the body of the document. Some of the calculations, however, are detailed and cumbersome. For those calculations, worksheets are included as an attachment to the risk assessment. The worksheets provide the details for the estimates cited in the body of the document. The worksheets are divided into the following sections: general data and assumptions, chemical specific data and assumptions, exposure assessments for workers, exposure assessments for the general public, and exposure assessments for effects on non-target organisms.

Technical grade picloram contains hexachlorobenzene as a contaminant and hexachlorobenzene is classified as a carcinogen. Because of the importance of and level of concern for this endpoint in humans, the human health risk assessment discusses the potential effects of hexachlorobenzene in some detail and a separate subset of worksheets for hexachlorobenzene are provided at the end of this document.

2. PROGRAM DESCRIPTION

2.1. OVERVIEW

Picloram is a herbicide used in the control of a number of broadleaf weeds and undesirable brush. Picloram is used in Forest Service programs almost exclusively for the control of noxious weeds, particularly Kudzu. Very minor uses include rights-of-way management and wildlife habitat maintenance. Tordon K and Tordon 22K are the formulations of picloram currently available and used by the Forest Service. Both formulations are produced by Dow AgroSciences as a liquid containing the potassium salt of picloram (24.4% w/v). This is equivalent to a concentration of 2 lb a.e./gallon. The remaining 75.6% of the formulation consists of polyglycol 26-2. The U.S. EPA has placed polyglycol 26-2 on list 3 of the inerts that may be used in the formulation of pesticides. Very little additional information is available on this compound.

Although picloram is most often applied in Forest Service programs as the sole herbicide, it is also applied in combination with 2,4-D and less commonly with other herbicides. The most common methods of ground application for Tordon involve backpack (selective foliar) and boom spray (broadcast foliar) operations. Mist blower application of picloram is not permitted. The Forest Service does not typically use aerial applications for picloram. Nonetheless, Tordon is registered for aerial applications and aerial applications are included in this risk assessment in the event the Forest Service may wish to consider this application method. The labeled application rates for picloram range from 0.13 to 1.5 lb a.e./acre. Typically, the Forest Service uses rates in the lower part of this range - i.e., 0.3 to 0.56 lb a.e./acre. For this risk assessment, the typical rate of 0.5 lb a.e./acre with a lower range of 0.3 lb a.e./acre is used to reflect Forest Service practice. An upper range of 1.5 lb a.e./acre is used to assess the consequences of using the highest labeled rate should the Forest Service need to consider this option.

Technical grade picloram contains hexachlorobenzene as a contaminant. Nominal or average concentrations of hexachlorobenzene are 8 ppm and the maximum concentration of hexachlorobenzene currently in technical grade picloram is 50 ppm (McMaster 1999). The impact of this contaminant on the human health risk assessment is detailed in section 3.

2.2. CHEMICAL DESCRIPTION AND COMMERCIAL FORMULATIONS

Picloram is the common name for 4-amino-3,5,6-trichloropicolinic acid:

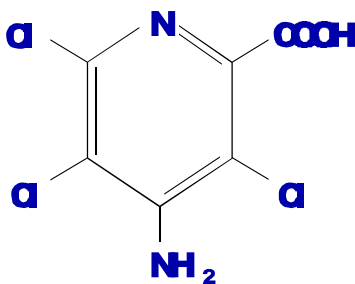


Table 2-1: Identification and Physical/Chemical Properties of Picloram and the Potassium salt of Picloram.		
Property	Value	Reference
Synonyms	Formulations: Tordon 22K, Tordon K	C&P Press 1998
CAS Number	1918-02-1 (acid) 081510-83-0 (salt)	Budavari 1989 C&P Press 1998
EPA Registration Number	62719-6	C&P Press 1998
MW $C_6H_3Cl_3N_2O_2$	241.48 (acid ⁺)	Budavari 1989
Henry's Law Constant (atm m ³ /mole)	3.3×10^{-10}	Mabury and Crosby 1996
pK _a	3.6 2.3 (22°C)	Budavari 1989 Baker 1989c
Vapor pressure	6.16×10^{-7} mm Hg (35°C) 6.0×10^{-10} mm Hg (25°C)	Budavari 1989 Baker 1989c
Water solubility	430 mg/L (acid) ∞ (salt) 200000 mg/L (salt) 430000 mg/L (K salt)	Budavari 1989 C&P Press 1998 Knisel et al. 1992 Neary et al. 1993
K _{ow} (acid)	22.9 84	SRC 1998 Baker 1989c
K _{oc} (acid)	16	Knisel et al. 1992
Foliar t _{1/2} (field dissipation)	8 days	Knisel et al. 1992
Water t _{1/2} (field dissipation)	15 days	USDA 1989d
Water t _{1/2} (surface water with degradation via photolysis.)	2.6 days	Woodburn et al. 1989

Selected chemical and physical properties of picloram are summarized in Table 2-1. Additional information is presented in worksheet B03.

The only formulations of picloram used by the Forest Service are Tordon K and Tordon 22K, both of which are produced by Dow AgroSciences. Both of these are formulated as a liquid containing the potassium salt of picloram (24.4% w/v). This is equivalent to a concentration of 2 lb a.e./gallon. The remaining 75.6% of the formulation consists of polyglycol 26-2, which is classified by the U.S. EPA as an inert.

Both of the Tordon formulations are labeled for the control of a variety of broadleaf weeds, woody plants, and vines in non-crop areas. Recommended uses include the control of undesirable vegetation on rights-of-way, forest planting sites, roadsides, and wildlife openings (C&P Press 1998). Tordon may not be used in crop areas and may not be directly applied to water. When used in forest planting sites, periods of 6 to 12 months after treatment are recommended before the planting of conifers. A cautionary note on the product label indicates that legume seedlings may not grow for two years after treatments (C&P Press 1998).

Recommended adjuvants include non-ionic surfactants such as Ortho X-77, Triton AG-98, or Tronic. In aerial and some ground broadcast applications, thickening agents such as Nalco-Trol are recommended to reduce the possibility of drift (C&P Press 1998).

2.3. APPLICATION METHODS

Detailed descriptions regarding the use of herbicides in silviculture and the various methods of herbicide application are available in the general literature [e.g., Cantrell and Hyland (1985)] and in earlier risk assessments conducted by the Forest Service (USDA 1989a,b,c). The following summary focuses on those aspects of application that are most relevant to the exposure assessments (sections 3.2 and 4.2).

The most common methods of ground application for Tordon involve backpack (selective foliar) and boom spray (broadcast foliar) operations. In selective foliar applications, the herbicide sprayer or container is carried by backpack and the herbicide is applied to selected target vegetation. Application crews may treat up to shoulder high brush, which means that chemical contact with the arms, hands, or face is plausible. To reduce the likelihood of significant exposure, application crews are directed not to walk through treated vegetation. Usually, a worker treats approximately 0.5 acre/hour with a plausible range of 0.25-1.0 acre/hour.

Boom spray is used primarily in rights-of-way management. Spray equipment mounted on tractors or trucks is used to apply the herbicide on either side of the roadway. Usually, about 8 acres are treated in a 45-minute period (approximately 11 acres/hour). Some special truck mounted spray systems may be used to treat up to 12 acres in a 35-minute period with approximately 300 gallons of herbicide mixture (approximately 21 acres/hour and 510 gallons/hour) (USDA 1989b, p 2-9 to 2-10). The Tordon formulations may not be applied with a mist-blower.

Tordon is registered for aerial applications (C&P Press 1998). Although this is not an application method that the Forest Service will typically employ for picloram, this method is covered by this risk assessment in the event that the Forest Service may need to consider aerial applications. Aerial applications may be made using helicopters. Tordon is applied under pressure through specially designed spray nozzles and booms. The nozzles are designed to minimize turbulence and maintain a large droplet size, both of which contribute to a reduction in spray drift. In aerial applications, approximately 40-100 acres may be treated per hour.

2.4. MIXING AND APPLICATION RATES

The specific application rates used in a ground application vary according to local conditions and the nature of the target vegetation. Application rates of ¼ to 3 quarts Tordon/acre are recommended on the product labels (C&P Press 1998). This is equivalent to 0.0625-0.75 gallons Tordon per acre. Given that there is 2 lbs picloram a.e./gallon in the Tordon formulations, these rates correspond to 0.125 to 1.5 lbs picloram a.e./acre. The upper range of this application rate is only recommended for the control of woody plants and broadleaf weeds in southern states. Elsewhere, the maximum recommended application rate is 2 quarts Tordon/acre or 1 lb picloram a.e./acre.

Mixing volumes of 5 to 25 gallons of water per acre are recommended for aerial applications. Recommended mixing volumes for ground applications range from 10 to 100 gallons of water per acre (C&P Press 1998). For this risk assessment, the extent to which a picloram formulation is diluted prior to application primarily influences dermal and direct spray scenarios, both of which are dependent on the 'field dilution' - i.e., the concentration of picloram in the applied spray. The higher the concentration of picloram, the greater the risk. For this risk assessment, the lowest dilution will be taken at 5 gallons/acre, the minimum recommended for aerial applications. The highest dilution - i.e., that which results in the lowest risk - will be based on 100 gallons of water per acre, the highest application volume recommended for ground applications.

The use of picloram by the Forest Service in 1997, the most recent year for which statistics are available, is summarized in Table 2-2. As indicated in this table, the Forest Service treated about 25,000 acres with about 14,000 lbs of picloram as the only herbicide for an average application rate of about 0.56 lbs/acre. Virtually all of the acreage, about 99% [$24786.33/25057.33=0.989$], of the acres treated with picloram only involved noxious weed control. For the most part, this use focused on the control of Kudzu. Of the total acres treated with picloram, about 25% [$8590.9/33648.23=0.255$] involved combinations with other herbicides, primarily 2,4-D. Again, most of these combinations were used in noxious weed control. Thus, the primary use of picloram, either alone or in combination with 2,4-D or other herbicides, involves noxious weed control and this use accounts for about 99% of the acres treated with picloram by the Forest Service in 1997 [$(24786.33+30+7901.9+148+2+427)/33648.23 = 0.9895$].

For this risk assessment, application rates used to construct the various exposure scenarios range from 0.3 lb a.e./acre to 1.5 lb a.e./acre with a typical rate taken as 0.5 lb a.e./acre. The typical application rate is close to the average application rate that the Forest Service used in 1997, when picloram was applied as the sole herbicide (Table 2-2). The lower limit of the application rate is taken as 0.3 lbs a.e./acre, the reported average application rate of picloram used by the Forest Service in 1997 for general weed control. The lowest application rate given in Table 2-2, 0.02 lb/acre in ROW management, appears to be atypical and represents an extremely minor use, about 0.2% of the total acres treated. The upper end of the range of application rates is taken as 1.5 lb picloram a.e./acre, the highest labeled application rate. This rate is used in this risk assessment to illustrate the consequences of using the highest rate but is below the rate that the Forest Service is likely to use in any of its programs.

Table 2-2. Uses of picloram by the Forest Service in 1997 (USDA 1998a).

Herbicide or Herbicide Mixture	Use	Acres Treated	Amount Used (lbs)	lbs/acre
Picloram as sole herbicide	noxious weeds	24786.33	13983.06	0.56
	ROW management	60	1	0.02
	weed control	105	35	0.3
	wildlife habitat	106	26	
	sole herbicide subtotal	25057.33	14045.06	0.56
with triclopyr	noxious weed control	30	142.5	
with 2,4-D	agric. weed control	75	71.2	
	noxious weed control	7901.9	5866.41	
with 2,4-D and clopyralid	noxious weed control	148	11.4	
with 2,4-D and metsulfuron-methyl	noxious weed control	2	0.12	
with 2,4-D and dicamba	noxious weed control	427	320.9	
	nursery disease control	7	0.5	
mixture subtotal		8590.9		
Total (sole herbicide plus mixture subtotals)		33648.23		

¹ For picloram as the sole herbicide, this column is calculated at the total number of pounds used divided by the total number of acres treated - i.e., average application rate. For tank mixtures, the Forest Service statistics (USDA 1998a) do not specify the amount or proportion of each herbicide in the mixture. Thus, average application rates for picloram with other herbicides are not calculated.

As discussed above, spray volumes of 5 to 100 gallons per acre are used in this risk assessment. Based on these application rates and spray volumes, the typical field concentration - i.e., the concentration of picloram in solution after mixing and dilution - is taken as 1.1 mg/L with a range of 0.36 mg/L to 36 mg/L. These values are summarized in picloram worksheet B02 and the calculations for these values are given in the text that follows picloram worksheet B01.

3. HUMAN HEALTH RISK ASSESSMENT

3.1. HAZARD IDENTIFICATION

3.1.1. Overview. The toxicity of picloram to experimental mammals has been very well-characterized. Most of the studies have been conducted in support of the registration of picloram and are summarized in the U.S. EPA (1995a) re-registration eligibility decision document. Picloram has a low order of acute toxicity, with acute oral LD₅₀ values in the range of 3000 to 5000 mg/kg body weight. Picloram can cause irritation to the eyes. Although picloram is not a strong skin irritant, repeated dermal exposures may lead to skin sensitization.

The subchronic and chronic toxicity of picloram has been assayed in several mammalian species. The most sensitive end-point appears to be changes in the liver, although the toxicologic significance of these changes is unclear. The highest NOAEL is 20 mg/kg/day with a corresponding LOAEL of 60 mg/kg/day. Picloram has been subject to several assays for reproductive toxicity, mutagenicity, and carcinogenicity. As reviewed by the U.S. EPA (1995a), exposure to picloram does not appear to be associated with mutagenic or carcinogenic effects and reproductive effects occur only at very high dose levels and may be secondary to other toxic effects.

Although technical grade picloram has been subject to several chronic bioassays for carcinogenicity and none of the bioassays have shown that picloram has carcinogenic potential, technical grade picloram does contain hexachlorobenzene, a compound that has shown carcinogenic activity in three mammalian species and has been classified as a potential human carcinogen by the U.S. EPA. Thus, this effect is considered both qualitatively and quantitatively in this risk assessment.

3.1.2. Acute Oral Toxicity. Standard acute toxicity studies, required by the U.S. EPA for pesticide registration, have been conducted (U.S. EPA 1995a). The LD₅₀ values for picloram acid as well as the potassium salt of picloram are over 5000 mg/kg for male rats. Female rats appear to be somewhat more sensitive, with LD₅₀ values of 4012 mg/kg for picloram acid and 3536 mg/kg for the potassium salt of picloram.

The oral absorption kinetics of picloram in humans has been studied by Nolan et al (1984), who administered picloram in about 100 ml of grape juice to six volunteers at doses of 0.5 and 5.0 mg/kg. These investigators report that picloram has a bitter taste that is not masked by grape juice. The average body weights of the volunteers was 78.5 kg. Thus, the concentrations of picloram in the grape juice were about 392.5 mg/L [$0.5 \text{ mg/kg} \times 78.5 \text{ kg} \div 0.1\text{L}$] and 3925 mg/L [$5 \text{ mg/kg} \times 78.5 \text{ kg} \div 0.1\text{L}$]. Taste thresholds for picloram in water or other liquids have not been encountered in the literature. The absorption and elimination kinetics of picloram in the human volunteers was described by a two compartment model and the average oral first order absorption rate coefficient was about 2 hour⁻¹.

3.1.3. Subchronic or Chronic Systemic Toxic Effects. Although some subchronic dermal toxicity studies have been conducted on picloram (section 3.1.7), most of the subchronic and

chronic toxicity studies on picloram have involved oral exposures. All of these studies have been conducted in support of the registration of picloram and submitted to the U.S. EPA (1995a). While these studies are summarized in the RED (U.S. EPA 1995a), more detailed summaries are given in various U.S. EPA reports that document the RfD for picloram (U.S. EPA 1992a, 1994, 1999).

The most sensitive effect for picloram in mammals involves effects on the liver. The current U.S. EPA RfD (section 3.3.2) is based on a two year feeding study in male and female Fischer rats (50 rats/sex/dose) in which picloram was administered at dietary concentrations that resulted in daily doses of 20, 60, and 200 mg/kg/day (Landry et al. 1986). Interim sacrifices (10 rats/sex/dose) were made at 6-months and 1-year. At the end of the two year exposure, the only statistically significant observations included an increase in liver size and an alteration in the staining properties of centrilobular hepatocytes in the 60 and 200 mg/kg/day dose groups. Both of these effects were more pronounced in males than in females. Increased liver weights as well as slight increases in the size and pallor of centrilobular hepatocytes were also seen in the 6 month and 12 month interim sacrifices. While the U.S. EPA has classified 60 mg/kg/day as the LOAEL for this study (U.S. EPA 1992b, 1999), the U.S. EPA/OPP RfD workgroup (U.S. EPA 1994) “...felt that the LOAEL might have been higher”. In other words, while effects were seen at 60 mg/kg/day, the magnitude and severity of these effects were not regarded with substantial concern by the workgroup.

Similar effects on the liver have been noted in a 6-month dog feeding study (Barna-Lloyd et al. 1982). In this study, male and female beagle dogs were administered picloram in the diet at levels that resulted in average daily doses of 0, 7, 35, and 175 mg/kg/day. At the two higher dose levels, increases were noted in absolute and relative liver weight and changes in liver enzyme activity were noted at the highest dose level. Additional effects included decreased food consumption and decreased body weight gain. As discussed further in section 3.3.2, this study served as the basis for the previous U.S. EPA RfD on picloram.

As reviewed in some detail by U.S. EPA (1992b), increased liver weight as well as changes in the appearance of the liver have also been observed in studies in mice as well as other studies in rats and dogs. There is very little evidence, however, that picloram is likely to impact other organs. At very high doses - i.e., 370 and 740 mg/kg/day - 80-week dietary exposures to picloram induced a number of different gross effects in rats including dermatitis accompanied by changes in hair coats and alopecia, diarrhea, abdominal distention, discolored urine, and vaginal bleeding. Pathological changes were also noted in the parathyroid, thyroid, and testes but not at frequencies that were statistically significantly different from control animals.

The relatively low chronic toxicity of picloram may be related to its rapid elimination from the body. After oral administration in humans, over 75% is eliminated after 6 hours and over 90% of the administered dose is eliminated after 72 hours. The elimination kinetics of picloram by humans follows a two-compartment model with halftimes of about 4 and 40 hours (Nolan et al. 1984). Similar biphasic elimination kinetics have been observed in rats, dogs, and cattle (U.S. EPA 1992b). Based on the plateau principle (e.g., Goldstein et al. 1974; O'Flaherty 1981), the

concentration at infinite time (C_{∞}) relative to the concentration after the first treatment (C_0) may be calculated as:

$$C_{\infty} \div C_0 = 1 \div (1 - e^{-k \Delta t})$$

where, k is the elimination rate in units of reciprocal time and Δt is the time interval between treatments. Taking the terminal halftime of 40 hours that corresponds to an elimination rate of 0.017 hours^{-1} [$k = \ln(2) \div t_{1/2}$] and assuming an exposure interval of 1 day (24 hours), the maximum accumulation of picloram in humans would be expected to be about a factor 3:

$$1 \div (1 - e^{-0.017 \times 24 \text{ hours}}) = 2.94$$

While this risk assessment does not specifically address the use of mixtures of picloram with other herbicides, Forest Service programs often involve the application of picloram in combination with 2,4-D (section 2). Thus, it is worth noting that a commercial formulation of picloram and 2,4-D, Tordon 202C, has been shown to inhibit immune function in mice (Blakley 1997). The design of this study does not permit the determination of which agent caused the immune response or whether the immune response was attributable to a toxicologic interaction of the two herbicides.

3.1.4. Reproductive and Teratogenic Effects. Picloram has been tested for teratogenic and reproductive effects in three mammalian species, rats, mice, and rabbits (U.S. EPA 1992b, 1999). The lowest observed adverse effects level (LOAEL) is 500 mg/kg/day and was associated with significant incidence of unossified fifth sternbrae in rats (Thompson et al. 1972). This LOAEL, however, is a factor of 25 above the systemic NOAEL of 20 mg/kg/day (section 3.1.3). NOAELs for reproductive effects range up to 400 mg/kg/day, a factor of 20 above the systemic NOAEL.

As with systemic toxic effects, there may be greater concern for mixtures of picloram and 2,4-D. Tordon 202c, a commercial formulation of picloram and 2,4-D, has been associated with adverse reproductive effects in mice (Blakley et al. 1989a,b,c).

3.1.5. Carcinogenicity and Mutagenicity. Picloram has been tested for mutagenicity in a number of different test systems and has been assayed for carcinogenic activity in rats and mice. A review and detailed evaluation of the mutagenicity assays on picloram has recently been completed by U.S. EPA (1992b) who concluded that:

No compelling evidence of a mutagenic effect in relevant biological systems was uncovered. Although picloram at a single reported dose was mutagenic in *S. coelicolor*, the weight of evidence from well-conducted microbial (Ames test), mammalian cell, and *Drosophila* mutagenicity studies tends to support the conclusion that picloram does not possess mutagenic activity (U.S. EPA 1992b, pp. V19 to V20).

Similarly, the Health Effects Division Carcinogenicity Peer Review Committee of the U.S. EPA Office of Pesticides has reviewed the carcinogenicity data on picloram acid as well as the potassium salt of picloram and has classified these agents as Group E (no evidence of carcinogenicity) based on the lack of carcinogenic activity in rats and mice (U.S. EPA 1999).

In the past, some commercial preparations of picloram were formulated as the isoocyl ester of picloram. The compound used to produce this ester (ethylhexyl phthalate) is a potential carcinogen (U.S. EPA 1994). Formulations of picloram as the ethylhexyl ester are not used by the Forest Service.

Technical grade picloram is contaminated with hexachlorobenzene, a compound classified as a potential carcinogen by the U.S. EPA (1997). A recent review of the extensive toxicity data on hexachlorobenzene is available from ATSDR (1998). As discussed further in section 3.1.9.1, the risk of cancer from this contaminant is considered both qualitatively and quantitatively in this risk assessment.

3.1.6. Effects on the Skin and Eyes. As part of the herbicide registration process, standardized tests for skin and eye irritation as well as dermal sensitization are required and have been summarized in the RED for picloram (U.S. EPA 1995a). Both picloram acid and the potassium salt of picloram (the forms used by the Forest Service) are classified as moderate eye irritants (Category III) but as non-irritant to the skin (Category IV). The potassium salt of picloram as well as the isoocyl ester and the triisopropanolamine salt of picloram, but not picloram acid, are classified as skin sensitizers.

3.1.7. Systemic Toxic Effects from Dermal Exposure. The toxicity studies summarized in the RED for picloram (U.S. EPA 1995a) indicate that dermal exposure to 2000 mg/kg picloram acid or the potassium salt of picloram was not associated with any signs of systemic toxicity in rabbits based on standard acute/single application bioassays with 14-day observation periods. In general, dermal LD₅₀ values are higher than oral LD₅₀ values (e.g., Gaines 1969). Since the reported acute oral LD₅₀ values of picloram are all 5000 mg/kg or greater, the lack of apparent toxicity at dermal doses of up to 2000 mg/kg/day is to be expected and these studies add little to the assessment of risk for picloram.

In addition to the acute dermal studies, a 21-day dermal toxicity assay of the potassium salt of picloram has been conducted in New Zealand white rabbits at doses of 0, 65, 217, and 650 mg a.e./kg/day, five days/week, for three weeks. No systemic toxic effects were observed (U.S. EPA 1995a).

The potential for systemic toxic effects from dermal exposure is important to this and other similar risk assessments because most of the occupational exposure scenarios and many of the exposure scenarios for the general public involve the dermal route of exposure. The available dermal toxicity data on picloram are not sufficient to derive a dermal-specific RfD and, for the characterization of risk, dermal absorption is estimated as an absorbed dose and compared with an estimated acceptable level of oral exposure based on subchronic or chronic toxicity studies. Thus,

it is necessary to assess the extent to which picloram is likely to be absorbed from the surface of the skin.

As discussed in Durkin et al. (1995), dermal exposure scenarios involving immersion or prolonged contact with chemical solutions use Fick's first law and require an estimate of the permeability coefficient, K_p , expressed in cm/hour. Because experimental estimates of the K_p for picloram have not been encountered in the literature, the method for estimating a zero-order absorption rate (U.S. EPA 1992c) is used in this risk assessment. Using this method, a dermal permeability coefficient for picloram is estimated at 0.000562 cm/hour with a 95% confidence interval of 0.000374-0.000845 cm/hour. These estimates are used in all exposure assessments that are based on Fick's first law. The calculations for these estimates are presented in worksheet B05.

The dermal absorption of picloram in humans has been studied by Nolan et al. (1984), who noted that an average proportion of 0.0015 of the applied dose was excreted by 6 human volunteers over a 72 hour period. As with the oral absorption kinetics discussed in section 3.1.2, Nolan et al. (1984) used a two compartment model to describe the elimination kinetics of picloram. Unlike the study of the oral absorption kinetics, however, the low dermal absorption of picloram prevented the direct estimate of the kinetic parameters from the dermal phase of the study. Using the methods detailed in Durkin et al. (1998), the estimated first-order dermal absorption coefficient for picloram is 0.0029 hour⁻¹ with 95% confidence intervals of 0.0013-0.0061 hour⁻¹. The calculations for these estimates are presented in worksheet B04. Taking the proportion of the absorbed dose of 0.0015 over 72 hours from Nolan et al. (1984) and assuming simple first-order absorption (e.g., Goldstein et al. 1974), a much lower first-order absorption rate can be calculated:

$$\ln(1-0.0015)/72 \text{ hours} = 0.00002 \text{ hour}^{-1}.$$

For this risk assessment, the more conservative calculated absorption rates are used and the consequences of any potential over-estimate of the absorbed dose is discussed in the risk characterization (section 3.4).

3.1.8. Inhalation Exposure. Picloram is relatively non-volatile (Neary et al. 1993). The inhalation toxicity LC₅₀ values of >0.035 mg/L for picloram acid (Category I) and >1.63 mg/L for the potassium salt of picloram (Category II) are classified as high to moderate (U.S. EPA 1995a). Brown-and-burn operations may result in the formation of combustion products of picloram, and these products may pose a health risk. On combustion, picloram undergoes decarboxylation and is converted to 2,3,5-trichloro-4-aminopyridine (4A-TCP) (Bush et al. 1987). As noted in Section 4, this combustion product is generally more toxic to microorganisms than picloram itself. No information on the toxicity of this combustion product to mammals is available.

3.1.9. Impurities, Adjuvants, and Metabolites.

3.1.9.1. Impurities – Virtually no chemical synthesis yields a totally pure product. Technical grade picloram, as with other technical grade products, undoubtedly contains some impurities. To some extent, concern for impurities in technical grade picloram is reduced by the fact that the

existing toxicity studies on picloram were conducted with the technical grade product. Thus, if toxic impurities are present in the technical grade product, they are likely to be encompassed by the available toxicity studies on the technical grade product.

An exception to this general rule involves carcinogens, most of which are presumed to act by non-threshold mechanisms. Because of the non-threshold assumption, any amount of a carcinogen in an otherwise non-carcinogenic mixture may pose a carcinogenic risk. This is the situation with picloram. As indicated in Section 2, technical grade picloram contains hexachlorobenzene. Nominal or average concentrations of hexachlorobenzene are 8 ppm and the maximum concentration is 50 ppm. The U.S. EPA has classified hexachlorobenzene as a probable human carcinogen for which the data are adequate to consider risk quantitatively (U.S. EPA 1997). While a detailed review of hexachlorobenzene is beyond the scope of this risk assessment, adequate information is available on hexachlorobenzene to quantify the carcinogenic risk associated with the use of picloram (section 3.3).

3.1.9.2. Metabolites – As with contaminants, the potential effect of metabolites on a risk assessment is often encompassed by the available *in vivo* toxicity studies under the assumption that the toxicologic consequences of metabolism in the species on which toxicity studies are available will be similar to those in the species of concern - i.e., humans. Uncertainties in this assumption are encompassed by using an uncertainty factor in deriving the RfD (section 3.3) and may sometimes influence the selection of the study used to derive the RfD.

As reviewed by U.S. EPA (1992b), the metabolism of picloram has been studied in several mammalian species and there is no indication that picloram is extensively metabolized. In the environment, however, picloram may undergo decarboxylation by microorganisms, photolysis, or pyrolysis and this may impact the assessment of the toxicity to some nontarget species (section 4.1.2.5). There are no studies, however, on the toxicity of this environmental metabolite to mammals.

3.1.9.3. Adjuvants – As indicated in section 2, the commercial formulation of picloram used by the Forest Service is in the form of the potassium salt of picloram. Both of the Tordon formulations also contain Polyglycol 26-2 [CAS No. 069029-39-6] (C&P Press 1998). This compound is classified by the U.S. EPA (1998b) as a List 3 inert. In other words, there is insufficient information to categorize this compound as either hazardous (Lists 1 or 2) or non-toxic (List 4). This lack of information adds uncertainty to this risk assessment. The minimal testing requirements for compounds that have been used as inerts or adjuvants for many years is a general problem in many pesticide risk assessments. For new inerts, the U.S. EPA does require more extensive testing (Levine 1996).

3.2. EXPOSURE ASSESSMENT

3.2.1. Overview. A number of studies have been conducted on workers handling picloram that permit an estimate of worker exposure rates in terms of absorbed dose (mg/kg body weight per lb a.e. handled). These studies, along with studies on several other pesticides, have been used to develop exposure estimates for workers involved in directed and broadcast ground applications as

well as broadcast aerial applications. For all three groups of workers, central estimates of exposure fall within a relatively narrow range: about 0.007 mg/kg/day to 0.01 mg/kg/day. The upper range of exposure is 0.04 mg/kg/day for aerial applications and ranges from 0.12 to 0.23 mg/kg/day for ground applications. Various accidental exposures are also considered for workers. Most of the accidental exposure scenarios result in dose estimates that are substantially below those based on general handling and application practices. The major exception is workers wearing contaminated gloves for one-hour. In this accidental scenario, the upper range of the estimated absorbed dose is about 0.4 mg/kg/day.

For the general public, most of the chronic or longer term exposure scenarios lead to central estimates of exposure that are below to those for workers but upper ranges of exposure for the general public are close to the upper ranges for workers. Several accidental exposure scenarios lead to upper ranges of estimated exposures that are between 0.3 and 3 mg/kg/day, substantially higher than any of the exposure estimates for workers. While these accidental exposure scenarios may be considered extreme, they illustrate the importance of controlling exposures to the general public in the application of picloram.

Hexachlorobenzene is a persistent ubiquitous environmental pollutant. Estimates of hexachlorobenzene release to the environment from the production of chlorinated solvents range from 70,343 to 241,311 kg/year. Based on the amount of picloram currently used in Forest Service programs and the proportion of hexachlorobenzene in picloram, the amount of hexachlorobenzene released each year in Forest Service programs is about 0.09 kg or 3 ounces. Thus, Forest Service programs contribute very little to the background levels of hexachlorobenzene in the environment.

ATSDR (1998) reports that general background contamination of the environment with hexachlorobenzene results in long-term daily national average doses of about 0.000001 mg/kg/day for the general public. The exposure assessments based on the use of picloram by the Forest Service result in long-term dose estimates for the general public that are below this amount by factors of about 1400 to about seven million. Based on central estimates of exposure, workers will be exposed to greater amount of hexachlorobenzene than members of the general public. The central estimates of worker exposure under normal conditions to hexachlorobenzene are above the background levels of exposure by factors of about 7 to 10. Upper ranges of worker exposure are above background levels of exposure by factors of about 120 to 225. Thus, the use of picloram by the Forest Service could result in substantial increases above normal background levels of exposure to hexachlorobenzene for workers but not for members of the general public.

Accidental exposure scenarios for both workers and members of the general public do result in short term exposures to hexachlorobenzene that are above the background dose of 0.000001 mg/kg/day. The highest dose estimate is about 0.02 mg/kg, the upper range of exposure for a worker wearing contaminated gloves for one-hour. For members of the general public, the highest dose estimate is about 0.006 mg/kg and is associated with the short term consumption of contaminated fish. As with the exposure scenarios for picloram, all of the accidental exposure

scenarios for hexachlorobenzene involve relatively brief periods of exposure and most should be regarded as extreme.

3.2.2. Workers. A summary of the estimated exposures to picloram involving workers is presented in Table 3-1. Two types of exposure assessments are considered: general and accidental/incidental. The term *general* exposure assessment is used to designate those exposures that involve estimates of absorbed dose based on the handling of a specified amount of a chemical during specific types of applications. The accidental/incidental exposure scenarios involve specific types of events that could occur during any type of application. Details regarding all of these exposure assessments are presented in the picloram worksheets that accompany this risk assessment, as indicated in Table 3-1.

As discussed further in section 3.2.4, a separate set of exposure assessments and worksheets are provided for hexachlorobenzene.

3.2.2.1. General Exposures – As detailed in Rubin et al. (1998), two studies have been conducted on workers handling picloram that permit an estimate of worker exposure rates in terms of absorbed dose (mg/kg body weight per lb a.e. handled). By far the most detailed study on worker exposure to picloram is that conducted by Lavy et al. (1987). In this study, the uptake of 2,4-D, picloram, and dichlorprop was assayed in four groups of forestry workers using four different application methods: backpack, injection bar, hypohatchet, and hack-and-squirt. In addition, for each method, uptake was studied under standard work practices [referred to as T1 in this publication] and work practices involving special precautions [referred to as T2 in this publication]. The special precautions involved the use of new gloves for mixing and application, improved personal hygiene, and exposure avoidance. Absorption of the herbicides was assayed using 5 day complete urine collections.

In another study, Libich et al. (1984) studied the exposure of herbicide applicators involved in electric power transmission rights-of-way maintenance to 2,4-D, dichlorprop, and picloram. Absorbed dose was estimated from daily urine sampling rather than total urine collection. Two application methods were examined: spray guns mounted on vehicles and mist blowers connected to a back pack. The spray guns were mounted either on trucks - for roadside spraying - or all terrain vehicles - ATV's - for spraying less accessible areas. The herbicides used were Tordon 101, a formulated 4:1 mixture of 2,4-D and picloram (463 g/L) and a 1:1 mixture of 2,4-D and dichlorprop (480 g/L). For spray gun applications, the commercial product was diluted with 100 parts water. For the backpack application, the product was

Table 3-1: Picloram - Summary of Worker Exposure Scenarios

Scenario	Dose (mg/kg/day or event)			Picloram Worksheet
	Typical	Lower	Upper	
General Exposures (dose in mg/kg/day)				
Directed ground spray (Backpack)	0.0066	0.000135	0.12	WSC01
Broadcast ground spray (Boom spray)	0.0112	0.000198	0.23	WSC02a
Aerial applications	0.0074	0.00012	0.04	WSC02b
Accidental/Incidental Exposures (dose in mg/kg/event)				
Immersion of Hands, 1 minute	0.00012	0.00003	0.00608	WSC03
Contaminated Gloves, 1 hour	0.00742	0.00162	0.36491	WSC03
Spill on hands, 1 hour	0.00030	0.00005	0.0211	WSC04
Spill on lower legs, 1 hour	0.00074	0.00011	0.052	WSC04

diluted with 16 parts water. A limitation in the comparison of this study with the study by Lavy et al. (1987) is that Libich et al. (1984) do not specify the amount of product handled.

Based on these two studies as well as studies on eight other pesticides with molecular weights ranging from 221 to 416 and log K_{ow} values ranging from -0.75 to 6.50, Rubin et al. (1998) developed estimates of exposure rates in workers (Rubin et al. 1998, Table 2) and these estimates are used in the current risk assessment for picloram. As further described in Rubin et al. (1998), the ranges of estimated occupational exposure rates vary substantially among individuals and groups, (i.e., by a factor of 50 for backpack applicators and a factor of 100 for mechanical ground sprayers). It seems that much of the variability can be attributed to the hygienic measures taken by individual workers (i.e., how careful the workers are to avoid unnecessary exposure).

The estimated number of acres treated per hour is taken from previous USDA risk assessments (USDA 1989a,b,c). The number of hours worked per day is expressed as a range, the lower end of which, 6 hours per day, is based on an 8-hour work day with 1 hour at each end of the work day spent in activities that do not involve herbicide exposure. The upper end of the range, 8 hours per day, is based on an extended (10-hour) work day, allowing for 1 hour at each end of the work day to be spent in activities that do not involve herbicide exposure.

It is recognized that the use of 6 hours as the lower range of time spent per day applying herbicides is not a true lower limit. It is conceivable and perhaps common for workers to spend much less time in the actual application of a herbicide if they are engaged in other activities. Thus, using 6 hours can be regarded as conservative. In the absence of any published or otherwise documented work practice statistics to support the use of a lower limit, this conservative approach is used.

The range of acres treated per hour and hours worked per day is used to calculate a range for the number of acres treated per day. For this calculation as well as others in this section involving the multiplication of ranges, the lower end of the resulting range is the product of the lower end of one range and the lower end of the other range. Similarly, the upper end of the resulting range is the product of the upper end of one range and the upper end of the other range. This approach is taken to encompass as broadly as possible the range of potential exposures.

The central estimate of the acres treated per day is taken as the arithmetic average of the range. Because of the relatively narrow limits of the ranges for backpack and boom spray workers, the use of the arithmetic mean rather than some other measure of central tendency such as the geometric mean has no marked effect on the risk assessment.

The range of application rates and the typical application rate are taken directly from the program description (see section 2.4). The central estimate of 0.5 lb picloram/acre is about the 1997 average application rate when picloram was used as the sole herbicide (see Table 2-2). The upper end of the range of application rates is taken as 1.5 lb picloram a.e./acre, the highest labeled application rate. The lower limit of the application rate is taken as 0.3 lbs a.e./acre, the reported average application rate of picloram used by the Forest Service in 1997 for general weed control.

The central estimate of the amount handled per day is calculated as the product of the central estimate of the acres treated per day and the typical application rate. The ranges for the amounts handled per day are calculated as the product of the range of acres treated per day and the range of application rates. Similarly, the central estimate of the daily absorbed dose is calculated as the product of the central estimate of the exposure rate and the central estimate of the amount handled per day. The ranges of the daily absorbed dose are calculated as the product of the range of exposure rates and the range for the amounts handled per day.

3.2.2.2. Accidental Exposures – Typical occupational exposures may involve multiple routes of exposure (i.e., oral, dermal, and inhalation); nonetheless, dermal exposure is generally the predominant route for herbicide applicators (van Hemmen 1992). Typical multi-route exposures are encompassed by the methods used in section 3.2.2.1 on general exposures. Accidental exposures, on the other hand, are most likely to involve splashing a solution of herbicides into the eyes or a variety of dermal exposure scenarios.

Picloram can cause irritant effects in the eyes (see section 3.1.6). The available literature does not include quantitative methods for characterizing exposure or responses associated with splashing a solution of a chemical into the eyes; furthermore, reasonable approaches to modeling this type of

exposure scenario quantitatively are not apparent. Consequently, accidental exposure scenarios of this type are considered qualitatively in the risk characterization (section 3.4).

There are various methods for estimating absorbed doses associated with accidental dermal exposure (U.S. EPA 1992, Durkin et al. 1995,1998). Two general types of exposure are modeled: those involving direct contact with a solution of the herbicide and those associated with accidental spills of the herbicide onto the surface of the skin. Any number of specific exposure scenarios could be developed for direct contact or accidental spills by varying the amount or concentration of the chemical on or in contact with the surface of the skin and by varying the surface area of the skin that is contaminated.

For this risk assessment, two exposure scenarios are developed for each of the two types of dermal exposure and the estimated absorbed dose for each scenario is expressed in units of mg chemical/kg body weight. Details of these exposure estimates are presented in the worksheets appended to this risk assessment as specified in Table 3-1.

Exposure scenarios involving direct contact with solutions of the chemical are characterized by immersion of the hands for 1 minute and wearing contaminated gloves for 1 hour. Generally, it is not reasonable to assume or postulate that the hands or any other part of a worker will be immersed in a solution of a herbicide for any period of time. On the other hand, contamination of gloves or other clothing is quite plausible. For these exposure scenarios, the key element is the assumption that wearing gloves grossly contaminated with a chemical solution is equivalent to immersing the hands in a solution. In either case, the concentration of the chemical in solution that is in contact with the surface of the skin and the resulting dermal absorption rate are essentially constant.

For both scenarios (the hand immersion and the contaminated glove), the assumption of zero-order absorption kinetics is appropriate. Following the general recommendations of U.S. EPA (1992c), Fick's first law is used to estimate dermal exposure.

Exposure scenarios involving chemical spills on to the skin are characterized by a spill on to the lower legs as well as a spill on to the hands. In these scenarios, it is assumed that a solution of the chemical is spilled on to a given surface area of skin and that a certain amount of the chemical adheres to the skin. The absorbed dose is then calculated as the product of the amount of the chemical on the surface of the skin (i.e., the amount of liquid per unit surface area multiplied by the surface area of the skin over which the spill occurs and the concentration of the chemical in the liquid), the first-order absorption rate, and the duration of exposure. For both scenarios, it is assumed that the contaminated skin is effectively cleaned after 1 hour. As with the exposure assessments based on Fick's first law, this product (mg of absorbed dose) is divided by body weight (kg) to yield an estimated dose in units of mg chemical/kg body weight. The specific equation used in these exposure assessments is taken from Durkin et al. (1998).

3.2.3. General Public.

3.2.3.1. General Considerations – Under normal conditions, members of the general public should not be exposed to substantial levels of picloram. Nonetheless, any number of exposure scenarios can be constructed for the general public, depending on various assumptions regarding application rates, dispersion, canopy interception, and human activity. Several highly conservative scenarios are developed for this risk assessment.

The two types of exposure scenarios developed for the general public include acute exposure and longer-term or chronic exposure. All of the acute exposure scenarios are primarily accidental. They assume that an individual is exposed to the compound either during or shortly after its application. Specific scenarios are developed for direct spray, dermal contact with contaminated vegetation, as well as the consumption of contaminated fruit, water, and fish. Most of these scenarios should be regarded as extreme, some to the point of limited plausibility. The longer-term or chronic exposure scenarios parallel the acute exposure scenarios for the consumption of contaminated fruit, water, and fish but are based on estimated levels of exposure for longer periods after application.

The exposure scenarios developed for the general public are summarized in Table 3-2. As with the worker exposure scenarios, details of the assumptions and calculations involved in these exposure assessments are given in the worksheets that accompany this risk assessment (worksheets D01-D09). The remainder of this section focuses on a qualitative description of the rationale for and quality of the data supporting each of the assessments.

3.2.3.2. Direct Spray – Direct sprays involving ground applications are modeled in a manner similar to accidental spills for workers (see section 3.2.2.2.). In other words, it is assumed that the individual is sprayed with a solution containing the compound and that an amount of the compound remains on the skin and is absorbed by first-order kinetics. As with the similar worker exposure scenarios, the first-order absorption kinetics are estimated from the empirical relationship of first-order absorption rate coefficients to molecular weight and octanol-water partition coefficients (Durkin et al. 1998), as defined in worksheet A07a.

For these exposure scenarios, it is assumed that during a ground application, a naked child is sprayed directly with picloram. These scenarios also assume that the child is completely covered (that is, 100% of the surface area of the body is exposed). These are extremely conservative exposure scenarios and are likely to represent upper limits of plausible exposure. An additional set of scenarios are included involving a young woman who is accidentally sprayed over the feet and legs. For each of these scenarios, some assumptions are made regarding the surface area of the skin and body weight, as detailed in worksheet A04.

3.2.3.3. Dermal Exposure from Contaminated Vegetation – In this exposure scenario, it is assumed that the herbicide is sprayed at a given application rate and that an individual comes in contact with sprayed vegetation or other contaminated surfaces at some period after the spray operation.

Table 3-2: Picloram - Summary of Exposure Scenarios for the General Public

Scenario	Target	Dose (mg/kg/day)			Worksheet
		Typical	Lower	Upper	
Acute/Accidental Exposures					
Direct spray, entire body	Child	0.01137	0.00175	0.797	WSD01
Direct spray, lower legs	Woman	0.001142	0.0001758	0.08	WSD02
Dermal, contaminated vegetation	Woman	0.04163	0.011206	0.2949	WSD03
Contaminated fruit, acute exposure	Woman	0.0053	0.00319	0.074	WSD04
Contaminated water, acute exposure	Child	0.062	0.0125	3.07	WSD06
Consumption of fish, general public	Man	0.0019	0.00062	0.0615	WSD08
Consumption of fish, subsistence populations	Man	0.0091	0.00297	0.3	WSD08
Chronic/Longer Term Exposures					
Contaminated fruit	Woman	0.0011	0.00069	0.037	WSD05
Consumption of water	Man	0.00036	6.00e-05	0.0031	WSD07
Consumption of fish, general public	Man	1.79e-06	4.29e-07	0.0002	WSD09

For these exposure scenarios, some estimates of dislodgeable residue and the rate of transfer from the contaminated vegetation to the surface of the skin must be available. No such data are directly available for picloram, and the estimation methods of Durkin et al. (1995) are used as defined in worksheet D03. Other estimates used in this exposure scenario involve estimates of body weight, skin surface area, and first-order dermal absorption rates, as discussed in the previous section.

3.2.3.4. Contaminated Water -- Water can be contaminated from runoff, as a result of leaching from contaminated soil, from a direct spill, or from unintentional contamination from aerial applications. For this risk assessment, the two types of estimates made for the concentration of picloram in ambient water are acute/accidental exposure and longer-term exposure. The accidental exposure scenario is based on a spill of a fixed amount of picloram into a body of water of a fixed size assuming instantaneous mixing. The longer-term exposure scenario is based on

monitoring data that can be used to associate the application rate of picloram with picloram concentrations in ambient water as well as estimates of ambient water concentrations modeled using GLEAMS (Knisel et al. 1992). GLEAMS is a root zone model that can be used to examine the fate of chemicals in various types of soils under different meteorological and hydrogeological conditions. As with many environmental fate and transport models, the input and output files for GLEAMS can be complex. The input files used for this analysis have been provided to the Forest Service and only the most relevant details are discussed below.

3.2.3.4.1. ACUTE EXPOSURE -- As detailed in worksheet D06, the acute exposure scenario assumes that a young child (2- to 3-years old) consumes 1 L of contaminated water shortly after an accidental spill of 200 gallons of a field solution into a pond that has an average depth of 1 m and a surface area of 1000 m² or about one-quarter acre. Because this scenario is based on the assumption that exposure occurs shortly after the spill, no dissipation or degradation of picloram is considered.

This is an extremely conservative scenario dominated by arbitrary variability. The actual concentrations in the water would depend heavily on the amount of compound spilled, the size of the water body into which it is spilled, the time at which water consumption occurs relative to the time of the spill, and the amount of contaminated water that is consumed. As indicated in Table 3-2, there is about a 250-fold difference in the upper and lower limits of the exposure assessment - i.e., 0.0125 mg/kg/day to 3.07 mg/kg/day. As detailed in worksheet D06, this wide range is attributable primarily to the differences in field concentrations (a factor of 100). Differences in the estimated amounts of water that might be consumed (a factor of only about 2.5) have relatively little impact on the exposure estimate.

3.2.3.4.2. LONGER-TERM EXPOSURE -- Both monitoring data as well as modeling can be used to estimate concentrations of picloram in ambient water over relatively long periods of time. Two monitoring studies have been encountered which help to define 'background' levels of contamination - i.e., levels in water that are not associated with specific applications of picloram. A recent study conducted by the U.S. Geologic Survey (USGS 1998) found picloram in only 0.15% of 3384 surface water samples. The maximum level detected was 0.0027 mg/L. In a much smaller monitoring study of a series of prairie lakes in Saskatchewan, no picloram was detected (limit of detection of 0.00005 mg/L) (Donald and Syrgiannis 1995).

The most relevant monitoring studies are those in which picloram has been detected in ambient water after the application of picloram at a known amount. Two such studies have been encountered involving the contamination of streams (Davis and Ingebo 1973; Michael and Neary 1993). Michael and Neary (1993) summarize monitoring data on the concentrations of picloram in surface water after the application of picloram by injection, broadcast ground, and broadcast aerial applications. Normalized for application rate, the reported peak concentrations of picloram in water are 7.4 to 37 mg/L per lb/acre for injection, 2.2 mg/L per lb/acre for broadcast ground applications, and 48 to 78 mg/L per lb/acre for broadcast aerial applications (Michael and Neary 1993, Table 3, p. 407). The injection data is also summarized in Michael et al. (1994) and the ground and aerial application data are detailed further in Neary et al. (1993). Both the ground

and aerial broadcast application involved pellet formulations and the ground application involved a 140 meter buffer. In another study using an application rate of 10.4 kg/ha (9.3 lb/acre), the maximum concentration noted in stream water draining from the watershed was 370 µg/L, which occurred after a 6.4 cm rainfall (Davis and Ingebo 1973). This is equivalent to 40 µg/L per lb/acre [370 µg/L ÷ 9.3 lb/acre], much lower than the concentration rates reported in Michael and Neary (1993). In a study by Watson et al. (1989), no picloram was detected in streams, at a limit of detection of 0.0005 mg/L, after the application of picloram at rates of 0.28 kg a.e./ha or 1.12 kg a.e./ha in areas with loam or sandy loam soil. As discussed further below, these apparent discrepancies are most probably due to rainfall patterns as well as local conditions which impact runoff potential.

Standing bodies of water such as small ponds may be at risk of contamination from picloram applied close to the body of water. The application of picloram at a rate of 1 lb a.e./acre resulted in peak concentrations of 1 mg/L in farm ponds adjacent to the application site. The concentration of picloram in the pond water decreased to 0.01 mg/L within 100 days after application (USDA 1989a), corresponding to a dissipation coefficient for picloram in surface water of 0.046 day⁻¹ [$-\ln(0.01)/100$ days]. This is very similar to the dissipation coefficient of 0.048 day⁻¹ that can be calculated from the 74% dissipation of picloram in a model ecosystem over a period of 28 days (Scifres et al. 1977) [$\ln(1-0.74)/28$ days = 0.048 day⁻¹].

Under laboratory conditions, a photochemical degradation half-time of 2-7 days has been measured for picloram (EPA 1992b, p. II-1). The rate of photochemical degradation in the environment, however, will be governed by the amount and intensity of sunlight as well as the turbidity of the water. Picloram is rapidly mineralized by ferric-catalyzed hydrogen peroxide under acid conditions. While this may be a process that could be used to treat picloram contaminated waste (Sun and Pignatello 1993), the conditions required for this reaction to occur rapidly are not plausible in the ambient environment.

For comparison, picloram concentrations in ambient water can be estimated using the GLEAMS model (Knisel et al. 1992). The basic exposure scenario used for the modeling involved picloram being applied along a ten acre right-of-way that is 50 feet wide and 8712 feet long. It is also assumed that a body of water runs along the length of the right-of-way and that the slope toward the water is 10 percent. Two types of soils are modeled: clay (high runoff potential) and sand (low runoff potential). Annual rainfall rates ranging from 5 to 250 inches are used to reflect the variability of regional rainfall rates based on statistics from the U.S. Weather Service (1998) for 152 cities in 45 states covering the period from 1961 to 1990. Average annual rainfall ranged from a low of 0.3 inches (lower range for Yuma, Arizona) to 172.2 inches (upper range for Yakutat, Alaska) with a average annual rainfall of 27.69 inches. For both clay and sand, the specific model parameters are selected to yield central estimates of pesticide runoff and percolation.

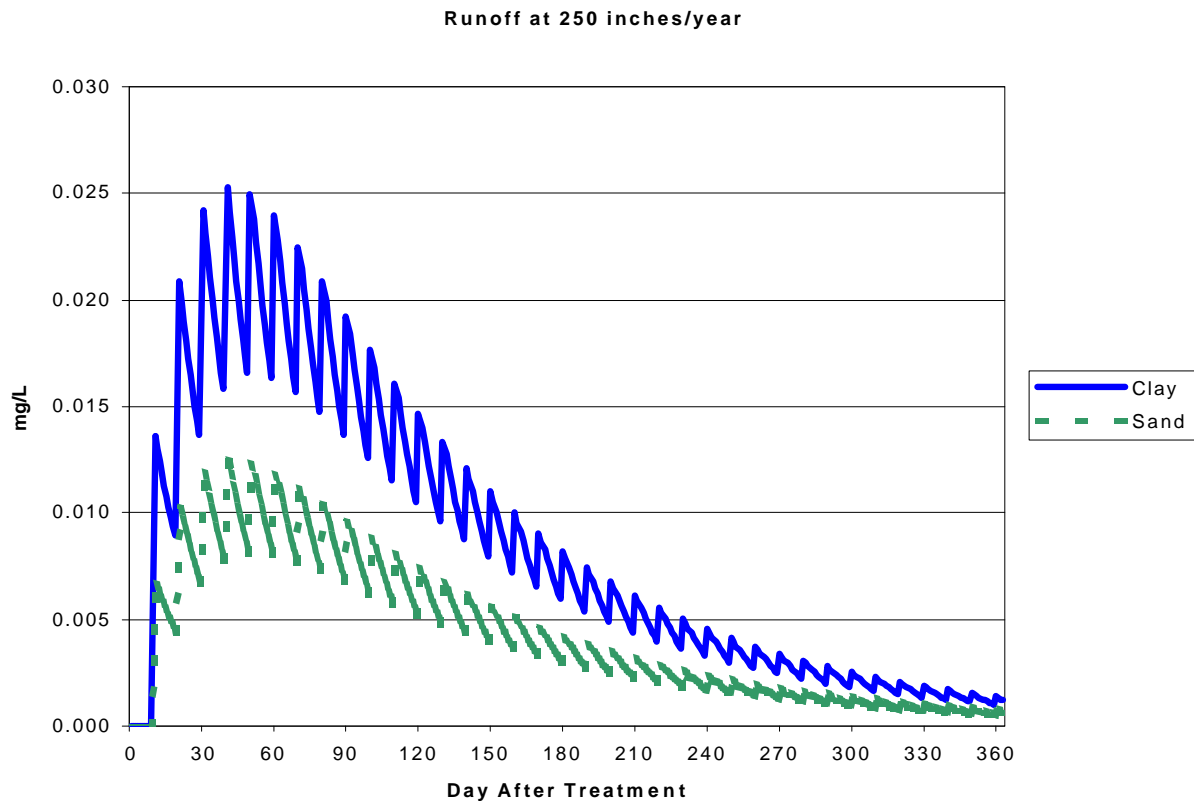


Figure 3-1: Modeled concentrations of picloram in water after the application of 1 lb a.e./acre to clay and sandy soil adjacent to a small pond (see text for details).

Based on the results of the GLEAMS modeling, contamination of ground or surface water from clay or sand is not likely in areas with annual rainfall of less than 50 inches. Because of the general rather than site-specific nature of the GLEAMS modeling, however, some loss could occur in arid areas during unusually severe rainfalls, at least at sites with high runoff or leaching potential.

Estimates of the modeled concentrations of picloram in a 1 meter deep pond at an annual rainfall rate of 250 inches is illustrated in Figure 3-1 for clay and sandy soil. These estimates are based on an application rate of 1 lb a.e./acre, a dissipation half-time of 15 days (USDA 1989d), and the assumptions that picloram in runoff is transported directly to the pond - i.e., any potential effect of a buffer zone is ignored. Under these conditions, peak levels in water range between about 0.012 mg/L (sand) to 0.025 mg/L (clay).

For this risk assessment, the longer-term estimate of the concentration of picloram in ambient water associated with an application rate of 1 lb a.e./acre is taken as 0.025 mg/L. While used as a central estimate, this value is conservative in that it is based on the peak level modeled from GLEAMS - i.e., clay soil at a rainfall rate of 250 inches per year - and is about a factor of 10

higher than the maximum concentration of picloram in ambient water monitored by the USGS (1998).

The upper range of the ambient water concentration is taken from the monitoring study in which the concentration of picloram in pond water decreased from 1 mg/L on the day of application to 0.01 mg/L within 100 days after the application of picloram at a rate of 1 lb a.e./acre (USDA 1989a). This study is selected because it involved a highly relevant field study at an application rate only modestly higher than the range of those used in Forest Service programs. In addition, the monitored level of 0.01 mg/L at day 100 is bracketed by the estimates from the GLEAMS model at 100 days after application (Figure 3-1). Nonetheless, it is likely that the peak level of 1 mg/L as well as the higher peak levels reported by Michael and Neary (1993) were probably the result of incidental direct contamination and these relatively high concentrations would not be expected to be maintained over prolonged periods of time. Thus, it does not seem reasonable to use an initial peak level as an upper limit for a chronic exposure scenario. In addition, it is worth noting that this peak level of 1 mg/L is in the range of concentrations estimated for an accidental spill - i.e., 0.83 (0.27-2.7) mg/L as detailed in picloram worksheet D06. Again, this suggests that the peak levels were the result of accidental direct contamination of the water.

As an alternative, the time-weighted average concentration over a one-year period can be calculated using the initial concentration of 1 mg/L and the dissipation coefficient of 0.046 day⁻¹ derived above. Under the assumption of first order dissipation, the concentration in the water at time t (C_t) can be estimated from the initial concentration (C_0) and the dissipation coefficient (k) as:

$$C_t = C_0 \times e^{-kt}.$$

The time-weighted average concentration over any interval, $\bar{A}t$, can be calculated as definite integral of the above expression between 0 and time t divided by $\bar{A}t$. Taking the definite integral as

$$-C_0 \times (1 - e^{-kt}) \div k$$

(e.g., De Sapio 1976, p. 281), the time-weighted average concentration over a one year period can be calculated as 0.06 mg/L:

$$((-1 \text{ mg/L} \times 1 - e^{-0.046/\text{day} \times 365 \text{ days}}) \div 0.046/\text{day}) \div 365 \text{ days} = 0.0596 \text{ mg/L}.$$

Thus, 0.06 mg/L is used as the upper range of water concentrations associated with the long term contamination of water after the application of picloram at a rate of 1 lb a.e./acre.

The lower range of concentrations in ambient water is taken as 0.01 mg/L, the monitored levels at day 100 from USDA (1989a) which, as noted above, is reasonably consistent with the GLEAMS modeling (Figure 3-1). Again, this is probably a conservative estimate in that a true lower limit

will probably approach the much lower values of <0.00005 mg/L to 0.0027 mg/L reported in USGS (1998).

3.2.3.5. Oral Exposure from Contaminated Fish -- Some chemicals, particularly those that are poorly soluble in water and highly soluble in organic material, may be concentrated or partitioned from water into the tissues of animals or plants in the water. This process is referred to as bioconcentration. Generally, bioconcentration is measured as the ratio of the concentration in the organism to the concentration in the water. For example, if the concentration in the organism is 5 mg/kg and the concentration in the water is 1 mg/L, the bioconcentration factor (BCF) is 5 L/kg [5 mg/kg ÷ 1 mg/L]. As with most absorption processes, bioconcentration depends initially on the duration of exposure but eventually reaches steady state. Details regarding the relationship of bioconcentration factor to standard pharmacokinetic principles are provided in Calabrese and Baldwin (1993). Picloram, however, is highly soluble in water and poorly soluble in organic material. Measured bioconcentration factors in fish and aquatic invertebrates indicate a bioconcentration factor of unity or less - i.e., picloram is not bioconcentrated (U.S. EPA 1995a; USDA 1989d). Thus, for this risk assessment a bioconcentration factor of 1 L/kg is used.

For both the acute and longer-term exposure scenarios involving the consumption of contaminated fish, the water concentrations of picloram used are identical to the concentrations used in the contaminated water scenarios (see section 3.2.3.4). The acute exposure scenario is based on the assumption that an adult angler consumes fish taken from contaminated water shortly after an accidental spill of 200 gallons of a field solution into a pond that has an average depth of 1 m and a surface area of 1000 m² or about one-quarter acre. No dissipation or degradation is considered. Because of the available and well-documented information and substantial differences in the amount of fish caught and consumed by the general public and native American subsistence populations (U.S. EPA 1996), separate exposure estimates are made for these two groups (picloram worksheet D08). The chronic exposure scenario is constructed in a similar way (picloram worksheet D09).

3.2.3.6. Oral Exposure from Contaminated Vegetation – None of the Forest Service applications of picloram will involve the treatment of crops. Thus, under normal circumstances and in most types of applications conducted as part of Forest Service programs, the consumption of vegetation contaminated with picloram is unlikely. Nonetheless, any number of scenarios could be developed involving either accidental spraying of crops or the spraying of edible wild vegetation, like berries. In most instances, and particularly for longer-term scenarios, treated vegetation would probably show signs of damage from exposure to picloram (section 4.3.2.4), thereby reducing the likelihood of consumption that would lead to significant levels of human exposure.

Notwithstanding that assertion, it is conceivable that individuals could consume contaminated vegetation. One of the more plausible scenarios involves the consumption of contaminated berries after treatment of a right-of-way or some other area in which wild berries grow. The two accidental exposure scenarios developed for this exposure assessment include one scenario for acute exposure (picloram worksheet D04) and one scenario for longer-term exposure (picloram

worksheet D05). In both scenarios, the concentration of picloram on contaminated vegetation is estimated using the empirical relationships between application rate and concentration in vegetation developed by Hoerger and Kenaga (1972). These relationships are defined in worksheet A05a. For the acute exposure scenario, the estimated residue level is taken as the product of the application rate and the residue rate given in worksheet A05a.

For the longer-term exposure scenario, a duration of 90 days is used - i.e., a fruit bearing plant is treated on day 0 and consumed by an individual over a 90-day post-treatment period. For this exposure scenario, the rate of decrease in the residues over time is taken from the vegetation half-time of 8 days reported by Knisel et al. (1992).

For the acute exposure scenario, it is assumed that a woman consumes 1 lb (0.4536 kg) of contaminated fruit. Based on statistics summarized in U.S. EPA (1996a) and presented in worksheet D04, this consumption rate is approximately the mid-range between the mean and upper 95% confidence interval for the total vegetable intake for a 64 kg woman. The range of exposures presented in Table 3-2 is based on the range of concentrations on vegetation from Hoerger and Kenaga (1972) and the range of application rates for picloram. The longer-term exposure scenario is constructed in a similar way, except that the estimated exposures include the range of vegetable consumption (U.S. EPA 1996a) as well as the range of concentrations on vegetation, and the range of application rates for picloram.

3.2.4. Hexachlorobenzene. As mentioned in section 2.2, technical grade picloram is contaminated with hexachlorobenzene. The average concentration of hexachlorobenzene in technical grade picloram is 8 ppm and the maximum concentration is 50 ppm. For all exposure assessments detailed in this risk assessment, the average concentration of 8 ppm is used. The impact of the 50 ppm level is detailed in the risk characterization.

In order to quantitatively consider the potential cancer risk posed by the use of technical grade picloram in Forest Service programs, separate exposure assessments are required for hexachlorobenzene. Summaries of the exposure assessments for workers and members of the general public are given in Tables 3-3 and 3-4, respectively. Details of these exposure assessments are presented in the hexachlorobenzene worksheets: worksheets C01 to C04 for workers and D01 to D10 for members of the general public. The following discussion of the exposure assessments for hexachlorobenzene focuses on aspects of the exposure assessments that differ substantially from those used for picloram.

3.2.4.1. Dermal Absorption – As with picloram, no studies have been encountered on the dermal absorption rate of hexachlorobenzene in humans. Thus, empirical relationships involving other compounds but based on human absorption rates are used to estimate both zero-order (hexachlorobenzene worksheet B05) and first-order (hexachlorobenzene worksheet B04) dermal

Table 3-3: Hexachlorobenzene - Summary of Worker Exposure Scenarios.

Scenario	Dose (mg/kg/day or event)			Hexachloro-benzene Exposure Assessment Worksheet
	Typical	Lower	Upper	
General Exposures (dose in mg/kg/day)				
Directed ground spray (Backpack)	6.56e-06	1.35e-07	1.20e-04	WSC01
Broadcast ground spray (Boom spray)	1.12e-05	1.98e-07	2.27e-04	WSC02a
Aerial	7.35e-06	1.20e-07	4.00e-05	WSC02b
Accidental/Incidental Exposures (dose in mg/kg/event)				
Immersion of Hands, 1 minute	1.17e-04	3.65e-05	3.78e-04	WSC03
Contaminated Gloves, 1 hour	7.05e-03	2.19e-03	2.25e-02	WSC03
Spill on hands, 1 hour	1.57e-06	3.36e-07	7.32e-06	WSC04
Spill on lower legs, 1 hour	3.87e-06	8.29e-07	1.80e-05	WSC04

absorption rate coefficients. The central estimate of first-order rate coefficient is 0.021 hour^{-1} with a range of about 0.005 to 0.1 hour^{-1} . This estimate is substantially higher than first-order rate coefficient of 0.0014 hour^{-1} measured in rats over a 72 hour period (Koizumi 1991). For this risk assessment, the more conservative estimates based on human data are used. As detailed in hexachlorobenzene worksheet B05, the estimated dermal permeability of hexachlorobenzene, used for dermal exposure assessments based on the assumption of zero-order absorption kinetics, is 0.78 (0.24 - 2.52) cm/hr.

As discussed further in section 3.4.7.1, the U.S. EPA assumed 100% dermal absorption of hexachlorobenzene in the cancer risk assessment for workers given in the RED (U.S. EPA 1995a). In other words, the U.S. EPA assumes that all of the hexachlorobenzene that is deposited on the workers skin is absorbed. This assumption is highly conservative and may be unreasonably

Table 3-4: Hexachlorobenzene - Summary of Exposure Scenarios for the General Public.

Scenario	Target	Dose (mg/kg/day)			Worksheet
		Typical	Lower	Upper	
Acute/Accidental Exposures					
Direct spray, entire body	Child	4.75e-07	1.02e-07	2.21e-06	WSD01
Direct spray, lower legs	Woman	4.77e-08	1.02e-08	2.22e-07	WSD02
Dermal, contaminated vegetation	Woman	8.85e-07	1.09e-07	1.37e-05	WSD03
Contaminated fruit, acute exposure	Woman	4.26e-08	2.55e-08	5.96e-07	WSD04
Contaminated water, acute exposure	Child	9.09e-07	2.50e-07	1.28e-05	WSD06
Consumption of fish, general public	Man	2.73e-04	1.23e-04	1.23e-03	WSD07
Consumption of fish, subsistence populations	Man	1.33e-03	5.99e-04	5.99e-03	WSD07
Chronic/Longer Term Exposures					
Contaminated fruit	Woman	7.15e-10	7.66e-13	4.99e-09	WSD05
Consumption of water	Man	1.46e-12	0.00e+00	1.10e-10	WSD08
Consumption of fish, general public	Man	7.29e-11	0.00e+00	7.22e-08	WSD09
Consumption of fish, subsistence populations	Man	5.90e-10	0.00e+00	3.52e-07	WSD09

so based on the experimental data of Koizumi (1991) as well as the estimated zero-order and first-order absorption rates discussed above. In addition, losses from the skin surface due to factors other than absorption (e.g., exfoliation, abrasion, volatilization, or washing), referred to as fugitive losses, are inevitable (Durkin et al. 1998). Data on fugitive losses from the surface of the skin for hexachlorobenzene are not available. As detailed in Appendix 1, the initial half-time for the loss of hexachlorobenzene from the upper 1 cm of soil is about 7.1 days, corresponding to

a rate of 0.0975 days⁻¹ or 0.004 hours⁻¹ and this rapid initial soil loss is probably attributable primarily to volatilization. Durkin et al. (1998) have estimated an average first-order fugitive loss rate from human skin for a group of 29 diverse compounds, at 0.032 hour⁻¹ with a 95% confidence interval 0.0028 to 0.037 hour⁻¹. Thus, it does not seem plausible to assert that all of the hexachlorobenzene deposited on the surface of the skin will be absorbed.

3.2.4.2. Acute Exposures – For all of the worker exposure assessments as well as the acute exposure assessments for members of the general public, the exposure estimates follow the same general methods used for the picloram exposure assessments, as detailed in sections 3.2.2 and 3.2.3. The calculations for hexachlorobenzene are summarized in the hexachlorobenzene worksheets appended to this risk assessment. The major differences in the exposure assessments for picloram and hexachlorobenzene involve lipophilicity and water solubility. Picloram is highly water soluble (430mg/L, Table 2-1). Consequently, picloram does not partition substantially into fatty tissue ($K_{o/w}$ of about 84 or less) and thus dermal absorption, binding to soil, and bioconcentration of picloram are low compared to hexachlorobenzene.

Hexachlorobenzene, on the other hand, is highly lipophilic. The $K_{o/w}$ of hexachlorobenzene is about 1,500,000 and the water solubility of hexachlorobenzene is only about 0.006 mg/L. Thus, hexachlorobenzene may be readily absorbed across the skin, will bind tightly to most soils, and will bioconcentrate in fish (ATSDR 1998). Although the amount of hexachlorobenzene in technical grade picloram is relatively low, the potential for human exposure, in terms of the proportion of the exposure dose that might be absorbed, is higher than that for picloram itself.

Because of the extremely high lipophilicity and low water solubility of hexachlorobenzene, one adjustment is made in the acute exposure assessments that are impacted by water solubility: the dermal spill scenarios. As detailed in hexachlorobenzene worksheets B01 and B02, the calculation of the concentration of a compound, either a herbicide or contaminant, in a solution that is applied in the field is dependent on the concentration of the compound in the formulation as well as the dilution rates for the formulation recommended by the manufacturer. For hexachlorobenzene, the range of concentrations in a field solution based on these rates can be calculated as 0.00000719 mg/mL to 0.0000719 mg/mL (hexachlorobenzene worksheets, page WS-13). This range of concentrations exceeds the water solubility of hexachlorobenzene, which is 0.006 mg/L (0.000006 mg/mL). Thus, as indicated in hexachlorobenzene worksheet B02, the maximum water concentration used in the dermal exposure assessments is taken as 0.006 mg/L. This is consistent with the dermal exposure guidelines proposed by U.S. EPA (1992c).

For acute exposure scenarios involving contaminated water (hexachlorobenzene worksheets D06 and D07), the nominal maximum concentration of hexachlorobenzene in field solutions - i.e., 0.00000719 mg/mL to 0.0000719 mg/mL - is used. Even though these concentrations exceed the solubility of hexachlorobenzene in water, these scenarios involve a spill of an amount of a contaminant into the water and the assumption of instantaneous mixing. Thus, the estimates of the concentrations of hexachlorobenzene in the ambient water are well below the solubility of hexachlorobenzene in water.

As with picloram, both the acute and chronic scenarios for the consumption of fish contaminated with hexachlorobenzene (hexachlorobenzene worksheets D07 and D10) require estimates of a bioconcentration factor - i.e., the concentration in fish divided by the concentration in water. As reviewed in ATSDR (1998), reported bioconcentration factors in fish range from about 2,000 to 20,000. For this risk assessment, a bioconcentration factor 10,000 is used in the exposure assessment.

The application of a bioconcentration factor of 10,000 to the acute exposure scenario for contaminated fish (hexachlorobenzene D07) is conservative. All of the bioconcentration factors reported in ATSDR (1998) involved exposure periods of at least one month. As detailed by Calabrese and Baldwin (1993, pp. 12-22), the kinetics of bioconcentration in fish are essentially identical to standard pharmacokinetic first-order absorption and first-order elimination models (e.g. Goldstein et al. 1974). Consequently, for compounds that are extensively bioconcentrated, such as hexachlorobenzene, the levels in fish after one day will reflect bioconcentration factors that are typically much less than those seen after long-term exposures.

3.2.4.3. General Considerations for Chronic Exposures – The major source of exposure for the general public to hexachlorobenzene involves the consumption of contaminated food. Based on current concentrations of hexachlorobenzene in environmental media and food, daily doses of hexachlorobenzene - i.e., background levels of exposure - are in the range of 0.000001 mg/kg/day (ATSDR 1998). The major source of hexachlorobenzene release to the environment is from the manufacture of chlorinated solvents which accounts for an annual release of 70,343 to 241,311 kg (154,000 to 532,000 pounds). The presence of hexachlorobenzene as a contaminant in pesticides results in the release of about 17,366 kg/year (38,285 lbs/year) (ATSDR 1998).

The use of picloram by the Forest Service is currently about 25,000 lbs/year or about 11,300 kg/year (section 2). Given an average concentration of 8 ppm hexachlorobenzene in technical grade picloram, the amount of hexachlorobenzene released to the environment as a result of Forest Service programs using picloram is about 0.09 kg:

$$11300 \text{ kg} \times 0.000008 = 0.0904 \text{ kg.}$$

This amount represents a factor of about one in 200,000 [$0.0904 \div 17,366$] relative to the amount of hexachlorobenzene released as a contaminant in all pesticides and a fraction of about 1 in 800,000 to 1 in 2.5 million [$0.0904 \div 70,343$ to $241,311$ kg] compared to the amount released from the manufacture of contaminated solvents. Thus, the use of picloram by the Forest Service will not substantially contribute to any wide-spread increase of ambient levels of hexachlorobenzene.

While the use of picloram by the Forest Service will not result in any general increase in environmental levels of hexachlorobenzene, this does not demonstrate that localized contamination would be insignificant. In order to better assess the potential impact of local contamination, three chronic exposure scenarios are considered quantitatively: contaminated vegetation, contaminated water, and contaminated fish.

3.2.4.4. Chronic Exposures Involving Contaminated Vegetation – Immediately after direct foliar application to vegetation, hexachlorobenzene will volatilize relatively rapidly from the surface of the vegetation and relatively little will be absorbed and available for longer-term exposures. Once hexachlorobenzene is absorbed into the soil column, however, it is relatively persistent, with reported half times in soil ranging from 3 to 6 years (ATSDR 1998). Thus, the primary concern for chronic exposures to contaminated vegetation is soil contamination with subsequent uptake by plants. This type of scenario requires estimates of long-term levels in soil as well as bioconcentration factors for terrestrial plants.

The highest bioconcentration factor for the uptake of hexachlorobenzene from soil into plants is 19 (ATSDR 1998). This BCF was measured in the edible portion of carrots and will be used directly for this exposure assessment (hexachlorobenzene worksheet D05).

The study by Beall (1976) is the most relevant and detailed study for estimating longer-term concentrations of hexachlorobenzene in soil after directed foliar applications. In this study, hexachlorobenzene was applied using a mechanical sprayer at a rate equivalent to 10 ppm (mg/kg) in the top 5 cm of soil in a simulated pasture maintained for 19 months in a greenhouse. Although Beall (1976) does not specify an application rate in units of quantity per unit area, such as lb/acre, the approximate application rate can be calculated. A 1 cm² soil surface that is 5 cm deep has a volume of 5 cm³:

$$5 \text{ cm} \times 1 \text{ cm}^2 = 5 \text{ cm}^3$$

The soil type used in the Beall (1976) study is specified as sandy loam but detailed soil characteristics are not provided in the publication. Taking a bulk density of 1.6 g/cm³ for sandy loam soil (Knisel et al. 1992), a 5 cm³ volume of soil would weigh 0.008 kg:

$$5 \text{ cm}^3 \times 1.6 \text{ g/cm}^3 = 8 \text{ g} = 0.008 \text{ kg.}$$

To achieve a nominal concentration of 10 mg hexachlorobenzene/kg soil, the amount applied to a 1 cm² surface of soil would be :

$$0.008 \text{ kg} \times 10 \text{ mg HCB/kg soil} = 0.08 \text{ mg} = 80 \text{ } \mu\text{g.}$$

Thus, the application rate can be calculated as 80 μg/cm² or about 7.1 lbs/acre [1.0 lb/acre = 11.21 μg/cm²]:

$$80 \text{ } \mu\text{g/cm}^2 \div (11.21 \text{ } \mu\text{g/cm}^2 \div 1 \text{ lb/acre}) = 7.136 \text{ lbs/acre.}$$

Over the 19 month duration of this study, the concentration of hexachlorobenzene in the 2-4 cm soil layer was initially 0.1124 mg/kg decreased linearly to 0.0876 mg/kg after one year. This decrease is equivalent to a dissipation coefficient of 0.25 year⁻¹:

$$0.0876 \div 0.1124 = e^{-kt}$$

$$k = -\ln(0.0876 \div 0.1124) / 1 \text{ year} = 0.25 \text{ year}^{-1}$$

which is equivalent to a half time of 2.8 years:

$$\ln(2) \div 0.25 \text{ year}^{-1} = 2.78 \text{ years}$$

This is reasonably consistent with other reported half times in soil of 3 to 6 years (ATSDR 1998).

For this risk assessment, the approximate average concentration of hexachlorobenzene in soil over the 1 year period, 0.1 ppm (mg/kg), will be used as the basis for estimating soil levels that could be associated with the application of hexachlorobenzene to vegetation. As detailed in worksheet B01, a deposition rate for hexachlorobenzene can be calculated at 0.000004 lb/acre based on the typical picloram application rate of 0.5 lb a.e./acre. Thus, for the 2-4 cm layer of soil, the average concentration of hexachlorobenzene in soil over a one year period after the deposition of 0.000004 lb/acre can be estimated at 0.000000056 or 5.6×10^{-8} ppm (mg/kg soil):

$$0.1 \text{ ppm} \times 0.000004 \text{ lb HCB/acre} \div 7.1 \text{ lbs HCB/acre} = 0.000000056 \text{ ppm per lb HCB/acre.}$$

Because of the relatively long half time of hexachlorobenzene, the potential impact of repeated applications must also be considered. Based on the plateau principle (e.g., Goldstein et al. 1974; O'Flaherty 1981), the concentration at infinite time (C_{∞}) relative to the concentration after the first treatment (C_0) may be calculated as:

$$C_{\infty} \div C_0 = 1 \div (1 - e^{-k \Delta t})$$

where, k is the dissipation rate in units of reciprocal time and Δt is the time interval between treatments. The reported half times of 3 to 6 years, correspond to dissipation rates of 0.11 to 0.23 years $[k = \ln(2) \div t_{1/2}]$. Assuming treatments every year, the maximum build up would be a factor of about 5 to 10:

$$1 \div (1 - e^{-0.11 \text{ to } 0.23 \times 1 \text{ year}}) = 4.9 \text{ to } 9.6.$$

Thus, in hexachlorobenzene worksheet D05, the concentration of hexachlorobenzene in soil of 5.6×10^{-8} ppm is multiplied by 10 and a concentration of 5.6×10^{-7} ppm is used for the typical application rate of 0.5 lb a.e. picloram/acre. Similar calculations are made for the lower (0.3 lb picloram a.e./acre) and upper (1.5 lb picloram a.e./acre) application rates.

3.2.4.5. Chronic Exposures Involving Contaminated Water – Immediately after application of a pesticide that is contaminated with hexachlorobenzene to soil or plants, there is not likely to be any immediate contamination of water attributable to the hexachlorobenzene in the contaminated pesticide. Nonetheless, because of the persistence of hexachlorobenzene, it will remain in the soil and could be transferred to surface waters where most of the hexachlorobenzene will be bound to sediments or bioconcentrated in aquatic organisms (ATSDR 1998).

No monitoring studies have been encountered that permit a direct estimate of the amount of hexachlorobenzene that would be found in ambient water as a result of applying a herbicide contaminated with hexachlorobenzene. Nonetheless, there are ample monitoring data to indicate that hexachlorobenzene can, over time, be transported to water either by runoff or by volatilization with subsequent redeposition in rainwater. Because hexachlorobenzene binds tightly to and is relatively immobile in soils, hexachlorobenzene is not likely to percolate through soils and directly contaminate ground water (ATSDR 1998). While volatilization may be an important route of environmental transport, volatilized hexachlorobenzene will be rapidly dispersed and transported over a relatively wide area. Although this will contribute to general background levels of hexachlorobenzene, the amounts of hexachlorobenzene released in Forest Service programs will not substantially contribute to background levels of hexachlorobenzene (section 3.2.4.2). Consequently, for this risk assessment, the contamination of ambient water is based on estimates of hexachlorobenzene runoff from contaminated soil.

In the absence of an appropriate monitoring study, the runoff of hexachlorobenzene to ambient water is estimated using the GLEAMS model (Knisel et al. 1992). Details of the application of this model to estimating hexachlorobenzene runoff are provided in Appendix 1. As with picloram, the basic exposure scenario assumes that hexachlorobenzene, as a contaminant in picloram, is applied along a ten acre right-of-way that is 50 feet wide and 8712 feet long and two types of soils are modeled: clay (high runoff potential) and sand (low runoff potential) at annual rainfall rates ranging from 5 to 250 inches.

For both clay and sand, the specific model parameters are selected to yield high estimates of pesticide runoff for each soil type. The model parameter having the greatest impact on runoff is the runoff curve number, a parameter that is used to estimate runoff based on soil texture and other physical characteristics of the soil. For both clay and sand, the runoff curve numbers are based on fallow straight row plots or hard packed surfaces.

As detailed in Appendix 1, runoff of hexachlorobenzene into surface water is not likely in relatively arid areas - i.e., annual rainfall of less than 10 inches. Because of the general rather than site-specific nature of the GLEAMS modeling, however, some runoff could occur in arid areas during unusually severe rainfalls, at least at sites with high runoff potential. In areas of extremely high rainfall - i.e., approaching 200 to 250 inches per year - annual runoff could range from about 5% of the applied amount in sandy soils to about 10% of the applied amount in clay soils.

All of these runoff estimates from GLEAMS apply to the edge of the field. In other words, for clay at rainfall rate of 100 inches per year, GLEAMS estimates that about 5% of the applied hexachlorobenzene will be transported off the right-of-way. The GLEAMS model runs, however, do not provide any information on the transport of hexachlorobenzene beyond of the borders of the right-of-way. In the absence of a buffer zone, all of the hexachlorobenzene could be projected to go directly into the water. In the application of picloram, however, the Forest Service uses a 100 foot buffer around surface water.

Any attempt to model realistically the impact of a buffer zone on water contamination would be highly site-specific. A simplifying assumption could be that all of the annual runoff occurs on the first day of each year, is evenly dispersed on the first 50 foot strip adjacent to the right-of-way, and thus available for runoff toward the body of water. Similarly, all of the runoff on this first section of buffer is assumed to occur on the first day of each year, be evenly dispersed on the second 50 foot strip adjacent to the body of water, and thus available for runoff into the body of water. Thus, 12% of the applied hexachlorobenzene would runoff the right-of-way to the first section of buffer, 12% of this runoff will runoff to the second section of buffer, and 12% of this runoff will be discharged into the water. Under this assumption, the proportion running into the water each year would be approximately 0.002 of the amount applied to the right-of-way:

$$0.12 \times 0.12 \times 0.12 = 0.001728$$

While this might appear to be a highly conservative and protective assumption, it could underestimate exposure for sites in which the runoff from the right-of-way enters a channel or is otherwise more directly transported to surface water. Such site-specific factors cannot be specifically addressed in any general exposure assessment. Thus, the impact of the buffer is not quantitatively considered in the exposure assessment.

The calculations for estimating the typical concentrations of hexachlorobenzene in ambient water that could be expected from the application of picloram at a rate of 0.5 lb a.e./acre along a right-of-way are detailed in Appendix 1. These calculations essentially involve the application of picloram along a 10 acre right-of-way adjacent to a 10 acre pond with an average depth of 1 meter. This scenario assumes that the hexachlorobenzene is bound to soil and mixed in the bottom 1 cm of the pond sediment. This assumption is intentionally conservative. Increasing the mixing depth will increase the amount of hexachlorobenzene bound to the sediment and hence decrease the amount of hexachlorobenzene in water. The amount of hexachlorobenzene in sediment relative to the amount in water is calculated from the soil sorption coefficient of hexachlorobenzene of 100,000 (U.S. EPA 1998a) (Appendix 1). Because of the persistence of hexachlorobenzene in the environment, modeled scenarios assumed the annual application of picloram over a 20 year period.

The resulting estimates of concentration of hexachlorobenzene in surface water vary substantially with rainfall rates and the number of years over which picloram is applied. At an annual rainfall rate of 25 inches, about the national average, the estimated concentration of hexachlorobenzene in water associated with runoff from clay after one year is about 8.5×10^{-12} mg/L. After 20 years of annual applications, the modeled concentration is about 5.1×10^{-11} mg/L. At this rainfall rate (25 inches/year), no runoff from sand is anticipated. Higher levels of water contamination are estimated in areas with higher rainfall rates. For example, at an annual rainfall rate of 150 inches, concentrations of hexachlorobenzene in water of about 6×10^{-10} mg/L to 1.5×10^{-9} mg/L are estimated as a result of runoff from sand and clay soils, respectively. At atypically high rainfall rates of 250 inches per year, concentrations increase to about 1.6×10^{-9} mg/L to 3.2×10^{-9} mg/L over a 20 year period.

For this risk assessment, the central estimate of the concentration of hexachlorobenzene in water is taken as 5.1×10^{-11} mg/L - runoff from clay after a 20 year period with an annual rainfall rate of 25 inches per year, close to the national average. The upper range of the concentration of hexachlorobenzene in water is taken as 3.2×10^{-9} mg/L - runoff from clay after a 20 year period with an annual rainfall rate of 250 inches, about 10 fold higher than the national average and substantially above upper range of rainfall rates in the United States - i.e., 172.2 inches for Yakutat, Alaska (U.S. Weather Service 1998). This may be viewed as and probably is an extremely conservative worst-case scenario. Nonetheless, given the persistence of hexachlorobenzene in water, the seriousness of the health endpoint for hexachlorobenzene - i.e., cancer - and the need to encompass as wide a range of conditions as reasonably possible, this conservative approach seems justified. The lower range for water contamination is taken as zero. This simply reflects that fact that under many conditions of application - i.e., an arid region in an area relatively far removed from open water - contamination of surface water is implausible.

As summarized in ATSDR (1998), monitored levels of hexachlorobenzene in ambient water or drinking water in the Great Lakes region range from essentially zero (below the limits of detection) to about 0.2 nanograms/L or 2×10^{-10} mg/L. Thus, it appears that the use of picloram contaminated with hexachlorobenzene in Forest Service programs could lead to the localized contamination of ambient water that is about a factor of 10 higher than general background levels of contamination.

3.2.4.6. Chronic Exposures Involving the Consumption of Contaminated Fish – Calculation of the doses of hexachlorobenzene that might be associated with the consumption of contaminated fish are detailed in hexachlorobenzene worksheet D09. These calculations are based on the same exposure scenario and estimates of hexachlorobenzene concentrations in ambient water that are detailed in the previous section as well as standard estimates of fish consumption data for the general public as well as subsistence populations (hexachlorobenzene worksheet A04).

The most important variable unique to this scenario is the bioconcentration factor. This exposure assessment uses a bioconcentration factor in fish of 10,000. ATSDR (1998) reports bioconcentration factors that range from about 2000 to 20,000, depending on the species and experimental design. As with the acute exposure scenario for contaminated fish, a BCF of 10,000 is selected as a reasonably conservative estimate. The subsequent dose estimates vary linearly with the bioconcentration factor. As discussed further in section 3.4.7.2, this relatively modest variability in this factor has no substantial impact on the characterization of risk.

3.3. DOSE-RESPONSE ASSESSMENT

3.3.1. Overview. The Office of Pesticide Programs of the U.S. EPA has derived an RfD of 0.2 mg/kg/day for picloram. This RfD is based on a chronic rat NOAEL of 20 mg/kg/day and an uncertainty factor of 100. In the same study, the LOAEL was 60 mg/kg/day and the effect noted was a change in the staining properties of liver cells. No frank signs of toxicity were seen at this or higher dose levels. This NOAEL for chronic toxic effects is below the NOAELs for reproductive effects. Thus, doses at or below the RfD will be below the level of concern for

reproductive effects. An earlier RfD of 0.07 mg/kg/day is listed on IRIS. This RfD was based on a subchronic rather than chronic study.

The contamination of technical grade picloram with hexachlorobenzene can be quantitatively considered to a limited extent. The U.S. EPA has derived an RfD and cancer potency parameter for hexachlorobenzene. Based on the levels of contamination of technical grade picloram with these compounds and the relative potencies of these compounds to picloram, this contamination is not significant in terms of potential systemic toxic effects. This assessment, however, does not impact the potential carcinogenicity associated with hexachlorobenzene and this risk, based on the U.S. EPA's cancer potency parameter, is quantitatively considered in the risk characterization.

3.3.2. Existing Guidelines for Picloram. The most recent RfD for picloram is 0.2 mg/kg/day, a value derived by the U.S. EPA's Office of Pesticide Programs (U.S. EPA 1994). This RfD is based on a NOAEL of 20 mg/kg/day from a two-year rat feeding study (Landry et al. 1986), discussed in section 3.1.3, with an uncertainty factor of 100. At doses of 60 and 200 mg/kg/day, changes in the staining properties of liver cells, but no frank signs of toxicity, were noted. This RfD is also cited in the RED for picloram (U.S. EPA 1995a) as well as recently proposed pesticide tolerances for picloram (U.S. EPA 1999).

An earlier RfD of 0.07 mg/kg/day is listed on IRIS (U.S. EPA 1992a). This RfD is based on a NOEL of 7 mg/kg/day from a 6-month dog feeding study (Barna-Lloyd et al. 1982), also discussed in section 3.1.3, and this RfD also was derived using an uncertainty factor of 100. While the U.S. EPA (1994) does not specifically discuss the rationale for adopting the higher RfD of 0.2 mg/kg/day, the two-year rat study was probably preferred because it is a lifetime study whereas a 6-month dog feeding study is substantially less than lifetime.

The U.S. EPA (1999) has not derived an acute exposure limit for picloram. In discussing the available acute toxicity data, the U.S. EPA (1999) has concluded that:

No toxicological effect that could be attributable to a single oral exposure was identified, and therefore picloram is not expected to present an acute dietary hazard (P. 421, section C.1.i.).

This statement appears to be based primarily on a review of the acute toxicity studies submitted to the U.S. EPA as part of the registration process. No information has been encountered in the published literature that would contradict EPA's assertion.

3.3.3. Existing Guidelines for Hexachlorobenzene.

3.3.3.1. Systemic Toxicity – The U.S. EPA RfD for hexachlorobenzene is 0.0008 mg/kg/day. This RfD is based on a 130-week feeding study in male and female rats that also included a 90-day exposure to offspring. The U.S. EPA judged the NOAEL for liver effects at a dose of 0.08 mg/kg/day with a LOAEL at 0.29 mg/kg/day. The LOAEL was characterized by U.S. EPA (1997) as “an increase ($p < 0.05$) in hepatic centrilobular basophilic chromogenesis” in the

offspring of the chronically exposed rats. As with picloram and for the same reasons as with picloram, the U.S. EPA used an uncertainty factor of 100 to derive the RfD of 0.0008 mg/kg/day.

ATSDR (1998) has derived an acute MRL for hexachlorobenzene of 0.008 mg/kg/day, a factor of 10 above the chronic RfD derived by U.S. EPA. The Office of Drinking Water of the U.S. EPA has derived a maximum contaminant level of 0.001 mg/L of drinking water and a maximum short term health advisory of 0.05 mg/L of drinking water (U.S. EPA 1998a).

3.3.3.2. Carcinogenic Potency – In addition to systemic toxicity, hexachlorobenzene has been shown to cause tumors of the liver, thyroid and kidney in three species of rodents - mice, rats, and hamsters (ExToxNet 1996b; U.S. EPA 1997). Based on a two-year feeding study in rats, the U.S. EPA (1997) derived a cancer slope factor for lifetime exposures of $1.6 \text{ (mg/kg/day)}^{-1}$. In other words, cancer risk over a lifetime (P) is calculated as the product of the daily dose (d) over a lifetime and the potency parameter (\hat{a}):

$$P = d \hat{a}$$

and the lifetime daily dose associated with a given risk level is:

$$d = P \div \hat{a}$$

Thus, the lifetime daily dose of hexachlorobenzene associated with a risk of one in one-million ($1 \div 1,000,000$ or 0.000001) is 0.000000625 mg/kg/day:

$$d_{\text{(mg/kg/day)}} = 0.000001 \div (1.6 \text{ (mg/kg/day)}^{-1}).$$

As noted in section 3.1.5, picloram is not classified as a carcinogen. While it can be argued that the technical grade picloram used in the standard bioassays encompasses any toxicologic effects that could be caused by hexachlorobenzene, this argument is less compelling for carcinogenic effects because, for most cancer causing agents, the cancer risk is conservatively viewed as a non-threshold phenomenon - i.e., zero risk is achieved only at zero dose.

The potency factor of $1.6 \text{ (mg/kg/day)}^{-1}$ is intended to be applied to lifetime daily doses. As summarized in section 3.2, many of the exposure assessments used in this risk assessment involve much shorter periods of time. Following the approach recommended by U.S. EPA (1997, p. 35), this risk assessment assumes that the average daily dose over a lifetime is the appropriate measure for the estimation of cancer risk. Thus, the lifetime potency of $1.6 \text{ (mg/kg/day)}^{-1}$ is scaled linearly when applied to shorter periods of exposure. For example, taking 70 years [70 years \times 365 days/year = 25,550 days] as a reference life span, the potency parameter for a one-day exposure is calculated as $0.000063 \text{ (mg/kg/day)}^{-1}$:

$$1.6 \text{ (mg/kg/day)}^{-1} \times (1 \text{ day} \div 25,550 \text{ days}) = 0.000062622 \text{ (mg/kg/day)}^{-1}.$$

Thus, the lifetime risk associated with a single dose of 0.001 mg/kg would be calculated as 6.3×10^{-8} :

$$0.000063 \text{ (mg/kg/day)}^{-1} \times 0.001 \text{ mg/kg/day} = 0.000000063 = 6.3 \times 10^{-8}$$

or 6.3 in one-hundred million. This method of estimating cancer risk from short-term exposures is used in the worksheets for hexachlorobenzene that are appended to this document.

3.4. RISK CHARACTERIZATION

3.4.1. Overview. Based on the estimated levels of exposure and the criteria for acute exposures by ATSDR and for chronic exposures by the U.S. EPA, there is no evidence that typical exposures to picloram will lead to dose levels that exceed the level of concern. For workers, only one accidental exposure scenario, wearing contaminated gloves for 1-hour, results in estimates of absorbed doses that exceeds the RfD by a modest amount. As discussed by U.S. EPA (1999), picloram has a very low acute toxicity. The consequences of this modest short-term excursion above the chronic RfD are not likely to be substantial.

For members of the general public, the upper limits for hazard quotients are below a level of concern and the risk characterization is relatively unambiguous. Based on the available information and under the foreseeable conditions of application, there is no route of exposure or scenario suggesting that the general public will be at any substantial risk from longer-term exposure to picloram. For the acute/accidental scenarios, none of the central estimates representing typical exposure conditions exceed the RfD. For several scenarios, however, estimates of the upper limits of exposure exceed a level of concern by margins greater than those for workers. While these exposure scenarios do not suggest that adverse effects would be likely, these and the other acute scenarios help to identify the types of scenarios that are of greatest concern and may warrant the greatest steps to mitigate. For picloram, such scenarios involve both oral (contaminated water) and dermal (spills or accidental spray) exposures.

Irritation and damage to the eyes can result from exposure to relatively high levels of picloram - i.e., placement of picloram directly onto the eye - and repeated exposures to picloram can lead to skin sensitization. From a practical perspective, eye irritation and skin sensitization are likely to be the only overt effects as a consequence of mishandling picloram. These effects can be minimized or avoided by prudent industrial hygiene practices during the handling and application of picloram.

Based on the standard assumptions used in this and other Forest Service risk assessments, the contamination of picloram with hexachlorobenzene does not appear to present any substantial cancer risk based on central and in most cases upper range estimates of exposure. Administratively, the Forest Service has adopted a cancer risk level of one in one-million ($1 \div 1,000,000$) as a trigger that would require special steps to mitigate exposure or restrict and possibly eliminate use.

Based on relatively conservative exposure assumptions and at the typical application rate of 0.5 lb a.e. picloram/acre, the risk levels estimated for members of the general public are below this trigger level. The highest risk level for the general public is estimated at about 6 in 10 million (5.63×10^{-7} or about 0.0000006) at an application rate of 0.5 lb a.e./acre. This is only a factor of about two below the level of concern. At an application rate of 1.5 lb a.e. picloram/acre, however, the resulting risk would be about 1.6 in one-million, slightly above the Forest Service trigger level of one in one-million. Based on central rather than upper estimates of exposure, the highest cancer risk is about one in one-billion.. The exposure scenario associated with this risk level involves the upper limit of exposure from the consumption of contaminated fish by subsistence populations - i.e., groups that consume relatively large amounts of fish. The consumption of fish contaminated with hexachlorobenzene is a primary exposure scenario of concern because of the tendency of hexachlorobenzene to bioconcentrate from water into fish. This is also consistent with the general observation that exposure to hexachlorobenzene occurs primarily through the consumption of contaminated food.

The cancer risk assessment for workers consistently leads to estimates of risk that are far below the Forest Service trigger level. It is worth noting, however, that the U.S. EPA's cancer risk assessment for workers resulted in much higher risk estimates in the range of 1.07×10^{-7} to 4.19×10^{-5} . The upper end of this range, about four in one-hundred thousand, is above the Forest Service trigger level by a factor of about 40. In the calculation of cancer risk, some of the assumptions used by the U.S. EPA differ substantially from those used in the current risk assessment. The U.S. EPA assumed 100% dermal absorption of hexachlorobenzene and appears to have assumed that hexachlorobenzene is present at the maximum allowed concentration cited in the RED, 100 ppm.

3.4.2. Workers.

A quantitative summary of the risk characterization for workers associated with exposure to picloram is presented in Table 3-5. The quantitative risk characterization is expressed as the hazard quotient, which is the ratio of the estimated doses from Table 3-1 to the RfD of 0.2 mg/kg/day (section 3.3.2).

Given the very low hazard quotients for central estimates of exposure for both general occupational exposures as well as accidental exposures, the risk characterization for workers is unambiguous. Under typical conditions of exposure, none of the exposure scenarios approach a level of concern. Even at the upper limits of exposure which are based on the highest anticipated application rate and the worst-case exposure assumptions, the hazard indices do not exceed unity for the general worker exposures.

Table 3-5: Summary of risk characterization for workers associated with exposure to picloram¹

RfD	0.2	mg/kg/day	Sect. 3.3.2.	
Scenario	Hazard Quotient			Exposure Assessment Worksheet
	Typical	Lower	Upper	
General Exposures				
Directed ground spray (Backpack)	0.03	0.001	0.6	WSC01
Broadcast ground spray (Boom spray)	0.06	0.001	1	WSC02a
Aerial	0.04	0.0006	0.2	WSC02b
Accidental/Incidental Exposures				
Immersion of Hands, 1 minute	0.0006	0.0001	0.03	WSC03
Contaminated Gloves, 1 hour	0.04	0.008	1.8	WSC03
Spill on hands, 1 hour	0.002	0.0002	0.1	WSC04
Spill on lower legs, 1 hour	0.004	0.0006	0.3	WSC04

While the accidental exposure scenarios are not the most severe one might imagine (e.g., complete immersion of the worker or contamination of the entire body surface for a prolonged period of time) they are representative of reasonable accidental exposures. Only one accidental exposure scenario, wearing contaminated gloves for 1-hour, results in estimates of absorbed doses that exceeds the RfD by a modest amount. As discussed by U.S. EPA (1999), picloram has a very low acute toxicity. The consequences of this modest short-term excursion above the chronic RfD are not likely to be substantial.

The simple verbal interpretation of this quantitative characterization of risk is that under the most conservative set of exposure assumptions, workers would not be exposed to levels of picloram that are regarded as unacceptable so long as reasonable and prudent handling practices are followed.

As discussed in section 3.1.6, picloram can cause irritation and damage to eyes and skin sensitization. Quantitative risk assessments for irritation are not derived; however, from a practical perspective, effects on the eyes or skin are likely to be the only overt effects as a

consequence of mishandling picloram. These effects can be minimized or avoided by prudent industrial hygiene practices during the handling of picloram.

3.4.3. General Public. The quantitative hazard characterization for the general public associated with exposure to picloram is summarized in Table 3-6. Like the quantitative risk characterization for workers, the quantitative risk characterization for the general public is expressed as the hazard quotient using the RfD of 0.2 mg/kg/day.

Although there are several uncertainties in the longer-term exposure assessments for the general public, as discussed in section 3.2, the upper limits for hazard quotients associated with the longer-term exposures are sufficiently below a level of concern that the risk characterization is relatively unambiguous: based on the available information and under the foreseeable conditions of application, there is no route of exposure or scenario suggesting that the general public will be at any substantial risk from longer-term exposure to picloram. At the central - i.e., most plausible - levels of longer-term exposure, the hazard quotients are below unity by factors of about 500 to over 100,000. Based on the estimated upper-range of exposure, only the exposure scenario for contaminated fruit is within a factor of 10 of the level of concern - i.e., a hazard quotient of 0.2.

For the acute/accidental scenarios, none of the central estimates representing typical exposure conditions exceed the RfD. Estimates of the upper limits of exposure resulting from the direct spray of a child, dermal contact with contaminated vegetation, consumption of contaminated water by a child, and the consumption of contaminated fish all exceed a level of concern. All of these exposure scenarios are dominated by situational or arbitrary variability. The direct spray of a young child is obviously a highly conservative and perhaps grossly implausible scenario. Nonetheless, this scenario is applied consistently as a screening scenario in Forest Service risk assessments as the most extreme scenario. If this scenario does not exceed the level of concern, other dermal scenarios are of little concern. For picloram, however, there is a modest excursion above the RfD and the dermal route exposure is regarded as potentially hazardous. Nonetheless, as discussed in the risk characterization for workers, the U.S. EPA has not identified toxic endpoints for acute exposures to picloram. Thus, while these exposure scenarios do not suggest that adverse effects would be likely, these and the other acute scenarios help to identify the types of scenarios that are of greatest concern and may warrant the greatest steps to mitigate. For picloram, such scenarios involve both oral (contaminated water) and dermal (spills or accidental spray) exposures. As with the acute exposure scenarios for workers, the hazard quotients for the general public that involve acute exposure scenarios are inherently conservative in that they are based on the chronic RfD.

Each of the hazard quotients summarized in Table 3-6 involves a single exposure scenario. In some cases, individuals could be exposed by more than one route and in such cases risk can be quantitatively characterized by simply adding the hazard quotients for each exposure scenario. For picloram, considerations of multiple exposure scenarios has little impact on the risk assessment. For example, typical levels of exposure for a woman being directly sprayed on the lower legs, staying in contact with contaminated vegetation, eating contaminated fruit, and consuming contaminated fish leads to a combined hazard quotient of 0.246

Table 3-6: Risk characterization for the general public associated with exposure to picloram ¹.

RfD		0.2	mg/kg/day	Sect. 3.3.2	
Scenario	Target	Hazard Quotient			Worksheet
	Typical	Lower	Upper		
Acute/Accidental Exposures					
Direct spray, entire body	Child	0.06	0.009	4	WSD01
Direct spray, lower legs	Woman	0.006	0.0009	0.4	WSD02
Dermal, contaminated vegetation	Woman	0.2	0.06	1.5	WSD03
Contaminated fruit, acute exposure	Woman	0.03	0.02	0.4	WSD04
Contaminated water, acute exposure	Child	0.3	0.06	15	WSD06
Consumption of fish, general public	Man	0.01	0.003	0.3	WSD08
Consumption of fish, subsistence populations	Man	0.05	0.01	1.5	WSD08
Chronic/Longer Term Exposures					
Contaminated fruit	Woman	0.006	0.003	0.2	WSD05
Consumption of water	Man	0.002	0.0003	0.02	WSD07
Consumption of fish, general public	Man	0.000009	0.000002	0.001	WSD09

[0.006+0.2+0.03+0.01]. Similarly, for all of the chronic exposure scenarios, the addition of all possible pathways lead to hazard quotients that are substantially less than unity.

3.4.4. Sensitive Subgroups. There is no information to suggest that specific groups or individuals may be especially sensitive to the systemic effects of picloram. As discussed in sections 3.1.3 and 3.3.2, the likely critical effect of picloram in humans cannot be identified clearly. In animals, the most sensitive effect of picloram involves changes in the staining characteristics of liver cells. These effects, however, were only noted in one study and are not consistent among species or even between different studies in the same species. Thus, it is unclear

if individuals with pre-existing diseases of the liver would be particularly sensitive to picloram exposures, although individuals with any severe disease condition could be considered more sensitive to many toxic agents.

In addition, some individuals may suffer from multiple chemical sensitivity (e.g., ATSDR 1995). Such individuals may respond adversely to extremely low levels of chemicals and in a manner that is atypical of the general population. There are no data or case reports, however, on idiosyncratic responses to picloram.

3.4.5. Connected Actions. As noted in section 3.1.3, a commercial formulation of picloram and 2,4-D, Tordon 202C, has been shown to inhibit immune response in mice (Blakley 1997). While the design of this study does not permit the determination of which agent caused the immune response, this observation is relevant to Forest Service activities because, as summarized in section 2, picloram is often applied with 2,4-D in Forest Service programs.

The effects of mixtures of picloram, alachlor, and atrazine compared to the activity of each chemical given alone have been characterized in both 90-day drinking water studies (10 ppm in water) and 90-day gavage studies (100 mg/kg in corn oil) using mice (Chaturvedi 1993). Again, the design of this study does not permit a quantitative characterization of interactions of these three pesticides. Nonetheless, exposures to picloram were associated with increased weights of the spleen, kidney, and liver.

3.4.6. Cumulative Effects. As noted above, this risk assessment specifically considers the effect of repeated exposure in that the chronic RfD is used as an index of acceptable exposure. Consequently, repeated exposure to levels below the toxic threshold should not be associated with cumulative toxic effects.

3.4.7. Hexachlorobenzene.

3.4.7.1. Workers – Summaries of the exposure assessments and risk characterization for workers are given in the hexachlorobenzene worksheets that accompany this risk assessment. Worksheet E01 summarizes the exposure assessment for workers and is analogous to the corresponding worksheet for picloram. Worksheets E02a, E02b, and E02c summarize the risk characterization for workers.

Worksheet E02a summarizes the risk characterization for systemic toxic effects. Unlike picloram, the toxicity data on hexachlorobenzene allows for separate dose-response assessments for acute and chronic exposures. For acute exposures, the hazard quotients are based on ATSDR's short-term MRL of 0.008 mg/kg/day (ATSDR 1998). For chronic exposures, the hazard quotients are based on the chronic RfD from U.S. EPA of 0.0008 mg/kg/day.

For general worker exposures, the hazard quotients associated with hexachlorobenzene (worksheet E02a) are approximately four orders of magnitude below the corresponding hazard quotients for picloram (Table 3-5). Similarly, hazard quotients associated with accidental scenarios are consistently lower for hexachlorobenzene than the corresponding scenarios for

picloram. Thus, for the reasonably diverse exposure scenarios covered in this risk assessment, the amount of hexachlorobenzene in technical grade picloram is not toxicologically significant.

Hexachlorobenzene worksheet E02b presents the cancer risks - i.e., the levels of exposure from worksheet E01 multiplied by the cancer potency factor. In worksheet E02b, the cancer potency factor is adjusted to estimate daily risks by dividing the lifetime cancer potency factor of 1.6 (mg/kg/day)⁻¹ by 25,500 days as detailed in section 3.3.3.2. The last worksheet for workers, worksheet E02c, presents the cancer risk relative to a risk level of one in one-million - i.e., each risk level from worksheet E02b is divided by one million. A risk level of one in one-million or less has been administratively selected by the Forest Service as a reference level for risk assessments. Thus, in worksheet E02c, any value greater than unity represents a risk that is considered unacceptable by the Forest Service.

For the general exposure scenarios, the upper limits of cancer risk are about 2×10^{-11} to 1×10^{-10} - i.e., two in one-hundred billion to 1 in ten-billion - for each day of exposure. Thus, using the upper levels of exposure, a worker would have to handle picloram contaminated with hexachlorobenzene for 10,000 to 50,000 days ($1 \times 10^{-6} \div 2 \times 10^{-11}$ to 1×10^{-10}) to reach a risk level of one in one-million (1×10^{-6}). This is equivalent to about 27 to 140 years. Based on daily risks associated with central estimates of exposure (i.e., risks of about 5×10^{-12}), a worker would have to handle picloram for 200,000 days [$1 \times 10^{-6} \div 5 \times 10^{-12}$] or about 550 years.

As indicated in Section 3, all of these risk characterizations are based on the typical or average 8 ppm concentration of hexachlorobenzene in technical grade picloram. Particularly for chronic exposures in which workers would be exposed over several years to hexachlorobenzene in many different batches of picloram, the use of the average concentration appears to be a much more reasonable approach than the use of the upper limit.

The maximum level of hexachlorobenzene currently in picloram is 50 ppm, a factor of about 6 higher than the average concentration. If this higher concentration of hexachlorobenzene were used as the basis for the risk assessment, a risk level of one in one-million would be estimated for workers at the highest risk - i.e., those involved in broadcast ground sprays - after a period of about 4 years [$27 \text{ years} \div (50 \text{ ppm}/8 \text{ ppm}) = 4.32 \text{ years}$]. Over a 35-year period, the resulting risk level would be about 8 in one-million.

This type of calculation appears to have been conducted by U.S. EPA (1995a) in the RED in which lifetime cancer risks to workers were calculated to be in the range of 1.07×10^{-7} to 4.19×10^{-5} or about 1 in ten-billion to 4 in one-hundred thousand. The upper limit of these risks is above the risks that the Forest Service considers tolerable by a factor of about 40. In the calculation of cancer risk, some of the assumptions used by the U.S. EPA differ substantially from those used in the current risk assessment. The U.S. EPA (1995a) assumed 100% dermal absorption of hexachlorobenzene and appears to have assumed that hexachlorobenzene is present at the maximum allowed in the RED, 100 ppm. As discussed in section 3.2.4.1, the assumption of 100% dermal absorption does not seem plausible. As indicated in section 2, the assumption of

100 ppm is substantially higher than average concentrations of hexachlorobenzene currently in picloram.

While there are substantial uncertainties involved in any cancer risk assessment, the verbal interpretation of the numeric risk characterization derived in this risk assessment is relatively simple. Using the assumptions and methods typically applied in Forest Service risk assessments, there is no plausible basis for asserting that the contamination of picloram with hexachlorobenzene will result in any substantial risk of cancer in workers applying picloram under normal circumstances. Using the more conservative assumptions in the U.S. EPA RED, much higher risks can be estimated that are far in excess of the risks considered acceptable by the Forest Service.

3.4.7.2. General Public – Summaries of the acute exposure assessments and risk characterization for the general public are given in the hexachlorobenzene worksheets that accompany this risk assessment and parallel those for the risk characterization for workers discussed in the previous section: worksheet E03 summarizes the exposure assessments and worksheets E04a, E04b, and E04c summarize the risk characterizations.

Worksheet E04a presents the hazard quotients for the general public associated with the acute exposure scenarios. As with the corresponding worksheet for workers, the hazard quotients for acute exposure are based on the short-term MRL of 0.008 mg/kg/day and the hazard quotients for chronic exposures are based on the U.S. EPA RfD of 0.0008 mg/kg/day.

All exposure scenarios result in hazard quotients that are below unity - i.e., the level of exposure is below the RfD for chronic exposures and below the MRL for acute exposures. In addition, all of the acute exposure scenarios result in hazard quotients that are substantially below the corresponding hazard quotient for picloram (Table 3-6). The highest acute hazard quotient for hexachlorobenzene is about 0.7 [7.48×10^{-1}], the upper range of the hazard quotient associated with the consumption of contaminated fish by subsistence populations.

The cancer risk assessment for acute exposure scenarios involving the general public is given in worksheet E04b. As with the corresponding worksheets for workers, the last worksheet for the general public, worksheet E04c, presents the cancer risk relative to a risk level of one in one-million. As with the acute exposure scenarios, the consumption of contaminated fish leads to the highest risk estimates for the longer-term scenarios involving the general public. Based on typical fish consumption values for members of the general public, the estimated lifetime cancer risks are below the reference risk level of one in one-million by factors of about 10 to 100. The upper limit of cancer risk for subsistence populations from the chronic consumption of contaminated fish, 5.53×10^{-7} , is very close to the upper-bound risk level of 7×10^{-7} calculated by the U.S. EPA (1995a, p. 36) and is a factor only 1.7 below the level of concern. These scenarios, however, are based on the typical application rate for picloram of 0.5 lb a.e./acre. At a three fold higher application rate - i.e., 1.5 lb picloram a.e./acre, the upper limit for cancer risk of subsistence populations would be about 1.7 in one-million.

This risk characterization must be interpreted in terms of the underlying assumptions. As detailed in appendix 1, the upper limits for all of the exposure scenarios involving contaminated water and fish are based on relatively conservative estimates of runoff at an annual rainfall rate of 250 inches. This rainfall rate is implausible in most areas of the country. In addition, all of the modeling scenarios are based on assumptions that tend to maximize runoff and subsequent water contamination. In relatively arid areas of the country or in areas with average rainfall rates, water contamination would be substantially less. Furthermore, even at relatively high rates of rainfall, runoff may be insignificant under site-specific conditions that do not favor runoff or in cases in which the picloram is applied at sites far from surface water. This type of situational or site-specific variability cannot be well-encompassed or well-represented in generic exposure assessments.

The simple verbal interpretation of this risk characterization is that, in general, the contamination of picloram with hexachlorobenzene does not appear to pose a risk to the general public. This is consistent with the conclusions reached by the U.S. EPA (1995a). The prolonged use of picloram at the highest plausible application rate, 1.5 lb a.e./acre, could approach or slightly exceed a level of concern in areas with small ponds or lakes used for fishing and in areas with local conditions that favor runoff. In such cases, site-specific exposure assessments and/or monitoring of hexachlorobenzene concentrations in water could be considered.

4. ECOLOGICAL RISK ASSESSMENT

4.1. HAZARD IDENTIFICATION

4.1.1. Overview. The toxicity of picloram is relatively well characterized in experimental mammals but few wildlife species have been assayed relative to the large number of nontarget species that might be potentially affected by the use of picloram. Within this admittedly substantial reservation, picloram appears to be relatively non-toxic to terrestrial animals but is moderately toxic to aquatic animals, particularly fish.

The assessment of the toxicity of picloram to nontarget terrestrial animals is based almost exclusively on toxicity studies using experimental mammals - i.e., the same studies used in the human health risk assessment. Acute oral LD₅₀ values for picloram are in the range of 3000 to 5000 mg/kg body weight and highest NOAEL from a chronic study is 20 mg/kg/day. Some additional studies are available on birds, bees, and snails that generally support the characterization of picloram as relatively non-toxic to terrestrial animals. This assessment is supported by one recent field study that reported no detectable effects on mammalian or avian diversity after the application of picloram.

Picloram is a pyridine herbicide that acts as a plant growth regulator. This is to say that picloram mimics naturally occurring plant auxins or hormones in a manner that leads to uncontrolled and abnormal growth. These effects can in turn lead to gross signs of toxicity or death. The toxicity of picloram to terrestrial plants has been assayed in relatively standardized studies of seed emergence, seed germination, and post-emergence applications that have been submitted to the U.S. EPA to support the registration of picloram. Picloram is more toxic to broadleaf plants than grains or grasses. The lowest reported adverse effect (the EC₂₅ for the inhibition of seed emergence in soybeans) for the potassium salt of picloram is 0.000014 kg or about 0.000012 lb a.e./acre. This is a factor of about 40,000 below the typical application rate of 0.5 lb a.e./acre. The highest reported NOAEL in any of the terrestrial plant bioassays is 70 g a.e./ha [equivalent to 0.07 kg/ha or 0.062 lb a.e./acre] for post-emergent application in wheat and seed germination in barley.

The acute and chronic toxicity of picloram to aquatic animals has been assayed in various species of trout and *Daphnia magna*, a small aquatic invertebrate. Acute (96-hour) LC₅₀ values for trout range from about 5 mg/L to about 20 mg/L. In *Daphnia*, the reported acute (48-hours) LC₅₀ value is 68.3 (63-75) mg/L. Chronic studies using reproductive or developmental parameters for trout and daphnia report no-effect levels of 0.55 mg/L (trout) and 11.8 mg/L (*Daphnia*) and adverse effect levels of 0.88 mg/L (trout) and 18.1 mg/L (*Daphnia*). Thus, it appears that fish, or at least trout, are more sensitive than daphids to both the acute and chronic effects of picloram. Based on standard bioassay in aquatic algae, the lowest effect level for the potassium salt of picloram (EC₂₅ for growth inhibition *Selenastrum capricornutum*) is 52.6 mg/L with a corresponding NOAEL of 13.1 mg/L. Thus, based on comparable toxicologic endpoints, it appears that trout are more sensitive to the toxicity of picloram than algae or aquatic invertebrates.

4.1.2. Toxicity to Terrestrial Organisms.

4.1.2.1. Mammals – As summarized in the human health risk assessment (see section 3), the toxicity of picloram to experimental mammals is well characterized. Acute oral LD₅₀ values for picloram are in the range of 3000 to 5000 mg/kg body weight and highest NOAEL from a chronic study is 20 mg/kg/day. As in the human health risk assessment, these data on experimental mammals can be used to assess the consequences of exposure to picloram in other mammalian species.

In addition to these laboratory bioassays, field studies are available in which the impact of picloram applications were assessed on mammalian wildlife communities. Brooks et al. (1995) examined the impact of a mixture of picloram and triclopyr as well as imazapyr and hexazinone, all used in site preparation, on small mammal and avian communities. The study area was located in Georgia and consisted of a 157-ha tract of residual hardwoods. Picloram was applied in combination with 2,4-D (Tordon 101) at a rate of 2.7 kg a.e./ha. After herbicide treatment and a prescribed burn, loblolly pine were planted. Data on small mammals was collected by trapping and data on birds involved visual surveys. Observations were made at pre-treatment and three times per year at 1, 2, and 3 years after treatment. No substantial differences were noted among the different herbicides. With all herbicides, the number of small animals trapped after treatment was diminished compared to pre-treatment levels. Because no non-herbicide treated sites - i.e., control sites - were used in this study, observed changes in populations of small mammals or birds cannot be clearly associated with herbicide treatment.

Nolte and Fulbright (1997) have conducted a field study assessing the effects of a combination of picloram and triclopyr on community structure. Each herbicide was applied by helicopter at a rate of “1.9 liters/ha” but neither the rate in units of lb/acre nor the specifics of the commercial formulation are given in the publication. This paper does indicate that the application is that “commonly used on mesquite in southern Texas”. No effects were seen on mammalian or avian diversity. In addition, no statistically significant effects were noted on vegetation species richness and evenness or the number of rare plant species.

4.1.2.2. Birds – As summarized by U.S. EPA (1995a), the acute toxicity of the potassium salt of picloram to birds appears to be similar to that in mammals with acute oral LD₅₀ values of >2000 mg/kg in quail and mallard ducks. In addition, 14-day dietary LC₅₀ values in these species are >10,000 ppm and supplemental studies on chickens and pheasants indicated NOAELs, expressed as application rates, of 2.8 kg/ha and 11.2 kg/ha, respectively.

4.1.2.3. Terrestrial Invertebrates – Acute toxicity studies using bees are required by the U.S. EPA in the registration of pesticides - using both dietary and direct contact exposures. For picloram, the acute contact LD₅₀ is >0.1 mg/bee and the dietary LC₅₀ is >1000 ppm. Taking an estimated body weight for the honey bee of 0.093 g (USDA 1993), the contact toxicity LD₅₀ value of >0.1 mg/bee corresponds to a dose of >1 mg/g or 1,000 mg/kg. There is relatively little additional data on terrestrial invertebrates. At dietary concentrations of about 5000 mg/kg over a 14-day period, picloram did not increase mortality in the brown garden snail, *Helix aspersa* (Schuytema et al. 1994). Based on these albeit limited data, there is no basis for asserting that

picloram is likely to be more toxic to terrestrial invertebrates than it is to terrestrial mammals or birds.

4.1.2.4. Terrestrial Plants (Macrophytes) – Picloram is a pyridine herbicide that acts as a plant growth regulator. This is to say that picloram mimics naturally occurring plant auxins or hormones in a manner that leads to uncontrolled and abnormal growth that can lead to gross signs of toxicity or death. In general, picloram is more toxic to broad leaf plants than to grasses or grains (Cox 1998; ExToxNet 1996a; USDA 1995; U.S. EPA 1995a,b). The yellow starthistle, *Centaurea solstitialis*, has developed resistance to picloram with resistant plants being more tolerant by factors ranging from 3 to 35 fold compared to non-resistant plants (Fuerst et al. 1996). Based on growth inhibition in sunflower seedlings, picloram was more toxic than metabolites of picloram by factors of about 300 to 3000 (Grover et al. 1975).

In assessing the potential effects of herbicides on nontarget plant species, the U.S. EPA has developed a standardized set of plant bioassays for seed germination, seed emergence, and post-emergence applications. As summarized in the RED for picloram, the lowest reported adverse effect for the potassium salt of picloram is 0.014 g a.e./ha or 0.000014 kg a.e./ha, the EC₂₅ for seed emergence in soybeans (U.S. EPA 1995a, p. 55). This corresponds to an application rate of about 0.000012 lb a.e./acre, a factor of about 40,000 below the typical application rate of 0.5 lb a.e./acre.

The highest reported NOAEL in any of the terrestrial plant bioassays is 70 g a.e./ha [equivalent to 0.07 kg/ha or 0.062 lb a.e./acre] for post-emergent application in wheat and seed germination in barley. This NOAEL of 0.07 kg/ha is a factor of about 5000 above the effect level of 0.000014 kg a.e./ha in soybeans but still a factor of about 8 below the typical application rate for Forest Service programs [0.5 lb a.e./acre ÷ 0.062 lb a.e./acre]. Thus, picloram can be considered highly selective to broad leaf plants such as soybean but may be toxic to many different plant species at the typical application rate of 0.5 lb a.e./acre.

4.1.2.5. Terrestrial Microorganisms – Unlike the case in macrophytes, the metabolism of picloram may result in increased rather than decreased toxicity in some microorganisms. In three species of fungi, EC₅₀ values for growth inhibition by picloram acid were >1600 ppm. Corresponding values for the decarboxylated metabolite, 4A-TCP, were 50 to 80 ppm. In two species of bacteria, *Arthrobacter globiformis* and *Pseudomonas pictorum*, differences in toxicity were not substantial and ranged between 60 and 380 ppm for picloram and 4A-TCP (Baarschers et al. 1988). The persistence of picloram in soil is inversely related to application rate (Krzyszowska et al. 1994) suggesting that picloram may inhibit microbial activity at higher application rates - i.e., > 1 kg/ha based on the data presented in Krzyszowska et al. (1994).

At a level of 10 ppm in sandy loam soil, picloram—and several other herbicides—caused a transient decrease in nitrification after 2 but not 3 weeks of incubation (Tu 1994). As discussed by this investigator, the decrease in nitrification is relatively mild and does not suggest the potential for a substantial or prolonged impact on microbial activity. In the same study, picloram had no effect on ammonia formation or sulfur oxidation.

4.1.3. Aquatic Organisms.

4.1.3.1. Fish – Information on the acute and chronic toxicity of picloram to aquatic organisms has been published in the open literature (Mayes and Dill 1984; Mayes et al. 1987). In the study by Mayes and Dill (1984), trout were the most sensitive species with a 96-hour LC₅₀ of 19.3 mg/L (Mayes and Dill 1984). The latter publication by Mayes et al. (1987) appears to be an extension of the earlier study, reporting LC₅₀s ranging from 4.8 mg/L for *Salmo clarki* to 19.3 mg/L for *Salmo gairdneri*. In a trout egg and fry study, the chronic NOAEL based on hatching and growth was 0.55 mg/L. Growth and survival of fry was reduced at concentrations of 0.88 mg/L and 1.34 mg/L, respectively (Mayes et al. 1987). The information on the toxicity of picloram to aquatic species summarized in the RED (U.S. EPA 1995a) is very similar to and appears to be taken from these published studies.

4.1.3.2. Amphibians – Neither the published literature nor the RED for picloram (U.S. EPA 1995a) includes data regarding the toxicity of picloram to amphibian species.

4.1.3.3. Aquatic Invertebrates – An acute (48-hours) LC₅₀ value of 68.3 (63-75) mg/L in *Daphnia magna* and a chronic NOAEL of 11.8 mg/L - based on mean total young per adult, total number of broods per adult, and mean brood size per adult - has been reported in the open literature (Gersich et al. 1985). At concentrations of 18.1 mg/L and higher, all of the indices for reproductive performance were decreased (Gersich et al. 1985). This information is identical to that summarized in the RED for picloram (U.S. EPA 1995a).

4.1.3.4. Aquatic Plants – The RED for picloram reports a NOAEL of 13.1 mg/L and an EC₂₅ for growth inhibition of 52.6 mg/L for the potassium salt of picloram in *Selenastrum capricornutum* (U.S. EPA 1995a). Forsyth et al. (1997) assayed the effects of picloram as well as a commercial mixture of picloram and 2,4-D (Tordon 202C) on two species of aquatic macrophytes: *Potamogeton pectinatus* and *Myriophyllum sibiricum* at concentrations of 0.01 and 0.1 mg a.i./L. Picloram had no effect on growth in either species but inhibited flowering at 0.1 mg/L. As with terrestrial microorganisms (section 4.1.2.5), decarboxylation of picloram appears to increase toxicity to two species of *Chlorella* with LC₅₀ values of greater than 160 ppm for the free acid of picloram and 8 ppm and 49 ppm for 4A-TCP, the decarboxylated metabolite of picloram, in *C. pyrenoidosa* and *C. vulgaris*, respectively (Baarschers et al. 1988).

At a concentration of 1.76 mg/L, picloram causes slight growth inhibition (2 to 12%) in some algae species as well as substantial growth inhibition in a cyanobacteria, *Microcystis aeruginosa*. No inhibition was noted in several other cyanobacteria species or the macrophyte *Lemna minor* (Peterson et al. 1994). In a study designed primarily to assess the consistency between two different types of algal bioassays (the standard flask assay and a microplate assay), EC₅₀ values for picloram in *Selenastrum capricornutum* were 21.7 (18.4-25.1) mg/L in the flask assay and 22.7 (18.5-27.0) mg/L in the microplate assay (St-Laurent and Blaise 1992).

4.2. EXPOSURE ASSESSMENT

4.2.1. Overview. Terrestrial animals might be exposed to any applied herbicide from direct spray, the ingestion of contaminated media (vegetation, prey species, or water), grooming activities, or indirect contact with contaminated vegetation. In acute exposure scenarios, the highest exposures for small terrestrial vertebrates will occur after a direct spray and could reach up to about 12 mg/kg under typical exposure conditions and up to about 40 mg/kg under more extreme conditions. Somewhat lower doses are anticipated from the consumption of contaminated vegetation: about 3 mg/kg under typical conditions with an upper range of 30 mg/kg. The consumption of contaminated water will generally lead to much lower levels of exposure. A similar pattern is seen for chronic exposures. Estimated daily doses for the a small vertebrate from the consumption of contaminated vegetation are in the range of 0.6 to 10 mg/kg/day and far exceed doses that are anticipated from the consumption of contaminated water, 0.00075 mg/kg/day to 0.023 mg/kg/day. Based on general relationships of body size to body volume, larger vertebrates will be exposed to lower doses and smaller animals, such as insects, to much higher doses than small vertebrates under comparable exposure conditions. Because of the apparently low toxicity of picloram to animals, the rather substantial variations in the different exposure assessments have little impact on the assessment of risk to terrestrial animals.

For terrestrial plants, five exposure scenarios are considered quantitatively: direct spray, spray drift, runoff, wind erosion and the use of contaminated irrigation water. Unintended direct spray is expressed simply as the application rates considered in this risk assessment, 0.5 lb a.e./acre with a range of 0.3 lb a.e./acre to 1.5 lb a.e./acre, and should be regarded as an extreme/accidental form of exposure that is not likely to occur in most Forest Service applications. Estimates for the other routes of exposure are much less, ranging from 0.000003 lb a.e./acre (the lower range for wind erosion) to 0.03 lb a.e./acre (the upper range for spray drift). All of these exposure scenarios are dominated by situational variability because the levels of exposure are highly dependent on site-specific conditions. Thus, the exposure estimates are intended to represent conservative but plausible ranges that could occur but these ranges may over-estimate or under-estimate actual exposures in some cases. Spray drift is based on estimates of drift from a review of numerous field studies. The central estimate of drift is taken as the expected drift at 500 feet down wind from the application site with lower and upper estimates based on distances of 2500 feet and 100 feet, respectively. The proportion of the applied amount transported off-site from runoff is based on GLEAMS modeling of clay and loams soils. The amount of picloram that might be transported off-site from wind erosion is based on estimates of annual soil loss associated with wind erosion and the assumption that the herbicide is incorporated into the top 1 cm of soil. Exposure from the use of contaminated irrigation water is based on the same data used to estimate human exposure from the consumption of contaminated ambient water and involves both monitoring studies as well as GLEAMS modeling.

Exposures to aquatic plants and animals is based on essentially the same information used to assess the exposure to terrestrial species from contaminated water. The estimated rate of contamination of ambient water associated with the normal application of picloram is 0.025 (0.01 to 0.06) mg a.e./L at an application rate of 1 lb a.e./acre. For acute exposure scenarios, the

highest estimated concentration of picloram in water after an accidental spill is about 0.8 mg a.e./L with a range of about 0.27 to 27 mg a.e./L.

4.2.2. Terrestrial Animals. Terrestrial animals might be exposed to any applied herbicide from direct spray, the ingestion of contaminated media (vegetation, prey species, or water), grooming activities, or indirect contact with contaminated vegetation.

In this exposure assessment, estimates of oral exposure are expressed in the same units as the available toxicity data (i.e., oral LD₅₀ and similar values). As in the human health risk assessment, these units are usually expressed as mg of agent per kg of body weight and abbreviated as mg/kg. For dermal exposure, the units of measure usually are expressed in mg of agent per cm of surface area of the organism and abbreviated as mg/cm². In estimating dose, however, a distinction is made between the exposure dose and the absorbed dose. The *exposure dose* is the amount of material on the organism (i.e., the product of the residue level in mg/cm² and the amount of surface area exposed), which can be expressed either as mg/organism or mg/kg body weight. The *absorbed dose* is the proportion of the exposure dose that is actually taken in or absorbed by the animal.

For the exposure assessments discussed below, general allometric relationships are used to model exposure. In the biological sciences, allometry is the study of the relationship of body size or mass to various anatomical, physiological, or pharmacological parameters (e.g., Boxenbaum and D'Souza 1990). Allometric relationships take the general form:

$$y = aW^x$$

where **W** is the weight of the animal, **y** is the variable to be estimated, and the model parameters are **a** and **x**.

For most allometric relationships used in this exposure assessment, such as the relationship of body weight to surface area as well as the consumption of food and water, **x** ranges from approximately 0.65 to 0.75. These relationships dictate that, for a fixed level of exposure (e.g., levels of a chemical in food or water), small animals will receive a higher dose, in terms of mg/kg body weight, than large animals will receive.

For many compounds, allometric relationships for interspecies sensitivity to toxicants indicate that for exposure levels expressed as mg toxicant per kg body weight (mg/kg body weight), large animals, compared with small animals, are more sensitive. As discussed in section 4.1.2 (Toxicity to Terrestrial Animals), the available information suggests that there are no substantial species differences in sensitivity to picloram. As with the dose-response relationship, generic estimates of exposure are given for a small mammal. A body weight of 20 g is used for a small animal, which approximates the body weight of small mammals such as mice, voles, shrews, and bats. All body weight values are taken from U.S. EPA (1989), unless otherwise specified.

Table 4-1: Summary of exposure scenarios for terrestrial animals

Scenario	Dose (mg/kg/day)			Worksheet
	Typical	Lower	Upper	
Acute/Accidental Exposures				
Direct spray, small mammal, first-order absorption	0.806	0.23149	4.98	F01
Direct spray, small animal, 100% absorption	12.2	7.31	36.6	F02
Direct spray, bee, 100% absorption	81	48.8	244	F03
Consumption of contaminated vegetation, acute exposure	2.63	1.58	28.1	F04
Consumption of contaminated water, acute exposure	0.208	0.068	6.81	F06
Longer Term Exposures				
Consumption of contaminated vegetation, chronic exposure	0.93	0.56	10	F05
Consumption of contaminated water, chronic exposure	0.0031	0.00075	0.023	F07

The exposure assessments for terrestrial animals are summarized in Table 4-1. As with the human health exposure assessment, the computational details for each exposure assessment presented in this section are provided in the attached worksheets (picloram worksheets F01 through F06).

4.2.2.1. Direct Spray – In the broadcast application of any herbicide, wildlife species may be sprayed directly. This scenario is similar to the accidental exposure scenarios for the general public discussed in section 3.2.3.2. In a scenario involving exposure to direct spray, the extent of dermal contact depends on the application rate, the surface area of the organism, and the rate of absorption.

For this risk assessment, three groups of direct spray exposure assessments are conducted. The first, which is defined in worksheet F01, involves a 20 g mammal that is sprayed directly over one half of the body surface as the chemical is being applied. The range of application rates as well as the typical application rate is used to define the amount deposited on the organism. The absorbed

dose over the first day (i.e., a 24-hour period) is estimated using the assumption of first-order dermal absorption. In the absence of any data regarding dermal absorption in a small mammal, the estimated absorption rate for humans is used (see section 3.1.7). An empirical relationship between body weight and surface area (Boxenbaum and D'Souza 1990) is used to estimate the surface area of the animal. The estimates of absorbed doses in this scenario may bracket plausible levels of exposure for small mammals based on uncertainties in the dermal absorption rate of picloram.

Other, perhaps more substantial, uncertainties affect the estimates for absorbed dose. For example, the estimate based on first-order dermal absorption does not consider fugitive losses from the surface of the animal and may overestimate the absorbed dose. Conversely, some animals, particularly birds and mammals, groom frequently, and grooming may contribute to the total absorbed dose by direct ingestion of the compound residing on fur or feathers. Furthermore, other vertebrates, particularly amphibians, may have skin that is far more permeable than the skin of most mammals (Moore 1964).

Quantitative methods for considering the effects of grooming or increased dermal permeability are not available. As a conservative upper limit, the second exposure scenario, detailed in worksheet F02, is developed in which complete absorption over day 1 of exposure is assumed.

Because of the relationship of body size to surface area, very small organisms, like bees and other terrestrial insects, might be exposed to much greater amounts of picloram per unit body weight, compared with small mammals. Consequently, a third exposure assessment is developed using a body weight of 0.093 g for the honey bee (USDA 1993) and the equation above for body surface area proposed by Boxenbaum and D'Souza (1990). Because there is no information regarding the dermal absorption rate of picloram by bees or other invertebrates, this exposure scenario, detailed in worksheet F03, also assumes complete absorption over the first day of exposure.

4.2.2.2. Indirect Contact – As in the human health risk assessment (see section 3.2.3.3), the only approach for estimating the potential significance of indirect dermal contact is to assume a relationship between the application rate and dislodgeable foliar residue. The study by Harris and Solomon (1992) (worksheet A04) is used to estimate that the dislodgeable residue will be approximately 10 times less than the nominal application rate.

Unlike the human health risk assessment in which transfer rates for humans are available, there are no transfer rates available for wildlife species. As discussed in Durkin et al. (1995), the transfer rates for humans are based on brief (e.g., 0.5- to 1-hour) exposures that measure the transfer from contaminated soil to uncontaminated skin. Wildlife, compared with humans, are likely to spend longer periods of time in contact with contaminated vegetation.

It is reasonable to assume that for prolonged exposures a steady-state may be reached between levels on the skin, rates of absorption, and levels on contaminated vegetation, although there are no data regarding the kinetics of such a process. The bioconcentration data on picloram (section 3.2.3.5) as well as the estimated rates of dermal absorption in humans (Section 3.1.7) suggest that

picloram is not likely to partition from the surface of contaminated vegetation to the surface of skin, feathers, or fur. Thus, a plausible partition coefficient is unity (i.e., the concentration of the chemical on the surface of the animal will be equal to the dislodgeable residue on the vegetation).

Under these assumptions, the absorbed dose resulting from contact with contaminated vegetation will be one-tenth that associated with comparable direct spray scenarios. As discussed in the risk characterization for ecological effects (section 4.4), the direct spray scenarios result in exposure levels below the estimated NOAEL - i.e., hazard quotients below one. Consequently, details of the indirect exposure scenarios for contaminated vegetation are not further elaborated in this document.

4.2.2.3. Ingestion of Contaminated Vegetation or Prey – For this component of the exposure assessment, the estimated amounts of residue on food are based on the relationship between application rate and residue rates on leaves and leafy vegetables. For the lower and central estimates of absorbed dose, the ‘typical’ value given in worksheet A05a is used because Hoerger and Kenaga (1972) do not provide estimates of the lower range of expected residues.

Allometric relationships and species specific data (U.S. EPA 1989) suggest that the amount of food consumed per day by a small mammal (i.e., an animal weighing approximately 20 g) is equal to about 15% of the mammal's total body weight. All of the estimates of ingested dose are based on the assumption that 100% of the diet is contaminated. Under the assumption that only 10% of the diet is contaminated, the dose estimates decrease by a factor of 10. Details regarding the calculations for these acute exposure scenarios are given in worksheet F04.

As discussed in section 4.4, the exposure estimates discussed above are of minimal concern for acute exposure. For estimating the effects of longer-term exposures, time-weighted average concentrations are used, which is similar to the approach taken in the human health risk assessment and using the same estimates of foliar half-time as were used in the corresponding human health risk assessment (worksheet B03). Also, the longer-term exposure scenario is based on a 90-day post-spray period and uses the geometric mean over this period as the central estimate of the exposed dose, as in the human health risk assessment. Like the acute exposure scenario, this exposure scenario assumes that 100% of the diet is contaminated. Details regarding the calculations for these chronic exposure scenarios are given in worksheet F05.

4.2.2.4. Ingestion of Contaminated Water -- Estimated concentrations of picloram in water are identical to those used in the human health risk assessment (worksheet B07). The only major differences involve the weight of the animal and the amount of water consumed. There are well-established relationships between body weight and water consumption across a wide range of mammalian species [e.g., U.S. EPA (1989a)]. Mice, weighing about 0.02 kg, consume approximately 0.005 L of water/day (i.e., 0.25 L/kg body weight/day). These values are used in the exposure assessment for the small (20g) mammal. Unlike the human health risk assessment, estimates of the variability of water consumption are not available. Thus, for the acute scenario, the only factors affecting the variability of the ingested dose estimates include the field dilution rates (i.e., the concentration of the chemical in the solution that is spilled) and the amount of

Table 4-2: Quantitative summary of exposure assessments for nontarget terrestrial vegetation.

Scenario	Central Estimate	Lower Range	Upper Range	Section
Proportion of Applied Amount Lost per Event				
Drift	0.002	0.0002	0.03	4.2.3.2.
Runoff	0.001	0.0003	0.004	4.2.3.3.
Wind erosion	0.00007	0.00001	0.0001	4.2.3.5.
Functional Application Rate (lb a.e./acre)				
Direct Spray	0.5	0.3	1.5	4.2.3.1.
Drift	0.001	0.00006	0.045	4.2.3.2.
Runoff	0.0005	0.00009	0.006	4.2.3.3.
Irrigation water	0.00028	0.0001	0.002	4.2.3.4.
Wind erosion	0.000035	0.000003	0.00015	4.2.3.5.

solution that is spilled. As in the acute exposure scenario for the human health risk assessment, the amount of the spilled solution is taken as 200 gallons. In the chronic exposure scenario, the factors that affect the variability are the water contamination rate, (see section 3.2.3.4.2) and the application rate. Details regarding these calculations are summarized in worksheet F06 (acute exposure) and worksheet F07 (chronic exposure).

4.2.3. Terrestrial Plants. The exposure assessments for nontarget terrestrial plants are summarized in Table 4-2 and detailed in the following subsections. As indicated in Table 4-2, five exposure scenarios are considered quantitatively: direct spray, spray drift, runoff, wind erosion and the use of contaminated irrigation water. For three of these exposure scenarios - drift, runoff, and wind erosion - the exposure assessments are based on estimates of the proportion of the applied amount that is transported off-site. These proportions are given in the top part of Table 4-2. The bottom part of Table 4-2 gives the functional application in units of lb a.e./acre. All of the values are presented as central estimates with lower and upper ranges.

Unintended direct spray is expressed simply as the application rates considered in this risk assessment, 0.5 lb a.e./acre with a range of 0.3 lb a.e./acre to 1.5 lb a.e./acre, and should be regarded as an extreme/accidental form of exposure that is not likely to occur in most Forest Service applications. Estimates for the other routes of exposure are much less, ranging from 0.000003 lb a.e./acre (the lower range for wind erosion) to 0.03 lb a.e./acre (the upper range for spray drift). All of these exposure scenarios are dominated by situational variability because the levels of exposure are highly dependent on site-specific conditions. Thus, the estimates given in

Table 4-2 are intended to represent conservative but plausible ranges of exposures that could occur but these ranges may over-estimate or under-estimate actual exposures in some cases. The impact of this situational variability is discussed further in the risk characterization.

Spray drift is based on estimates of drift from a review of numerous field studies. The central estimate of drift is taken as the expected drift at 500 feet down wind from the application site with lower and upper estimates based on distances of 2500 feet and 100 feet, respectively. The proportion of the applied amount transported off-site from runoff is based on GLEAMS modeling of clay and loams soils. The amount of picloram that might be transported off-site from wind erosion is based on estimates of annual soil loss associated with wind erosion and the assumption that the herbicide is incorporated into the top 1 cm of soil. Exposure from the use of contaminated irrigation water is based on the same data used to estimate human exposure from the consumption of contaminated ambient water and involves both monitoring studies as well as GLEAMS modeling.

4.2.3.1. Direct Spray – Unintended direct spray will result in an exposure level equivalent to the application rate. As summarized in Section 2, the typical application rate used in this risk assessment is 0.5 lb a.e./acre with a range of 0.3 lb a.e./acre to 1.5 lb a.e./acre.

4.2.3.2. Off-Site Drift – Data regarding the drift of picloram during ground or aerial applications were not found in the literature. Because off-site drift is more or less a physical process that depends on droplet size and meteorological conditions rather than the specific properties of the herbicide, estimates of off-site drift can be made based on data for other compounds. The potential for spray drift was investigated in numerous field studies reviewed recently by Bird (1995), as summarized in worksheet A06. The monitoring studies involved low-flight agricultural applications of pesticides and employed various types of nozzles under a wide range of meteorological conditions. The central estimates of off-site drift for single swath applications, expressed as a proportion of the nominal application rate, were approximately 0.03 at 100 feet, 0.002 at 500 feet, 0.0006 at 1000 feet, and 0.0002 at 2500 feet (Bird 1995, Figure 2, p. 204). Although multiple swath applications lead to higher rates of off-site deposition, they are less suitable for estimating drift from ground spray applications of picloram.

Another approach to estimating drift involves the use of Stoke's law, which describes the viscous drag on a moving sphere. According to Stoke's law:

$$v = \frac{D^2 \cdot g}{18n}$$

or

$$v = 2.87 \cdot 10^5 \cdot D^2$$

where v is the velocity of fall (cm sec^{-1}), D is the diameter of the sphere (cm), g is the force of gravity (980 cm sec^{-2}), and n is the viscosity of air ($1.9 \cdot 10^{-4} \text{ g sec}^{-1} \text{ cm}^{-1}$ at 20°C) (Goldstein et al. 1974).

In typical backpack ground sprays, droplet sizes are greater than 100μ , and the distance from the spray nozzle to the ground is 3 feet or less. In mechanical sprays, raindrop nozzles might be used.

These nozzles generate droplets that are usually greater than 400 μ , and the maximum distance above the ground is about 6 feet. In both cases, the sprays are directed downward.

Thus, the amount of time required for a 100 μ droplet to fall 3 feet (91.4 cm) is approximately 3.2 seconds,

$$91.4 \div (2.87 \cdot 10^5(0.01)^2).$$

The comparable time for a 400 μ droplet to fall 6 feet (182.8 cm) is approximately 0.4 seconds,

$$182.8 \div (2.87 \cdot 10^5(0.04)^2).$$

For most applications, the wind velocity will be no more than 5 miles/hour, which is equivalent to approximately 7.5 feet/second (1 mile/hour = 1.467 feet/second). Assuming a wind direction perpendicular to the line of application, 100 μ particles falling from 3 feet above the surface could drift as far as 23 feet (3 seconds \cdot 7.5 feet/second). A raindrop or 400 μ particle applied at 6 feet above the surface could drift about 3 feet (0.4 seconds \cdot 7.5 feet/second).

For backpack applications, wind speeds of up to 15 miles/hour are allowed in Forest Service programs. At this wind speed, a 100 μ droplet can drift as far as 68 feet (3 seconds \cdot 15 \cdot 1.5 feet/second). Smaller droplets will of course drift further, and the proportion of these particles in the spray as well as the wind speed will affect the proportion of the applied herbicide that drifts off-site.

4.2.3.3. Soil Contamination – Picloram is extremely mobile in soil. Ismail and Kalithasan (1997) have found that picloram moves rapidly out of the top 5 cm of soil with halftimes of about 4 to 10 days. Somewhat longer halftimes of 13 days to 23 days have been reported by Krzyszowska et al. (1994) who also noted that picloram is degraded more rapidly under anaerobic than aerobic conditions and also degrades more rapidly at lower application rates. Picloram can be detected in the soil at concentrations as low as 0.01 ppm although the recovery of picloram from soil samples decreases as the organic matter in the soil increases (Tan et al. 1996).

The off-site movement of picloram will be governed by the binding of picloram to soil, the persistence of picloram in soil, as well as site-specific topographic, climatic, and hydrological conditions. While generic exposure models such as GLEAMS cannot reflect all of the potential site-specific and situational variability, such models are useful for identifying conditions under which off-site transfer through runoff is likely to be most important. In order to encompass a wide range of plausible conditions, three types of soil were modeled using GLEAMS: clay, loam, and sand.

Model parameters were selected to yield upper estimates of runoff from clay and central estimates of runoff from loam and sand. The physical conditions of the application of picloram are identical to those used in Section 3.2.3.4.2 for the estimate of water contamination from runoff - i.e., application along a ten acre right-of-way that is 50 feet wide and 8712 feet long. As with the

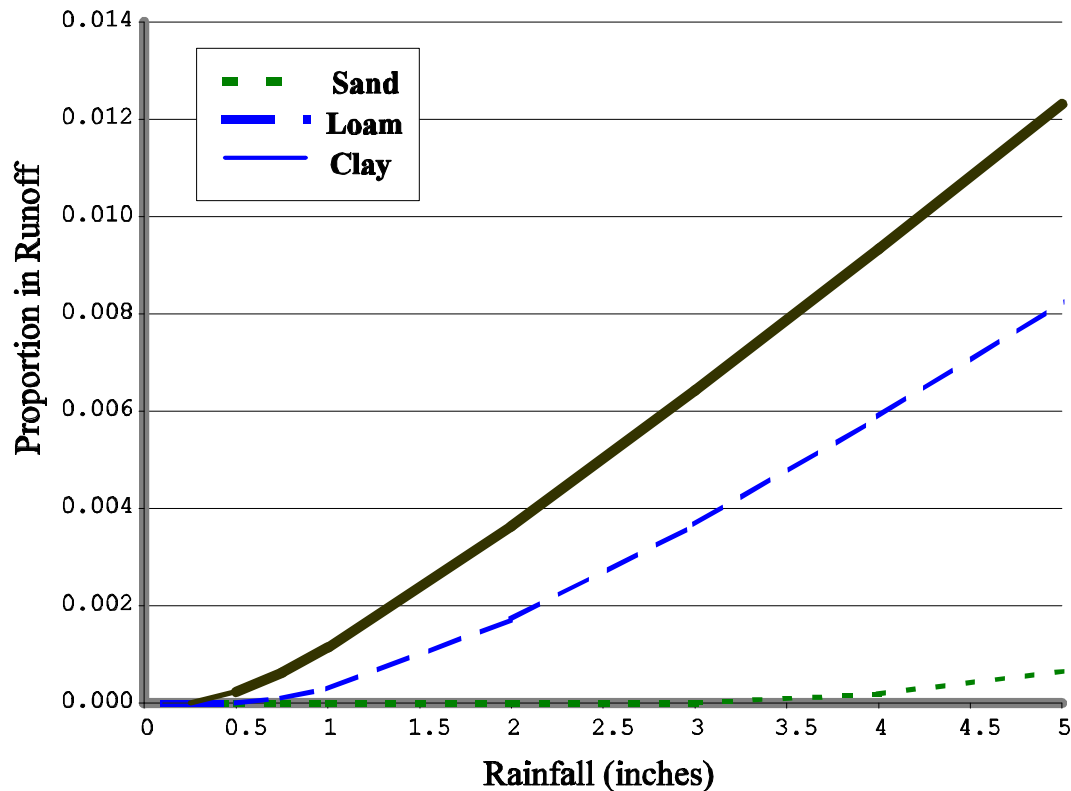


Figure 4-1: Run-off of picloram from clay, loam, and sand as a proportion of the applied amount.

GLEAMS modeling summarized in section 3, the input files for the modeling described in this section are included with the disk copy of this risk assessment.

The results of the GLEAMS modeling are illustrated in Figure 4-1 as the proportion of the applied amount in runoff following varying amounts of rain one day after application. In very sandy and porous soils, percolation into the soil column rather than runoff will predominate even at relatively high rainfall rates. Particularly in areas with a relatively shallow water table, percolation could be associated with the contamination of ambient water. As discussed in the following section, this could in turn impact nontarget vegetation. At the other extreme, clay soils are likely to be associated with the highest levels of runoff but relatively little percolation into the soil column. Loamy soil is likely to be associated with less runoff than clay but more runoff than sand. For any given soil type, the proportion of run-off will be directly related to the amount of rainfall.

While it is plausible that substantial differences will be evident between extremely different soil types such as clay and sand, no substantial differences in soil mobility between sandy loam soil (76.9% sand, 1.7% OM, pH 5.2) and loam soil (24% sand, 5.7% OM, pH 7.2) were noted in a

study by Gallina and Stephenson (1992). Thus, the modeled results may reflect relative and general differences among different types of soils but site-specific factors that could impact soil transport may not be encompassed by the generic model conditions used for this exposure assessment.

For this risk assessment, rainfall rates between 1 and 2 inches will be used to characterize risk. For clay soil, the proportion of runoff is 0.001 to 0.004 of the applied amount. For loam, the proportion of runoff is 0.0003 to 0.002 of the applied amount. For sand, no runoff would be anticipated after rainfalls of 1 to 2 inches. As indicated in Table 4-2, the central estimate for runoff is taken as 0.001 of the applied amount. This is the lower limit for clay following a one inch rainfall and near the upper limit for loam following a two inch rainfall. The range is taken from 0.0003 (loam after a one inch rainfall) to 0.004 (clay after a two inch rainfall).

The potential exposure of off-site vegetation will be highly dependent on the deposition of the picloram in the runoff. Under some conditions, runoff could disperse over a relatively large area and be of no toxicological consequence. In other cases, local topographical conditions might favor the concentration of the runoff from a large treated area into a relatively small off-site area. This type of situational variability cannot be generically modeled. For this risk assessment, it will be assumed that the runoff is dispersed over an area identical to the application site. For example, as illustrated in Figure 4-1, approximately 0.004 of the applied amount is estimated to runoff from clay after a two inch rainfall. Thus, at an application rate of 1 lb/acre, the effective off-site application rate would be 0.004 lb/acre. The consequences and limitations of assuming a uniform distribution is discussed further in the risk characterization.

Another factor that impacts the consequences of runoff involves the occurrence of multiple rainfalls. Figure 4-1 illustrates the runoff associated with one rainfall event on the day after application. Heavy rain on multiple days immediately following application would result in greater amounts of runoff. Conversely, light rainfall would cause the picloram or any other herbicide to percolate into the soil with lesser amounts on the soil surface subject to runoff. Again, this type of situational variability cannot be generically modeled but is discussed further in the risk characterization.

4.2.3.4. Contaminated Irrigation Water – Unintended direct exposures of nontarget plant species may occur through the use of contaminated ambient water for irrigation. As discussed further in section 4.4.2.2, Bovey and Scifres (1971) have discussed the potential effects on irrigation water contaminated with picloram on alfalfa and effects on non-target vegetation have been observed irrigation water contaminated with other herbicides (e.g., Bhandary et al. 1997; Gomez de Barreda et al. 1993).

The levels of exposure associated with this scenario will depend on the concentration of picloram in the ambient water used for irrigation and the amount of irrigation water that is applied. As detailed in section 3.2.3.4, picloram is relatively mobile and contamination of ambient water may be anticipated and can be quantified - i.e. 0.025 (0.01 to 0.06) mg a.e./L at an application rate of 1 lb a.e./acre (worksheet B07).

The amount of irrigation water that may be applied will be highly dependent on the climate, soil type, topography, and plant species under cultivation. Thus, the selection of an irrigation rate is somewhat arbitrary. Typically, plants require 0.1 to 0.3 inch of water per day (Delaware Cooperative Extension Service 1999). In the absence of any general approach of determining and expressing the variability of irrigation rates, the application of one inch of irrigation water will be used in this risk assessment. This is somewhat higher than the maximum daily irrigation rate for sandy soil (0.75 inches/day) and substantially higher than the maximum daily irrigation rate for clay (0.15 inches/day) (Delaware Cooperative Extension Service 1999). This variability is addressed further in the risk characterization (section 4.4.2.2).

Based on the estimated concentrations of picloram in ambient water and an irrigation rate of 1 inch per day, the estimated functional application rate of picloram to the irrigated area is 0.00028 (0.0001-0.002) lb a.e./acre [see worksheet F08 for details of these calculations].

4.2.3.5. Wind Erosion – Wind erosion is a major transport mechanism for soil (e.g., Winegardner 1996). Although no specific incidents of nontarget damage from wind erosion have been encountered in the literature for picloram, this mechanism has been associated with the environmental transport of other herbicides (Buser 1990). Numerous models have been developed for wind erosion (e.g., Streck and Spaan 1997, Streck and Stein 1997) and the quantitative aspects of soil erosion by wind are extremely complex and site specific. Field studies conducted on agricultural sites found that wind erosion may account for annual soil losses ranging from 2 to 6.5 metric tons/ha (Allen and Fryrear 1977). The upper range reported by Allen and Fryrear (1977) is nearly the same as the rate of 2.2 tons/acre (5.4 tons/ha) recently reported by the USDA (1998b). The temporal sequence of soil loss (i.e., the amount lost after a specific storm event involving high winds) depends heavily on soil characteristics as well as meteorological and topographical conditions.

To estimate the potential transport of picloram by wind erosion, this risk assessment uses average soil losses ranging from 1 to 10 tons/ha-year, with a typical value of 5 tons/ha-year. The value of 5 tons/ha-year is equivalent to 500 g/m^2 [1 ton=1000 kg and 1 ha = 10,000 m^2] or 0.05 g/cm^2 [$1 \text{ m}^2=10,000 \text{ cm}^2$]. Using a soil density of 2 g/cm^3 , the depth of soil removed from the surface per year would be $0.025 \text{ cm} [(0.05 \text{ g/cm}^2) \div (2 \text{ g/cm}^3)]$. The average amount per day would be about $0.00007 \text{ cm/day} [0.025 \text{ cm per year} \div 365 \text{ days/year}]$. This central estimate is based on a typical soil loss rate of 5 tons/ha-year. Since the range of plausible rates of annual soil loss is 1 to 10 tons/ha-year, the range of soil loss per day may be calculated as $0.00001 \text{ cm/day} [0.00007 \div 5 = 0.000014]$ to $0.0001 \text{ cm/day} [0.00007 \times 2 = 0.00014]$.

The amount of picloram that might be transported by wind erosion depends on several factors, including the application, the depth of incorporation into the soil, the persistence in the soil, the wind speed, and the topographical and surface conditions of the soil. Under desirable conditions, like relatively deep (10 cm) soil incorporation, low wind speed, and surface conditions that inhibit wind erosion, it is likely that wind transport of picloram would be neither substantial or nor significant. For this risk assessment, it will be assumed that picloram is incorporated into the top

1 cm of soil. Thus, daily soil losses expressed as a proportion of applied amount would be 0.00007 with a range of 0.00001 to 0.001.

As with the deposition of picloram in runoff, the deposition of the picloram contaminated soil from wind erosion will vary substantially with local conditions and, for this risk assessment, neither concentration nor dispersion is considered quantitatively. Nonetheless, these factors together with the general and substantial uncertainties in the exposure assessment are considered in the risk characterization (see section 4.4).

4.2.4. Aquatic Organisms. The potential for effects on aquatic species are based on estimated concentrations of picloram in water that are identical to those used in the human health risk assessment (worksheet B07). As summarized in worksheet B07, the estimated rate of contamination of ambient water associated with the normal application of picloram is 0.025 (0.01 to 0.06) mg a.e./L at an application rate of 1 lb a.e./acre. Thus, at the typical application rate of 0.5 lb a.e./acre, the estimated concentration in ambient water is 0.0124 (0.005 to 0.03) mg/L. For acute exposure scenarios (worksheet D06), the highest estimated concentration of picloram in water after an accidental spill is about 0.8 mg a.e./L with a range of about 0.27 to 27 mg a.e./L.

4.3. DOSE-RESPONSE ASSESSMENT

4.3.1. Overview. For terrestrial mammals, the dose-response assessment is based on the same data used to derive the RfD in the human health risk assessment: a NOAEL of 20 mg/kg/day from a 2-year rat feeding study. The data on other terrestrial animals, both birds and invertebrates, is not as detailed as the available information on experimental mammals. Fewer toxicologic endpoints have been examined and no lifetime studies are available. Within this limitation, the available information does not suggest that birds or terrestrial invertebrates are likely to be more sensitive to picloram than experimental mammals.

The most sensitive nontarget plant species appears to be soybeans, with an EC₂₅ for seed emergence 0.000014 kg a.e./ha or about 0.000012 lb a.e./acre. Exposures that are likely to cause effects in tolerant plant species is taken as 0.04 lb a.e./acre, the approximate level associated with an inhibition of seed emergence in wheat - i.e., an EC₂₅ of 0.0388 kg a.e./ha with a NOEL of 0.0175 kg a.e./ha. While it is apparent that broadleaf plants are more sensitive to picloram than grains or grasses, all plant species on which data are available are likely to be affected by picloram at application rates used in the field - i.e. 0.3 to 1.5 lb a.e./acre.

Bioassays on the toxicity of picloram to aquatic animals is limited to studies on trout and *Daphnia magna*. Based on these studies, fish appear to be somewhat more sensitive to picloram than aquatic invertebrates in both acute and chronic studies. The lowest reported no-effect level for fish is 0.55 mg/L. Concentrations of 0.88 mg/L were associated with decreased growth of trout fry. Concentrations of picloram in water causing fifty percent mortality in some species of trout has been estimated at about 5 mg/L. Comparable estimates in *Daphnia* are about 70 mg/L. Standard bioassays of aquatic plant species submitted to support the registration of picloram have yielded EC₅₀ values for growth inhibition in the range of 20 mg/L to over 50 mg/L. Based on these studies, aquatic plants would appear to be less sensitive to picloram than fish. Some more

recent and non-standard field studies, however, have noted inhibition of flowering in aquatic macrophytes at concentrations as low as 0.1 mg/L.

4.3.2. Toxicity to Terrestrial Organisms.

4.3.2.1. Mammals – As summarized in the dose-response assessment for the human health risk assessment (section 3.3.3), the Office of Pesticide Programs of the U.S. EPA has derived an RfD of 0.2 mg/kg/day for picloram based on a two-year rat feeding study in which the NOEL was 20 mg/kg/day. The upper range of the estimated chronic exposures involving a small mammal (Table 4-1) are below the NOEL of 20 mg/kg/day by a factor of at least two. In addition, the central estimates of acute and chronic exposures are below the chronic NOEL of 20 mg/kg/day. Consequently, there is relatively little need to elaborate on the dose response assessment. The highest acute exposure does exceed the NOEL of 20 mg/kg/day by a factor of about two - i.e., about 40 mg/kg/day. As discussed in Section 3.1.3, however, a dose of 60 mg/kg/day, while classified as a LOAEL by the U.S. EPA, lead to effects that are not clearly of toxicologic concern - i.e., a change in the staining properties of liver hepatocytes.

4.3.2.2. Birds – As noted in section 4.1.2.2, the acute and subchronic dietary toxicity studies in birds are not substantially different from the studies in mammals and there are no chronic toxicity studies in birds that would support the development of a separate RfD for avian species. Consequently, a separate criteria for bird is not developed in this risk assessment - i.e., the chronic of NOEL of 20 mg/kg/day is used to characterize potential risk.

4.3.2.3. Terrestrial Invertebrates – As discussed in section 4.1.2.3, there is little information on the toxicity of picloram to terrestrial invertebrates compared to the more extensive studies available in mammals. The estimated LD₅₀ value of greater than 1,000 mg/kg is consistent with the available LD₅₀ values on mammals and birds. Similarly, the 14-day dietary NOEL of 5000 mg/kg for the snail is similar to dietary NOAELs in rodents and birds. Thus, although the information is limited compared to the very large number of potential nontarget terrestrial invertebrates, there is no basis for developing a separate dose/response assessment for this group.

4.3.2.4. Terrestrial Plants (Macrophytes) – As discussed in section 4.1.2.4, picloram is more toxic to broadleaf plants than to grasses or grains. For assessing the potential consequences of exposures to nontarget broadleaf plants, the EC₂₅ for seed emergence in soybeans of 0.000014 kg a.e./ha is used. At the other extreme, the NOEL of 0.07 kg/ha for post-emergent application in wheat and seed germination in barley is used to characterize the upper range of exposures that might be associated with no apparent adverse effects in nontarget plant species that are relatively insensitive to picloram. Exposures that are likely to cause effects in such tolerant plant species, however, is taken as 0.04 lb a.e./acre, the approximate level associated with an inhibition of seed emergence in wheat - i.e., an EC₂₅ of 0.0388 kg a.e./ha with a NOEL of 0.0175 kg a.e./ha. Higher application rates of 227.7 g a.e./acre, or about 0.2 lb a.e./acre, are associated with decreased growth (EC₂₅) in post-emergent applications to wheat (U.S. EPA 1995a, p. 54).

As also indicated in section 4.1.2.4, some plant species may develop resistance to picloram. While this may impact an assessment of the efficacy of picloram in some types of applications, the

potential for resistance to picloram in nontarget plant species has not been documented and is not used to modify the risk characterization (section 4.4.2.2).

4.3.2.5. Terrestrial Microorganisms – Relatively little quantitative information is available of the toxicity of picloram to terrestrial microorganisms (Section 4.1.2.5.). The lowest reported effect level is 10 ppm, associated with a transient decrease in nitrification (Tu 1994). In bacteria or fungal cultures, EC₅₀s for growth inhibition were in the range of 50-400 ppm for picloram or 4A-TCP (Baarschers et al. 1988).

4.3.3. Aquatic Organisms.

4.3.3.1. Animals – Fish appear to be somewhat more sensitive to picloram than aquatic invertebrates in both acute and chronic studies. The acute toxicity of picloram has been assayed in several species of trout with 96-hour LC₅₀ values in the range of 4.8 mg/L to 19.3 mg/L (Mayes et al. 1987). Only one bioassay has been encountered for the aquatic invertebrate, *Daphnia magna*, in which a 48-hour LC₅₀ of 68.3 (63-75) mg/L was reported (Gersich et al. 1985). Similarly, developmental (egg and fry) studies in trout yielded a NOEL of 0.55 mg/L with a corresponding effect level (decreased growth) of 0.88 mg/L. The standard assay for reproductive capacity in *Daphnia* yielded a NOEL of 11.8 mg/L, about a factor of 20 higher than the NOEL in trout.

4.3.3.2. Aquatic Plants – Typically, aquatic plants are more sensitive to herbicides than fish or aquatic invertebrates. For picloram, however, aquatic plants appear to be less sensitive than aquatic animals. EC₅₀ values for growth inhibition in aquatic plants are in the range of 20 mg/L to over 50 mg/L (section 4.1.3.4), all of which are less than the acute LC₅₀ values in trout, 4.8 to 19.3 mg/L. The most sensitive effect reported in aquatic plants is the inhibition of flowering in *Potamogeton pectinatus* and *Myriophyllum sibiricum* at a concentration of 0.1 mg a.i./L (Forsyth et al. 1997). As indicated in the previous section, this is not that far below the reproductive NOEL of 0.55 mg/L in trout.

4.4. RISK CHARACTERIZATION

4.4.1. Overview. Picloram is a herbicide and the most likely damage to nontarget species will involve terrestrial plants. As is the case with any herbicide, the likelihood of damage to nontarget plant species is related directly to the difference between the sensitivity of target species—which dictates the application rate—and the sensitivity of the potential nontarget species. Although picloram is more toxic to broadleaf plants than grains or grasses, direct spray at application rates between 0.3 and 1.5 lb a.e./acre are likely to damage all groups of terrestrial plants although the most severe damage would probably be apparent in broadleaf plants. With picloram, both broadleaf and non-broadleaf plants could be adversely affected by off-site drift over a relatively narrow band - i.e., about 100 feet. Some sensitive broadleaf species could be affected by off-site drift at a much greater distances.

The scenarios for the exposure of terrestrial plants from runoff, wind erosion, and irrigation water are dominated by situational variability. This variability, nonetheless, has only a minor impact the characterization of risk to relatively tolerant plant species. Except for the upper

limit associated with spray drift, there is little basis for asserting that substantial or detectable evidence of damage would be noted in tolerant plant species. The situational variability in the exposure assessments for runoff, wind erosion, and irrigation water does have a substantial impact on the characterization of risk for sensitive nontarget plant species. All of these scenarios may overestimate or underestimate risk under certain conditions. Nonetheless, it is apparent that sensitive plant species could be adversely affected by the off-site transport of picloram under a variety of different scenarios depending on local site-specific conditions that cannot be generically modeled. More tolerant plant species are not likely to be affected unless they are directly sprayed or subject to substantial drift.

The potential for adverse effects on other terrestrial nontarget animal species appears to be remote. The weight of evidence suggests that no adverse effects in terrestrial animals are plausible using typical or even very conservative worst case exposure assumptions.

Information on aquatic animals and plants are limited. Picloram appear to be more toxic to trout than to an aquatic invertebrate, *Daphnia magna*, a commonly used test species in toxicity studies. Based on a standard set of assumptions used in constructing accidental spill scenarios, some fish mortality would be expected and could be substantial if picloram were spilled into a relatively small body of water with a low water turnover rate. This characterization of risk, however, is dominated by arbitrary or situational uncertainty.

Longer term water concentrations associated with the normal application of picloram at an application rate of 1 lb a.e./acre are likely to be in the range of 0.01 to 0.06 mg/L in areas with substantial rainfall or as the result of applications in which some initial incidental contamination of water occurs. All of these concentrations are substantially below concentrations that have been shown to impact aquatic plants or animal. At the highest plausible application rate, the upper estimate of the range of longer-term water concentrations would be very close to the concentration of 0.1 mg/L that causes inhibition of flowering in two aquatic plant species. Even at the highest estimated concentrations, however, no effects would be anticipated in aquatic animals and substantial mortality would not be anticipated in aquatic plants.

The risk characterization for both terrestrial and aquatic species is limited by the relatively few animal and plant species on which data are available compared to the large number of species that could potentially be exposed. This limitation and consequent uncertainty is common to most if not all ecological risk assessments.

4.4.2. Terrestrial Organisms.

4.4.2.1. Terrestrial Animals – The quantitative risk characterization for terrestrial animals is summarized in Table 4-3. Except for the direct spray scenario for the bee, all of the quantitative risk characterizations apply to a 20 g mammal. In Table 4-3, the hazard quotient for each scenario, except that for the honey bee, is calculated as the exposure estimate presented in Table 4-1 divided by the chronic NOEL for rats of 20 mg/kg/day, discussed in section 4.3.2.1. In some respects, this approach may be regarded as extremely conservative, particularly in the application

of the chronic NOEL to acute exposure scenarios. For the honey bee, the hazard quotient is based on the non-lethal acute dose level of 1000 mg/kg (U.S. EPA 1995a).

As specified in Table 4-3, both the central estimates as well as the upper range of the hazard quotients associated with the longer-term exposure scenarios are below unity, indicating that toxic effects are not likely to occur. The upper limit for the exposure scenario for the chronic consumption of contaminated vegetation approaches a level of concern - i.e., the hazard quotient is 0.5. This hazard quotient is based on a 20 mg/kg/day NOEL and the effect noted at the next highest dose level, 60 mg/kg/day, involved only a change in the staining characteristics of liver cells. As discussed by the U.S. EPA (1994), the toxicologic significance of this change is unclear. Thus, the hazard quotient of 0.5 - while close to unity - is not a substantial cause for concern.

For acute exposures of small mammals, none of the central values for the hazard quotient reaches a level of concern. With regard to the upper limit of the estimated hazard quotients, the direct spray with 100% absorption and the consumption of contaminated vegetation, both of which are acute exposure scenarios, reach or slightly exceed a level of concern based on the chronic NOEL. As indicated in Table 4-1, these hazard quotients are associated with dose levels of about 30 mg/kg to 40 mg/kg. These doses are a factor of 2 to 3 below the chronic LOAEL of 60 mg/kg/day and a factor of 50 to over 150 below the acute oral LD₅₀ - i.e., 3000 mg/kg to 5000 mg/kg (section 4.1.2.1).

The simple verbal interpretation of this quantitative risk characterization is similar to that of the human health risk assessment: the weight of evidence suggests that no adverse effects in mammals are plausible using typical or even very conservative worst case exposure assumptions.

As with most ecological risk assessments, this characterization of risk must be qualified. Picloram has been tested in only a limited number of species and under conditions that may not well-

Table 4-3: Summary of quantitative risk characterization for terrestrial animals¹

Scenario	Hazard Quotient ²		
	Typical	Lower	Upper
Acute/Accidental Exposures			
Direct spray, small mammal, first-order absorption	0.04	0.01	0.2
Direct spray, small animal, 100% absorption	0.6	0.4	2
Direct spray, bee, 100% absorption ³	0.1	0.05	0.2
Consumption of contaminated vegetation, acute exposure	0.1	0.08	1
Consumption of contaminated water, acute exposure	0.01	0.003	0.3
Longer Term Exposures			
Consumption of contaminated vegetation, chronic exposure	0.05	0.03	0.5
Consumption of contaminated water, chronic exposure	0.0002	0.00004	0.001
	Toxicity value for mammal ²	20	mg/kg/day
	Toxicity value for bee ³	1000	mg/kg

represent populations of free-ranging nontarget animals. Notwithstanding this limitation, the available data are sufficient to assert that adverse effects in terrestrial animals from the use of this compound in Forest Service programs do not appear to be likely.

4.4.2.2. Terrestrial Plants – A quantitative summary of the risk characterization for terrestrial plants is presented in Table 4-4. Analogous to the approach taken in Table 4-3 for the small terrestrial mammal, risk in Table 4-4 is characterized as a ratio of the exposure to benchmark exposures - i.e., exposures associated with a fixed response. Unlike the case with the small mammal, however, the benchmarks used in Table 4-4 are EC₂₅ values for both sensitive and tolerant plant species rather than NOEL's. This approach is taken because, as noted by U.S. EPA (1995a), a NOEL for the most sensitive plant species has not been determined. The exposures

Table 4-4: Quantitative summary of risk characterization for effects in nontarget terrestrial vegetation.

Scenario	Typical	Lower	Upper
Sensitive Species [Exposure÷Benchmark]¹			
Direct Spray	50000	30000	150000
Drift	100	6	4500
Runoff	50	9	600
Wind erosion	28	10	200
Irrigation water	3	0.3	15
Tolerant Species [Exposure÷Benchmark]¹			
Direct Spray	17	10	50
Drift	0.03	0.002	2
Runoff	0.02	0.003	0.2
Wind erosion	0.009	0.003	0.1
Irrigation water	0.001	0.0001	0.005
Benchmark doses			
Sensitive species	0.00001	lb/acre	EC ₂₅ for seed emergence in soybeans
Tolerant species	0.03	lb/acre	EC ₂₅ for seed emergence in wheat

¹ See Table 4-4 for the exposure values on which the ratios are based.

used to generate the ratios summarized in Table 4-4 are taken directly from the corresponding values in Table 4-2.

Picloram is an effective herbicide, at least for a number of different broadleaf weeds and adverse effects on some nontarget plant species are likely under certain application conditions and circumstances. As is the case with any herbicide, the likelihood of damage to nontarget plant species is related directly to the difference between the sensitivity of target species—which dictates the application rate—and the sensitivity of the potential nontarget species. Although picloram is less toxic to grains and grasses than broadleaves, the range of application rates that might be used in Forest Service programs are likely to adversely impact even relatively tolerant

nontarget plant species. More sensitive broadleaf nontarget plant species will be more severely affected if they are accidentally sprayed.

For the other exposure scenarios summarized in Table 4-4, sensitive plant species are much more likely to be impacted than tolerant plant species. As detailed in section 4.2.3, all of these exposure scenarios are dominated by arbitrary or situational variability. For example, the central estimate of drift is based on a distance 500 feet down wind of the application site and the range of exposures is based on distances of 100 to 2,500 feet. The selection of these distances is relatively arbitrary. Nonetheless, it is apparent from the ratios in Table 4-4 that sensitive plant species could be affected by drift over a very wide range but resistant plant species would be impacted over a much narrower range. Based on estimates using Stoke's Law (see section 4.2.2.2), it is plausible that droplets ranging in size from 100 μ to 400 μ might drift about 3-23 feet at a wind speed of 5 miles per hour and 9-69 feet at a wind speed of 15 miles per hour. Although this drift might cause damage to some sensitive species, the impact would be limited and damage to nontarget species probably could be minimized or avoided during the application process.

The scenarios for runoff, wind erosion, and irrigation water are dominated by situational variability. This variability, nonetheless, has only a minor impact the characterization of risk to relatively tolerant plant species. Except for the upper limit associated with spray drift, there is little basis for asserting that substantial or detectable evidence of damage would be noted in tolerant plant species. In addition, the risk characterization for spray drift is inherently conservative in that the drift estimates from Bird (1995) are based on aerial application. Well-directed ground applications conducted under conditions that do not favor off-site drift will probably have no impact on off-site plant species that are relatively tolerant to picloram.

The situational variability in the exposure assessments for runoff, wind erosion, and irrigation water does have a substantial impact on the characterization of risk for sensitive nontarget plant species. All of these scenarios may overestimate or underestimate risk under certain conditions. For example, the exposure conditions involving runoff and contaminated irrigation water are plausible for applications in which relatively substantial rainfall occurs shortly after application and in which local topographic and/or hydrological conditions favor either runoff or percolation.

In this risk assessment, ambient water concentrations are estimated at 0.025 (0.01 to 0.06) mg a.e./L and effects of contaminated irrigation water in sensitive plant species are plausible (Table 4-4). This is consistent with an early assessment by Bovey and Scifres (1971) suggesting that concentrations of picloram in water in the range of 0.001 to 0.004 mg/L are not likely to be associated with adverse effects but that multiple watering at concentrations of 0.004 mg/L could reduce growth and 0.01 mg/L could severely impact growth.

Wind erosion of soil contaminated with picloram is most plausible in relatively arid environments and if local soil surface and topographic conditions favor wind erosion. On the

other hand, none of these exposure scenarios are extreme. Specifically, the runoff and wind erosion scenarios are based on only a single day - i.e. 1 to 2 inch rainfalls or substantial wind erosion over the course of one day after application. In some cases, more extreme events could occur over more than one day that would increase off-site exposures.

The simple verbal interpretation for this quantitative risk characterization is that sensitive plant species could be adversely affected by the off-site transport of picloram under a variety of different scenarios depending on local site-specific conditions that cannot be generically modeled. If picloram is applied in the proximity of sensitive crops or other desirable sensitive plant species, site-specific conditions and anticipated weather patterns will need to be considered if unintended damage is to be avoided. More tolerant plant species are not likely to be affected unless they are directly sprayed or subject to substantial drift.

4.4.3. Aquatic Organisms. As discussed in section 4.3.3.1, fish appear to be more sensitive to picloram than aquatic invertebrates as well as several species of aquatic plants. Acute 96-hour LC₅₀ values for picloram to trout, which range from 4.8 to about 20 mg/L, are in the range of concentrations that are anticipated after an accidental spill, 0.27 to 27 mg/L. The lower end of this range of water concentrations would not be expected to result in any mortality to fish. Using an aquatic dissipation rate of 0.046 day⁻¹, as detailed in section 3.2.3.4.2., the upper end of the concentration range, 27 mg/L, would remain at or above the lower range of the fish LC₅₀ values for about 90 days:

$$-\ln(4.8/27)/0.046 \text{ days}^{-1} = 87.6 \text{ days.}$$

This characterization of risk for the accidental spill scenario has a very high level of arbitrary or situational uncertainty. In cases of severe spills in areas with low or moderate water turnover rates, such as small pond, fish mortality in sensitive fish species would be expected and could be substantial. Based on the available acute toxicity data, effects on aquatic invertebrates and aquatic plants would likely be less severe.

Longer-term water concentrations associated with the normal application of picloram at an application rate of 1 lb a.e./acre are likely to be in the range of 0.01 to 0.06 mg/L in areas with substantial rainfall or as the result of applications in which some initial incidental contamination of water occurs (section 3.2.3.4). All of these concentrations are substantially below concentrations that have been shown to impact aquatic plants or animals. At the highest plausible application rate, the upper estimate of the range of longer-term water concentrations would be about 0.09 mg/L (0.06 mg/L per 1 lb a.e./acre × 1.5 lb a.e./acre). This is very close to the concentration of 0.1 mg/L that caused an inhibition of flowering in two aquatic plant species (Forsyth et al. 1997).

As with the risk characterization for terrestrial species, this risk characterization is limited by the relatively few animal and plant species on which data are available compared to the large number of species that could potentially be exposed. This limitation and consequent uncertainty is common to most if not all ecological risk assessments.

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6. GLOSSARY

Absorption -- The process by which the agent is able to pass through the body membranes and enter the bloodstream. The main routes by which toxic agents are absorbed are the gastrointestinal tract, lungs, and skin.

Acute exposure -- A single exposure or multiple exposure occurring within a short time (24 hours or less).

Additive effect -- A situation in which the combined effects of two chemicals is equal to the sum of the effect of each chemical given alone. The effect most commonly observed when two chemicals are given together is an additive effect.

Adjuvant(s) -- Formulation factors used to enhance the pharmacological or toxic agent effect of the active ingredient.

Adsorption -- The tendency of one chemical to adhere to another material.

Adverse-effect level (AEL) -- Signs of toxicity that must be detected by invasive methods, external monitoring devices, or prolonged systematic observations. Symptoms that are not accompanied by grossly observable signs of toxicity. In contrast to Frank-effect level.

Alkaline phosphatase -- An enzyme that occurs in various normal and malignant tissues. The activity of the enzyme in blood is useful in diagnosing many illnesses.

Allelopathy -- translocation of a herbicide to the roots of plants and subsequent loss from the roots to the surrounding soil, possibly posing a risk to neighboring vegetation.

Allometric -- pertaining to allometry, the study and measure of growth. In toxicology, the study of the relationship of body size to various physiological, pharmacological, pharmacokinetic, or toxicodynamic processes among species.

Amphibian -- A cold-blooded vertebrate capable of operating on land and in water.

Arid -- A terrestrial region lacking moisture, or a climate in which the rainfall is not sufficient to support the growth of trees or woody plants.

Assay -- A kind of test (noun); to test (verb).

Bioconcentration factor (BCF) -- The concentration of a compound in an aquatic organism divided by the concentration in the ambient water of the organism.

Biologically sensitive -- A term used to identify a group of individuals who, because of their developmental stage or some other biological condition, are more susceptible than the general population to a chemical or biological agent in the environment.

Broadleaf weed -- A nonwoody dicotyledonous plant with wide bladed leaves designated as a pest species in gardens, farms, or forests.

Cancer potency parameter -- A model-dependent measure of cancer potency (mg/kg/day)⁻¹ over lifetime exposure. [Often expressed as a q_1^* which is the upper 95% confidence limit of the first dose coefficient (q_1) from the multistage model.]

Carcinogen -- A chemical capable of inducing cancer.

Carcinoma -- A malignant tumor.

Carrier -- In commercial formulations of insecticides or control agents, a substance added to the formulation to make it easier to handle or apply.

Chlorosis -- yellowing or blanching of the leaves of plants. Restricted to causes other than light deficiency.

Chronic exposure -- Long-term exposure studies often used to determine the carcinogenic potential of chemicals. These studies are usually performed in rats, mice, or dogs and extend over the average lifetime of the species (for a rat, exposure is 2 years).

Conifer -- An order of the Gymnospermae, comprising a wide range of trees, mostly evergreens that bear cones and have needle-shaped or scalelike leaves; timber commercially identified as softwood.

Connected actions -- Exposure to other chemical and biological agents in addition to exposure to the control agent during program activities to control vegetation.

Contaminants -- For chemicals, impurities present in a commercial grade chemical. For biological agents, other agents that may be present in a commercial product.

Controls -- In toxicology or epidemiology studies, a population that is not exposed to the potentially toxic agent under study.

Creatine -- An organic acid composed of nitrogen. It supplies the energy required for muscle contraction.

Creatinine -- The end product of the metabolism of creatine. It is found in muscle and blood and is excreted in the urine.

Cumulative exposures -- Exposures that may last for several days to several months or exposures resulting from program activities that are repeated more than once during a year or for several consecutive years.

Dams -- A term used to designate females of some species such as rats.

Degraded -- Broken down or destroyed.

Dermal -- Pertaining to the skin.

Dislodgeable residues – The residue of a chemical or biological agent on foliage as a result of aerial or ground spray applications, which can be removed readily from the foliage by washing, rubbing or having some other form of direct contact with the treated vegetation.

Dose-response assessment -- A description of the relationship between the dose of a chemical and the incidence of occurrence or intensity of an effect. In general, this relationship is plotted by statistical methods. Separate plots are made for experimental data obtained on different species or strains within a species.

Drift -- That portion of a sprayed chemical that is moved by wind off a target site.

EC₅₀ -- A concentration that causes 50% inhibition or reduction. As used in this document, this values refers to a 50% inhibition of growth.

EC₁₀₀ -- A concentration that causes complete inhibition or reduction. As used in this document, this values refers to a complete inhibition of growth.

Electrochemical process -- A newer manufacturing process for clopyralid. Details of the method are proprietary.

Empirical -- Refers to an observed, but not necessarily fully understood, relationship in contrast to a hypothesized or theoretical relationship.

Enzymes -- A biological catalyst; a protein, produced by an organism itself, that enables the splitting (as in digestion) or fusion of other chemicals.

Epidemiology study -- A study of a human population or human populations. In toxicology, a study which examines the relationship of exposures to one or more potentially toxic agent to adverse health effects in human populations.

Exposure assessment -- The process of estimating the extent to which a population will come into contact with a chemical or biological agent.

Extrapolation -- The use of a model to make estimates outside of the observable range.

Fetal anomaly – An abnormal condition in a fetus, which is usually the result of a congenital defect.

Formulation -- A commercial preparation of a chemical including any inerts or contaminants.

Frank effects -- Obvious signs of toxicity.

Frank-effect level (FEL) -- The dose or concentration of a chemical or biological agent that causes gross and immediately observable signs of toxicity.

Gavage -- The placement of a toxic agent directly into the stomach of an animal, using a gastric tube.

Genotoxic -- Causing direct damage to genetic material. Associated with carcinogenicity.

Geometric mean -- The measure of an average value often applied to numbers for which a log normal distribution is assumed.

Gestation -- The period between conception and birth; in humans, the period known as pregnancy.

Half-time or half-life -- For compounds that are eliminated by first-order kinetics, the time required for the concentration of the chemical to decrease by one-half.

Hazard quotient (HQ) -- The ratio of the estimated level of exposure to the RfD or some other index of acceptable exposure.

Hazard identification -- The process of identifying the array of potential effects that an agent may induce in an exposed human population.

Hematological -- Pertaining to the blood.

Hematology -- One or more measurements regarding the state or quality of the blood.

Henry's law constant -- An index of the tendency of a compound to volatilize from aqueous solutions.

Herbaceous -- A plant that does not develop persistent woody tissue above the ground (annual, biennial, or perennial, but whose aerial portion naturally dies back to the ground at the end of a growing season. They include such categories as grasses and grass-like vegetation.

Herbicide -- A chemical used to control, suppress, or kill plants, or to severely interrupt their normal growth processes.

Histopathology -- Signs of tissue damage that can be observed only by microscopic examination.

Hydrolysis -- Decomposition or alteration of a chemical substance by water.

Hydroxylation -- The addition of a hydrogen-oxygen or hydroxy (-OH) group to one of the rings. Hydroxylation increases the water solubility of aromatic compounds. Particularly when followed by conjugation with other water soluble compounds in the body, such as sugars or amino acids, hydroxylation greatly facilitates the elimination of the compound in the urine or bile.

Hymolytic anemia -- A medical condition in which the number of red blood cells is decreased due to intravascular fragmentation or destruction.

***In vivo* -- Occurring in the living organism.**

In vitro -- Isolated from the living organism and artificially maintained, as in a test tube.

Inerts -- Adjuvants or additives in commercial formulations of glyphosate that are not readily active with the other components of the mixture.

Interpolation -- The use of mathematical models within the range of observations

Intraperitoneal -- Injection into the abdominal cavity.

Invertebrate -- An animal that does not have a spine (backbone).

Irritant effect -- A reversible effect, compared with a corrosive effect.

LC₅₀ (lethal concentration₅₀) -- A calculated concentration of a chemical in air to which exposure for a specific length of time is expected to cause death in 50% of a defined experimental animal population.

LD₅₀ (lethal dose₅₀) -- The dose of a chemical calculated to cause death in 50% of a defined experimental animal population over a specified observation period. The observation period is typically 14 days.

Lowest-observed-adverse-effect level (LOAEL) -- The lowest dose of a chemical in a study, or group of studies, that produces statistically or biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control.

Lymphatic -- Pertaining to lymph, a lymph vessel, or a lymph node.

Lymph -- A clear water fluid containing white blood cells. Lymph circulates throughout the lymphatic system, removing bacteria and certain proteins from body tissue. It also is responsible for transporting fat from the small intestine and supplying mature lymphocytes to the blood.

Macrophyte -- Terrestrial plant

Malignant -- Cancerous.

Margin of safety (MOS) -- The ratio between an effect or no effect level in an animal and the estimated human dose.

Metabolite -- A compound formed as a result of the metabolism or biochemical change of another compound.

Metameter -- Literally, the unit of measure. Used in dose-response or exposure assessments to describe the most relevant way of expressing dose or exposure.

Microorganisms -- A generic term for all organisms consisting only of a single cell, such as bacteria, viruses, and fungi.

Microsomal -- Pertaining to portions of cell preparations commonly associated with the oxidative metabolism of chemicals.

Minimal risk level (MRL) -- A route-specific (oral or inhalation) and duration- specific estimate of an exposure level that is not likely to be associated with adverse effects in the general population, including sensitive subgroups.

Mitochondria -- Subcellular organelles involved in the conversion of food to stored chemical energy.

Most sensitive effect -- The adverse effect observed at the lowest dose level, given the available data. This is an important concept in risk assessment because, by definition, if the most sensitive effect is prevented, no other effects will develop. Thus, RfDs and other similar values are normally based on doses at which the most sensitive effect is not likely to develop.

Multiple chemical sensitivity -- A syndrome that affects individuals who are extremely sensitive to chemicals at extremely low levels of exposure.

Mutagenicity -- The ability to cause genetic damage (that is damage to DNA or RNA). A mutagen is substance that causes mutations. A mutation is change in the genetic material in a body cell. Mutations can lead to birth defects, miscarriages, or cancer.

Non-target -- Any plant or animal that a treatment inadvertently or unavoidably harms.

No-observed-adverse-effect level (NOAEL) -- The dose of a chemical at which no statistically or biologically significant increases in frequency or severity of adverse effects were observed between the exposed population and its appropriate control. Effects may be produced at this dose, but they are not considered to be adverse.

No-observed-effect level (NOEL) -- The dose of a chemical at no treatment-related effects were observed.

Normal distribution -- One of several standard patterns used in statistics to describe the way in which variability occurs in a populations.

Octanol-water partition coefficient (K_{ow}) -- The equilibrium ratio of the concentrations of a chemical in n-octanol and water, in dilute solution.

Ocular -- Pertaining to the eye.

Parenteral -- Any form of injection.

Partition -- In chemistry, the process by which a compound or mixture moves between two or more media.

Pathogen -- A living organism that causes disease; for example, a fungus or bacteria.

Pathway -- In metabolism, a sequence of metabolic reactions.

Penta process -- The original manufacturing process for clopyralid. Details of the method are proprietary.

Perennial -- A plant species having a life span of more than 2 years.

Permeability -- The property or condition of being permeable. In this risk assessment, dermal permeability refers to the degree to which a chemical or herbicide in contact with the skin is able to penetrate the skin.

pH -- The negative log of the hydrogen ion concentration. A high pH (> 7) is alkaline or basic and a low pH (< 7) is acidic.

pK_a -- The negative log of the hydrogen ion concentration or pH at which 50% of a weak acid is dissociated.

Pharmacokinetics -- The quantitative study of metabolism (i.e., the processes of absorption, distribution, biotransformation, elimination).

Prospective -- looking ahead. In epidemiology, referring to a study in which the populations for study are identified prior to exposure to a presumptive toxic agent, in contrast to a retrospective study.

Pup -- The offspring or young of various animal species.

Release -- A work done to free desirable trees from competition with overstory trees, less desirable trees or grasses, and other forms of vegetative growth.

Reference dose (RfD) -- Oral dose (mg/kg/day) not likely to be associated with adverse effects over lifetime exposure, in the general population, including sensitive subgroups.

Relative weight -- The weight of an organ, such as the liver or kidney, divided by the total body weight of the animal.

Reproductive effects -- Adverse effects on the reproductive system that may result from exposure to a chemical or biological agent. The toxicity of the agents may be directed to the reproductive organs or the related endocrine system. The manifestations of these effects may be noted as alterations in sexual behavior, fertility, pregnancy outcomes, or modifications in other functions dependent on the integrity of this system.

Resorption -- Removal by absorption. Often used in describing the unsuccessful development and subsequent removal of post-implantation embryos.

Retrospective -- looking behind. In epidemiology, referring to a study in which the populations for study are identified after exposure to a presumptive toxic agent, in contrast to a prospective study.

RfD -- A daily dose which is not anticipated to cause any adverse effects in a human population over a lifetime of exposure. These values are derived by the U.S. EPA.

Right-of-way -- A corridor of low growing shrubs or grasses that facilitate the maintenance and protection of utility power lines and provide transport pathways for humans or wildlife.

Route of exposure -- The way in which a chemical or biological agent enters the body. Most typical routes include oral (eating or drinking), dermal (contact of the agent with the skin), and inhalation.

Scientific notation -- The method of expressing quantities as the product of number between 1 and 10 multiplied by 10 raised to some power. For example, in scientific notation, 1 kg = 1,000 g would be expressed as $1 \text{ kg} = 1 \times 10^3 \text{ g}$ and 1 mg = 0.001 would be expressed as $1 \text{ mg} = 1 \times 10^{-3}$.

Sensitive subgroup -- Subpopulations that are much more sensitive than the general public to certain agents in the environment.

Sensitization -- A condition in which one is or becomes hypersensitive or reactive to an agent through repeated exposure.

Site preparation -- The removal of competition and conditioning of the soil to enhance the survival and growth of seedlings or to enhance the seed germination.

Species-to-species extrapolation -- A method involving the use of exposure data on one species (usually an experimental mammal) to estimate the effects of exposure in another species (usually humans).

Subchronic exposure -- An exposure duration that can last for different periods of time, but 90 days is the most common test duration. The subchronic study is usually performed in two species (rat and dog) by the route of intended use or exposure.

Substrate -- With reference to enzymes, the chemical that the enzyme acts upon.

Synergistic effect -- A situation in which the combined effects of two chemicals is much greater than the sum of the effect of each agent given alone.

Systemic toxicity -- Effects that require absorption and distribution of a toxic agent to a site distant from its entry point at which point effects are produced. Systemic effects are the obverse of local effects.

Teratogenic -- Causing structural defects that affect the development of an organism; causing birth defects.

Teratology -- The study of malformations induced during development from conception to birth.

Terrestrial -- Anything that lives on land as opposed to living in an aquatic environment.

Threshold -- The maximum dose or concentration level of a chemical or biological agent that will not cause an effect in the organism.

Thymus -- A small gland that is the site of T-cell production. The gland is composed largely of lymphatic tissue and is situated behind the breastbone. The gland play an important role in the human immune system.

Toxicity -- The inherent ability of an agent to affect living organisms adversely.

Uncertainty factor (UF) -- A factor used in operationally deriving the RfD and similar values from experimental data. UFs are intended to account or (1) the variation in sensitivity among members of the human population; (2) the uncertainty in extrapolating animal data to the case of humans; (3) the uncertainty in extrapolating from data obtained in a study that is less than lifetime exposure; and (4) the uncertainty in using LOAEL data rather than NOAEL data. Usually each of these factors is set equal to 10. See table 2-4 for additional details.

Vehicle -- A substance (usually a liquid) used as a medium for suspending or dissolving the active ingredient. Commonly used vehicles include water, acetone, and corn oil.

Vertebrate -- An animal that has a spinal column (backbone).

Volatile -- Referring to compounds or substances that have a tendency to vaporize. A material that will evaporate quickly.

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Appendix 1: GLEAMS modeling of Hexachlorobenzene

In terms of estimating runoff, the key chemical-specific parameters for hexachlorobenzene are water solubility, K_{oc} , and soil half-time. The water solubility of hexachlorobenzene is 0.006 mg/L and reported K_{oc} values range from about 4,000 to 1,200,000 (ATSDR 1998). For the GLEAMS modeling, the K_{oc} was set at 100,000. This is the geometric mean of the range reported by ATSDR (1998), rounded to one significant figure.

The kinetics of hexachlorobenzene in the topmost soil layer are somewhat complex. When hexachlorobenzene is applied to the surface of soil, volatilization will be a major mechanism of dissipation for that portion of the compound that remains on or near the soil surface (ATSDR 1998). Typical reported half-times for hexachlorobenzene in soil are in the range of 3 to 6 years (ATSDR 1998). As detailed in section 3.2.4.2, a half-time of 2.8 years for hexachlorobenzene in soil can be calculated for the 2-4 cm soil layer from relatively detailed data provided in Bealls (1976). While these half-times are appropriate for estimating uptake from vegetation associated with hexachlorobenzene residues below the soil surface, they are not appropriate for estimating runoff values using the GLEAMS model because they do not take into account the volatilization of hexachlorobenzene from the soil surface.

A more relevant soil half-time can be estimated from data on the top 0-2 cm soil layer reported in the study by Bealls (1976) and illustrated in Figure A7-1. In this figure, the squares represent the actual measurements over the 19-month observation period (Table 1, p. 369 of Bealls, 1976). The relatively rapid initial drop in soil residues followed by a more gradual decline suggests a bi-exponential kinetics,

$$C_t = Ae^{\alpha t} \times Be^{\beta t}$$

where C_t is the soil concentration at time t , α , and β are dissipation coefficients, and A and B , are model constants. These general types of models are detailed in most texts on kinetics (e.g., Goldstein et al. 1974). This model was fit to the data on the 0-2 cm soil layer (Bealls 1976) using the SOLVER function in EXCEL (Middleton 1997).

As illustrated by the solid line in Figure A7-1, the bi-exponential model fits the observed data extremely well yielding coefficients of 0.0975 days⁻¹ (α) and 0.0054 days⁻¹ (β), corresponding to initial and terminal half-times of 7.1 days (α) and 128 day (β) [$t_{1/2} = \ln(2)/k$]. Given the importance of volatilization in the dissipation of hexachlorobenzene from soil (ATSDR 1998), the fit of these data to a bi-exponential model seems reasonable.

The GLEAMS model, however, requires a simple first-order (mono-exponential) half-time in soil and does not accommodate bi-exponential dissipation. Fitting the data from Bealls (1976) to a simple first-order model,

$$C_t = Ae^{\alpha t},$$

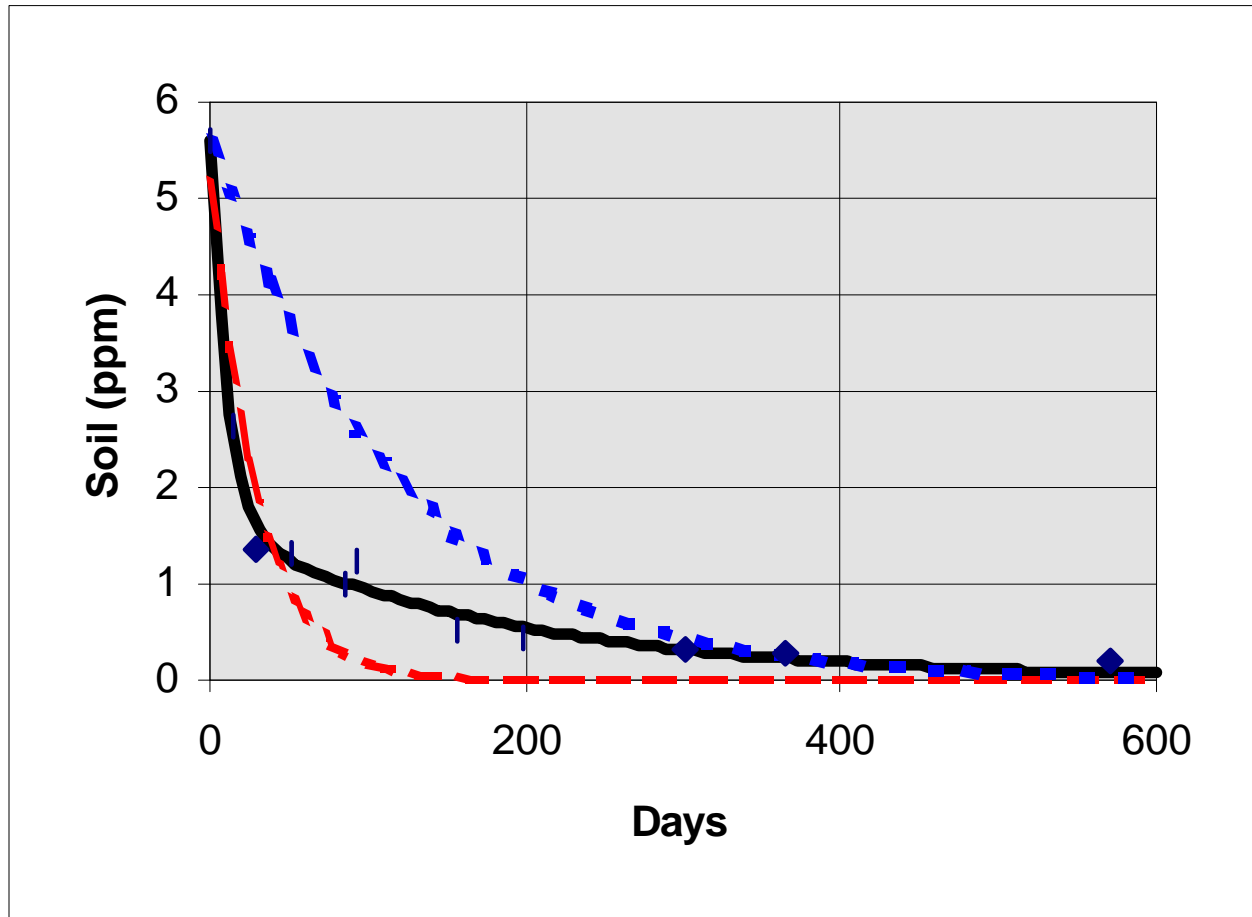


Figure A2-1: Residues of hexachlorobenzene in the 0-2 inch soil layer (data from Bealls 1976. Solid line: bi-exponential dissipation, dashed line: first-order dissipation, dotted line: first-order approximation. See text for discussion).

yields a dissipation coefficient (α) of 0.0344 days^{-1} with a corresponding halftime of 20 days. In the first-order model, the A parameter is the concentration at time-zero and is estimated at 5.355 ppm. As illustrated in Figure A2-1 with the longer dashed lines, this model does not fit the data well and tends to underestimate the concentrations of hexachlorobenzene in soil over most of the observation period. This underestimation by the simple first-order model is important because, in estimating runoff over a prolonged period of time, the amount of runoff will be dependent on the estimated amount of the chemical remaining on or near the soil surface and thus subject to runoff.

The magnitude of the underestimate can be found by calculating the time-weighted average soil concentration based on each model - i.e., integrating with respect to time and dividing by the time interval. In this analysis, all integrations were performed using Mathematica (Wolfram Research 1997). Since repeated applications may be conducted each year in Forest Service programs, a one-year time interval is most relevant. The definite integral of the bi-exponential model between t_0 and t_{365} is approximately 300 ppm and the time-weighted average concentration is about 0.823 ppm [$300 \text{ ppm} \div 365 \text{ days}$]. The definite integral of the simple first-order model between t_0 and t_{365} is approximately 155 and the time-weighted average concentration is about 0.426 ppm [$155 \text{ ppm} \div 365 \text{ days}$]. Thus, the simple first-order model underestimates the average soil concentration over a one-year period by a factor of about 2 [$0.823 \text{ ppm} \div 0.426 \text{ ppm} = 1.96$].

As an alternative, a conservative first-order approximation of a dissipation rate coefficient (α) can be calculated from the concentrations in the 0-2 cm soil layer on day one and day 365. These values are 5.5992 ppm and 0.2654 ppm, respectively (Table 1, p. 369 of Bealls, 1976). The first-order approximation of the dissipation rate coefficient (α) is thus:

$$-\ln(0.2654 \div 5.5992) / 365 - 1 \text{ day} = 0.00837 \text{ days}^{-1}$$

which corresponds to a halftime of 82.7 days. This approximation is illustrated by the short dashed line in Figure A2-1 and is above either of the lines generated from the bi-exponential or simple first-order methods. Consequently, using this approximation will result in over-estimates of the amount of hexachlorobenzene available for runoff in the upper layer of soil. The definite integral of the first-order approximation between t_0 and t_{365} is 638 ppm and the time-weighted average concentration is about 1.75 ppm [638 ppm \div 365 days]. Thus, the magnitude of the overestimate relative to the bi-exponential model is about a factor of 2 [1.75 ppm \div 0.823 ppm = 2.126]. Because GLEAMS requires a simple first-order halftime, the first-order approximation of 83 days is used.

The only other noteworthy chemical-specific parameters required by GLEAMS involve foliar interception, foliar wash-off, and foliar half-time. For all GLEAMS models used in this exposure assessment, foliar interception is set to zero - i.e., the assumption is made that all of the applied hexachlorobenzene reaches the soil surface. Because of this assumption, foliar wash-off and foliar half-time do not impact the estimates. As will the use of soil halftimes, this will over-estimate the amount deposited on soil and hence the amount available for runoff.

No attempt is made to correct for these over-estimates because of the tendency of GLEAMS to under-estimate runoff. For example, Reyes et al. (1994) have noted that GLEAMS and various modifications to the GLEAMS model under-estimate runoff losses by factors of about 2 to 3. Thus, while some of the chemical-specific assumptions used in the GLEAMS modeling will tend to over-estimate runoff, these factors will be at least partially offset by the tendency of the GLEAMS model to underestimate runoff.

Two types of soils are modeled: clay (high runoff potential) and sand (low runoff potential). Two erosion parameter files and two hydrology parameter files are used, one each for clay and sand. Both sets of files specify a 10 acre (435,600 sq. ft.) area that is 50 feet wide and 8712 feet long - e.g., a right-of-way. For estimating runoff to water, it is assumed that a body of water runs along the length of the right-of-way and that the slope toward the water is 20 percent. Because of the general rather than site-specific nature of this exposure assessment, only a single overland profile is used. Additional parameters specified in this file are consistent with a clay or sand with little resistance to runoff. The most sensitive hydrological parameters affecting runoff are organic carbon and runoff curve numbers, both of which are directly related to runoff. As with the parameters used in the pesticide file, the parameters used in these files should lead to relatively high but reasonable estimates of pesticide runoff for each soil type. Specific parameter values were selected based on reference tables provided in the documentation for GLEAMS (Knisel et al. 1992) as well as texts dealing with runoff (Boulding 1995; Leng et al. 1995; Nix 1994; Winegardner 1996).

Rainfall also has a substantial influence on runoff and GLEAMS requires daily rainfall data files. National monthly rainfall statistics covering the period from 1961 to 1990 were obtained from the U.S. Weather Service (1998). Based on these files, national annual summary statistics were generated in a DBASE file. Average annual rainfall ranged from a low of 0.3 inches (lower range for Yuma, Arizona) to 172.2 inches (upper range for Yakutat, Alaska) with a mean average annual rainfall of 27.69 inches. Based on these statistics, model runs for both clay and sandy soil were conducted using precipitation rates of 5, 10, 25, 50, 100, 150, 200, and 250 inches per year.

Each GLEAMS model run was conducted over a 20 year period, with applications of hexachlorobenzene contaminated herbicide on Julian day 002 of years 1 through 20. For each year, equal amounts of rainfall were generated every tenth day to yield the average annual rainfall. This approach was taken because most runoff as well as soil erosion will occur during periods of relatively intense rainfall. Combined with the pesticide, erosion, and hydrology parameters discussed above, this should yield relatively high but still plausible estimates of runoff.

As summarized in hexachlorobenzene worksheet B01, the typical application rate for picloram is 0.5 lb a.e./acre and this corresponds to a functional application rate for hexachlorobenzene of 0.000004 lb/acre - i.e., 8 ppm hexachlorobenzene in technical grade picloram. GLEAMS does not permit application rates in the range of 0.000008 lb/acre. Thus, for the GLEAMS runs, an application rate of 1 lb/acre was used and the outputs were adjusted by a factor of 0.000004.

Consistent with the information on hexachlorobenzene reviewed by ATSDR (1998), all off-site movement of hexachlorobenzene occurred in runoff and no losses occurred through percolation. Also consistent with general patterns of pesticide runoff (e.g., Knisel et al. 1992), the proportion of runoff was greater for clay than sandy soil and directly proportional to rainfall. For clay, no runoff occurred at annual rainfall rates of 5 or 10 inches. For sand, no runoff occurred at annual rainfall rates of 5, 10, or 50 inches.

The runoff rates provided by GLEAMS are in units of g/ha (output field 601). Based on a 50 foot wide ROW, one hectare (10,760 ft²) is about 215 feet long [10,760 ft² ÷ 50 ft = 215.2 feet]. Using a 50 foot wide standing body of water adjacent to the ROW, the volume of water can be calculated from the dimensions - 215 ft (65.532 meters) by 50 ft (15.24 meters) by 1 meter deep - as 1,000,000 liters:

$$65.532 \text{ m} \times 15.24 \text{ m} \times 1 \text{ m} = 998.70 \text{ m}^3 \quad 1000 \text{ m}^3 \times 1000 \text{ L/m}^3 = 1,000,000 \text{ L.}$$

For any time, t , amount of hexachlorobenzene in water A_t in units of g/ha is calculated as:

$$A_t = A_{t-1} - (A_{t-1} * k_e) + \delta$$

where δ is the amount added at time t by runoff read from the GLEAM output files.

ATSDR (1998) gives reported halftimes for hexachlorobenzene in surface water ranging from 2.7 to 5.7 years, corresponding to dissipation rates of 0.122 year⁻¹ to 0.256 year⁻¹ or 0.00031 day⁻¹ to 0.00070 day⁻¹. Thus, the value of k_e used in the above equation is taken at 0.19 year⁻¹ or 0.0005 day⁻¹ the mid-range of k_e 's based on halftimes in surface water.

The amount added at time t by runoff, δ , is adjusted using two factors. The first factor of 0.000004 adjusts to an application rate of 0.000004 lb hexachlorobenzene/acre which, as discussed above, is associated with an application rate of 0.1 lb picloram a.e./acre.

The second factor is 0.000999 [1 ÷ 1001], which is used to account for the partitioning of hexachlorobenzene to sediment. This factor is derived from the soil-water partition coefficient of 100000 from U.S. EPA (1998). This value is defined as the ratio of the concentration of hexachlorobenzene in soil (mg/kg soil) to the concentration of hexachlorobenzene in water (mg/L water). Assuming a 1 cm (0.01 meter) mixing depth for sediment and a 1 meter water depth, the amount of hexachlorobenzene in water relative to the amount in sediment is thus 1000:

$$100,000 \times 0.01 \div 1 = 1000.$$

Thus, of the total amount of hexachlorobenzene transported to water, a proportion of 0.000999 [1 ÷ 1001] will be in the aqueous phase.

Using these factors, the amount of runoff each day that is added to water, δ , was calculated as:

$$\delta = R \times 0.000004 \times 0.000999$$

where R is the amount read from the GLEAMS output file.

The concentration in water at time t (C_t) in units of picograms/L is then calculated as:

$$C_t \text{ (pg/L)} = A_t \text{ (g/ha)} \times 1,000,000,000 \text{ pg/g} \div 1,000,000 \text{ L/ha.}$$

Units of picograms per liter (pg/L), which is equivalent to 10^{-12} g/L or 10^{-9} mg/L, were used because of the extremely low concentrations of hexachlorobenzene in water.

Based on the GLEAMS model runs and the above calculations, the estimated concentrations of hexachlorobenzene in water associated with a picloram application rate of 0.5 lb a.e./acre in areas with clay and sand soil are illustrated in Figures A2-2 and A2-3, respectively. At an annual rainfall rate of 25 inches, about the national average, the estimated concentration of hexachlorobenzene in water associated with runoff from clay after 1 year is about 0.00846 picograms/L or about 8.5×10^{-12} mg/L. After 20 years of annual applications, the modeled concentration is 0.050958 picograms/L or about 5.1×10^{-11} mg/L. At this rainfall rate (25 inches/year), no runoff from sand is anticipated. As illustrated in Figures A2-2 and A2-3, higher levels of water contamination are estimated in areas with higher rainfall rates. For example, at an annual rainfall rate of 150 inches over a 20 year period, water concentrations of about 0.6 to 1.5 picograms/L or 6×10^{-10} mg/L to 1.5×10^{-9} mg/L are estimated for sand and clay soils, respectively. At atypically high rainfall rates of 250 inches per year, concentrations increase to about 1.6 to 3.2 picograms/L or 1.6×10^{-9} mg/L to 3.2×10^{-9} mg/L over a 20 year period.

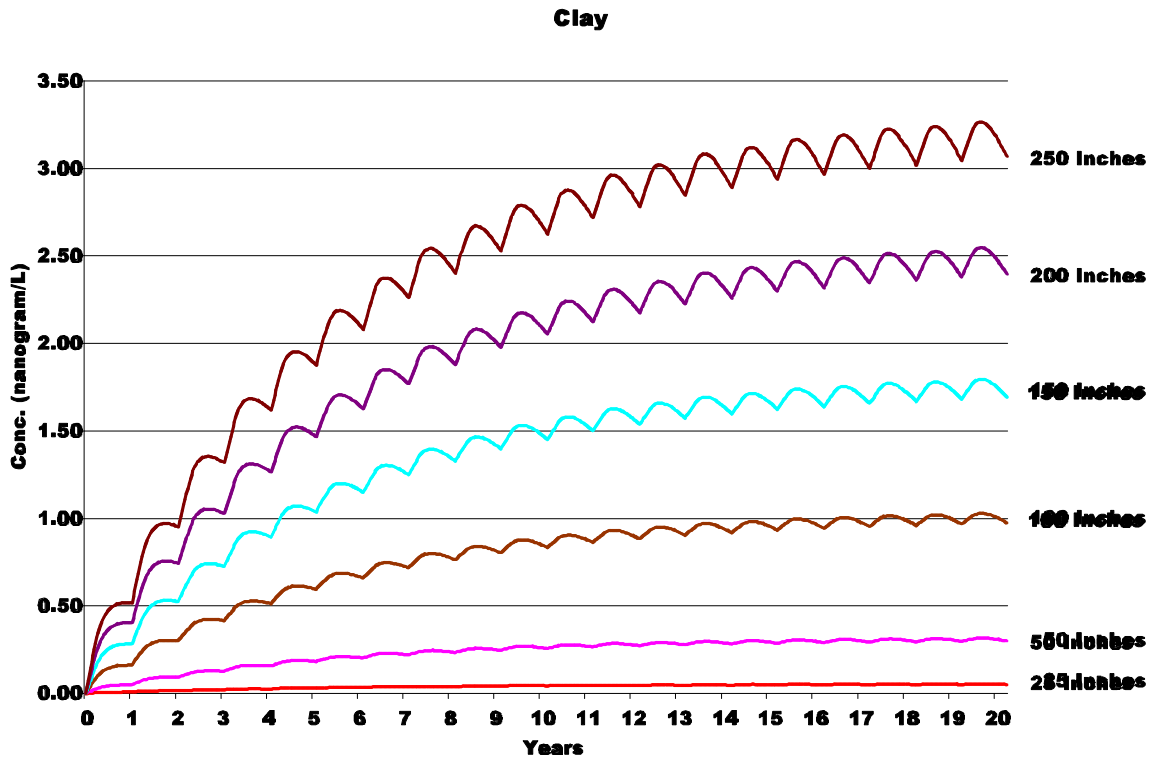


Figure A2-2: Estimated concentrations of hexachlorobenzene in water (in units of picograms/L or 10^{-9} mg/L) associated with runoff from clay at rainfall rates of 25 inches to 250 inches per year.

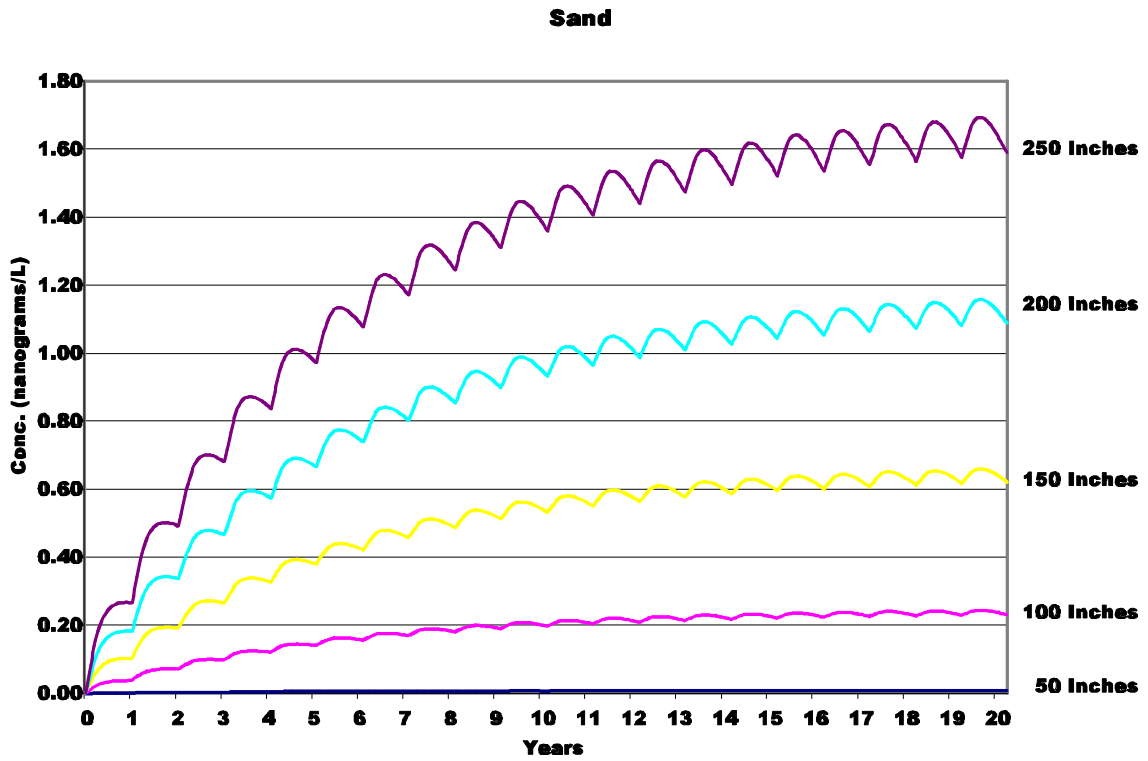


Figure A2-3: Estimated concentrations of hexachlorobenzene in water (in units of picograms/L or 10^{-9} mg/L) associated with runoff from sand at rainfall rates of 50 inches to 250 inches per year.

**WORKSHEETS FOR
Picloram**

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GENERAL ASSUMPTIONS, VALUES, and MODELS

Worksheet A01: Constants and conversion factors used in calculations [CONST]		
Conversion	ID	Value
mg/lb	mg_lb	453,600
mL/gallon	ml_gal	3,785
lb/gallon to mg/mL	lbg_mgml	119.8
lb/acre to µg/cm ²	lbac_ugcm	11.21
lb/acre to mg/cm ²	lbac_mgcm	0.01121
gallons to liters	gal_lit	3.785

Worksheet A02: General Assumptions Used in Worker Exposure Assessments [STD]				
Parameter	ID	Value	Units	Reference
Body Weight (General)	BW	70	kg	ICRP (1975), p. 13
Surface area of hands	Hands	840	cm ²	U.S. EPA 1992c
Surface area of lower legs	LLegs	2070	cm ²	U.S. EPA 1992c
Weight of liquid adhering to surface of skin after a spill	Liq	0.008	mg/cm ²	Mason and Johnson 1987

Worksheet A03a: Directed Ground Sprays (includes backpack, cut surface, and streamline applications) - General Assumptions Used in Worker Exposure Assessments [BACKPACK]

Parameter/Assumption	ID	Value	Units	Reference
Hours of application per day				
Central estimate		7	hours	USDA 1989a,b,c
Lower estimate		6		
Upper estimate		8		
Acres treated per hour				
Central estimate		0.625	acres/hour	USDA 1989a,b,c
Lower estimate		0.25		
Upper estimate		1		
Acres treated per day				
Central estimate	ACREC	4.375	acres/day	N/A ¹
Lower estimate	ACREL	1.5		
Upper estimate	ACREU	8		
Absorbed dose rate (mg/day)				
Central estimate	RATEC	0.003	(mg agent/kg bw) ÷ (lbs agent handled per day) ²	Rubin et al. 1998, Table 5
Lower estimate	RATEL	0.0003		
Upper estimate	RATEU	0.01		

¹ Calculated as the product of the number of hours of application and the number of acres treated per hour for each category - i.e., central estimate, lower estimate, and upper estimate.

² “Agent” refers to the material being handled and may be expressed in units of a.i. or a.e. Depending on the agent under consideration, additional exposure conversions may be made in the exposure assessment and dose response assessment. For the risk assessment, the only important point is that the exposure and dose/response assessments must use the same units - that is, a.i., a.e., etc. - or the units must be converted to some equivalent form in the risk characterization.

Worksheet A03b: Hydraulic/Broadcast Ground Sprays - General Assumptions Used in Worker Exposure Assessments [HYDSPRAY]

Parameter/Assumption	ID	Value	Units	Reference
Hours of application per day				
Central estimate		7	hours	USDA 1989a,b,c
Lower estimate		6		
Upper estimate		8		
Acres treated per hour				
Central estimate		16	acres/hour	USDA 1989a,b,c
Lower estimate		11		
Upper estimate		21		
Acres treated per day				
Central estimate	ACREC	112	acres/day	N/A ¹
Lower estimate	ACREL	66		
Upper estimate	ACREU	168		
Absorbed dose rate				
Central estimate	RATEC	0.0002	(mg agent/kg bw) ÷ (lbs agent handled per day) ₂	Rubin et al. 1988, Table 5
Lower estimate	RATEL	0.00001		
Upper estimate	RATEU	0.0009		
<p>¹ Calculated as the product of the number of hours of application and the number of acres treated per hour for each category - i.e., central estimate, lower estimate, and upper estimate.</p> <p>² “Agent” refers to the material being handled and may be expressed in units of a.i. or a.e. Depending on the agent under consideration, additional exposure conversions may be made in the exposure assessment and dose response assessment. For the risk assessment, the only important point is that the exposure and dose/response assessments must use the same units - that is, a.i., a.e., etc. - or the units must be converted to some equivalent form in the risk characterization.</p>				

Worksheet 03c: Aerial Broadcast Sprays (includes pilots, mixers, and loaders) - General Assumptions Used in Worker Exposure Assessments. [AERIAL]

Parameter/Assumption	Code	Value	Units	Reference
Hours of application per day				
Central estimate		7	hours	USDA 1989a,b,c
Lower estimate		6		
Upper estimate		8		
Acres treated per hour				
Central estimate		70	acres/hour	USDA 1989a,b,c
Lower estimate		40		
Upper estimate		100		
Acres treated per day				
Central estimate	ACREC	490	acres/day	N/A ¹
Lower estimate	ACREL	240		
Upper estimate	ACREU	800		
Absorbed dose rate				
Central estimate	RATEC	0.00003	(mg agent/kg bw) ÷ (lbs agent handled per day) ₂	Rubin et al. 1998, Table 5
Lower estimate	RATEL	0.000001		
Upper estimate	RATEU	0.0001		
<p>¹ Calculated as the product of the number of hours of application and the number of acres treated per hour for each category - i.e., central estimate, lower estimate, and upper estimate.</p> <p>² “Agent” refers to the material being handled and may be expressed in units of a.i. or a.e. Depending on the agent under consideration, additional exposure conversions may be made in the exposure assessment and dose response assessment. For the risk assessment, the only important point is that the exposure and dose/response assessments must use the same units - that is, a.i., a.e., etc. - or the units must be converted to some equivalent form in the risk characterization.</p>				

Worksheet A04: General Assumptions Used in Exposure Assessments for the General Public [PUBL]

Narrative: This table contains various values used in the exposure assessments for the general public. Three general groups of individuals are considered: adult male, adult female, and a 2 year old child. Values are specified for body weight, surface areas for various parts of the body, water intake, fish consumption, and the consumption of fruits or vegetables. *NOTE: Not all types of value are specified for each group. The only values specified are those used in the risk assessment.*

Description	ID	Value	Units	Reference
Body Weights				
Male, Adult	BWM	70	kg	ICRP (1975), p. 13.
Female, Adult	BWF	64	kg	Burnmaster 1998; U.S. EPA 1985 ¹
Child, 2-3 years old	BWC	13.3	kg	U.S. EPA, 1996, page 7-1, Table 7-2
Body Surface Areas				
Female, feet and lower legs	SAF1	2915	cm ²	U.S. EPA, 1992a, p. 8-11, Table 8-3, total for feet and lower legs
Female, exposed skin when wearing shorts and a T-shirt	SAF2	5300	cm ²	U.S. EPA, 1992a, p. 8-11, Table 8-3, total for arms, hands, lower legs, and feet.
Child, male, 2-3 years old, total body surface area	SAC	6030	cm ²	U.S. EPA, 1996, p. 6-15, Table 6-6, 50 th percentile.
Water Intake				
Adult				
typical	WCAT	2	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, midpoint of mean (1.4 L/day) and 90 th percentile (2.4 L/day) rounded to one significant place.
lower range for exposure assessment	WCAL	1.4	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, mean
upper range	WCAH	2.4	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, 90 th percentile
Child, <3 years old				
typical	WCT	1	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, midpoint of mean (0.61L/day) and 90 th percentile (1.5 L/day) rounded to one significant place.
lower range for exposure assessment	WCL	0.61	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, mean
upper range	WCH	1.50	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, 90 th percentile

Worksheet A04: General Assumptions Used in Exposure Assessments for the General Public [PUBL]

Narrative: This table contains various values used in the exposure assessments for the general public. Three general groups of individuals are considered: adult male, adult female, and a 2 year old child. Values are specified for body weight, surface areas for various parts of the body, water intake, fish consumption, and the consumption of fruits or vegetables. *NOTE: Not all types of value are specified for each group. The only values specified are those used in the risk assessment.*

Description	ID	Value	Units	Reference
Fish Consumption				
Freshwater anglers, typical intake per day over a prolonged period	FAT	0.010	kg/day	U.S. EPA, 1996, p. 10-51, average of means from four studies
Freshwater anglers, maximum consumption for a single day	FAU	0.158	kg/day	Ruffle et al. 1994
Native American subsistence populations, typical intake per day	FNT	0.081	kg/day	U.S. EPA, 1996, p. 10-51, median value of 94 individuals
Native American subsistence populations, maximum for a single day	FNU	0.770	kg/day	U.S. EPA, 1996, p. 10-51, highest value of 94 individuals
Consumption of Fruits or Vegetables				
Amount of food consumed per kg bw per day for longer term exposures scenarios.				
Typical	VT	0.0043	kg food/kg bw/day	U.S. EPA, 1996, Table 9-21, p. 9-39, mean intake of vegetables
Upper	VU	0.01	kg food/kg bw/day	U.S. EPA, 1996, Table 9-21, p. 9-39, 95 th percentile for intake of vegetables
Worst-case scenario for consumption in a single day, acute exposure scenario only.	VAcute	0.454	kg food	1 lb. The approximate mid range of the above typical and upper limits based on the 64 kg body weight.
Miscellaneous				
Estimate of dislodgeable residue as a proportion of application rate shortly after application.	DisL	0.1	none	Harris and Solomon 1992, data on 2,4-D
¹ This is the average value (63.79 kg), rounded to the nearest kg for 3 different groups of women between 15-49 years old: control (62.07 kg), pregnant (65.90 kg), and lactating (63.48 kg). See Burnmaster 1998, p.218, Table III., Risk Analysis. 18(2): 215-219. This is identical to the body weight for females, 45-55 years old, 50 th percentile from U.S. EPA, 1985, page 5, Table 2-2, rounded to nearest kilogram.				

Worksheet A05a: Estimated concentrations of pesticides on or in various types of vegetation shortly after application at 1 lb a.i./acre [from Hoerger and Kenaga (1972), Table 9, p. 22]. [HK]

Type of Vegetation	Concentration (mg chemical/kg vegetation)			
	Typical		Upper Limit	
	ID	Value	ID	Value
Range grass	RGT	125	RGU	240
Grass	GST	92	GSU	110
Leaves and leafy crops	LVT	35	LVU	125
Forage crops	FCT	33	FCU	58
Pods containing seeds	PDT	3	PDU	12
Grain	GNT	3	GNU	10
Fruit	FRT	1.5	FRU	7

Worksheet A05b: Concentrations of chemical on spheres (berries) at the specified application rate. [FRUIT]

Diameter (cm)	Planar Surface Area (cm ²) ^a	Amount deposited (mg) ^b	Weight of sphere (kg) ^c	Concentration (mg/kg) ^d
1	0.7853981634	0.008796459	0.0005236	16.8
5	19.6349540849	0.21991148575	0.065449847	3.36
10	78.5398163397	0.87964594301	0.5235987756	1.68
Application rate		1 lb/acre =	0.0112	mg/cm ²

- a Planar surface area of a sphere = πr^2 where r is the radius in cm.
- b Amount deposited is calculated as the application rate in mg/cm² multiplies by the planar surface area.
- c Assumes a density of 1 g/cm³ for the fruit. The volume of a sphere is $(1\div 6) \times \pi \times d^3$ where d is the diameter in cm. Assuming a density of 1 g/cm³, the weight of the sphere in kg is equal to:

$$\text{kg} = (1\div 6) \times \pi \times d^3 \div 1000$$
- d Amount of chemical in mg divided by the weight of the sphere in kg.

Worksheet A06: Central estimates of off-site drift associated with aerial application of pesticides (from Bird 1995, p. 205) [OFFSITE]

Distance Down Wind (meters)	ID	Drift as a proportion of application rate
100	DRFT100	0.05
200	DRFT200	0.02
300	DRFT300	0.01

400	DRFT400	0.008
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Worksheet A07a: Estimate of first-order absorption rate (k_a in hours⁻¹) and 95% confidence intervals (from Durkin et al. 1998). [KAMODEL]

Model parameters	ID	Value	
Coefficient for $k_{o/w}$	C_KOW	0.233255	
Coefficient for MW	C_MW	0.005657	
Model Constant	C	1.49615	
Number of data points	DP	29	
Degrees of Freedom (d.f.)	DF	26	
Critical value of $t_{0.025}$ with 26 d.f. ¹	CRIT	2.056	
Standard error of the estimate	SEE	16.1125	
Mean square error or model variance	MDLV	0.619712	
Standard deviation of model (s)	MSD	0.787218	
		MDLV ^{0.5}	
X X, cross products matrix	0.307537	-0.00103089	0.00822769
	-0.00103089	0.000004377	-0.0000944359
	0.0082	-0.0000944359	0.0085286

¹ Mendenhall and Scheaffer, 1973, Appendix 3, 4, p. A31.

Central (maximum likelihood) estimate:

$$\log_{10} k_a = 0.233255 \log_{10}(k_{o/w}) - 0.005657 MW - 1.49615$$

95% Confidence intervals for $\log_{10} k_a$

$$\log_{10} k_a \pm t_{0.025} \times s \times (a' X' X a)^{0.5}$$

where a is a column vector of {1, MW, $\log_{10}(k_{o/w})$ }.

NB: Although the equation for the central estimate is presented with $k_{o/w}$ appearing before MW to be consistent with the way a similar equation is presented by EPA, MW must appear first in column vector a because of the way the statistical analysis was conducted to derive X X .

See following page for details of calculating $a' X' X a$ without using matrix arithmetic.

Worksheet A07a (continued)

Details of calculating $a'X'Xa$

The term $a'(X'X)^{-1}a$ requires matrix multiplication. While this is most easily accomplished using a program that does matrix arithmetic, the calculation can be done with a standard calculator.

Letting

$$a = \{a_1, a_2, a_3\}$$

and

$$(X'X)^{-1} = \begin{Bmatrix} \{b_1, b_2, b_3\}, \\ \{c_1, c_2, c_3\}, \\ \{d_1, d_2, d_3\} \\ \} \end{Bmatrix}$$

$a'(X'X)^{-1}a$ is equal to

$$\begin{aligned} &\text{Term 1: } \{a_1 \times ([a_1 \times b_1] + [a_2 \times c_1] + [a_3 \times d_1])\} + \\ &\text{Term 2: } \{a_2 \times ([a_1 \times b_2] + [a_2 \times c_2] + [a_3 \times d_2])\} + \\ &\text{Term 3: } \{a_3 \times ([a_1 \times b_3] + [a_2 \times c_3] + [a_3 \times d_3])\}. \end{aligned}$$

Worksheet A07b: Estimate of dermal permeability (K_p in cm/hr) and 95% confidence intervals (data from U.S. EPA 1992c). [PKMODEL]

Model parameters	ID	Value	
Coefficient for $k_{o/w}$	C_KOW	0.706648	
Coefficient for MW	C_MW	0.006151	
Model Constant	C	2.72576	
Number of data points	DP	90	
Degrees of Freedom (d.f.)	DF	87	
Critical value of $t_{0.025}$ with 87 d.f. ¹	CRIT	1.96	
Standard error of the estimate	SEE	45.9983	
Mean square error or model variance	MDLV	0.528716	
Standard deviation of model (s)	MSD	0.727129	$MDLV^{0.5}$
X X, cross products matrix		0.0550931	-0.0000941546
		-0.0000941546	0.0000005978
		-0.0103443	-0.0000222508
		-0.0000222508	0.00740677

¹ Mendenhall and Scheaffer, 1973, Appendix 3, Table 4, p. A31.

NOTE: The data for this analysis is taken from U.S. EPA (1992c), Dermal Exposure Assessment: Principles and Applications, EPA/600/8-91/011B, Table 5-4, pp. 5-15 through 5-19. The EPA report, however, does not provide sufficient information for the calculation of confidence intervals. The synopsis of the above analysis was conducted in STATGRAPHICS Plus for Windows, Version 3.1 (Manugistics, 1995) as well as Mathematica, Version 3.0.1.1 (Wolfram Research, 1997). Although not explicitly stated in the EPA report, 3 of the 93 data points are censored from the analysis because they are statistical outliers: [Hydrocortisone-21-yl]-hemipimelate, n-nonanol, and n-propanol. The model parameters reported above are consistent with those reported by U.S. EPA but are carried out to greater number of decimal places to reduce rounding errors when calculating the confidence intervals. See notes to Worksheet A07a for details of calculating maximum likelihood estimates and confidence intervals.

CHEMICAL SPECIFIC VALUES

Worksheet B01: Anticipated Application and Dilution Rates for picloram [WSB01]				
Item	Code	Value	Units	Reference/Source
Typical application rate	Typ	0.5	lb a.e./acre	Section 2.4
Lowest application rate	Low	0.3	lb a.e./acre	Section 2.4
Highest application rate	Hi	1.5	lb a.e./acre	Section 2.4
Lowest dilution	LDil	5	gal./acre	C&P Press 1998*
Highest dilution	Hdil	100	gal./acre	C&P Press 1998*
*Product label for Transline				

Typical concentration in applied solution:

Typical application rate divided by the average of the lowest and highest dilutions, converted to mg/mL, and rounded to two significant places after the decimal.

$$0.5 \text{ lb/acre} \div [(5 \text{ gal/acre} + 100 \text{ gal/acre})/2] \times 119.8 \text{ (mg/mL)/(lb/gal)} = \mathbf{1.1 \text{ mg/mL}} \text{ [TypDr]}$$

Lowest estimated concentration in applied solution:

Lowest application rate divided by the highest dilution, converted to mg/mL, and rounded to two significant places after the decimal.

$$0.3 \text{ lb/acre} \div 100 \text{ gal/acre} \times 119.8 \text{ (mg/mL)/(lb/gal)} = \mathbf{0.36 \text{ mg/mL}} \text{ [LowDr]}$$

Highest estimated concentration in applied solution:

Highest application rate divided by the lowest dilution, converted to mg/mL, and rounded to two significant decimal places after the decimal.

$$1.5 \text{ lb/acre} \div 5 \text{ gal/acre} \times 119.8 \text{ (mg/mL)/(lb/gal)} = \mathbf{36.0 \text{ mg/mL}} \text{ [Hi_Dr]}$$

Worksheet B02: Summary of central estimate and range of concentrations of picloram in field solutions.				
Parameter	ID	Value	Units	Reference/Source
Typical	TypDR	1.1	mg/mL	See calculations above
Low	LowDR	0.36	mg/mL	
High	Hi_DR	36	mg/mL	

Worksheet B03: Summary of chemical specific values used for picloram in exposure assessment worksheets. [WSB03]

Parameter	ID	Value	Units	Source/Reference
Molecular weight (acid)	MW	241.48	grams/mole	Budavari 1989
Water Solubility, pH 7	WS	430	mg/L	Budavari 1989
$K_{o/w}$	Kow	22.9	unitless	SRC 1998
Foliar half-time ($t_{1/2}$)	FT12	30	days	^c Knisel et al. 1992
Half-time on fruit, central	FrT12C	30	days	No data found. Use general foliar half-time.
strawberries lower	FrT12L	30	days	
upper	FrT12U	30	days	
Bioconcentration factor ($BCF_{(kg\ fish/L)}$)	BCFT	1	kg fish/L	U.S. EPA 1995a; USDA 1989d
EPA/OPP RfD ^a	RfDP	0.2	mg/kg bw/day	U.S. EPA 1999, see Section 3.3.3

^a This RfD is that derived by EPA/OPP (U.S. EPA 1994, 1995a, 1999). There is an old RfD on IRIS (U.S. EPA 1992cb)

Worksheet B04: Calculation of first-order dermal absorption rate (k_a) for picloram.							
Parameters	Value	Units			Reference		
Molecular weight	241.48	g/mole					
$K_{o/w}$ at pH 7	22.9	unitless					
$\log_{10} K_{o/w}$	1.36						
Column vector a for calculating confidence intervals (see Worksheet 08 for definitions.)							
a_1	1						
a_2	241.48						
a_3	1.36						
Calculation of $a' \cdot (X'X)^{-1} \cdot a$ - see Worksheet A07a for details of calculation.							
Term 1	0.0697496828						
Term 2	-0.0247190674						
Term 3	-0.004049801						
$a' \cdot (X'X)^{-1} \cdot a$	0.041	calculation verified in Mathematica 3.0.1.1					
$\log_{10} k_a = 0.233255 \log_{10}(k_{o/w}) - 0.005657 MW - 1.49615$					Worksheet A07a		
\log_{10} of first order absorption rate (k_a)							
Central estimate	-2.54501393457	\pm	$t_{0.025}$	\times	s	\times	$(a' \cdot (X'X)^{-1} \cdot a)^{0.5}$
Lower limit	-2.87273929857	-	2.0560	\times	0.787218	\times	0.20248456731
Upper limit	-2.21728857056		2.0560	\times	0.787218	\times	0.20248456731
First order absorption rates (i.e., antilog or 10^x of above values).							
Central estimate	0.002850927	hours ⁻¹					
Lower limit	0.001340481	hours ⁻¹					
Upper limit	0.006063333	hours ⁻¹					

Worksheet B05: Calculation of dermal permeability rate (K_p) in cm/hour for picloram.							
Parameters	Value	Units			Reference		
Molecular weight	241.48	g/mole					
$K_{o/w}$ at pH 7	22.9	unitless					
$\log_{10} K_{o/w}$	1.35983548234						
Column vector a for calculating confidence intervals (see Worksheet A07a for definitions.)							
a_1	1						
a_2	241.48						
a_3	1.35983548234						
Calculation of $a' \cdot (X'X)^{-1} \cdot a$ - see Worksheet A07b for details of calculation.							
Term 1	0.018290101						
Term 2	0.00481625						
Term 3	-0.007676862						
$a' \cdot (X'X)^{-1} \cdot a$	0.0154	calculation verified in Mathematica 3.0.1.1					
$\log_{10} k_p = 0.706648 \log_{10}(k_{o/w}) - 0.006151 MW - 2.72576$					Worksheet A07b		
\log_{10} of dermal permeability							
Central estimate	-3.25017845608	\pm	$t_{0.025}$	\times	s	\times	$a' \cdot (X'X)^{-1} \cdot a^{0.5}$
Lower limit	-3.42703775441	-	1.9600	\times	0.727129	\times	0.12409673646
Upper limit	-3.07331915774		1.9600	\times	0.727129	\times	0.12409673646
Dermal permeability							
Central estimate	0.000562	cm/hour					
Lower limit	0.000374	cm/hour					
Upper limit	0.000845	cm/hour					

Worksheet B06: Summary of chemical specific dermal absorption values used for picloram dermal absorption. [WSB06]				
Description	Code	Value	Units	Reference/Source
Zero-order absorption (K_p)				
Central estimate	KpC	0.000562	cm/hour	Worksheet B05, values rounded to two significant figures
Lower limit	KpL	0.000374	cm/hour	
Upper limit	KpU	0.000845	cm/hour	
First-order absorption rates (k_a)				
Central estimate	AbsC	0.00285	hour ⁻¹	Worksheet B04, values rounded to two significant figures
Lower limit	AbsL	0.00134	hour ⁻¹	
Upper limit	AbsU	0.0061	hour ⁻¹	

Worksheet B07: Estimates of the concentration of picloram in ambient water per lb a.e. applied per acre. [Used in chronic contaminated water exposure assessment.]					
Scenario	Ambient Conc. mg/L	Appl. Rate (lb a.e./acre)	ID	WCR ^a (mg/L) ÷ (lb a.e./acre)	Reference
Typical	0.025	1.0	AWT	0.025	See section 3.2.3.
Low	0.01	1.0	AWL	0.01	
High	0.06	1.0	AWU	0.06	

^a Expected water contamination rate - mg/L in water after the application of picloram at a given rate in lb a.e./acre.

WORKER EXPOSURE ASSESSMENTS

Worksheet C01: Worker exposure estimates for directed foliar (backpack) applications of picloram				
Parameter/Assumption	Code	Value	Units	Source/Designation
Application rates				
Central estimate	ApplC	0.5	lbs a.e./day	WSB01.TYP
Lower estimate	ApplL	0.3	lbs a.e./day	WSB01.LOW
Upper estimate	ApplU	1.5	lbs a.e./day	WSB01.HI
Acres treated per day				
Central estimate	ACREC	4.375	acres/day	WSA03.ACREC
Lower estimate	ACREL	1.5	acres/day	WSA03.ACREL
Upper estimate	ACREU	8	acres/day	WSA03.ACREU
Amount handled per day (product of application rate and acres treated per day)				
Central estimate	HANDLC	2.1875	lb/day	
Lower estimate	HANDLL	0.45	lb/day	
Upper estimate	HANDLU	12	lb/day	
Absorbed dose rate (mg/day)				
Central estimate	RATEC	0.003	(mg agent/kg bw) ÷ (lbs agent handled per day)	WSA03.RATEC
Lower estimate	RATEL	0.0003		WSA03.RATEL
Upper estimate	RATEU	0.01		WSA03.RATEU
Absorbed dose (product of amount handled and absorbed dose rate)				
Central estimate	DOSEC	0.0066	mg/kg bw/day	N/A
Lower estimate	DOSEL	0.000135		
Upper estimate	DOSEU	0.120		

Worksheet C02a: Worker exposure estimates for boom spray (hydraulic ground spray) applications of picloram [WSC01]				
Parameter/Assumption	Code	Value	Units	Source/Designation
Application rates				
Central estimate	APPLC	0.5	lbs a.e./day	WSB01.TYP
Lower estimate	APPLL	0.3	lbs a.e./day	WSB01.LOW
Upper estimate	APPLU	1.5	lbs a.e./day	WSB01.HI
Acres treated per day				
Central estimate	ACREC	112	acres/day	WSA04.ACREC
Lower estimate	ACREL	66	acres/day	WSA04.ACREL
Upper estimate	ACREU	168	acres/day	WSA04.ACREU
Amount handled per day (product of application rate and acres treated per day)				
Central estimate	HANDLC	56	lb/day	
Lower estimate	HANDLL	19.8	lb/day	
Upper estimate	HANDLU	252	lb/day	
Absorbed dose rate				
Central estimate	RATEC	0.00020	(mg agent/kg bw) ÷ (lbs agent handled per day)	WSA04.RATEC
Lower estimate	RATEL	0.00001		WSA04.RATEL
Upper estimate	RATEU	0.00090		WSA04.RATEU
Absorbed dose (product of amount handled and absorbed dose rate)				
Central estimate	DOSEC	0.0112	mg/kg bw/day	N/A
Lower estimate	DOSEL	0.000198		
Upper estimate	DOSEU	0.2268		

WSC02b: Worker exposure estimates for aerial applications of picloram [WKAREXP01]				
NOTE: The upper and lower estimates of dose are based on the typical application rate. Variability is encompassed by differences in the number of acres treated and the absorbed dose rate.				
Parameter/Assumption	Code	Value	Units	Source/Designation
Application rates				
Central estimate	WS10C	0.5	lbs a.e./day	APPL.TYP
Lower estimate	WS10L	0.3	lbs a.e./day	APPL.LOW
Upper estimate	WS10U	1.5	lbs a.e./day	APPL.HI
Acres treated per day				
Central estimate	ACREC	490	acres/day	AERIAL.ACREC
Lower estimate	ACREL	240	acres/day	AERIAL.ACREL
Upper estimate	ACREU	800	acres/day	AERIAL.ACREU
Amount handled per day (product of application rate and acres treated per day)				
Central estimate	HANDLC	245	lb/day	N/A ¹
Lower estimate	HANDLL	120	lb/day	
Upper estimate	HANDLU	400	lb/day	
Absorbed dose rate				
Central estimate	RATEC	0.00003	(mg agent/kg bw) ÷ (lbs agent handled per day) ²	AERIAL.RATEC
Lower estimate	RATEL	0.000001		AERIAL.RATEL
Upper estimate	RATEU	0.0001		AERIAL.RATEU
Absorbed dose (product of amount handled and absorbed dose rate)				
Central estimate	DOSEC	0.00735	mg/kg bw	N/A
Lower estimate	DOSEL	0.0001200		
Upper estimate	DOSEU	0.04		
<p>¹ Calculated as the product of the number of hours of application and the number of acres treated per hour for each category - i.e., central estimate, lower estimate, and upper estimate.</p> <p>² "Agent" refers to the material being handled and may be expressed in units of a.i. or a.e. Depending on the agent under consideration, additional exposure conversions may be made in the exposure assessment and dose response assessment. For the risk assessment, the only important point is that the exposure and dose/response assessments must use the same units - that is, a.i., a.e., etc. - or the units must be converted to some equivalent form in the risk characterization.</p>				

Worksheet C03: Workers: Accidental Dermal Exposure Assessments Using Zero-Order Absorption			
Parameter	Value	Units	Source
Body weight (W)	70	kg	WSA02.BW
Surface Area of hands (S)	840	cm ²	WSA02.Hands
Dermal permeability (K _p , cm/hour) [see Worksheet B05]			
Typical	0.0005620	cm/hour	WSB06.KpC
Lower	0.00037400	cm/hour	WSB06.KpL
Upper	0.0008450	cm/hour	WSB06.KpU
Concentration in solution (C) [see Worksheet B02]			
Typical	1.1	mg/mL	WSB02.TypDr
Lower	0.36	mg/mL	WSB02.LowDr
Upper	36	mg/mL	WSB02.HI_Dr

Note that 1 mL is equal to 1 cm³ and thus mg/mL = mg/cm³.

Details of calculations for worker zero-order dermal absorption scenarios.

Equation (U.S. EPA 1992c)

$$K_p \cdot C \cdot \text{Time (hr)} \cdot S \div W = \text{Dose (mg/kg)}$$

where: C = concentration in mg/cm³ or mg/mL, S = Surface area of skin in cm², W = Body weight in kg.

Immersion of Hands or Wearing Contaminated Gloves for One-Minute

Typical Value: Use typical concentration and central estimate of K_p.

$$0.0005620 \text{ cm/hr} \times 1.1 \text{ mg/cm}^3 \times 1/60 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 1.24\text{e-}04 \text{ mg/kg [WZHT1M]}$$

Lower Estimate: Use lower range of estimated concentration and lower limit of K_p.

$$0.0003740 \text{ cm/hr} \times 0.36 \text{ mg/cm}^3 \times 1/60 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 2.69\text{e-}05 \text{ mg/kg [WZHL1M]}$$

Upper Estimate: Use upper range of estimated concentration and upper limit of K_p.

$$0.0008450 \text{ cm/hr} \times 36 \text{ mg/cm}^3 \times 1/60 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 0.006084 \text{ mg/kg [WZHU1M]}$$

Wearing Contaminated Gloves for One-Hour

Typical Value: Use typical concentration and central estimate of K_p.

$$0.0005620 \text{ cm/hr} \times 1.1 \text{ mg/cm}^3 \times 1 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 0.0074184 \text{ mg/kg [WZHT1H]}$$

Lower Estimate: Use lower range of estimated concentration and lower limit of K_p.

$$0.0003740 \text{ cm/hr} \times 0.36 \text{ mg/cm}^3 \times 1 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 1.62\text{e-}03 \text{ mg/kg [WZHL1H]}$$

Upper Estimate: Use upper range of estimated concentration and upper limit of K_p.

$$0.0008450 \text{ cm/hr} \times 36 \text{ mg/cm}^3 \times 1 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 0.36504 \text{ mg/kg [WZHU1H]}$$

Worksheet C04: Worker Accidental Spill Based on the Assumption of First-Order Absorption			
Parameter	Value	Units	Source
Liquid adhering to skin after a spill (<i>L</i>)	0.008	mg/mL	WSA02.Liq
Body weight (<i>W</i>)	70	kg	WSA02.BW
Surface Areas (<i>A</i>)			
Hands	840	cm ²	WSA02.Hands
Lower legs	2070	cm ²	WSA02.LLegs
First-order dermal absorption rates (<i>k_a</i>)			
Central Estimate	0.00285	hour ⁻¹	WSB06.ABSC
Lower limit of range	0.001340	hour ⁻¹	WSB06.ABSL
Upper limit of range	0.00610	hour ⁻¹	WSB06.ABSU
Concentration in solution (<i>C</i>) [see Worksheet B01]			
Typical	1.1	mg/mL	TypDr
Lower	0.36	mg/mL	LowDr
Upper	36	mg/mL	HI_Dr

Details of calculations.

Equation (from Durkin et al. 1995)

$$Dose_{(mg/kg\ bw)} = k_a_{(1/hours)} \times L_{(mg/cmsq)} \times C_{(mg/mL)} \times T_{(hours)} \times A_{(cm\ sq)} \div W_{(kg)}$$

where *T* is the duration of exposure in hours and other terms are defined as above.

Lower Legs: Spill with 1 Hour (*T*) Exposure Period

Typical Value [WFLT1H],

$$0.0028500\ h^{-1} \times 0.008\ mL/cm^2 \times 1.1\ mg/cm^3 \times 1\ hr \times 2070\ cm^2 \div 70\ kg = 7.4e-04\ mg/kg$$

Lower range [WFL1H],

$$0.0013400\ h^{-1} \times 0.008\ mL/cm^2 \times 0.36\ mg/cm^3 \times 1\ hr \times 2070\ cm^2 \div 70\ kg = 1.1e-04\ mg/kg$$

Upper range [WFLU1H],

$$0.0061000\ h^{-1} \times 0.008\ mL/cm^2 \times 36\ mg/cm^3 \times 1\ hr \times 2070\ cm^2 \div 70\ kg = 5.2e-02\ mg/kg$$

Hands: Spill with 1 Hour (*T*) Exposure Period

Typical Value [WFHT1H],

$$0.0028500\ h^{-1} \times 0.008\ mL/cm^2 \times 1.1\ mg/cm^3 \times 1\ hr \times 840\ cm^2 \div 70\ kg = 3.0e-04\ mg/kg$$

Lower range [WFH1H],

$$0.0013400\ h^{-1} \times 0.008\ mL/cm^2 \times 0.36\ mg/cm^3 \times 1\ hr \times 840\ cm^2 \div 70\ kg = 4.6e-05\ mg/kg$$

Upper range [WFHU1H],

$$0.0061000\ h^{-1} \times 0.008\ mL/cm^2 \times 36\ mg/cm^3 \times 1\ hr \times 840\ cm^2 \div 70\ kg = 2.1e-02\ mg/kg$$

EXPOSURE ASSESSMENTS for the GENERAL PUBLIC

Worksheet D01: Direct spray of child.			
<i>Verbal Description: A naked child is accidentally sprayed over the entire body surface with a field dilution as it is being applied. The child is effectively washed - i.e., all of the compound is removed - after 1 hour. The absorbed dose is estimated using the assumption of first-order dermal absorption.</i>			
Parameter/Assumption	Value	Units	Source/Reference
Period of exposure (<i>T</i>)	1	hour	N/A
Body weight (<i>W</i>)	13.3	kg	WSA04.BWC
Exposed surface area (<i>A</i>)	6030	cm ²	WSA04.SAC
Liquid adhering to skin per cm ² of exposed skin (<i>L</i>)	0.008	mL/cm ²	WSA02.LIQ
Concentrations in solution (<i>C</i>)			
Typical/Central	1.1	mg/mL	WSB02.TYPDR
Low	0.36	mg/mL	WSB02.LOWDR
High	36	mg/mL	WSB02.HI_DR
First-order dermal absorption rate (<i>k_a</i>)			
Central	0.00285	hour ⁻¹	WSB06.AbsC
Low	0.001340	hour ⁻¹	WSB06.AbsL
High	0.0061	hour ⁻¹	WSB06.AbsU
Estimated Absorbed Doses (<i>D</i>) - see calculations below.			
Central	0.01137	mg/kg	SPRYC
Low	0.001750	mg/kg	SPRYL
High	0.797	mg/kg	SPRYH

Details of calculations

Equation: $L \times C \times A \times k_a \times T \div W$

Central Estimate [SPRYCC]:

$$0.008 \text{ mL/cm}^2 \times 1.1 \text{ mg/mL} \times 6030 \text{ cm}^2 \times 0.00285 \text{ h}^{-1} \times 1 \text{ h} \div 13.3 \text{ kg} = 0.01137 \text{ mg/kg}$$

Lower Range of Estimate [SPRYCL]:

$$0.008 \text{ mL/cm}^2 \times 0.36 \text{ mg/mL} \times 6030 \text{ cm}^2 \times 0.00134 \text{ h}^{-1} \times 1 \text{ h} \div 13.3 \text{ kg} = 0.00175 \text{ mg/kg}$$

Upper Range of Estimate [SPRYCH]:

$$0.008 \text{ mL/cm}^2 \times 36 \text{ mg/mL} \times 6030 \text{ cm}^2 \times 0.0061 \text{ h}^{-1} \times 1 \text{ h} \div 13.3 \text{ kg} = 0.797 \text{ mg/kg}$$

Worksheet D02: Direct spray of woman.			
<i>Verbal Description: A woman is accidentally sprayed over the feet and legs with a field dilution as it is being applied. The woman washes and removes all of the compound after 1 hour. The absorbed dose is estimated using the assumption of first-order dermal absorption.</i>			
Parameter/Assumption	Value	Units	Source/Reference
Period of exposure (<i>T</i>)	1	hour	N/A
Body weight (<i>W</i>)	64	kg	WSA04.BWF
Exposed surface area (<i>A</i>)	2915	cm ²	WSA04.SAF1
Liquid adhering to skin per cm ² of exposed skin (<i>L</i>)	0.008	mL/cm ²	WSA02.LIQ
Concentrations in solution (<i>C</i>)			
Typical/Central	1.1	mg/mL	WSB02.TYPDR
Low	0.36	mg/mL	WSB02.LOWDR
High	36	mg/mL	WSB02.HI_DR
First-order dermal absorption rate (<i>k_a</i>)			
Central	0.00285	hour ⁻¹	WSB06.AbsC
Low	0.001340	hour ⁻¹	WSB06.AbsL
High	0.0061	hour ⁻¹	WSB06.AbsU
Estimated Absorbed Doses (<i>D</i>) - see calculations below.			
Central	0.001142	mg/kg	SPRYWC
Low	0.000176	mg/kg	SPRYWL
High	0.08	mg/kg	SPRYWH

Details of calculations

Equation: $L \times C \times S \times k_a \times T \div W$

Central Estimate [SPRYWC]:

$0.008 \text{ mL/cm}^2 \times 1.1 \text{ mg/mL} \times 2915 \text{ cm}^2 \times 0.00285 \text{ h}^{-1} \times 1 \text{ h} \div 64 \text{ kg} = 0.001142 \text{ mg/kg}$

Lower Range of Estimate [SPRYWL]:

$0.008 \text{ mL/cm}^2 \times 0.36 \text{ mg/mL} \times 2915 \text{ cm}^2 \times 0.00134 \text{ h}^{-1} \times 1 \text{ h} \div 64 \text{ kg} = 0.0001758 \text{ mg/kg}$

Upper Range of Estimate [SPRYWH]:

$0.008 \text{ mL/cm}^2 \times 36 \text{ mg/mL} \times 2915 \text{ cm}^2 \times 0.0061 \text{ h}^{-1} \times 1 \text{ h} \div 64 \text{ kg} = 0.08 \text{ mg/kg}$

Worksheet D03: Dermal contact with contaminated vegetation.			
<i>Verbal Description: A woman wearing shorts and a short sleeved shirt is in contact with contaminated vegetation for 1 hour shortly after application of the compound - i.e. no dissipation or degradation is considered. The chemical is effectively removed from the surface of the skin - i.e., washing - after 24 hours.</i>			
Parameter/Assumption	Value	Units	Source/Reference
Contact time (T_c)	1	hour	N/A
Exposure time (T_e)	24	hours	N/A
Body weight (W)	64	kg	WSA04.BWF
Exposed surface area (A)	5300	cm ²	WSA04.SAF2
Dislodgeable residue (Dr) as a proportion of application rate	0.1	none	WSA04.DisL
Application Rates(R)			
Typical/Central	0.5	lb a.i/acre	WSB01.TYP
Low	0.3	lb a.i/acre	WSB01.LOW
High	1.5	lb a.i/acre	WSB01.HI
First-order dermal absorption rate (k_a)			
Central	0.00285	hour ⁻¹	WSB06.AbsC
Low	0.001340	hour ⁻¹	WSB06.AbsL
High	0.00610	hour ⁻¹	WSB06.AbsU
Estimated Absorbed Doses (D) - see calculations on next page.			
Central	0.041630	mg/kg	VEGDWC
Low	0.011206	mg/kg	VEGDWL
High	0.2949	mg/kg	VEGDWH

Description of Calculations:

Step 1:

Use method of Durkin et al. (1995, p. 68, equation 4) to calculate dislodgeable residue (Dr) in units of $\mu\text{g}/(\text{cm}^2\cdot\text{hr})$ after converting application rate in lb a.e./acre to units of $\mu\text{g}/\text{cm}^2$:

$$x = \log(Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr}))) = (1.09 \times \log_{10}(R \times \text{WSA01.lbac_ugcm})) + 0.05$$

$$Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr})) = 10^x$$

Step 2:

Convert Dr from units of $\mu\text{g}/(\text{cm}^2\cdot\text{hr})$ to units of $\text{mg}/(\text{cm}^2\cdot\text{hr})$ by dividing by 1000:

$$Dr(\text{mg}/(\text{cm}^2\cdot\text{hr})) = Dr(\mu\text{g}/(\text{cm}^2\cdot\text{hr}))/1000$$

Step 3:

Estimate amount ($Amnt$) transferred to skin in mg during the exposure period:

$$Amnt(\text{mg}) = Dr(\text{mg}/(\text{cm}^2\cdot\text{hr})) \times T_c (\text{hours}) \times A (\text{cm}^2)$$

Step 4:

Estimate the absorbed dose (D_{Abs}) in mg/kg bw as the product of the amount on the skin, the first-order absorption rate, and the duration of exposure divided by the body weight:

$$D_{Abs} = Amnt(\text{mg}) \times k_a (\text{hours}^{-1}) \times T_e (\text{hours}) \div W (\text{kg})$$

See next page for details of calculations.

Worksheet D03 Details of calculations: Dermal Exposure to Contaminated Vegetation

Central Estimate:

Step 1:

$$\log_{10}(Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr})))0.866 = (1.09 \times \log_{10}(0.5 \times 11.21)) + 0.05 = 0.866 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$
$$Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr})) = 10^{0.866} = 7.35 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$

Step 2:

$$Dr (\text{mg}/(\text{cm}^2\cdot\text{hr})) = 7.35 \mu\text{g}/(\text{cm}^2\cdot\text{hr}) \div 1000 \mu\text{g}/\text{mg} = 0.00735 \text{mg}/(\text{cm}^2\cdot\text{hr})$$

Step 3:

$$Amnt(\text{mg}) = 0.00735 \text{mg}/(\text{cm}^2\cdot\text{hr}) \times 1 \text{hr} \times 5300 \text{cm}^2 = 38.955 \text{mg}$$

Step 4:

$$D_{Abs} (\text{mg}/\text{kg bw}) = 38.955 \text{mg} \times 0.00285 \text{hr}^{-1} \times 24 \text{hours} \div 64 \text{kg} = 0.04163 \text{ [VEGDWC]}$$

Lower Range of Estimate:

Step 1:

$$\log_{10}(Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr}))) = (1.09 \times \log_{10}(0.3 \times 11.21)) + 0.05 = 0.624 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$
$$Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr})) = 10^{0.624} = 4.207 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$

Step 2:

$$Dr (\text{mg}/(\text{cm}^2\cdot\text{hr})) = 4.207 \mu\text{g}/(\text{cm}^2\cdot\text{hr}) \div 1000 \mu\text{g}/\text{mg} = 0.004207 \text{mg}/(\text{cm}^2\cdot\text{hr})$$

Step 3:

$$Amnt(\text{mg}) = 0.004207 \text{mg}/(\text{cm}^2\cdot\text{hr}) \times 1 \text{hr} \times 5300 \text{cm}^2 = 22.3 \text{mg}$$

Step 4:

$$D_{Abs} (\text{mg}/\text{kg bw}) = 22.3 \text{mg} \times 0.00134 \text{hr}^{-1} \times 24 \text{hours} \div 64 \text{kg} = 0.0112058 \text{ [VEGDWL]}$$

Upper Range of Estimate:

Step 1:

$$\log_{10}(Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr}))) = (1.09 \times \log_{10}(1.5 \times 11.21)) + 0.05 = 1.386 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$
$$Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr})) = 10^{1.386} = 24.32 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$

Step 2:

$$Dr (\text{mg}/(\text{cm}^2\cdot\text{hr})) = 24.32 \mu\text{g}/(\text{cm}^2\cdot\text{hr}) \div 1000 \mu\text{g}/\text{mg} = 0.02432 \text{mg}/(\text{cm}^2\cdot\text{hr})$$

Step 3:

$$Amnt(\text{mg}) = 0.02432 \text{mg}/(\text{cm}^2\cdot\text{hr}) \times 1 \text{hr} \times 5300 \text{cm}^2 = 128.9 \text{mg}$$

Step 4:

$$D_{Abs} (\text{mg}/\text{kg bw}) = 128.9 \text{mg} \times 0.0061 \text{hr}^{-1} \times 24 \text{hours} \div 64 \text{kg} = 0.2949 \text{ [VEGDWH]}$$

Worksheet D04: Consumption of contaminated fruit, acute exposure scenario.			
<i>Verbal Description: A woman consumes 1 lb (0.4536 kg) of contaminated fruit shortly after application of the chemical - i.e. no dissipation or degradation is considered. Residue estimates based on relationships from Hoerger and Kenaga (1972) summarized in WSA07.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Body weight (W)	64	kg	WSA04.BWF
Amount of fruit consumed (A)	0.454	kg	N/A
Application rates (R)			
Typical	0.5	lb a.e./acre	WSB01.TYP
Lower	0.3	lb a.e./acre	WSB01.Low
Upper	1.5	lb a.e./acre	WSB01.Hi
Residue rates (rr)			
Typical	1.5	RUD ¹	WSA05a.FRT
Upper	7	RUD ¹	WSA05a.FRU
Dose estimates (D) - see details of calculations below			
Typical	0.0053	mg/kg bw	VEGCWAT
Lower	0.00319	mg/kg bw	VEGCWAL
Upper	0.074	mg/kg bw	VEGCWAU
¹ RUD: Residue Unit Dosage, term used by Hoerger and Kenaga (1972) for anticipated concentration on vegetation (mg chemical per kg of vegetation) for each 1 lb a.e./acre applied.			

Equation (terms defined in above table):

$$D \text{ (mg/kg bw)} = A(\text{kg}) \times R(\text{lb a.e./acre}) \times rr(\text{mg/kg} \div \text{lb a.e./acre}) \div W(\text{kg bw})$$

Details of Calculations

Typical: Use typical application rate and typical RUD.

$$D = 0.454 \text{ kg} \times 0.5 \text{ lb a.e./acre} \times 1.5 \text{ mg/kg} \div \text{lb a.e./acre} \div 64 \text{ kg} = 0.0053 \text{ mg/kg bw}$$

Lower: Use lowest estimated application rate. Use typical RUD because no lower estimate of the RUD is available.

$$D = 0.454 \text{ kg} \times 0.3 \text{ lb a.e./acre} \times 1.5 \text{ mg/kg} \div \text{lb a.e./acre} \div 64 \text{ kg} = 0.00319 \text{ mg/kg bw}$$

Upper: Use highest estimated application rate and highest RUD.

$$D = 0.454 \text{ kg} \times 1.5 \text{ lb a.e./acre} \times 7 \text{ mg/kg} \div \text{lb a.e./acre} \div 64 \text{ kg} = 0.074 \text{ mg/kg bw}$$

Worksheet D05: Consumption of contaminated fruit, chronic exposure scenario.

Verbal Description: A woman consumes contaminated fruit for a 90 day period starting shortly after application of the chemical. Initial residue estimates are based on relationships from Hoerger and Kenaga (1972) summarized in Worksheet A05a. The foliar half-time is used to estimate the concentration on vegetation after 90 days. The geometric mean of the initial and 90 day concentrations is used as a central/typical dose.

Parameters/Assumptions	Value	Units	Source/Reference	
Halftime on fruit ($t_{1/2}$)	central	??	days	WSB03.FrT12C
	lower	??	days	WSB03.FrT12L
	upper	??	days	WSB03.FrT12U
Duration of exposure (t)	90	days	N/A	
Body weight (W)	64	kg	WSA04.BWF	
Amount of vegetation consumed per unit body weight(A)				
Typical	0.0043	kg veg./kg bw	WSA04.VT	
Upper	0.01	kg veg./kg bw	WSA04.VU	
Application rates (R)				
Typical	0.5	lb a.e./acre	WSB01.Typ	
Lower	0.3	lb a.e./acre	WSB01.Low	
Upper	1.5	lb a.e./acre	WSB01.Hi	
Residue rates (rr)				
Typical	1.5	RUD ¹	WSA05a.FRT	
Upper	7	RUD ¹	WSA05aFRU	
Dose estimates (D) - see details of calculations on next page				
Typical	0.00110	mg/kg bw/day	VEGCWCT	
Lower	0.000690	mg/kg bw/day	VEGCWCL	
Upper	0.037	mg/kg bw/day	VEGCWCU	

¹ RUD: Residue Unit Dosage, term used by Hoerger and Kenaga (1972) for anticipated concentration on fruit (mg chemical per kg of vegetation) for each 1 lb a.e./acre applied.

Details of calculations on next page

Subchronic consumption of vegetation: Details of calculations

Equations (terms defined below or in table on previous page):

Step 1: Calculate C_0 , concentration in vegetation on Day 0 - i.e., day of application- as the product of the application rate (R) and the residue rate (rr):

$$C_0 \text{ (mg/kg)} = R \text{ (lb a.e./acre)} \times rr \text{ (mg/kg} \div \text{lb a.e./acre)}$$

Step 2: Calculate C_{90} , concentration in vegetation on Day 90 ($t=90$ days) based on dissipation coefficient (k) derived from foliar half-life ($t_{1/2}$).

$$k \text{ (days}^{-1}\text{)} = \ln(2) \div t_{1/2} \text{ (days)}$$

$$C_{90} \text{ (mg/kg)} = C_0 \text{ (mg/kg)} \times e^{-tk}$$

Step 3: Use the geometric mean of C_0 and C_{90} to get a central estimate of concentration in vegetation (mg/kg veg.) and multiply this value by the vegetation consumption (kg veg/kg bw) to calculate the daily dose (mg/kg bw) over the exposure period.

$$\begin{aligned} D \text{ (mg/kg bw)} &= (C_0 \times C_{90})^{0.5} \text{ (mg/kg veg.)} \times A \text{ kg veg./kg bw} \times W \text{ kg bw} \div B \text{ (kg bw)} \\ &= (C_0 \times C_{90})^{0.5} \text{ (mg/kg veg.)} \times A \text{ kg veg./kg bw} \end{aligned}$$

Central Estimate:

Use the typical application rate, the typical vegetation consumption rate, and the typical residue rate along with the central estimate of half-time on fruit.

Step 1:

$$C_0 = 0.5 \text{ lb a.e./acre} \times 1.5 \text{ mg/kg veg.} = 0.75 \text{ mg/kg veg.}$$

Step 2:

$$k = \ln(2) \div 30 \text{ days}^{-1} = 0.023$$

$$C_{90} = 0.75 \text{ mg/kg} \times e^{-0.023 \times 90} = 0.09 \text{ mg/kg veg.}$$

Step 3:

$$D \text{ (mg/kg bw/day)} = (0.75 \times 0.09)^{0.5} \text{ (mg/kg veg.)} \times 0.0043 \text{ kg veg/kg bw} = 0.0011 \text{ mg/kg bw}$$

Lower Estimate:

Use the lowest anticipated application rate along with the lower limit of the half-time of fruit. Also the typical vegetation consumption rate and the typical residue rate because lower limits on these estimates are not available.

Step 1:

$$C_0 = 0.3 \text{ lb a.e./acre} \times 1.5 \text{ mg/kg veg.} = 0.45 \text{ mg/kg veg.}$$

Step 2:

$$k = \ln(2) \div 30 \text{ days}^{-1} = 0.023$$

$$C_{90} = 0.45 \text{ mg/kg} \times e^{-0.023 \times 90} = 0.057 \text{ mg/kg veg.}$$

Step 3:

$$D \text{ (mg/kg bw)} = (0.45 \times 0.057)^{0.5} \text{ (mg/kg veg.)} \times 0.0043 \text{ (kg veg/kg bw)} = 0.00069 \text{ (mg/kg bw)}$$

Upper Estimate:

Use the highest anticipated application rate, the upper range of the vegetation consumption rate and the upper range of the residue rate along with the upper limit of the half-time on fruit.

Step 1:

$$C_0 = 1.5 \text{ lb a.e./acre} \times 7 \text{ mg/kg veg.} = 10.5 \text{ mg/kg veg.}$$

Step 2:

$$k = \ln(2) \div 30 \text{ days}^{-1} = 0.023$$

$$C_{90} = 10.5 \text{ mg/kg} \times e^{-0.023 \times 90} = 1.3 \text{ mg/kg veg.}$$

Step 3:

$$D \text{ (mg/kg bw)} = (10.5 \times 1.3)^{0.5} \text{ (mg/kg veg.)} \times 0.01 \text{ (kg veg/kg bw)} = 0.037 \text{ (mg/kg bw)}$$

Worksheet D06: Consumption of contaminated water, acute exposure scenario.			
<i>Verbal Description: A young child (2-3 years old) consumes 1 liter of contaminated water shortly after an accidental spill of 200 gallons of a field solution into a pond that has an average depth of 1 m and a surface area of 1000 m² or about one-quarter acre . No dissipation or degradation is considered.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Surface area of pond [SA]	1000	m ²	N/A
Average depth [DPTH]	1	m	N/A
Volume of pond in cubic meters [VM]	1000	m ³	N/A
Volume of pond in Liters [VL]	1000000	L	1 m ³ = 1,000 L
Volume of spill [VS]	200	gallons	N/A
Concentrations in solution (C_(mg/L))			
Central	1100	mg/L	WSB02.TypDR
Low	360	mg/L	WSB02.LowDR
High	36000	mg/L	WSB02.Hi_DR
Concentrations in ambient water (C_(mg/L))			
Central	0.83	mg/L	see calculations on next page
Low	0.273	mg/L	
High	27.25	mg/L	
Body weight (W)	13.3	kg	WSA04.BWC
Amount of water consumed (A)			
Typical	1	L/day	WSA04.WCT
Lower	0.61	L/day	WSA04.WCL
Upper	1.5	L/day	WSA04.WCH
Dose estimates (D) - see details of calculations on next page.			
Typical	0.062	mg/kg bw	WATCCAT
Lower	0.0125	mg/kg bw	WATCCAL
Upper	3.07	mg/kg bw	WATCCAU

Details of calculations on next page

Acute Consumption of Contaminated Water from an Accidental Spill

Details of calculations

Equations (terms defined below or in table on previous page)

Step 1: Calculate the concentration in the pond based on the concentration in the spilled solution, the volume spilled and the volume of the pond, assuming instantaneous mixing.

$$\text{Conc. (mg/L)} = \text{VS (gal)} \times 3.785 \text{ L/gal} \times C \text{ (mg/L)} \div \text{VL (liters)}$$

Step 2: Calculate the dose based on the concentration in the water, the amount of water consumed, and the body weight.

$$D \text{ (mg/kg bw)} = \text{Conc. (mg/L)} \times A \text{ (L)} \div W \text{ (kg)}$$

Calculations

Central Estimate:

Use the typical field dilution, and the typical water consumption.

Step 1:

$$\text{Conc. (mg/L)} = 200 \text{ (gal)} \times 3.785 \text{ L/gal} \times 1100 \text{ (mg/L)} \div 1000000 \text{ (liters)} = 0.83 \text{ (mg/L)}$$

Step 2:

$$D \text{ (mg/kg bw)} = 0.83 \text{ (mg/L)} \times 1 \text{ (L)} \div 13.3 \text{ (kg)} = 0.062 \text{ (mg/kg bw)} \text{ [WATCCAT]}$$

Lower Estimate:

Use the lowest estimated field dilution and the lower range of water consumption.

Step 1:

$$\text{Conc. (mg/L)} = 200 \text{ (gal)} \times 3.785 \text{ L/gal} \times 360 \text{ (mg/L)} \div 1000000 \text{ (liters)} = 0.273 \text{ (mg/L)}$$

Step 2:

$$D \text{ (mg/kg bw)} = 0.273 \text{ (mg/L)} \times 0.61 \text{ (L)} \div 13.3 \text{ (kg)} = 0.0125 \text{ (mg/kg bw)} \text{ [WATCCAL]}$$

Upper Estimate:

Use the highest estimated field concentration and the upper range of water consumption.

Step 1:

$$\text{Conc. (mg/L)} = 200 \text{ (gal)} \times 3.785 \text{ L/gal} \times 36000 \text{ (mg/L)} \div 1000000 \text{ (liters)} = 27.25 \text{ (mg/L)}$$

Step 2:

$$D \text{ (mg/kg bw)} = 27.25 \text{ (mg/L)} \times 1.5 \text{ (L)} \div 13.3 \text{ (kg)} = 3.07 \text{ (mg/kg bw)} \text{ [WATCCAU]}$$

Worksheet D07: Consumption of contaminated water, chronic exposure scenario.			
<i>Verbal Description: An adult (70 kg male) consumes contaminated ambient water for a lifetime. The levels in water are estimated from monitoring data and thus dissipation, degradation and other environmental processes are implicitly considered.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Application Rates (R (lb a.e./acre))			
Central	0.5	lb a.e./gal	WSB01.TYP
Low	0.3		WSB01.Low
High	1.5		WSB01.Hi
Water Contamination Rate (WCR)(C (mg/L) ÷ R (lb a.e./acre))			
Central	0.025	mg/L/lb a.e./acre	WSB07.AWT
Low	0.01		WSB07.AWL
High	0.06		WSB07.AWU
Body weight (W)	70	kg	WSA046.BWM
Amount of water consumed (A (L/day))			
Typical	2	L/day	WSA04.WCAT
Lower	1.4	L/day	WSA04.WCAL
Upper	2.4	L/day	WSA04.WCAH
Dose estimates (D) - see details of calculations on next page.			
Typical	0.00036	mg/kg bw/day	WATCMCT
Lower	0.0000600	mg/kg bw/day	WATCMCL
Upper	0.0031	mg/kg bw/day	WATCMCU

Details of calculations on next page

Chronic Consumption of Contaminated Ambient Water

Details of calculations

Equations (terms defined in table on previous page)

Verbal Description: Multiply the application rate (R (lb a.e./acre)) by the water contamination rate (WCR ((mg/L)×(lb a.e./acre))) to get the concentration in ambient water. This product is in turn multiplied by the amount of water consumed per day (A (L/day)) and then divided by the body weight (W (kg)) to get the estimate of the absorbed dose (D (mg/kg bw)).

$$D_{(\text{mg/kg bw})} = R_{(\text{lb a.e./acre})} \times WCR_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times A_{(\text{L/day})} \div W_{(\text{kg})}$$

Central Estimate:

Use the typical application rate, typical contamination rate (WCR), and the typical water consumption.

$$D_{(\text{mg/kg bw})} = 0.5_{(\text{lb a.e./acre})} \times 0.025_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 2_{(\text{L/day})} \div 70_{(\text{kg bw})} = 0.00036_{(\text{mg/kg bw})} \text{ [WATCMCT]}$$

Lower Range of Estimate:

Use the lowest anticipated application rate, the low end of the range of the water contamination rate (WCR), and the low end of the range for water consumption.

$$D_{(\text{mg/kg bw})} = 0.3_{(\text{lb a.e./acre})} \times 0.01_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 1.4_{(\text{L/day})} \div 70_{(\text{kg bw})} = 0.0000600_{(\text{mg/kg bw})} \text{ [WATCMCL]}$$

Upper range of Estimate:

Use the highest anticipated application rate, the high end of the range of the water contamination rate (WCR), and the high end of the range for water consumption.

$$D_{(\text{mg/kg bw})} = 1.5_{(\text{lb a.e./acre})} \times 0.06_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 2.4_{(\text{L/day})} \div 70_{(\text{kg bw})} = 0.0031_{(\text{mg/kg bw})} \text{ [WATCMCU]}$$

Worksheet D08: Consumption of contaminated fish, acute exposure scenario.

Verbal Description: An adult angler consumes fish taken from contaminated water shortly after an accidental spill of 200 gallons of a field solution into a pond that has an average depth of 1 m and a surface area of 1000 m² or about one-quarter acre . No dissipation or degradation is considered. Because of the available and well documented information and substantial differences in the amount of caught fish consumed by the general public and native American subsistence populations, separate exposure estimates are made for these two groups.

Parameters/Assumptions	Value	Units	Source/Reference
Surface area of pond [SA]	1000	m ²	N/A
Average depth [DPTH]	1	m	N/A
Volume of pond in cubic meters [VM]	1000	m ³	N/A
Volume of pond in Liters [VL]	1000000	L	1 m ³ = 1,000 L
Volume of spill [VS]	200	gallons	N/A
Concentrations in spilled solution (C_(mg/L))			
Central	1100	mg/L	WSB02.TYPDR×1000
Low	360	mg/L	WSB02.LOWDR×1000
High	36000	mg/L	WSB02.HI_DR×1000
Body weight (W)	70	kg	WSA04.BWM
Amount of fish consumed (A)			
General Population	0.158	kg/day	WSA04.FAU
Native American subsistence populations	0.77	kg/day	WSA04.FNU
Bioconcentration factor (BCF _(kg fish/L))	1	kg fish/L	WSB03.BCFT
Dose estimates (D) - see details of calculations on next page.			
General Population			
Typical	0.0019	mg/kg bw	FISHAMGPT
Lower	0.00062	mg/kg bw	FISHAMGPL
Upper	0.0615	mg/kg bw	FISHAMGPU
Native American subsistence populations			
Typical	0.0091	mg/kg bw	FISHAMNAT
Lower	0.00297	mg/kg bw	FISHAMNAL
Upper	0.3	mg/kg bw	FISHAMNAU

Details of calculations on next page

Acute Consumption of Contaminated Fish after an Accidental Spill

Details of calculations

Equations (terms defined below or in table on previous page)

Step 1: As in the acute drinking water scenario, calculate the concentration in the pond based on the concentration in the spilled solution, the volume spilled and the volume of the pond, assuming instantaneous mixing.

$$\text{Conc. (mg/L)} = VS_{\text{(gal.)}} \times 3.785_{\text{L/gal}} \times C_{\text{(mg/L)}} \div VL_{\text{(liters)}}$$

Step 2: Calculate the dose based on the concentration in the water, the bioconcentration factor, the amount of fish consumed, and the body weight.

$$D_{\text{(mg/kg bw)}} = \text{Conc. (mg/L)} \times BCF_{\text{(kg fish/L)}} \times A_{\text{(kg fish)}} \div W_{\text{(kg bw)}}$$

General Public

Central Estimate:

Use the typical field dilution as well as the experimental BCF and upper range of daily fish consumption for the general public.

Step 1:

$$\text{Conc. (mg/L)} = 200_{\text{(gal.)}} \times 3.785_{\text{L/gal}} \times 1100_{\text{(mg/L)}} \div 1000000_{\text{(liters)}} = 0.83_{\text{(mg/L)}}$$

Step 2:

$$D_{\text{(mg/kg bw)}} = 0.83_{\text{(mg/L)}} \times 1_{\text{(L/kg)}} \times 0.158_{\text{(kg fish)}} \div 70_{\text{(kg)}} = 0.00190_{\text{(mg/kg bw)}} \quad [\text{FISHAMGPT}]$$

Lower End of Range for the Estimate:

Use the lower field dilution as well as the experimental BCF and upper range of daily fish consumption for the general public.

Step 1:

$$\text{Conc. (mg/L)} = 200_{\text{(gal.)}} \times 3.785_{\text{L/gal}} \times 360_{\text{(mg/L)}} \div 1000000_{\text{(liters)}} = 0.273_{\text{(mg/L)}}$$

Step 2:

$$D_{\text{(mg/kg bw)}} = 0.273_{\text{(mg/L)}} \times 1_{\text{(L/kg)}} \times 0.158_{\text{(kg fish)}} \div 70_{\text{(kg)}} = 0.00062_{\text{(mg/kg bw)}} \quad [\text{FISHAMGPL}]$$

Upper End of Range for the Estimate:

Use the upper field dilution as well as the experimental BCF and upper range of daily fish consumption for the general public.

Step 1:

$$\text{Conc. (mg/L)} = 200_{\text{(gal.)}} \times 3.785_{\text{L/gal}} \times 36000_{\text{(mg/L)}} \div 1000000_{\text{(liters)}} = 27.25_{\text{(mg/L)}}$$

Step 2:

$$D_{\text{(mg/kg bw)}} = 27.25_{\text{(mg/L)}} \times 1_{\text{(L/kg)}} \times 0.158_{\text{(kg fish)}} \div 70_{\text{(kg)}} = 0.0615_{\text{(mg/kg bw)}} \quad [\text{FISHAMGPU}]$$

(continued on next page)

Acute Consumption of Contaminated Fish after an Accidental Spill

Details of calculations (continued)

Native American Subsistence Populations

Central Estimate:

Use the typical field dilution as well as the experimental BCF and upper range of daily fish consumption for the native American subsistence populations.

Step 1:

$$\text{Conc. (mg/L)} = 200_{(\text{gal})} \times 3.785_{\text{L/gal}} \times 1100_{(\text{mg/L})} \div 1000000_{(\text{liters})} = 0.83_{(\text{mg/L})}$$

Step 2:

$$D_{(\text{mg/kg bw})} = 0.83_{(\text{mg/L})} \times 1_{(\text{L/kg})} \times 0.77_{(\text{kg fish})} \div 70_{(\text{kg})} = 0.0091_{(\text{mg/kg bw})} \text{ [FISHAMNAT]}$$

Estimate of Lower End of Range:

Use the lower field dilution as well as the experimental BCF and upper range of daily fish consumption for the native American subsistence populations.

Step 1:

$$\text{Conc. (mg/L)} = 200_{(\text{gal})} \times 3.785_{\text{L/gal}} \times 360_{(\text{mg/L})} \div 1000000_{(\text{liters})} = 0.270_{(\text{mg/L})}$$

Step 2:

$$D_{(\text{mg/kg bw})} = 0.27_{(\text{mg/L})} \times 1_{(\text{L/kg})} \times 0.77_{(\text{kg fish})} \div 70_{(\text{kg})} = 0.00297_{(\text{mg/kg bw})} \text{ [FISHAMNAL]}$$

Estimate of Upper End of Range:

Use the upper field dilution as well as the experimental BCF and upper range of daily fish consumption for the native American subsistence populations.

Step 1:

$$\text{Conc. (mg/L)} = 200_{(\text{gal})} \times 3.785_{\text{L/gal}} \times 36000_{(\text{mg/L})} \div 1000000_{(\text{liters})} = 27.250_{(\text{mg/L})}$$

Step 2:

$$D_{(\text{mg/kg bw})} = 27.25_{(\text{mg/L})} \times 1_{(\text{L/kg})} \times 0.77_{(\text{kg fish})} \div 70_{(\text{kg})} = 0.3_{(\text{mg/kg bw})} \text{ [FISHAMNAU]}$$

Worksheet D09: Consumption of contaminated fish, chronic exposure scenario.			
<i>Verbal Description: An adult (70 kg male) consumes fish taken from contaminated ambient water for a lifetime. The levels in water are estimated from monitoring data and thus dissipation, degradation and other environmental processes are implicitly considered.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Application Rates (R (lb a.e./acre))			
Central	0.5	lb a.e./gal	WSB01.TYP
Low	0.3		WSB01.Low
High	1.5		WSB01.Hi
Water Contamination Rate (WCR)(C (mg/L) ÷ R (lb a.e./gal))			
Central	0.025	mg/L/lb a.e./acre	WSB07.AWT
Low	0.01		WSB07.AWL
High	0.06		WSB07.AWU
Bioconcentration factor (BCF (kg fish/L))	1	kg fish/L	WSB03.BCFT
Body weight (W)	70	kg	WSA04.BWM
Amount of fish consumed (A)			
General Population typical	0.01	kg/day	WSA04.FAT
upper limit	0.158	kg/day	WSA04.FAU
Native American subsistence populations typical	0.081	kg/day	WSA04.FNT
upper limit	0.77	kg/day	WSA04.FNU
Dose estimates (D) - see details of calculations on next page.			
General Public			
Typical	0.00000179	mg/kg bw/day	FISHMCT
Lower	0.000000429	mg/kg bw/day	FISHMCL
Upper	0.00020	mg/kg bw/day	FISHMCU
Native American Subsistence Population			
Typical	0.0000145	mg/kg bw/day	FISHNMCT
Lower	0.00000347	mg/kg bw/day	FISHNMCL
Upper	0.00099	mg/kg bw/day	FISHNMCU

Details of calculations on next page

Chronic Consumption of Contaminated Fish, Details of calculations

Equations (terms defined below or in table on previous page)

Verbal Description: Multiply the application rate (R (lb a.e./acre)) by the water contamination rate (WCR ((mg/L)×(lb a.e./acre))) to get the concentration in ambient water. This product is in turn multiplied by the bioconcentration factor (BCF (kg fish/L)) and the amount of fish consumed per day (A (kg fish/day)) and then divided by the body weight (W (kg bw)) to get the estimate of the absorbed dose (D (mg/kg bw)).

$$D_{(\text{mg/kg bw})} = R_{(\text{lb a.e./acre})} \times WCR_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times A_{(\text{kg/day})} \times BCF_{(\text{kg fish/L})} \div W_{(\text{kg})}$$

General Public

Central Estimate:

Use the typical application rate, typical contamination rate (WCR), the typical fish consumption, the measured bioconcentration factor, and standard body weight.

$$D_{(\text{mg/kg bw})} = 0.5_{(\text{lb a.e./acre})} \times 0.025_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 1_{(\text{kg fish/L})} \times 0.01_{(\text{kg fish/day})} \div 70_{(\text{kg bw})} = 0.00000179_{(\text{mg/kg bw})} \text{ [FISHMCT]}$$

Lower Range of Estimate:

Use the lowest anticipated application rate, lower range of contamination rate (WCR), the typical fish consumption, the measured bioconcentration factor, and standard body weight. Typical fish consumption is used because there is no published lower estimate.

$$D_{(\text{mg/kg bw})} = 0.3_{(\text{lb a.e./acre})} \times 0.01_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 1_{(\text{kg fish/L})} \times 0.01_{(\text{kg fish/day})} \div 70_{(\text{kg bw})} = 0.000000429_{(\text{mg/kg bw})} \text{ [FISHMCL]}$$

Upper Range of Estimate:

Use the highest labelled application rate, upper range of contamination rate (WCR), the maximum fish consumption, the measured bioconcentration factor, and standard body weight.

$$D_{(\text{mg/kg bw})} = 1.5_{(\text{lb a.e./acre})} \times 0.06_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 1_{(\text{kg fish/L})} \times 0.158_{(\text{kg fish/day})} \div 70_{(\text{kg bw})} = 0.00020_{(\text{mg/kg bw})} \text{ [FISHMCU]}$$

Chronic Consumption of Contaminated Fish

Details of calculations (continued)

Native American Subsistence Populations

Central Estimate:

Use the typical application rate, typical contamination rate (WCR), the typical fish consumption for native American subsistence populations, the measured bioconcentration factor, and standard body weight.

$$D_{(\text{mg/kg bw})} = 0.5_{(\text{lb a.e./acre})} \times 0.025_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 1_{(\text{kg fish/L})} \times 0.081_{(\text{kg fush/day})} \div 70_{(\text{kg bw})} = 0.0000145_{(\text{mg/kg bw})} \text{ [FISHMCT]}$$

Lower Range of Estimate:

Use the lowest anticipated application rate, lower range of contamination rate (WCR), the typical fish consumption for native American subsistence populations, the measured bioconcentration factor, and standard body weight. Typical fish consumption is used because there is no published lower estimate.

$$D_{(\text{mg/kg bw})} = 0.3_{(\text{lb a.e./acre})} \times 0.01_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 1_{(\text{kg fish/L})} \times 0.081_{(\text{kg fush/day})} \div 70_{(\text{kg bw})} = 0.00000347_{(\text{mg/kg bw})} \text{ [FISHMCL]}$$

Upper Range of Estimate:

Use the highest labelled application rate, upper range of contamination rate (WCR), the maximum fish consumption for native American subsistence populations, the measured bioconcentration factor, and standard body weight.

$$D_{(\text{mg/kg bw})} = 1.5_{(\text{lb a.e./acre})} \times 0.06_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 1_{(\text{kg fish/L})} \times 0.77_{(\text{kg fush/day})} \div 70_{(\text{kg bw})} = 0.00099_{(\text{mg/kg bw})} \text{ [FISHMCU]}$$

SUMMARY TABLES FOR HUMAN HEALTH RISK ASSESSMENT

Worksheet E01: Summary of Worker Exposure Scenarios

Scenario	Dose (mg/kg/day or event)			Exposure Assessment Worksheet
	Typical	Lower	Upper	
General Exposures (dose in mg/kg/day)				
Directed ground spray (Backpack)	0.0066	0.000135	0.12	WSC01
Broadcast ground spray (Boom spray)	0.0112	0.000198	0.23	WSC02a
Aerial applications	0.0074	0.00012	0.04	WSC02b
Accidental/Incidental Exposures (dose in mg/kg/event)				
Immersion of Hands, 1 minute	0.00012	0.00003	0.00608	WSC03
Contaminated Gloves, 1 hour	0.00742	0.00162	0.36504	WSC03
Spill on hands, 1 hour	0.00030	0.00005	0.0211	WSC04
Spill on lower legs, 1 hour	0.00074	0.00011	0.052	WSC04

Worksheet E02: Summary of risk characterization for workers¹

RfD	0.2	mg/kg/day	Sect. 3.3.3.	
Scenario	Hazard Quotient			Exposure Assessment Worksheet
	Typical	Lower	Upper	
General Exposures				
Directed ground spray (Backpack)	0.03	0.001	0.6	WSC01
Broadcast ground spray (Boom spray)	0.06	0.001	1	WSC02a
Aerial applications	0.04	0.0006	0.2	WSC02b
Accidental/Incidental Exposures				
Immersion of Hands, 1 minute	0.0006	0.0001	0.03	WSC03
Contaminated Gloves, 1 hour	0.04	0.008	1.8	WSC03
Spill on hands, 1 hour	0.002	0.0002	0.1	WSC04
Spill on lower legs, 1 hour	0.004	0.0006	0.3	WSC04

¹ Hazard quotient is the level of exposure divided by the provisional RfD then rounded to one significant decimal place or digit. See Worksheet E01 for summary of exposure assessment.

Worksheet E03: Summary of Exposure Scenarios for the General Public

Scenario	Target	Dose (mg/kg/day)			Worksheet
	Typical	Lower	Upper		
Acute/Accidental Exposures					
Direct spray, entire body	Child	0.01137	0.00175	0.797	WSD01
Direct spray, lower legs	Woman	0.001142	0.0001758	0.08	WSD02
Dermal, contaminated vegetation	Woman	0.04163	0.011206	0.2949	WSD03
Contaminated fruit, acute exposure	Woman	0.0053	0.00319	0.074	WSD04
Contaminated water, acute exposure	Child	0.062	0.0125	3.07	WSD06
Consumption of fish, general public	Man	0.0019	0.00062	0.0615	WSD08
Consumption of fish, subsistence populations	Man	0.0091	0.00297	0.3	WSD08
Chronic/Longer Term Exposures					
Contaminated fruit	Woman	0.0011	0.00069	0.037	WSD05
Consumption of water	Man	0.00036	6.00e-05	0.0031	WSD07
Consumption of fish, general public	Man	1.79e-06	4.29e-07	0.0002	WSD09
Consumption of fish, subsistence populations	Man	1.45e-05	3.47e-06	0.00099	WSD09

Worksheet E04: Summary of risk characterization for the general public ¹.

RfD		0.2	mg/kg/day	Sect. 3.3.3.	
Scenario	Target	Hazard Quotient			Worksheet
	Typical	Lower	Upper		
Acute/Accidental Exposures					
Direct spray, entire body	Child	0.06	0.009	4	WSD01
Direct spray, lower legs	Woman	0.006	0.0009	0.4	WSD02
Dermal, contaminated vegetation	Woman	0.2	0.06	1.5	WSD03
Contaminated fruit, acute exposure	Woman	0.03	0.02	0.4	WSD04
Contaminated water, acute exposure	Child	0.3	0.06	15	WSD06
Consumption of fish, general public	Man	0.01	0.003	0.3	WSD08
Consumption of fish, subsistence populations	Man	0.05	0.01	1.5	WSD08
Chronic/Longer Term Exposures					
Contaminated fruit	Woman	0.006	0.003	0.2	WSD05
Consumption of water	Man	0.002	0.0003	0.02	WSD07
Consumption of fish, general public	Man	0.000009	0.000002	0.001	WSD09
Consumption of fish, subsistence populations	Man	0.00007	0.00002	0.005	WSD09

¹ Hazard quotient is the level of exposure divided by the RfD then rounded to one significant decimal place or digit. See Worksheet E02 for summary of exposure assessments.

EXPOSURE ASSESSMENTS for Terrestrial Species

Worksheet F01: Direct spray of small mammal assuming first order absorption kinetics.			
<i>Verbal Description: A 20 g mammal is directly sprayed over one half of the body surface as the chemical is being applied. The absorbed dose over the first day - i.e., a 24 hour period) is estimated using the assumption of first-order dermal absorption. In the absence of any data on dermal absorption in a small mammal, the estimated absorption rate for humans is used. An empirical relationship between body weight and surface area (Boxenbaum and D'Souze 1990) is used to estimate the surface area of the animal.</i>			
Parameter/Assumption	Value	Units	Source/Reference
Period of exposure (<i>T</i>)	24	hour	N/A
Body weight (<i>W</i>)	0.020	kg	Section 4.2.1.
Exposed surface area (<i>A</i>)	$\text{cm}^2=1110 \times \text{BW}(\text{kg})^{0.65}$		Boxenbaum and D'Souza 1990
	87	cm ²	
Application rate (<i>R</i>)			
Typical/Central	0.5	lb a.e. /acre	WSB01.TYP
Low	0.3		WSB01.LOW
High	1.5		WSB01.HI
Conversion Factor (<i>F</i>) for lb/acre to mg/cm ²	0.01121		WSA01.LBAC_MGCM
First-order dermal absorption rate (<i>k_a</i>)			
Central	0.00285	hour ⁻¹	WSB06.AbsC
Low	0.001340	hour ⁻¹	WSB06.AbsL
High	0.00610	hour ⁻¹	WSB06.AbsU
Estimated Absorbed Doses (<i>D</i>) - see calculations below.			
Central	0.806	mg/kg	SMDSDC
Low	0.23149	mg/kg	SMDSDL
High	4.98	mg/kg	SMDSDH

Details of calculations on next page.

Direct Spray of Small Mammal, first-order absorption, Details of calculations

Equation: $0.5 \times F \times R \times A \times I^{-ka \times T} \div W$

Verbal Description: Multiply by 0.5 because only one half of the body surface is assumed to be sprayed. Calculate the amount deposited on the animal as the product of the application rate converted to mg/cm² and the surface area of the animal in cm². Get the proportion of the amount that is absorbed using the assumption of first order absorption kinetics. Divide by the body weight.

Central Estimate: Use the central estimate of the application rate and dermal absorption rate,
 $0.5 \times 0.01121 \text{ (mg/cm}^2\text{:lb/acre)} \times 0.5 \text{ lb/acre} \times 87 \text{ cm}^2$
 $\times 1\text{-e}^{-0.00285/\text{h} \times 24\text{h}} \div 0.02 \text{ kg} = 0.806 \text{ mg/kg}$ [SMDSDC]

Lower Range of Estimate: Use the lowest anticipated application rate and lower 95% limit of the estimated dermal absorption rate,
 $0.5 \times 0.01121 \text{ (mg/cm}^2\text{:lb/acre)} \times 0.3 \text{ lb/acre} \times 87 \text{ cm}^2$
 $\times 1\text{-e}^{-0.00134/\text{h} \times 24 \text{ h}} \div 0.02 \text{ kg} = 0.23149 \text{ mg/kg}$ [CMDSDL]

Upper Range of Estimate: Use the highest anticipated application rate and upper 95% limit of the estimated dermal absorption rate,
 $0.5 \times 0.01121 \text{ (mg/cm}^2\text{:lb/acre)} \times 1.5 \text{ lb/acre} \times 87 \text{ cm}^2$
 $\times 0.0061/\text{h} \times 24 \text{ h)} \div 0.02 \text{ kg} = 4.98 \text{ mg/kg}$ [DMDS DH]

Worksheet F02: Direct spray of small mammal assuming 100% absorption over the first 24 hour period.			
<i>Verbal Description: A 20 g mammal is directly sprayed over one half of the body surface as the chemical is being applied. The deposited dose is assumed to be completely absorbed during the first day. An empirical relationship between body weight and surface area (Boxenbaum and D'Souza 1990) is used to estimate the surface area of the animal.</i>			
Parameter/Assumption	Value	Units	Source/Reference
Period of exposure (T)	24	hour	N/A
Body weight (W)	0.020	kg	Section 4.2.1.
Exposed surface area (A)	$\text{cm}^2=1110 \times \text{BW}(\text{kg})^{0.65}$		Boxenbaum and D'Souza 1990
	87	cm^2	
Application rate (R)			
Typical/Central	0.5	lb a.e. /acre	WSB01.TYP
Low	0.3		WSB01.LOW
High	1.5		WSB01.HI
Conversion Factor (F) for lb/acre to mg/cm^2	0.01121		WSA01.LBAC_MGCM
Estimated Absorbed Doses (D) - see calculations below.			
Central	12.2	mg/kg	SMDS2DC
Low	7.31	mg/kg	SMDS2DL
High	36.6	mg/kg	SMDS2DH

Direct Spray of Small Mammal, Complete absorption, Details of calculations

Equation: $0.5 \times F \times R \times A \div W$

Verbal Description: Multiply by 0.5 because only one half of the body surface is assumed to be sprayed. Calculate the amount deposited on the animal as the product of the application rate converted to mg/cm^2 and the surface area of the animal in cm^2 . Divide by the body weight.

Central Estimate: Use the central estimate of the application rate,
 $0.5 \times 0.01121 \text{ (mg}/\text{cm}^2 \div \text{lb}/\text{acre}) \times 0.5 \text{ lb}/\text{acre} \times 87 \text{ cm}^2 \div 0.02 \text{ kg} = 12.2 \text{ mg}/\text{kg}$ [SMDS2DC]

Lower Range of Estimate [WSE042DL]: Use the lowest anticipated application rate,
 $0.5 \times 0.01121 \text{ (mg}/\text{cm}^2 \div \text{lb}/\text{acre}) \times 0.3 \text{ lb}/\text{acre} \times 87 \text{ cm}^2 \div 0.02 \text{ kg} = 7.31 \text{ mg}/\text{kg}$ [SMDS2DL]

Upper Range of Estimate [WSE042DH]: Use the highest anticipated application rate,
 $0.5 \times 0.01121 \text{ (mg}/\text{cm}^2 \div \text{lb}/\text{acre}) \times 1.5 \text{ lb}/\text{acre} \times 87 \text{ cm}^2 \div 0.02 \text{ kg} = 36.6 \text{ mg}/\text{kg}$ [SMDS2DU]

Worksheet F03: Direct spray of bee assuming 100% absorption over the first 24 hour period.			
<i>Verbal Description: A 0.093 g bee is directly sprayed over one half of the body surface as the chemical is being applied. The deposited dose is assumed to be completely absorbed during the first day. An empirical relationship between body weight and surface area (Boxenbaum and D'Souza 1990) is used to estimate the surface area of the animal.</i>			
Parameter/Assumption	Value	Units	Source/Reference
Period of exposure (T)	24	hour	N/A
Body weight (W)	0.000093	kg	Section 4.2.1.
Exposed surface area (A)	$\text{cm}^2 = 1110 \times \text{BW}(\text{kg})^{0.65}$		Boxenbaum and D'Souza 1990
	2.7	cm ²	
Application rate (R)			
Typical/Central	0.5	lb a.e. /acre	WSB01.TYP
Low	0.3		WSB01.LOW
High	1.5		WSB01.HI
Conversion Factor (F) for lb/acre to mg/cm ²	0.01121		WSA01.LBAC_MGCM
Estimated Absorbed Doses (D) - see calculations below.			
Central	81	mg/kg	BEEDS2DC
Low	48.8	mg/kg	BEEDS2DL
High	244	mg/kg	BEEDS2DH

Direct Spray of Bee, Complete absorption, Details of calculations

Equation: $0.5 \times F \times R \times A \div W$

Verbal Description: Multiply by 0.5 because only one half of the body surface is assumed to be sprayed. Calculate the amount deposited on the animal as the product of the application rate converted to mg/cm² and the surface area of the animal in cm². Divide by the body weight.

Central Estimate: Use the central estimate of the application rate,
 $0.5 \times 0.01121 \text{ (mg/cm}^2 \div \text{lb/acre)} \times 0.5 \text{ lb/acre} \times 2.7 \text{ cm}^2 \div 0.000093 \text{ kg} = 81 \text{ mg/kg [BEEDS2DC]}$

Lower Range of Estimate: Use the lowest anticipated application rate,
 $0.5 \times 0.01121 \text{ (mg/cm}^2 \div \text{lb/acre)} \times 0.3 \text{ lb/acre} \times 2.7 \text{ cm}^2 \div 0.000093 \text{ kg} = 48.8 \text{ mg/kg [BEEDS2DL]}$

Upper Range of Estimate: Use the highest anticipated application rate,
 $0.5 \times 0.01121 \text{ (mg/cm}^2 \div \text{lb/acre)} \times 1.5 \text{ lb/acre} \times 2.7 \text{ cm}^2 \div 0.000093 \text{ kg} = 244 \text{ mg/kg [BEEDS2DH]}$

Worksheet F04: Consumption of contaminated vegetation by a small mammal, acute exposure scenario.			
<i>Verbal Description: A 20 g mammal consumes vegetation shortly after application of the chemical - i.e. no dissipation or degradation is considered. The contaminated vegetation accounts for 100% of the diet. Residue estimates based on relationships for leaves and leafy vegetables from Hoerger and Kenaga (1972) summarized in Worksheet A05a.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Body weight (<i>W</i>)	0.020	kg	N/A
Food consumed per day (<i>A</i>)	0.003	kg	U.S. EPA 1989a
Duration of exposure (<i>D</i>)	1	day	N/A
Application rates (<i>R</i>)			
Typical	0.5	lb a.e./acre	WSB01.Typ
Lower	0.3	lb a.e./acre	WSB01.Low
Upper	1.5	lb a.e./acre	WSB01.Hi
Residue rates (<i>rr</i>)			
Typical	35	RUD ¹	WSA05a.LVT
Upper	125	RUD ¹	WSA05a.LVU
Dose estimates (<i>D</i>) - see details of calculations below			
Typical	2.63	mg/kg bw	VGCSMAC
Lower	1.58	mg/kg bw	VGCSMAL
Upper	28.1	mg/kg bw	VGCSMAU
¹ RUD: Residue Unit Dosage, term used by Hoerger and Kenaga (1972) for anticipated concentration on vegetation (mg chemical per kg of vegetation) for each 1 lb a.e./acre applied.			

Equation (terms defined in above table):

$$D \text{ (mg/kg bw)} = A(\text{kg}) \times R(\text{lb a.e./acre}) \times rr(\text{mg/kg veg.} \div \text{lb a.e./acre}) \div W(\text{kg bw})$$

Details of Calculations

Typical: Use typical application rate and typical RUD.

$$D = 0.003 \text{ kg} \times 0.5 \text{ lb a.e./acre} \times 35 \text{ mg/kg} \div \text{lb a.e./acre} \div 0.02 \text{ kg} = 2.63 \text{ mg/kg bw [VGCSMAC]}$$

Lower: Use lowest estimated application rate. Use typical RUD because no lower estimate of the RUD is available.

$$D = 0.003 \text{ kg} \times 0.3 \text{ lb a.e./acre} \times 35 \text{ mg/kg} \div \text{lb a.e./acre} \div 0.02 \text{ kg} = 1.58 \text{ mg/kg bw [VGCSMAL]}$$

Upper: Use highest estimated application rate and highest RUD.

$$D = 0.003 \text{ kg} \times 1.5 \text{ lb a.e./acre} \times 125 \text{ mg/kg} \div \text{lb a.e./acre} \div 0.02 \text{ kg} = 28.1 \text{ mg/kg bw [VGCSMAU]}$$

Worksheet F05: Consumption of contaminated vegetation by a small mammal, chronic exposure scenario.

Verbal Description: A 20 g mammal consumes contaminated vegetation for a 90 day period starting shortly after application of the chemical. It is assumed that 100% of the diet is contaminated. Initial residue estimates are based on relationships for leaves and leafy vegetables from Hoerger and Kenaga (1972) summarized in Worksheet A05a. The foliar half-time is used to estimate the concentration on vegetation after 90 days. The geometric mean of the initial and 90 day concentrations is used as the estimate of the dose.

Parameters/Assumptions	Value	Units	Source/Reference
Duration of exposure (D)	90	days	N/A
Body weight (W)	0.02	kg	
Food consumed per day (A)	0.003	kg	U.S. EPA 1989a
kg food consumed per kg bw	0.15	Unitless	0.003/0.02
Application rates (R)			
Typical	0.5	lb a.e./acre	WSB01.Typ
Lower	0.3	lb a.e./acre	WSB01.Low
Upper	1.5	lb a.e./acre	WSB01.Hi
Residue rates (rr)			
Typical	35	RUD ¹	WSA05a.LVT
Upper	125	RUD ¹	WSA05a.LVU
Dose estimates (D) - see details of calculations on next page			
Typical	0.93	mg/kg bw	VGCSMCT
Lower	0.5600	mg/kg bw	VGCSMCL
Upper	10	mg/kg bw	VGCSMCU

¹ RUD: Residue Unit Dosage, term used by Hoerger and Kenaga (1972) for anticipated concentration on fruit (mg chemical per kg of vegetation) for each 1 lb a.e./acre applied.

Equations (terms defined below or in above table):

Step 1: Calculate C_0 , concentration in vegetation on Day 0 - i.e., day of application.

$$C_0 \text{ (mg/kg)} = R \text{ (lb a.e./acre)} \times rr \text{ (mg/kg} \div \text{lb a.e./acre)}$$

Step 2: Calculate C_{90} , concentration in vegetation on Day 90 (t=90 days) based on dissipation coefficient (k) derived from foliar half-life ($t_{1/2}$).

$$k \text{ (days}^{-1}\text{)} = \ln(2) \div t_{1/2} \text{ (days)}$$

$$C_{90} \text{ (mg/kg)} = C_0 \text{ (mg/kg)} \times e^{-tk}$$

Step 3: Use the geometric mean of C_0 and C_{90} to get a central estimate of concentration in vegetation (mg/kg veg.) and multiply this value by the vegetation consumption (kg veg/kg bw) to calculate the daily dose (mg/kg bw) over the exposure period.

$$D \text{ (mg/kg bw)} = (C_0 \times C_{90})^{0.5} \text{ (mg/kg veg.)} \times A \text{ kg veg./kg bw}$$

Details of calculations on next page

*Subchronic consumption of vegetation by a small mammal:
Details of calculations*

Central Estimate:

Use the typical application rate, the typical vegetation consumption rate, and the typical residue rate along with the central estimate of half-time on fruit.

Step 1:

$$C_0 = 0.5 \text{ lb a.e./acre} \times 35 \text{ mg/kg veg.} = 17.5 \text{ mg/kg veg.}$$

Step 2:

$$k = \ln(2) \div 30 \text{ days}^{-1} = 0.023$$

$$C_{90} = 17.5 \text{ mg/kg} \times e^{-0.023 \times 90} = 2.21 \text{ mg/kg veg.}$$

Step 3:

$$D \text{ (mg/kg bw/day)} = (17.5 \times 2.21)^{0.5} \text{ (mg/kg veg.)} \times 0.15 \text{ kg veg/kg bw} = 0.93 \text{ mg/kg bw [VGCSMCT]}$$

Lower Estimate:

Use the lowest anticipated application rate along with the upper estimate of the half-time on fruit. Also the typical vegetation consumption rate and the typical residue rate because lower limits on these estimates are not available.

Step 1:

$$C_0 = 0.3 \text{ lb a.e./acre} \times 35 \text{ mg/kg veg.} = 10.5 \text{ mg/kg veg.}$$

Step 2:

$$k = \ln(2) \div 30 \text{ days}^{-1} = 0.023$$

$$C_{90} = 10.5 \text{ mg/kg} \times e^{-0.023 \times 90} = 1.32 \text{ mg/kg veg.}$$

Step 3:

$$D \text{ (mg/kg bw)} = (10.5 \times 1.32)^{0.5} \text{ (mg/kg veg.)} \times 0.15 \text{ (kg veg/kg bw)} = 0.56 \text{ (mg/kg bw) [VGCSMCL]}$$

Upper Estimate:

Use the highest anticipated application rate, the upper range of the vegetation consumption rate and the upper range of the residue rate along with the lower range of the estimated of half-time on fruit.

Step 1:

$$C_0 = 1.5 \text{ lb a.e./acre} \times 125 \text{ mg/kg veg.} = 187.5 \text{ mg/kg veg.}$$

Step 2:

$$k = \ln(2) \div 30 \text{ days}^{-1} = 0.023$$

$$C_{90} = 187.5 \text{ mg/kg} \times e^{-0.023 \times 90} = 23.7 \text{ mg/kg veg.}$$

Step 3:

$$D \text{ (mg/kg bw)} = (187.5 \times 23.7)^{0.5} \text{ (mg/kg veg.)} \times 0.15 \text{ (kg veg/kg bw)} = 10 \text{ (mg/kg bw) [VGCSMCU]}$$

Worksheet F06: Consumption of contaminated water by a small mammal, acute exposure scenario.			
<i>Verbal Description: A small (20g) mammal consumes contaminated water shortly after an accidental spill of 200 gallons of a field solution into a pond that has an average depth of 1 m and a surface area of 1000 m² or about one-quarter acre . No dissipation or degradation is considered.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Surface area of pond [SA]	1000	m ²	N/A
Average depth [DPTH]	1	m	N/A
Volume of pond in cubic meters [VM]	1000	m ³	N/A
Volume of pond in Liters [VL]	1000000	L	1 m ³ = 1,000 L
Volume of spill [VS]	200	gallons	N/A
Concentrations in solution (C _(mg/L))			
Central	1100	mg/L	WSB02.TYPDR×1000
Low	360	mg/L	WSB02.LOWDR×1000
High	36000	mg/L	WSB02.HI_DR×1000
Body weight (W)	0.02	kg	N/A
Amount of water consumed (A)	0.005	L/day	U.S. EPA 1989a
Dose estimates (D) - see details of calculations below.			
Typical	0.208	mg/kg bw	WTCSMAT
Lower	0.0680	mg/kg bw	WTCSMAL
Upper	6.81	mg/kg bw	WTCSMAU

Equations (terms defined below or in table)

Step 1: Calculate the concentration in the pond based on the concentration in the spilled solution, the volume spilled and the volume of the pond, assuming instantaneous mixing.

$$\text{Conc.}_{(mg/L)} = \text{VS}_{(gal)} \times 3.785 \frac{L}{gal} \times C_{(mg/L)} \div \text{VL}_{(liters)}$$

Step 2: Calculate the dose based on the concentration in the water, the amount of water consumed, and the body weight.

$$D_{(mg/kg\ bw)} = \text{Conc.}_{(mg/L)} \times A_{(L)} \div W_{(kg)}$$

Central Estimate: Use the typical field dilution,

Step 1: $\text{Conc.}_{(mg/L)} = 200_{(gal)} \times 3.785 \frac{L}{gal} \times 1100_{(mg/L)} \div 1000000_{(liters)} = 0.83_{(mg/L)}$

Step 2: $D_{(mg/kg\ bw)} = 0.83_{(mg/L)} \times 0.005_{(L)} \div 0.02_{(kg)} = 0.208_{(mg/kg\ bw)}$ [WTCSMAT]

Lower Estimate: Use the lowest estimated field dilution,

Step 1: $\text{Conc.}_{(mg/L)} = 200_{(gal)} \times 3.785 \frac{L}{gal} \times 360_{(mg/L)} \div 1000000_{(liters)} = 0.273_{(mg/L)}$

Step 2: $D_{(mg/kg\ bw)} = 0.273_{(mg/L)} \times 0.005_{(L)} \div 0.02_{(kg)} = 0.068_{(mg/kg\ bw)}$ [WTCSMAL]

Upper Estimate: Use the highest estimated field concentration,

Step 1: $\text{Conc.}_{(mg/L)} = 200_{(gal)} \times 3.785 \frac{L}{gal} \times 36000_{(mg/L)} \div 1000000_{(liters)} = 27.25_{(mg/L)}$

Step 2: $D_{(mg/kg\ bw)} = 27.25_{(mg/L)} \times 0.005_{(L)} \div 0.02_{(kg)} = 6.81_{(mg/kg\ bw)}$ [WTCSMAU]

Worksheet F07: Consumption of contaminated water by a small mammal, chronic exposure scenario.			
<i>Verbal Description: A small (20 g) mammal consumes contaminated ambient water for a lifetime. The levels in water are estimated from monitoring data and thus dissipation, degradation and other environmental processes are implicitly considered.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Application Rates (R (lb a.e./acre))			
Central	0.5	lb a.e./gal	WSB01.Typ
Low	0.3		WSB01.Low
High	1.5		WSB01.Hi
Water Contamination Rate (WCR)(C (mg/L) ÷ R (lb a.e./gal))			
Central	0.025	mg/L/lb a.e./acre	WSB07.AWT
Low	0.01		WSB07.AWL
High	0.06		WSB07.AWU
Body weight (W)	0.02	kg	U.S. EPA 1989a
Amount of water consumed (A (L/day))	0.005	L/day	U.S. EPA 1989a
Dose estimates (D) - see details of calculations on next page.			
Typical	0.0031	mg/kg bw	WTCSMCT
Lower	0.000750	mg/kg bw	WTCSMCL
Upper	0.023	mg/kg bw	WTCSMCU

Equations (terms defined in table)

Verbal Description: Multiply the application rate (R (lb a.e./acre)) by the water contamination rate (WCR ((mg/L)×(lb a.e./acre))) to get the concentration in ambient water. This product is in turn multiplied by the amount of water consumed per day (A (L/day)) and then divided by the body weight (W (kg)) to get the estimate of the absorbed dose (D (mg/kg bw)).

$$D_{(\text{mg/kg bw})} = R_{(\text{lb a.e./acre})} \times WCR_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times A_{(\text{L/day})} \div W_{(\text{kg})}$$

Central Estimate: Use the typical application rate and typical water contamination rate (WCR)

$$D_{(\text{mg/kg bw})} = 0.5_{(\text{lb a.e./acre})} \times 0.025_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 0.005_{(\text{L/day})} \div 0.02_{(\text{kg bw})} = 0.0031_{(\text{mg/kg bw})} \text{ [WTCSMCT]}$$

Lower Range of Estimate: Use the lowest anticipated application rate and the low end of the range of the water contamination rate (WCR)

$$D_{(\text{mg/kg bw})} = 0.3_{(\text{lb a.e./acre})} \times 0.01_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 0.005_{(\text{L/day})} \div 0.02_{(\text{kg bw})} = 0.00075_{(\text{mg/kg bw})} \text{ [WTCSMCL]}$$

Upper range of Estimate: Use the highest anticipated application rate and the high end of the range of the water contamination rate (WCR)

$$D_{(\text{mg/kg bw})} = 1.5_{(\text{lb a.e./acre})} \times 0.06_{((\text{mg/L}) \times (\text{lb a.e./acre}))} \times 0.005_{(\text{L/day})} \div 0.02_{(\text{kg bw})} = 0.023_{(\text{mg/kg bw})} \text{ [WTCSMCU]}$$

Worksheet F08: Potential exposures of non-target plants through the use of contaminated irrigation water.			
<i>Verbal Description: Non-target plants/crops are irrigated with 1 inch of contaminated ambient water. The levels in water are estimated from modeling and/or monitoring data thus dissipation, degradation and other environmental processes are considered.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Application Rates (R (lb a.e./acre))			
Central	0.5	lb a.e./acre	WSB01.Typ
Low	0.3		WSB01.Low
High	1.5		WSB01.Hi
Water Contamination Rate (WCR)($C_{(mg/L)} \div R_{(lb\ a.e./acre)}$)			
Central	0.025	mg/L/lb a.e./acre	WSB07.AWT
Low	0.01		WSB07.AWL
High	0.06		WSB07.AWU
Concentrations in irrigation water ($C_{(mg/L)}$) ($A \times WRC$)			
Central	0.0125	mg/L	
Low	0.003	mg/L	
High	0.09	mg/L	
Irrigation rate	1	inch	U.S. EPA 1989a
Liters of water applied per acre (L)	10,279	L	see below
Functional Application Rate($A_{lb/acre}$) ($C \times L \times 0.0000022\ lbs/mg \div 1\ acre$)			
Central	0.00028	lb/acre	
Low	0.0001	lb/acre	
High	0.002035	lb/acre	

Calculations of constants:

Liters of water applied per acre per inch irrigation water:

$$1\ m^2 = 100\ cm \times 100\ cm = 10,000\ cm^2$$

$$1\ acre = 4047\ m^2 = 4047\ m^2 \times 10,000\ cm^2/m^2 = 4,047,000\ cm^2$$

$$1\ inch = 2.54\ cm.$$

$$2.54\ cm \times 4,047,000\ cm^2 = 10,279,380\ cm^3 = 10,279,380\ mL = 10,279\ L.$$

Number of lbs/mg:

$$1\ kg = 2.2\ lbs.$$

$$1\ g = 0.0022\ lbs.$$

$$1\ mg = 0.000022\ lbs.$$

Worksheet G01: Summary of Exposure Scenarios for terrestrial animals

Scenario	Dose (mg/kg/day)			Worksheet
	Typical	Lower	Upper	
Acute/Accidental Exposures				
Direct spray, small mammal, first-order absorption	0.806	0.23149	4.98	WSF01
Direct spray, small animal, 100% absorption	12.2	7.31	36.6	WSF02
Direct spray, bee, 100% absorption	81	48.8	244	WSF03
Consumption of contaminated vegetation, acute exposure	2.63	1.58	28.1	WSF04
Consumption of contaminated water, acute exposure	0.208	0.068	6.81	WSF06
Longer Term Exposures				
Consumption of contaminated vegetation, chronic exposure	0.93	0.56	10	WSF05
Consumption of contaminated water, chronic exposure	0.0031	0.00075	0.023	WSF07

Worksheet G02: Summary of quantitative risk characterization for terrestrial animals¹

Scenario	Hazard Quotient ²		
	Typical	Lower	Upper
Acute/Accidental Exposures			
Direct spray, small mammal, first-order absorption	0.04	0.01	0.2
Direct spray, small animal, 100% absorption	0.6	0.4	2
Direct spray, bee, 100% absorption ³	0.1	0.05	0.2
Consumption of contaminated vegetation, acute exposure	0.1	0.08	1
Consumption of contaminated water, acute exposure	0.01	0.003	0.3
Longer Term Exposures			
Consumption of contaminated vegetation, chronic exposure	0.05	0.03	0.5
Consumption of contaminated water, chronic exposure	0.0002	0.00004	0.001
	Toxicity value for mammal ²	20	mg/kg/day
	Toxicity value for bee ³	1000	mg/kg

¹ See Worksheet F07 for details of exposure assessment.

² Except for the honey bee, the hazard quotient is calculated as the estimated exposure divided by the chronic rats NOAEL of 20 mg/kg/day, the study on which the RfD is based, and then rounded to one significant decimal or digit.

³ The hazard quotient is based on the reported acute dose level of >100 µg/bee or >1000 mg/kg as summarized in U.S. EPA (1995a).

**WORKSHEETS FOR
Hexachlorobenzene
in Picloram**

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GENERAL ASSUMPTIONS, VALUES, and MODELS

Worksheet A01: Constants and conversion factors used in calculations [CONST]		
Conversion	ID	Value
mg/lb	mg_lb	453,600
mL/gallon	ml_gal	3,785
lb/gallon to mg/mL	lbg_mgml	119.8
lb/acre to µg/cm ²	lbac_ugcm	11.21
lb/acre to mg/cm ²	lbac_mgcm	0.01121
gallons to liters	gal_lit	3.785

Worksheet A02: General Assumptions Used in Worker Exposure Assessments [STD]				
Parameter	ID	Value	Units	Reference
Body Weight (General)	BW	70	kg	ICRP (1975), p. 13
Surface area of hands	Hands	840	cm ²	U.S. EPA 1992c
Surface area of lower legs	LLegs	2070	cm ²	U.S. EPA 1992c
Weight of liquid adhering to surface of skin after a spill	Liq	0.008	mg/cm ²	Mason and Johnson 1987

Worksheet A03a: Directed Ground Sprays (includes backpack, cut surface, and streamline applications) - General Assumptions Used in Worker Exposure Assessments [BACKPACK]

Parameter/Assumption	ID	Value	Units	Reference
Hours of application per day				
Central estimate		7	hours	USDA 1989a,b,c
Lower estimate		6		
Upper estimate		8		
Acres treated per hour				
Central estimate		0.625	acres/hour	USDA 1989a,b,c
Lower estimate		0.25		
Upper estimate		1		
Acres treated per day				
Central estimate	ACREC	4.375	acres/day	N/A ¹
Lower estimate	ACREL	1.5		
Upper estimate	ACREU	8		
Absorbed dose rate (mg/day)				
Central estimate	RATEC	0.003	(mg agent/kg bw) ÷ (lbs agent handled per day) ²	Rubin et al. 1998, Table 5
Lower estimate	RATEL	0.0003		
Upper estimate	RATEU	0.01		

¹ Calculated as the product of the number of hours of application and the number of acres treated per hour for each category - i.e., central estimate, lower estimate, and upper estimate.

² “Agent” refers to the material being handled and may be expressed in units of a.i. or a.e. Depending on the agent under consideration, additional exposure conversions may be made in the exposure assessment and dose response assessment. For the risk assessment, the only important point is that the exposure and dose/response assessments must use the same units - that is, a.i., a.e., etc. - or the units must be converted to some equivalent form in the risk characterization.

Worksheet A03b: Hydraulic/Broadcast Ground Sprays - General Assumptions Used in Worker Exposure Assessments [HYDSPRAY]

Parameter/Assumption	ID	Value	Units	Reference
Hours of application per day				
Central estimate		7	hours	USDA 1989a,b,c
Lower estimate		6		
Upper estimate		8		
Acres treated per hour				
Central estimate		16	acres/hour	USDA 1989a,b,c
Lower estimate		11		
Upper estimate		21		
Acres treated per day				
Central estimate	ACREC	112	acres/day	N/A ¹
Lower estimate	ACREL	66		
Upper estimate	ACREU	168		
Absorbed dose rate				
Central estimate	RATEC	0.0002	(mg agent/kg bw) ÷ (lbs agent handled per day) ₂	Rubin et al. 1988, Table 5
Lower estimate	RATEL	0.00001		
Upper estimate	RATEU	0.0009		
<p>¹ Calculated as the product of the number of hours of application and the number of acres treated per hour for each category - i.e., central estimate, lower estimate, and upper estimate.</p> <p>² “Agent” refers to the material being handled and may be expressed in units of a.i. or a.e. Depending on the agent under consideration, additional exposure conversions may be made in the exposure assessment and dose response assessment. For the risk assessment, the only important point is that the exposure and dose/response assessments must use the same units - that is, a.i., a.e., etc. - or the units must be converted to some equivalent form in the risk characterization.</p>				

Worksheet 03c: Aerial Broadcast Sprays (includes pilots, mixers, and loaders) - General Assumptions Used in Worker Exposure Assessments. [AERIAL]

Parameter/Assumption	Code	Value	Units	Reference
Hours of application per day				
Central estimate		7	hours	USDA 1989a,b,c
Lower estimate		6		
Upper estimate		8		
Acres treated per hour				
Central estimate		70	acres/hour	USDA 1989a,b,c
Lower estimate		40		
Upper estimate		100		
Acres treated per day				
Central estimate	ACREC	490	acres/day	N/A ¹
Lower estimate	ACREL	240		
Upper estimate	ACREU	800		
Absorbed dose rate				
Central estimate	RATEC	0.00003	(mg agent/kg bw) ÷ (lbs agent handled per day) ₂	Rubin et al. 1998, Table 5
Lower estimate	RATEL	0.000001		
Upper estimate	RATEU	0.0001		
<p>¹ Calculated as the product of the number of hours of application and the number of acres treated per hour for each category - i.e., central estimate, lower estimate, and upper estimate.</p> <p>² “Agent” refers to the material being handled and may be expressed in units of a.i. or a.e. Depending on the agent under consideration, additional exposure conversions may be made in the exposure assessment and dose response assessment. For the risk assessment, the only important point is that the exposure and dose/response assessments must use the same units - that is, a.i., a.e., etc. - or the units must be converted to some equivalent form in the risk characterization.</p>				

Worksheet A04: General Assumptions Used in Exposure Assessments for the General Public [PUBL]

Narrative: This table contains various values used in the exposure assessments for the general public. Three general groups of individuals are considered: adult male, adult female, and a 2 year old child. Values are specified for body weight, surface areas for various parts of the body, water intake, fish consumption, and the consumption of fruits or vegetables. *NOTE: Not all types of value are specified for each group. The only values specified are those used in the risk assessment.*

Description	ID	Value	Units	Reference
Body Weights				
Male, Adult	BWM	70	kg	ICRP (1975), p. 13.
Female, Adult	BWF	64	kg	Burnmaster 1998; U.S. EPA 1985 ¹
Child, 2-3 years old	BWC	13.3	kg	U.S. EPA, 1996, page 7-1, Table 7-2
Body Surface Areas				
Female, feet and lower legs	SAF1	2915	cm ²	U.S. EPA, 1992a, p. 8-11, Table 8-3, total for feet and lower legs
Female, exposed skin when wearing shorts and a T-shirt	SAF2	5300	cm ²	U.S. EPA, 1992a, p. 8-11, Table 8-3, total for arms, hands, lower legs, and feet.
Child, male, 2-3 years old, total body surface area	SAC	6030	cm ²	U.S. EPA, 1996, p. 6-15, Table 6-6, 50 th percentile.
Water Intake				
Adult				
typical	WCAT	2	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, midpoint of mean (1.4 L/day) and 90 th percentile (2.4 L/day) rounded to one significant place.
lower range for exposure assessment	WCAL	1.4	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, mean
upper range	WCAH	2.4	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, 90 th percentile
Child, <3 years old				
typical	WCT	1	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, midpoint of mean (0.61L/day) and 90 th percentile (1.5 L/day) rounded to one significant place.
lower range for exposure assessment	WCL	0.61	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, mean
upper range	WCH	1.50	L/day	U.S. EPA, 1996, p. 3-28, Table 3-30, 90 th percentile

Worksheet A04: General Assumptions Used in Exposure Assessments for the General Public [PUBL]

Narrative: This table contains various values used in the exposure assessments for the general public. Three general groups of individuals are considered: adult male, adult female, and a 2 year old child. Values are specified for body weight, surface areas for various parts of the body, water intake, fish consumption, and the consumption of fruits or vegetables. *NOTE: Not all types of value are specified for each group. The only values specified are those used in the risk assessment.*

Description	ID	Value	Units	Reference
Fish Consumption				
Freshwater anglers, typical intake per day over a prolonged period	FAT	0.010	kg/day	U.S. EPA, 1996, p. 10-51, average of means from four studies
Freshwater anglers, maximum consumption for a single day	FAU	0.158	kg/day	Ruffle et al. 1994
Native American subsistence populations, typical intake per day	FNT	0.081	kg/day	U.S. EPA, 1996, p. 10-51, median value of 94 individuals
Native American subsistence populations, maximum for a single day	FNU	0.770	kg/day	U.S. EPA, 1996, p. 10-51, highest value of 94 individuals
Consumption of Fruits or Vegetables				
Amount of food consumed per kg bw per day for longer term exposures scenarios.				
Typical	VT	0.0043	kg food/kg bw/day	U.S. EPA, 1996, Table 9-21, p. 9-39, mean intake of vegetables
Upper	VU	0.01	kg food/kg bw/day	U.S. EPA, 1996, Table 9-21, p. 9-39, 95 th percentile for intake of vegetables
Worst-case scenario for consumption in a single day, acute exposure scenario only.	VAcute	0.454	kg food	1 lb. The approximate mid range of the above typical and upper limits based on the 64 kg body weight.
Miscellaneous				
Estimate of dislodgeable residue as a proportion of application rate shortly after application.	DisL	0.1	none	Harris and Solomon 1992, data on 2,4-D

¹This is the average value (63.79 kg), rounded to the nearest kg for 3 different groups of women between 15-49 years old: control (62.07 kg), pregnant (65.90 kg), and lactating (63.48 kg). See Burnmaster 1998, p.218, Table III., Risk Analysis. 18(2): 215-219. This is identical to the body weight for females, 45-55 years old, 50th percentile from U.S. EPA, 1985, page 5, Table 2-2, rounded to nearest kilogram.

Worksheet A05a: Estimated concentrations of pesticides on or in various types of vegetation shortly after application at 1 lb a.i./acre [from Hoerger and Kenaga (1972), Table 9, p. 22]. [HK]

Type of Vegetation	Concentration (mg chemical/kg vegetation)			
	Typical		Upper Limit	
	ID	Value	ID	Value
Range grass	RGT	125	RGU	240
Grass	GST	92	GSU	110
Leaves and leafy crops	LVT	35	LVU	125
Forage crops	FCT	33	FCU	58
Pods containing seeds	PDT	3	PDU	12
Grain	GNT	3	GNU	10
Fruit	FRT	1.5	FRU	7

Worksheet A05b: Concentrations of chemical on spheres (berries) at the specified application rate. [FRUIT]

Diameter (cm)	Planar Surface Area (cm ²) ^a	Amount deposited (mg) ^b	Weight of sphere (kg) ^c	Concentration (mg/kg) ^d
1	0.7853981634	0.008796459	0.0005236	16.8
5	19.6349540849	0.21991148575	0.065449847	3.36
10	78.5398163397	0.87964594301	0.5235987756	1.68
Application rate		1 lb/acre =	0.0112	mg/cm ²

- a Planar surface area of a sphere = δr^2 where r is the radius in cm.
- b Amount deposited is calculated as the application rate in mg/cm² multiplies by the planar surface area.
- c Assumes a density of 1 g/cm³ for the fruit. The volume of a sphere is $(1\div 6) \times \delta \times d^3$ where d is the diameter in cm. Assuming a density of 1 g/cm³, the weight of the sphere in kg is equal to:
 $kg = (1\div 6) \times \delta \times d^3 \div 1000$
- d Amount of chemical in mg divided by the weight of the sphere in kg.

Worksheet A06: Central estimates of off-site drift associated with aerial application of pesticides (from Bird 1995, p. 205) [OFFSITE]

Distance Down Wind (meters)	ID	Drift as a proportion of application rate
100	DRFT100	0.05
200	DRFT200	0.02
300	DRFT300	0.01
400	DRFT400	0.008

Hexachlorobenzene WS-11

Worksheet A07a: Estimate of first-order absorption rate (k_a in hours⁻¹) and 95% confidence intervals (from Durkin et al. 1998). [KAMODEL]

Model parameters	ID	Value	
Coefficient for $k_{o/w}$	C_KOW	0.233255	
Coefficient for MW	C_MW	0.005657	
Model Constant	C	1.49615	
Number of data points	DP	29	
Degrees of Freedom (d.f.)	DF	26	
Critical value of $t_{0.025}$ with 26 d.f. ¹	CRIT	2.056	
Standard error of the estimate	SEE	16.1125	
Mean square error or model variance	MDLV	0.619712	
Standard deviation of model (s)	MSD	0.787218	MDLV ^{0.5}
X X, cross products matrix		0.307537	-0.00103089
		-0.00103089	0.000004377
		0.0082	-0.0000944359
		0.00822769	-0.0000944359
		-0.0000944359	0.0085286

¹ Mendenhall and Scheaffer, 1973, Appendix 3, 4, p. A31.

Central (maximum likelihood) estimate:

$$\log_{10} k_a = 0.233255 \log_{10}(k_{o/w}) - 0.005657 MW - 1.49615$$

95% Confidence intervals for $\log_{10} k_a$

$$\log_{10} k_a \pm t_{0.025} \times s \times (a' X' X a)^{0.5}$$

where a is a column vector of {1, MW, $\log_{10}(k_{o/w})$ }.

NB: Although the equation for the central estimate is presented with $k_{o/w}$ appearing before MW to be consistent with the way a similar equation is presented by EPA, MW must appear first in column vector a because of the way the statistical analysis was conducted to derive X X .

See following page for details of calculating $a' X' X a$ without using matrix arithmetic.

Worksheet Worksheet A07a (continued)
Details of calculating $a'X'X a$

The term $a'(X'X)^{-1}a$ requires matrix multiplication. While this is most easily accomplished using a program that does matrix arithmetic, the calculation can be done with a standard calculator.

Letting

$$a = \{a_1, a_2, a_3\}$$

and

$$(X'X)^{-1} = \begin{Bmatrix} \{b_1, b_2, b_3\}, \\ \{c_1, c_2, c_3\}, \\ \{d_1, d_2, d_3\} \\ \} \end{Bmatrix}$$

$a'(X'X)^{-1}a$ is equal to

$$\begin{aligned} \text{Term 1: } & \{a_1 \times ([a_1 \times b_1] + [a_2 \times c_1] + [a_3 \times d_1])\} + \\ \text{Term 2: } & \{a_2 \times ([a_1 \times b_2] + [a_2 \times c_2] + [a_3 \times d_2])\} + \\ \text{Term 3: } & \{a_3 \times ([a_1 \times b_3] + [a_2 \times c_3] + [a_3 \times d_3])\}. \end{aligned}$$

Worksheet A07b: Estimate of dermal permeability (K_p in cm/hr) and 95% confidence intervals (data from U.S. EPA 1992c). [PKMODEL]

Model parameters	ID	Value	
Coefficient for k_{ow}	C_KOW	0.706648	
Coefficient for MW	C_MW	0.006151	
Model Constant	C	2.72576	
Number of data points	DP	90	
Degrees of Freedom (d.f.)	DF	87	
Critical value of $t_{0.025}$ with 87 d.f. ¹	CRIT	1.96	
Standard error of the estimate	SEE	45.9983	
Mean square error or model variance	MDLV	0.528716	
Standard deviation of model (s)	MSD	0.727129	MDLV ^{0.5}
X X, cross products matrix		0.0550931	-0.0000941546
		-0.0000941546	0.0000005978
		-0.0103443	-0.0000222508
		-0.0103443	0.00740677

¹ Mendenhall and Scheaffer, 1973, Appendix 3, Table 4, p. A31.

NOTE: The data for this analysis is taken from U.S. EPA (1992c), Dermal Exposure Assessment: Principles and Applications, EPA/600/8-91/011B, Table 5-4, pp. 5-15 through 5-19. The EPA report, however, does not provide sufficient information for the calculation of confidence intervals. The synopsis of the above analysis was conducted in STATGRAPHICS Plus for Windows, Version 3.1 (Manugistics, 1995) as well as Mathematica, Version 3.0.1.1 (Wolfram Research, 1997). Although not explicitly stated in the EPA report, 3 of the 93 data points are censored from the analysis because they are statistical outliers: [Hydrocortisone-21-yl]-hemipimelate, n-nonanol, and n-propanol. The model parameters reported above are consistent with those reported by U.S. EPA but are carried out to greater number of decimal places to reduce rounding errors when calculating the confidence intervals. See notes to Worksheet A07a for details of calculating maximum likelihood estimates and confidence intervals.

LIMITATIONS: This equation is based on measured K_p values for 95 organic compounds (Flynn 1990, Table 5-4 in U.S. EPA 1992c) with $\log K_{ow}$ values ranging from about -2.5 to 5.5 and molecular weights ranging from about 30 to 770. As reviewed by U.S. EPA (1992c), some analyses (e.g., Flynn 1990) suggest that the effects of both molecular weight and lipophilicity on permeability may be linear only within certain limits. Based on the analysis by Flynn (1990), relatively lipophobic compounds with $\log Kow$ values <0.5 appear to have $\log Kp$ values of approximately -3 (MW<150) or -5 (MW>150). At the upper limit, highly lipophilic compounds with $\log Kow$ values >3 and molecular weights <150 appear to have $\log Kp$ values of about -0.5. Compounds with $\log Kow$ values >3.5 and molecular weights >150 appear to have $\log Kp$ values of about -1.5 (Flynn 1990).

CHEMICAL SPECIFIC VALUES

Worksheet B01: Anticipated Application and Dilution Rates for hexachlorobenzene [WSB01]				
Item	Code	Value	Units	Reference/Source
Typical application rate ¹	Typ	0.000004	lb a.i./acre	See note below and Section 2.4 for application rate of picloram.
Lowest application rate	Low	0.0000024	lb a.i./acre	
Highest application rate	Hi	0.000012	lb a.i./acre	
Lowest dilution	LDil	20	gal./acre	C&P Press 1998*
Highest dilution	Hdil	40	gal./acre	judgmental
*Product label for Transline				

¹ Based on average concentration of 8 ppm of hexachlorobenzene in technical grade picloram - i.e. a proportion of 0.000008. The typical 'application' rate of hexachlorobenzene associated with the application of picloram at 0.5 lb a.e./acre is 0.000004 lb hexachlorobenzene/acre [0.000008×0.5]. Similar calculations are made for the lower range of the application rate (0.3 lb a.e. picloram/acre × 0.000008 = 0.0000024 lb hexachlorobenzene/acre) and the upper range of the application rate (1.5 lb a.e. picloram/acre × 0.000008 = 0.000012 lb hexachlorobenzene/acre).

Typical concentration in applied solution:

Typical application rate divided by the average of the lowest and highest dilutions, converted to mg/mL, and rounded to two significant places after the decimal.

$$2.50\text{e-}05 \text{ lb/acre} \div [(20 \text{ gal/acre} + 40 \text{ gal/acre})/2] \times 119.8 \text{ (mg/mL)/(lb/gal)} = 1.60\text{e-}05 \text{ mg/mL [TypDr]}$$

Lowest estimated concentration in applied solution:

Lowest application rate divided by the highest dilution, converted to mg/mL, and rounded to two significant places after the decimal.

$$2.40\text{e-}06 \text{ lb/acre} \div 40 \text{ gal/acre} \times 119.8 \text{ (mg/mL)/(lb/gal)} = 7.19\text{e-}06 \text{ mg/mL [LowDr]}$$

Highest estimated concentration in applied solution:

Highest application rate divided by the lowest dilution, converted to mg/mL, and rounded to two significant decimal places after the decimal.

$$1.20\text{e-}05 \text{ lb/acre} \div 20 \text{ gal/acre} \times 119.8 \text{ (mg/mL)/(lb/gal)} = 7.19\text{e-}05 \text{ mg/mL [HI_Dr]}$$

Worksheet B02: Summary of central estimate and range of concentrations of hexachlorobenzene in field solutions used for dermal exposure assessments.

Parameter	ID	Value	Units	Reference/Source
Acute Scenarios				
Typical	TypDR	6.00e-06	mg/mL	All values are set at the solubility of hexachlorobenzene in water. See calculations above.
Low	LowDR	6.00e-06	mg/mL	
High	Hi_DR	6.00e-06	mg/mL	

Worksheet B03: Summary of chemical specific values used for hexachlorobenzene in exposure assessment worksheets. [WSB03]

Parameter	ID	Value	Units	Source/Reference
Molecular weight	MW	284	grams/mole	Budavari 1989
Water Solubility	WS	0.006	mg/L	ATSDR 1998
K_{o/w} (given as log K_{o/w} of 6.18)	K_{ow}	1510000	unitless	ATSDR 1998
Measured Bioconcentration factor (BCF_(kg fish/L))	BCFT	10000	kg fish/L	Section 3.4.4.3
ATSDR Acute MRL	RfDA	0.008	mg/kg bw/day	Section 3.3.3
EPA Chronic RfD	RfDP	0.0008	mg/kg bw/day	Section 3.3.3
EPA Cancer Potency Factor	Q1	1.6	(mg/kg/day)⁻¹	Section 3.3.3

Worksheet B04: Calculation of first-order dermal absorption rate (k_a) for hexachlorobenzene.							
Parameters	Value	Units	Reference				
Molecular weight	284	g/mole					
$K_{o/w}$ at pH 7	1510000	unitless					
$\log_{10} K_{o/w}$	6.18						
Column vector a for calculating confidence intervals (see Worksheet 08 for definitions.)							
a_1	1						
a_2	284						
a_3	6.18						
Calculation of $a' \cdot (X'X)^{-1} \cdot a$ - see Worksheet Worksheet A07a for details of calculation.							
Term 1	0.06544024						
Term 2	-0.10548778481						
Term 3	0.21082849003						
$a' \cdot (X'X)^{-1} \cdot a$	0.1708	calculation verified in Mathematica 3.0.1.1					
$\log_{10} k_a = 0.233255 \log_{10}(k_{o/w}) - 0.005657 MW - 1.49615$						WSA07a	
\log_{10} of first order absorption rate (k_a)							
Central estimate	-1.66146073216	\pm	$t_{0.025}$	\times	s	\times	$(a' \cdot (X'X)^{-1} \cdot a)^{0.5}$
Lower limit	-2.33036206192	-	2.0560	\times	0.787218	\times	0.4132795664
Upper limit	-0.99255940239		2.0560	\times	0.787218	\times	0.4132795664
First order absorption rates (i.e., antilog or 10^x of above values).							
Central estimate	0.0218041554	hours ⁻¹					
Lower limit	0.004673454	hours ⁻¹					
Upper limit	0.1017280214	hours ⁻¹					

Worksheet B05: Calculation of dermal permeability rate (K_p) in cm/hour for hexachlorobenzene.							
Parameters	Value	Units			Reference		
Molecular weight	284	g/mole					
$K_{o/w}$	1510000	unitless					
$\log_{10} K_{o/w}$	6.17897694729						
Column vector a for calculating confidence intervals (see Worksheet A07a for definitions.)							
a_1	1						
a_2	284						
a_3	6.17897694729						
Calculation of $a' \cdot (X'X)^{-1} \cdot a$ - see Worksheet A07b for details of calculation.							
Term 1	-0.0355639976						
Term 2	-0.0175701088						
Term 3	0.17982512177						
$a' \cdot (X'X)^{-1} \cdot a$	0.12669101534	calculation verified in Mathematica 3.0.1.1					
$\log_{10} k_p = 0.706648 \log_{10}(k_{o/w}) - 0.006151 MW - 2.72576$					Worksheet A07b		
\log_{10} of dermal permeability							
Central estimate	-0.10628229815	\pm	$t_{0.025}$	\times	s	\times	$a' \cdot (X'X)^{-1} \cdot a^{0.5}$
Lower limit	-0.61355377778	-	1.9600	\times	0.727129	\times	0.35593681369
Upper limit	0.40098918148		1.9600	\times	0.727129	\times	0.35593681369
Dermal permeability							
Central estimate	0.78	cm/hour					
Lower limit	0.24	cm/hour					
Upper limit	2.52	cm/hour					

NOTE: U.S. EPA (1992c) gives an estimated K_p of 0.21 cm/hr based on a $\text{Log } K_{o/w}$ of 5.31. The U.S. EPA (1992c) does not provide a reference for this lower $K_{o/w}$. The more conservative and documented $\text{Log}(K_{o/w})$ of about 6.18 is used in this risk assessment and documented in Worksheet B03. As discussed by Flynn, compounds with $\log Kow$ values > 3.5 and molecular weights > 150 appear to have $\log Kp$ values of about -1.5 or Kp values of about 0.03. Thus, the use of the central estimate of 0.78 may over-estimate exposure by a factor of about 25. As discussed in Section 3.4, this very conservative approach has no impact on the risk characterization.

Worksheet B06: Summary of chemical specific dermal absorption values used for hexachlorobenzene dermal absorption. [WSB06]				
Description	Code	Value	Units	Reference/Source
Zero-order absorption (K_p)				
Central estimate	KpC	0.78292057	cm/hour	Worksheet B05
Lower limit	KpL	0.24347043	cm/hour	
Upper limit	KpU	2.51761421	cm/hour	
First-order absorption rates (k_a)				
Central estimate	AbsC	0.0218041554	hour⁻¹	Worksheet B04
Lower limit	AbsL	0.004673454	hour⁻¹	
Upper limit	AbsU	0.1017280214	hour⁻¹	

WORKER EXPOSURE ASSESSMENTS

Worksheet C01: Worker exposure estimates for directed foliar (backpack) applications of hexachlorobenzene				
Parameter/Assumption	Code	Value	Units	Source/Designation
Application rates				
Central estimate	ApplC	4.00e-06	lbs a.i./day	WSB01.TYP
Lower estimate	ApplL	2.40e-06	lbs a.i./day	WSB01.LOW
Upper estimate	ApplU	1.20e-05	lbs a.i./day	WSB01.HI
Acres treated per day				
Central estimate	ACREC	4.375	acres/day	WSA03.ACREC
Lower estimate	ACREL	1.5	acres/day	WSA03.ACREL
Upper estimate	ACREU	8	acres/day	WSA03.ACREU
Amount handled per day (product of application rate and acres treated per day)				
Central estimate	HANDLC	1.75e-05	lb/day	
Lower estimate	HANDLL	3.60e-06	lb/day	
Upper estimate	HANDLU	9.60e-05	lb/day	
Absorbed dose rate (mg/day)				
Central estimate	RATEC	0.003	(mg agent/kg bw) ÷ (lbs agent handled per day)	WSA03.RATEC
Lower estimate	RATEL	0.0003		WSA03.RATEL
Upper estimate	RATEU	0.01		WSA03.RATEU
Absorbed dose (product of amount handled and absorbed dose rate)				
Central estimate	DOSEC	5.25e-08	mg/kg bw/day	N/A
Lower estimate	DOSEL	1.08e-09		
Upper estimate	DOSEU	9.60e-07		

Worksheet C02a: Worker exposure estimates for boom spray (hydraulic ground spray) applications of hexachlorobenzene [WSC01]				
Parameter/Assumption	Code	Value	Units	Source/Designation
Application rates				
Central estimate	APPLC	4.00e-06	lbs a.i./day	WSB01.TYP
Lower estimate	APPLL	2.40e-06	lbs a.i./day	WSB01.LOW
Upper estimate	APPLU	1.20e-05	lbs a.i./day	WSB01.HI
Acres treated per day				
Central estimate	ACREC	112	acres/day	WSA04.ACREC
Lower estimate	ACREL	66	acres/day	WSA04.ACREL
Upper estimate	ACREU	168	acres/day	WSA04.ACREU
Amount handled per day (product of application rate and acres treated per day)				
Central estimate	HANDLC	4.48e-04	lb/day	
Lower estimate	HANDLL	1.58e-04	lb/day	
Upper estimate	HANDLU	2.02e-03	lb/day	
Absorbed dose rate				
Central estimate	RATEC	2.00e-04	(mg agent/kg bw) ÷ (lbs agent handled per day)	WSA04.RATEC
Lower estimate	RATEL	1.00e-05		WSA04.RATEL
Upper estimate	RATEU	9.00e-04		WSA04.RATEU
Absorbed dose (product of amount handled and absorbed dose rate)				
Central estimate	DOSEC	8.96e-08	mg/kg bw/day	N/A
Lower estimate	DOSEL	1.58e-09		
Upper estimate	DOSEU	1.81e-06		

WSC02b: Worker exposure estimates to hexachlorobenzene associated with aerial applications of picloram [WKAREXP01]				
NOTE: The upper and lower estimates of dose are based on the typical application rate. Variability is encompassed by differences in the number of acres treated and the absorbed dose rate.				
Parameter/Assumption	Code	Value	Units	Source/Designation
Application rates				
Central estimate	WS10C	4.00e-06	lbs a.e./day	APPL . TYP
Lower estimate	WS10L	2.40e-06	lbs a.e./day	APPL . LOW
Upper estimate	WS10U	1.20e-05	lbs a.e./day	APPL . HI
Acres treated per day				
Central estimate	ACREC	490	acres/day	AERIAL . ACREC
Lower estimate	ACREL	240	acres/day	AERIAL . ACREL
Upper estimate	ACREU	800	acres/day	AERIAL . ACREU
Amount handled per day (product of application rate and acres treated per day)				
Central estimate	HANDLC	0.00196	lb/day	N/A ¹
Lower estimate	HANDLL	0.00096	lb/day	
Upper estimate	HANDLU	0.0032	lb/day	
Absorbed dose rate				
Central estimate	RATEC	3.00e-05	(mg agent/kg bw) ÷ (lbs agent handled per day) ²	AERIAL . RATEC
Lower estimate	RATEL	1.00e-06		AERIAL . RATEL
Upper estimate	RATEU	1.00e-04		AERIAL . RATEU
Absorbed dose (product of amount handled and absorbed dose rate)				
Central estimate	DOSEC	5.88e-08	mg/kg bw	N/A
Lower estimate	DOSEL	9.60e-10		
Upper estimate	DOSEU	3.20e-07		
¹ Calculated as the product of the number of hours of application and the number of acres treated per hour for each category - i.e., central estimate, lower estimate, and upper estimate.				
² “Agent” refers to the material being handled and may be expressed in units of a.i. or a.e. Depending on the agent under consideration, additional exposure conversions may be made in the exposure assessment and dose response assessment. For the risk assessment, the only important point is that the exposure and dose/response assessments must use the same units - that is, a.i., a.e., etc. - or the units must be converted to some equivalent form in the risk characterization.				

Worksheet C03: Workers: Accidental Dermal Exposure Assessments Using Zero-Order Absorption			
Parameter	Value	Units	Source
Body weight (W)	70	kg	WSA02.BW
Surface Area of hands (S)	840	cm ²	WSA02.Hands
Dermal permeability (K _p , cm/hour) [see Worksheet B05]			
Typical	0.7829206	cm/hour	WSB06.KpC
Lower	0.24347043	cm/hour	WSB06.KpL
Upper	2.5176142	cm/hour	WSB06.KpU
Concentration in solution (C) [see Worksheet B02]			
Typical	6.00e-06	mg/mL	WSB02.TypDr
Lower	6.00e-06	mg/mL	WSB02.LowDr
Upper	6.00e-06	mg/mL	WSB02.HI_Dr

Note that 1 mL is equal to 1 cm³ and thus mg/mL = mg/cm³.

Details of calculations for worker zero-order dermal absorption scenarios.

Equation (U.S. EPA 1992c)

$$K_p \cdot C \cdot \text{Time (hr)} \cdot S \div W = \text{Dose (mg/kg)}$$

where: C = concentration in mg/cm³ or mg/mL, S = Surface area of skin in cm², W = Body weight in kg.

Immersion of Hands or Wearing Contaminated Gloves for One-Minute

Typical Value: Use typical concentration and central estimate of K_p.

$$0.7829206 \text{ cm/hr} \times 6.00\text{e-}06 \text{ mg/cm}^3 \times 1/60 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 9.40\text{e-}07 \text{ mg/kg [WZHT1M]}$$

Lower Estimate: Use lower range of estimated concentration and lower limit of K_p.

$$0.2434704 \text{ cm/hr} \times 6.00\text{e-}06 \text{ mg/cm}^3 \times 1/60 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 2.92\text{e-}07 \text{ mg/kg [WZHL1M]}$$

Upper Estimate: Use upper range of estimated concentration and upper limit of K_p.

$$2.5176142 \text{ cm/hr} \times 6.00\text{e-}06 \text{ mg/cm}^3 \times 1/60 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 0.000003 \text{ mg/kg [WZHU1M]}$$

Wearing Contaminated Gloves for One-Hour

Typical Value: Use typical concentration and central estimate of K_p.

$$0.7829206 \text{ cm/hr} \times 6.00\text{e-}06 \text{ mg/cm}^3 \times 1 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 0.0000564 \text{ mg/kg [WZHT1H]}$$

Lower Estimate: Use lower range of estimated concentration and lower limit of K_p.

$$0.2434704 \text{ cm/hr} \times 6.00\text{e-}06 \text{ mg/cm}^3 \times 1 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 1.75\text{e-}05 \text{ mg/kg [WZHL1H]}$$

Upper Estimate: Use upper range of estimated concentration and upper limit of K_p.

$$2.5176142 \text{ cm/hr} \times 6.00\text{e-}06 \text{ mg/cm}^3 \times 1 \text{ hr} \times 840 \text{ cm}^2 \div 70 \text{ kg} = 0.00018 \text{ mg/kg [WZHU1H]}$$

Worksheet C04: Worker Accidental Spill Based on the Assumption of First-Order Absorption			
Parameter	Value	Units	Source
Liquid adhering to skin after a spill (<i>L</i>)	0.008	mL/cm ²	WSA02.Liq
Body weight (<i>W</i>)	70	kg	WSA02.BW
Surface Areas (<i>A</i>)			
Hands	840	cm ²	WSA02.Hands
Lower legs	2070	cm ²	WSA02.LLegs
First-order dermal absorption rates (<i>k_a</i>)			
Central Estimate	0.02180	hour ⁻¹	WSB06.ABSC
Lower limit of range	0.004673	hour ⁻¹	WSB06.ABSL
Upper limit of range	0.10173	hour ⁻¹	WSB06.ABSU
Concentration in solution (<i>C</i>) [see Worksheet B01]			
Typical	6.00e-06	mg/mL	TypDr
Lower	6.00e-06	mg/mL	LowDr
Upper	6.00e-06	mg/mL	HI_Dr

Details of calculations.

Equation (from Durkin et al. 1995)

$$Dose_{(mg/kg\ bw)} = k_a_{(1/hours)} \times L_{(mg/cmsq)} \times C_{(mg/mL)} \times T_{(hours)} \times A_{(cm\ sq)} \div W_{(kg)}$$

where *T* is the duration of exposure in hours and other terms are defined as above.

Lower Legs: Spill with 1 Hour (*T*) Exposure Period

Typical Value [WFLT1H],

$$0.0218042\ h^{-1} \times 0.008\ mL/cm^2 \times 6.00e-06\ mg/cm^3 \times 1\ hr \times 2070\ cm^2 \div 70\ kg = 3.1e-08\ mg/kg$$

Lower range [WFL1H],

$$0.0046735\ h^{-1} \times 0.008\ mL/cm^2 \times 6.00e-06\ mg/cm^3 \times 1\ hr \times 2070\ cm^2 \div 70\ kg = 6.6e-09\ mg/kg$$

Upper range [WFLU1H],

$$0.1017280\ h^{-1} \times 0.008\ mL/cm^2 \times 6.00e-06\ mg/cm^3 \times 1\ hr \times 2070\ cm^2 \div 70\ kg = 1.4e-07\ mg/kg$$

Hands: Spill with 1 Hour (*T*) Exposure Period

Typical Value [WFHT1H],

$$0.0218042\ h^{-1} \times 0.008\ mL/cm^2 \times 6.00e-06\ mg/cm^3 \times 1\ hr \times 840\ cm^2 \div 70\ kg = 1.3e-08\ mg/kg$$

Lower range [WFHL1H],

$$0.0046735\ h^{-1} \times 0.008\ mL/cm^2 \times 6.00e-06\ mg/cm^3 \times 1\ hr \times 840\ cm^2 \div 70\ kg = 2.7e-09\ mg/kg$$

Upper range [WFHU1H],

$$0.1017280\ h^{-1} \times 0.008\ mL/cm^2 \times 6.00e-06\ mg/cm^3 \times 1\ hr \times 840\ cm^2 \div 70\ kg = 5.9e-08\ mg/kg$$

EXPOSURE ASSESSMENTS for the GENERAL PUBLIC

Worksheet D01: Direct spray of child.			
<i>Verbal Description: A naked child is accidentally sprayed over the entire body surface with a field dilution as it is being applied. The child is effectively washed - i.e., all of the compound is removed - after 1 hour. The absorbed dose is estimated using the assumption of first-order dermal absorption.</i>			
Parameter/Assumption	Value	Units	Source/Reference
Period of exposure (<i>T</i>)	1	hour	N/A
Body weight (<i>W</i>)	13.3	kg	WSA04.BWC
Exposed surface area (<i>A</i>)	6030	cm ²	WSA04.SAC
Liquid adhering to skin per cm ² of exposed skin (<i>L</i>)	0.008	mL/cm ²	WSA02.LIQ
Concentrations in solution (<i>C</i>)			
Typical/Central	6.00e-06	mg/mL	WSB02.TYPDR
Low	6.00e-06	mg/mL	WSB02.LOWDR
High	6.00e-06	mg/mL	WSB02.HI_DR
First-order dermal absorption rate (<i>k_a</i>)			
Central	2.18e-02	hour ⁻¹	WSB06.AbsC
Low	4.67e-03	hour ⁻¹	WSB06.AbsL
High	1.02e-01	hour ⁻¹	WSB06.AbsU
Estimated Absorbed Doses (<i>D</i>) - see calculations below.			
Central	4.75e-07	mg/kg	SPRYC
Low	1.02e-07	mg/kg	SPRYL
High	2.21e-06	mg/kg	SPRYH

Details of calculations

Equation: $L \times C \times A \times k_a \times T \div W$

Central Estimate [SPRYCC]:

$$0.008 \text{ mL/cm}^2 \times 6.00\text{e-}06 \text{ mg/mL} \times 6030 \text{ cm}^2 \times 2.18\text{e-}02 \text{ h}^{-1} \times 1 \text{ h} \div 13.3 \text{ kg} = 4.75\text{e-}07 \text{ mg/kg}$$

Lower Range of Estimate [SPRYCL]:

$$0.008 \text{ mL/cm}^2 \times 6.00\text{e-}06 \text{ mg/mL} \times 6030 \text{ cm}^2 \times 4.67\text{e-}03 \text{ h}^{-1} \times 1 \text{ h} \div 13.3 \text{ kg} = 1.02\text{e-}07 \text{ mg/kg}$$

Upper Range of Estimate [SPRYCH]:

$$0.008 \text{ mL/cm}^2 \times 6.00\text{e-}06 \text{ mg/mL} \times 6030 \text{ cm}^2 \times 1.02\text{e-}01 \text{ h}^{-1} \times 1 \text{ h} \div 13.3 \text{ kg} = 2.21\text{e-}06 \text{ mg/kg}$$

Worksheet D02: Direct spray of woman.			
<i>Verbal Description: A woman is accidentally sprayed over the feet and legs with a field dilution as it is being applied. The woman washes and removes all of the compound after 1 hour. The absorbed dose is estimated using the assumption of first-order dermal absorption.</i>			
Parameter/Assumption	Value	Units	Source/Reference
Period of exposure (<i>T</i>)	1	hour	N/A
Body weight (<i>W</i>)	64	kg	WSA04.BWF
Exposed surface area (<i>A</i>)	2915	cm ²	WSA04.SAF1
Liquid adhering to skin per cm ² of exposed skin (<i>L</i>)	0.008	mL/cm ²	WSA02.LIQ
Concentrations in solution (<i>C</i>)			
Typical/Central	6.00e-06	mg/mL	WSB02.TYPDR
Low	6.00e-06	mg/mL	WSB02.LOWDR
High	6.00e-06	mg/mL	WSB02.HI_DR
First-order dermal absorption rate (<i>k_a</i>)			
Central	2.18e-02	hour ⁻¹	WSB06.AbsC
Low	4.67e-03	hour ⁻¹	WSB06.AbsL
High	1.02e-01	hour ⁻¹	WSB06.AbsU
Estimated Absorbed Doses (<i>D</i>) - see calculations below.			
Central	4.77e-08	mg/kg	SPRYWC
Low	1.02e-08	mg/kg	SPRYWL
High	2.22e-07	mg/kg	SPRYWH

Details of calculations

$$\text{Equation: } L \times C \times S \times k_a \times T \div W$$

Central Estimate [SPRYWC]:

$$0.008 \text{ mL/cm}^2 \times 6.00\text{e-}06 \text{ mg/mL} \times 2915 \text{ cm}^2 \times 0.0218041554 \text{ h}^{-1} \times 1 \text{ h} \div 64 \text{ kg} = 4.77\text{e-}08 \text{ mg/kg}$$

Lower Range of Estimate [SPRYWL]:

$$0.008 \text{ mL/cm}^2 \times 6.00\text{e-}06 \text{ mg/mL} \times 2915 \text{ cm}^2 \times 0.004673454 \text{ h}^{-1} \times 1 \text{ h} \div 64 \text{ kg} = 1.02\text{e-}08 \text{ mg/kg}$$

Upper Range of Estimate [SPRYWH]:

$$0.008 \text{ mL/cm}^2 \times 6.00\text{e-}06 \text{ mg/mL} \times 2915 \text{ cm}^2 \times 0.1017280214 \text{ h}^{-1} \times 1 \text{ h} \div 64 \text{ kg} = 2.22\text{e-}07 \text{ mg/kg}$$

Worksheet D03: Dermal contact with contaminated vegetation.			
<i>Verbal Description: A woman wearing shorts and a short sleeved shirt is in contact with contaminated vegetation for 1 hour shortly after application of the compound - i.e. no dissipation or degradation is considered. The chemical is effectively removed from the surface of the skin - i.e., washing - after 24 hours.</i>			
Parameter/Assumption	Value	Units	Source/Reference
Contact time (T_c)	1	hour	N/A
Exposure time (T_e)	24	hours	N/A
Body weight (W)	64	kg	WSA04.BWF
Exposed surface area (A)	5300	cm ²	WSA04.SAF2
Dislodgeable residue (Dr) as a proportion of application rate	0.1	none	WSA04.DisL
Application Rates(R)			
Typical/Central	4.00e-06	lb a.i./acre	WSB01.TYP
Low	2.40e-06	lb a.i./acre	WSB01.LOW
High	1.20e-05	lb a.i./acre	WSB01.HI
First-order dermal absorption rate (k_a)			
Central	2.18e-02	hour ⁻¹	WSB06.AbsC
Low	4.67e-03	hour ⁻¹	WSB06.AbsL
High	1.02e-01	hour ⁻¹	WSB06.AbsU
Estimated Absorbed Doses (D) - see calculations on next page.			
Central	8.85e-07	mg/kg	VEGDWC
Low	1.09e-07	mg/kg	VEGDWL
High	1.37e-05	mg/kg	VEGDWH

Description of Calculations:

Step 1:

Use method of Durkin et al. (1995, p. 68, equation 4) to calculate dislodgeable residue (Dr) in units of $\mu\text{g}/(\text{cm}^2\cdot\text{hr})$ after converting application rate in lb a.i./acre to units of $\mu\text{g}/\text{cm}^2$:

$$x = \log(Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr}))) = (1.09 \times \log_{10}(R \times \text{WSA01.lbac_ugcm})) + 0.05$$

$$Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr})) = 10^x$$

Step 2:

Convert Dr from units of $\mu\text{g}/(\text{cm}^2\cdot\text{hr})$ to units of $\text{mg}/(\text{cm}^2\cdot\text{hr})$ by dividing by 1000:

$$Dr(\text{mg}/(\text{cm}^2\cdot\text{hr})) = Dr(\mu\text{g}/(\text{cm}^2\cdot\text{hr}))/1000$$

Step 3:

Estimate amount ($Amnt$) transferred to skin in mg during the exposure period:

$$Amnt(\text{mg}) = Dr(\text{mg}/(\text{cm}^2\cdot\text{hr})) \times T_c (\text{hours}) \times A (\text{cm}^2)$$

Step 4:

Estimate the absorbed dose (D_{Abs}) in mg/kg bw as the product of the amount on the skin, the first-order absorption rate, and the duration of exposure divided by the body weight:

$$D_{Abs} = Amnt(\text{mg}) \times k_a (\text{hours}^{-1}) \times T_e (\text{hours}) \div W (\text{kg})$$

See next page for details of calculations.

Worksheet D03 Details of calculations: Dermal Exposure to Contaminated Vegetation

Central Estimate:

Step 1:

$$\log_{10}(Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr}))) - 4.69 = (1.09 \times \log_{10}(0.000004 \times 11.21)) + 0.05 = -4.69 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$
$$Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr})) = 10^{-4.69} = 2.04\text{e-}05 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$

Step 2:

$$Dr (\text{mg}/(\text{cm}^2\cdot\text{hr})) = 2.04\text{e-}05 \mu\text{g}/(\text{cm}^2\cdot\text{hr}) \div 1000 \mu\text{g}/\text{mg} = 2.04\text{e-}08 \text{mg}/(\text{cm}^2\cdot\text{hr})$$

Step 3:

$$Amnt(\text{mg}) = 2.04\text{e-}08 \text{mg}/(\text{cm}^2\cdot\text{hr}) \times 1 \text{ hr} \times 5300 \text{ cm}^2 = 1.08\text{e-}04 \text{ mg}$$

Step 4:

$$D_{Abs} (\text{mg}/\text{kg bw}) = 1.08\text{e-}04 \text{ mg} \times 0.0218041554 \text{ hr}^{-1} \times 24 \text{ hours} \div 64 \text{ kg} = 8.85\text{e-}07 \text{ [VEGDWC]}$$

Lower Range of Estimate:

Step 1:

$$\log_{10}(Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr}))) = (1.09 \times \log_{10}(0.000002 \times 11.21)) + 0.05 = -4.931 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$
$$Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr})) = 10^{-4.931} = 1.17\text{e-}05 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$

Step 2:

$$Dr (\text{mg}/(\text{cm}^2\cdot\text{hr})) = 1.17\text{e-}05 \mu\text{g}/(\text{cm}^2\cdot\text{hr}) \div 1000 \mu\text{g}/\text{mg} = 1.17\text{e-}08 \text{mg}/(\text{cm}^2\cdot\text{hr})$$

Step 3:

$$Amnt(\text{mg}) = 1.17\text{e-}08 \text{mg}/(\text{cm}^2\cdot\text{hr}) \times 1 \text{ hr} \times 5300 \text{ cm}^2 = 6.21\text{e-}05 \text{ mg}$$

Step 4:

$$D_{Abs} (\text{mg}/\text{kg bw}) = 6.21\text{e-}05 \text{ mg} \times 0.004673454 \text{ hr}^{-1} \times 24 \text{ hours} \div 64 \text{ kg} = 1.09\text{e-}07 \text{ [VEGDWL]}$$

Upper Range of Estimate:

0.008Step 1:

$$\log_{10}(Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr}))) = (1.09 \times \log_{10}(0.000012 \times 11.21)) + 0.05 = -4.17 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$
$$Dr (\mu\text{g}/(\text{cm}^2\cdot\text{hr})) = 10^{-4.17} = 6.76\text{e-}05 \mu\text{g}/(\text{cm}^2\cdot\text{hr})$$

Step 2:

$$Dr (\text{mg}/(\text{cm}^2\cdot\text{hr})) = 6.76\text{e-}05 \mu\text{g}/(\text{cm}^2\cdot\text{hr}) \div 1000 \mu\text{g}/\text{mg} = 6.76\text{e-}08 \text{mg}/(\text{cm}^2\cdot\text{hr})$$

Step 3:

$$Amnt(\text{mg}) = 6.76\text{e-}08 \text{mg}/(\text{cm}^2\cdot\text{hr}) \times 1 \text{ hr} \times 5300 \text{ cm}^2 = 3.58\text{e-}04 \text{ mg}$$

Step 4:

$$D_{Abs} (\text{mg}/\text{kg bw}) = 3.58\text{e-}04 \text{ mg} \times 0.1017280214 \text{ hr}^{-1} \times 24 \text{ hours} \div 64 \text{ kg} = 1.37\text{e-}05 \text{ [VEGDWH]}$$

Worksheet D04: Consumption of contaminated fruit, acute exposure scenario.			
<i>Verbal Description: A woman consumes 1 lb (0.4536 kg) of contaminated fruit shortly after application of the chemical - i.e. no dissipation or degradation is considered. Residue estimates based on relationships from Hoerger and Kenaga (1972) summarized in WSA07.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Body weight (W)	64	kg	WSA04.BWF
Amount of fruit consumed (A)	0.454	kg	N/A
Application rates (R)			
Typical	4.00e-06	lb a.i./acre	WSB01.TYP
Lower	2.40e-06	lb a.i./acre	WSB01.Low
Upper	1.20e-05	lb a.i./acre	WSB01.Hi
Residue rates (rr)			
Typical	1.5	RUD ¹	WSA05a.FRT
Upper	7	RUD ¹	WSA05a.FRU
Dose estimates (D) - see details of calculations below			
Typical	4.26e-08	mg/kg bw	VEGCWAT
Lower	2.55e-08	mg/kg bw	VEGCWAL
Upper	5.96e-07	mg/kg bw	VEGCWAU
¹ RUD: Residue Unit Dosage, term used by Hoerger and Kenaga (1972) for anticipated concentration on vegetation (mg chemical per kg of vegetation) for each 1 lb a.i./acre applied.			

Equation (terms defined in above table):

$$D \text{ (mg/kg bw)} = A(\text{kg}) \times R(\text{lb a.i./acre}) \times rr(\text{mg/kg} \div \text{lb a.i./acre}) \div W(\text{kg bw})$$

Details of Calculations

Typical: Use typical application rate and typical RUD.

$$D = 0.454 \text{ kg} \times 4.00\text{e-}06 \text{ lb a.i./acre} \times 1.5 \text{ mg/kg} \div \text{lb a.i./acre} \div 64 \text{ kg} = 4.26\text{e-}08 \text{ mg/kg bw}$$

Lower: Use lowest estimated application rate. Use typical RUD because no lower estimate of the RUD is available.

$$D = 0.454 \text{ kg} \times 2.40\text{e-}06 \text{ lb a.i./acre} \times 1.5 \text{ mg/kg} \div \text{lb a.i./acre} \div 64 \text{ kg} = 2.55\text{e-}08 \text{ mg/kg bw}$$

Upper: Use highest estimated application rate and highest RUD.

$$D = 0.454 \text{ kg} \times 1.20\text{e-}05 \text{ lb a.i./acre} \times 7 \text{ mg/kg} \div \text{lb a.i./acre} \div 64 \text{ kg} = 5.96\text{e-}07 \text{ mg/kg bw}$$

Worksheet D05: Consumption of vegetation, chronic exposure scenario.				
<i>Verbal Description: A woman consumes contaminated vegetation daily for a life time. This scenario makes the assumption that concentration of hexachlorobenzene in the lower surface layers is essentially constant.</i>				
Parameters/Assumptions	Value	Units	Source/Reference	
Concentration in soil			Section 3.2.4.2.	
0.5 lb picloram a.e./acre	5.60e-07	mg/kg		
0.3 lb picloram a.e./acre	3.36e-07	mg/kg		
1.5 lb picloram a.e./acre	1.68e-06	mg/kg		
Bioconcentration factor in vegetation	19	value for carrots	ATSDR 1998	
Concentration in vegetation	central	1.06e-05	Concentration in soil multiplied by bioconcentration factor for vegetation.	
	lower	6.38e-06		
	upper	3.19e-05		
Duration of exposure (t)	365	days	N/A	
Body weight (W)	64	kg	WSA04.BWF	
Amount of vegetation consumed per unit body weight(A)				
	Typical	0.0043	kg veg./kg bw	WSA04.VT
	Upper	0.01	kg veg./kg bw	WSA04.VU
Dose estimates (D) ¹				
	Typical	7.15e-10	mg/kg bw/day	VEGCWCT
	Lower	4.29e-10	mg/kg bw/day	VEGCWCL
	Upper	4.99e-09	mg/kg bw/day	VEGCWCU
¹ The product of the concentration in vegetation and the amount of vegetation consumed divided by the body weight. Typical and lower ranges are based on the typical consumption of vegetation as well as the central and lower ranges, respectively, of the application rates. The upper range is based on the upper ranges of the application rate and resulting upper range on contaminated vegetation as well as the upper range of consumption of vegetation.				

Worksheet D06: Consumption of contaminated water, acute exposure scenario.			
<i>Verbal Description: A young child (2-3 years old) consumes 1 liter of contaminated water shortly after an accidental spill of 200 gallons of a field solution into a pond that has an average depth of 1 m and a surface area of 1000 m² or about one-quarter acre . No dissipation or degradation is considered.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Surface area of pond [SA]	1000	m ²	N/A
Average depth [DPTH]	1	m	N/A
Volume of pond in cubic meters [VM]	1000	m ³	N/A
Volume of pond in Liters [VL]	1000000	L	1 m ³ = 1,000 L
Volume of spill [VS]	200	gallons	N/A
Concentrations in solution (C_(mg/L))			
Central	1.60e-02	mg/L	WSB02.TypDR
Low	7.19e-03	mg/L	WSB02.LowDR
High	1.50e-01	mg/L	Section 3.2.4.
Body weight (W)			
	13.3	kg	WSA04.BWC
Amount of water consumed (A)			
Typical	1	L/day	WSA04.WCT
Lower	0.61	L/day	WSA04.WCL
Upper	1.5	L/day	WSA04.WCH
Estimated Concentration in Water (Conc) - see details of calculations on next page.			
Typical	1.21e-05	mg/kg bw	
Lower	5.44e-06	mg/kg bw	
Upper	1.14e-04	mg/kg bw	
Dose estimates (D) - see details of calculations on next page.			
Typical	9.09e-07	mg/kg bw	WATCCAT
Lower	2.50e-07	mg/kg bw	WATCCAL
Upper	1.28e-05	mg/kg bw	WATCCAU

Details of calculations on next page

Acute Consumption of Contaminated Water from an Accidental Spill Details of calculations

Equations (terms defined below or in table on previous page)

Step 1: Calculate the concentration in the pond based on the concentration in the spilled solution, the volume spilled and the volume of the pond, assuming instantaneous mixing.

$$\text{Conc. (mg/L)} = VS_{(\text{gal.})} \times 3.785_{\text{L/gal}} \times C_{(\text{mg/L})} \div VL_{(\text{liters})}$$

Step 2: Calculate the dose based on the concentration in the water, the amount of water consumed, and the body weight.

$$D_{(\text{mg/kg bw})} = \text{Conc. (mg/L)} \times A_{(\text{L})} \div W_{(\text{kg})}$$

Calculations

Central Estimate:

Use the typical field dilution, and the typical water consumption.

Step 1:

$$\text{Conc. (mg/L)} = 200_{(\text{gal.})} \times 3.785_{\text{L/gal}} \times 1.60\text{e-}02_{(\text{mg/L})} \div 1000000_{(\text{liters})} = 1.21\text{e-}05_{(\text{mg/L})}$$

Step 2:

$$D_{(\text{mg/kg bw})} = 1.21\text{e-}05_{(\text{mg/L})} \times 1_{(\text{L})} \div 13.3_{(\text{kg})} = 9.09\text{e-}07_{(\text{mg/kg bw})} \text{ [WATCCAT]}$$

Lower Estimate:

Use the lowest estimated field dilution and the lower range of water consumption.

Step 1:

$$\text{Conc. (mg/L)} = 200_{(\text{gal.})} \times 3.785_{\text{L/gal}} \times 7.19\text{e-}03_{(\text{mg/L})} \div 1000000_{(\text{liters})} = 5.44\text{e-}06_{(\text{mg/L})}$$

Step 2:

$$D_{(\text{mg/kg bw})} = 5.44\text{e-}06_{(\text{mg/L})} \times 0.61_{(\text{L})} \div 13.3_{(\text{kg})} = 2.50\text{e-}07_{(\text{mg/kg bw})} \text{ [WATCCAL]}$$

Upper Estimate:

Use the highest estimated field concentration and the upper range of water consumption.

Step 1:

$$\text{Conc. (mg/L)} = 200_{(\text{gal.})} \times 3.785_{\text{L/gal}} \times 1.50\text{e-}01_{(\text{mg/L})} \div 1000000_{(\text{liters})} = 1.14\text{e-}04_{(\text{mg/L})}$$

Step 2:

$$D_{(\text{mg/kg bw})} = 1.14\text{e-}04_{(\text{mg/L})} \times 1.5_{(\text{L})} \div 13.3_{(\text{kg})} = 1.28\text{e-}05_{(\text{mg/kg bw})} \text{ [WATCCAU]}$$

Worksheet D07: Consumption of contaminated fish, acute exposure scenario.

Verbal Description: An adult angler consumes fish taken from contaminated water shortly after an accidental spill of 200 gallons of a field solution into a pond that has an average depth of 1 m and a surface area of 1000 m² or about one-quarter acre . No dissipation or degradation is considered. Because of the available and well documented information and substantial differences in the amount of caught fish consumed by the general public and native American subsistence populations, separate exposure estimates are made for these two groups.

Parameters/Assumptions	Value	Units	Source/Reference
Surface area of pond [SA]	1000	m ²	N/A
Average depth [DPTH]	1	m	N/A
Volume of pond in cubic meters [VM]	1000	m ³	N/A
Volume of pond in Liters [VL]	1000000	L	1 m ³ = 1,000 L
Volume of spill [VS]	200	gallons	N/A
Concentrations in spilled solution ($C_{(mg/L)}$)			
Central	1.60e-02	mg/L	WSB02.TYPDR×1000
Low	7.19e-03	mg/L	WSB02.LOWDR×1000
High	7.19e-02	mg/L	Section 3.2.4.
Body weight (W)	70	kg	WSA04.BWM
Amount of fish consumed (A)			
General Population	0.158	kg/day	WSA04.FAU
Native American subsistence populations	0.77	kg/day	WSA04.FNU
Bioconcentration factor ($BCF_{(kg\ fish/L)}$)	10000	kg fish/L	WSB03.BCFT
Dose estimates (D) - see details of calculations on next page.			
General Population			
Typical	2.73e-04	mg/kg bw	FISHAMGPT
Lower	1.23e-04	mg/kg bw	FISHAMGPL
Upper	1.23e-03	mg/kg bw	FISHAMGPU
Native American subsistence populations			
Typical	1.33e-03	mg/kg bw	FISHAMNAT
Lower	5.99e-04	mg/kg bw	FISHAMNAL
Upper	5.99e-03	mg/kg bw	FISHAMNAU

Details of calculations on next page

Acute Consumption of Contaminated Fish after an Accidental Spill

Details of calculations

Equations (terms defined below or in table on previous page)

Step 1: As in the acute drinking water scenario, calculate the concentration in the pond based on the concentration in the spilled solution, the volume spilled and the volume of the pond, assuming instantaneous mixing.

$$\text{Conc. (mg/L)} = VS \text{ (gal.)} \times 3.785 \text{ L/gal} \times C \text{ (mg/L)} \div VL \text{ (liters)}$$

Step 2: Calculate the dose based on the concentration in the water, the bioconcentration factor, the amount of fish consumed, and the body weight.

$$D \text{ (mg/kg bw)} = \text{Conc. (mg/L)} \times BCF \text{ (kg fish/L)} \times A \text{ (kg fish)} \div W \text{ (kg bw)}$$

General Public

Central Estimate:

Use the typical field dilution as well as the experimental BCF and upper range of daily fish consumption for the general public.

Step 1:

$$\text{Conc. (mg/L)} = 200 \text{ (gal.)} \times 3.785 \text{ L/gal} \times 1.60\text{e-}02 \text{ (mg/L)} \div 1000000 \text{ (liters)} = 1.21\text{e-}05 \text{ (mg/L)}$$

Step 2:

$$D \text{ (mg/kg bw)} = 1.21\text{e-}05 \text{ (mg/L)} \times 10000 \text{ (L/kg)} \times 0.158 \text{ (kg fish)} \div 70 \text{ (kg)} = 2.73\text{e-}04 \text{ (mg/kg bw)} \text{ [FISHAMGPT]}$$

Lower End of Range for the Estimate:

Use the lower field dilution as well as the experimental BCF and upper range of daily fish consumption for the general public.

Step 1:

$$\text{Conc. (mg/L)} = 200 \text{ (gal.)} \times 3.785 \text{ L/gal} \times 7.19\text{e-}03 \text{ (mg/L)} \div 1000000 \text{ (liters)} = 5.44\text{e-}06 \text{ (mg/L)}$$

Step 2:

$$D \text{ (mg/kg bw)} = 5.44\text{e-}06 \text{ (mg/L)} \times 10000 \text{ (L/kg)} \times 0.158 \text{ (kg fish)} \div 70 \text{ (kg)} = 1.23\text{e-}04 \text{ (mg/kg bw)} \text{ [FISHAMGPL]}$$

Upper End of Range for the Estimate:

Use the upper field dilution as well as the experimental BCF and upper range of daily fish consumption for the general public.

Step 1:

$$\text{Conc. (mg/L)} = 200 \text{ (gal.)} \times 3.785 \text{ L/gal} \times 0.07188 \text{ (mg/L)} \div 1000000 \text{ (liters)} = 5.44\text{e-}05 \text{ (mg/L)}$$

Step 2:

$$D \text{ (mg/kg bw)} = 5.44\text{e-}05 \text{ (mg/L)} \times 10000 \text{ (L/kg)} \times 0.158 \text{ (kg fish)} \div 70 \text{ (kg)} = 1.23\text{e-}03 \text{ (mg/kg bw)} \text{ [FISHAMGPU]}$$

(continued on next page)

Acute Consumption of Contaminated Fish after an Accidental Spill

Details of calculations (continued)

Native American Subsistence Populations

Central Estimate:

Use the typical field dilution as well as the experimental BCF and upper range of daily fish consumption for the native American subsistence populations.

Step 1:

$$\text{Conc. (mg/L)} = 200_{(\text{gal.})} \times 3.785_{\text{L/gal}} \times 0.0159733333_{(\text{mg/L})} \div 1000000_{(\text{liters})} = 1.21\text{e-}05_{(\text{mg/L})}$$

Step 2:

$$D_{(\text{mg/kg bw})} = 1.21\text{e-}05_{(\text{mg/L})} \times 10000_{(\text{L/kg})} \times 0.77_{(\text{kg fish})} \div 70_{(\text{kg})} = 1.33\text{e-}03_{(\text{mg/kg bw})} \text{ [FISHAMNAT]}$$

Estimate of Lower End of Range:

Use the lower field dilution as well as the experimental BCF and upper range of daily fish consumption for the native American subsistence populations.

Step 1:

$$\text{Conc. (mg/L)} = 200_{(\text{gal.})} \times 3.785_{\text{L/gal}} \times 0.007188_{(\text{mg/L})} \div 1000000_{(\text{liters})} = 5.44\text{e-}06_{(\text{mg/L})}$$

Step 2:

$$D_{(\text{mg/kg bw})} = 5.44\text{e-}06_{(\text{mg/L})} \times 10000_{(\text{L/kg})} \times 0.77_{(\text{kg fish})} \div 70_{(\text{kg})} = 5.99\text{e-}04_{(\text{mg/kg bw})} \text{ [FISHAMNAL]}$$

Estimate of Upper End of Range:

Use the upper field dilution as well as the experimental BCF and upper range of daily fish consumption for the native American subsistence populations.

Step 1:

$$\text{Conc. (mg/L)} = 200_{(\text{gal.})} \times 3.785_{\text{L/gal}} \times 0.07188_{(\text{mg/L})} \div 1000000_{(\text{liters})} = 5.44\text{e-}05_{(\text{mg/L})}$$

Step 2:

$$D_{(\text{mg/kg bw})} = 5.44\text{e-}05_{(\text{mg/L})} \times 10000_{(\text{L/kg})} \times 0.77_{(\text{kg fish})} \div 70_{(\text{kg})} = 5.99\text{e-}03_{(\text{mg/kg bw})} \text{ [FISHAMNAU]}$$

Worksheet D08: Consumption of contaminated water, chronic exposure scenario.			
<i>Verbal Description: An adult (70 kg male) consumes contaminated ambient water for a lifetime. The levels in water are estimated from GLEAMS model as detailed in Worksheet D08.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Body weight (W)	70	kg	WSA046.BWM
Amount of water consumed ($A_{(L/day)}$)			
Typical	2	L/day	WSA04.WCAT
Lower	1.4	L/day	WSA04.WCAL
Upper	2.4	L/day	WSA04.WCAH
Estimated Concentration in Water (Conc)			
Typical	5.10e-11	mg/L	Section 3.2.4.3, last paragraph
Lower	0.00e+00	mg/L	
Upper	3.20e-09	mg/L	
Dose estimates : $Conc \times A / W$			
Typical	1.46e-12	mg/kg bw/day	WATCMCT
Lower	0.00e+00	mg/kg bw/day	WATCMCL
Upper	1.10e-10	mg/kg bw/day	WATCMCU

Worksheet D09: Consumption of contaminated fish, chronic exposure scenario.			
<i>Verbal Description: An adult (70 kg male) consumes fish taken from contaminated ambient water for a lifetime. The levels in water are estimated from GLEAMS model as detailed in Worksheet D08.</i>			
Parameters/Assumptions	Value	Units	Source/Reference
Bioconcentration factor ($BCF_{(kg\ fish/L)}$)	10000	kg fish/L	WSB03.BCFT
Estimated Concentration in Water (Conc)			
Typical	5.10e-11	mg/L	Section 3.2.4.3, last paragraph
Lower	0.00e+00	mg/L	
Upper	3.20e-09	mg/L	
Body weight (W)	70	kg	WSA04.BWM
Amount of fish consumed (A)			
General Population typical	0.01	kg/day	WSA04.FAT
upper limit	0.158	kg/day	WSA04.FAU
Native American subsistence populations typical	0.081	kg/day	WSA04.FNT
upper limit	0.77	kg/day	WSA04.FNU
Dose estimates: $BCF \times Conc \times A \div W$			
General Public			For the lower range of dose, the typical fish consumption is used because there is no published lower estimate of typical food consumption.
Typical	7.29e-11	mg/kg bw/day	
Lower	0.00e+00	mg/kg bw/day	
Upper	7.22e-08	mg/kg bw/day	
Native American Subsistence Population			
Typical	5.90e-10	mg/kg bw/day	
Lower	0.00e+00	mg/kg bw/day	
Upper	3.52e-07	mg/kg bw/day	

SUMMARY TABLES FOR HUMAN HEALTH RISK ASSESSMENT

Worksheet E01: Summary of Worker Exposure Scenarios

Scenario	Dose (mg/kg/day or event)			Exposure Assessment Worksheet
	Typical	Lower	Upper	
General Exposures (dose in mg/kg/day)				
Directed ground spray (Backpack)	5.25e-08	1.08e-09	9.60e-07	WSC01
Broadcast ground spray (Boom spray)	8.96e-08	1.58e-09	1.81e-06	WSC02a
Aerial application	5.88e-08	9.60e-10	3.20e-07	WSC02b
Accidental/Incidental Exposures (dose in mg/kg/event)				
Immersion of Hands, 1 minute	9.40e-07	2.92e-07	3.02e-06	WSC03
Contaminated Gloves, 1 hour	5.64e-05	1.75e-05	1.80e-04	WSC03
Spill on hands, 1 hour	1.26e-08	2.69e-09	5.86e-08	WSC04
Spill on lower legs, 1 hour	3.09e-08	6.63e-09	1.44e-07	WSC04

Worksheet E02a: Summary of risk characterization for workers¹

ATSDR Acute MRL	0.008	mg/kg/day	Sect. 3.3.3.	
U.S. EPA Chronic RfD	0.0008	mg/kg/day	Sect. 3.3.3.	
Scenario	Hazard Quotient			Exposure Assessment Worksheet
	Typical	Lower	Upper	
General Exposures				
Directed ground spray (Backpack)	6.56e-06	1.35e-07	1.20e-04	WSC01
Broadcast ground spray (Boom spray)	1.12e-05	1.98e-07	2.27e-04	WSC02a
Aerial applications	7.35e-06	1.20e-07	4.00e-05	WSC02b
Accidental/Incidental Exposures				
Immersion of Hands, 1 minute	1.17e-03	3.65e-04	3.78e-03	WSC03
Contaminated Gloves, 1 hour	7.05e-02	2.19e-02	2.25e-01	WSC03
Spill on hands, 1 hour	1.57e-05	3.36e-06	7.32e-05	WSC04
Spill on lower legs, 1 hour	3.87e-05	8.29e-06	1.80e-04	WSC04

¹ Hazard quotient is the level of exposure divided by the RfD then rounded to one significant decimal place or digit. See Worksheet E01 for summary of exposure assessment.

Worksheet E02b: Summary of cancer risk assessment for workers expressed as increased cancer risk per day of exposure.¹

Adjusted Cancer potency parameter	6.26e-05	(mg/kg/day) ⁻¹	see note below ¹	
Scenario	Cancer Risk			Exposure Assessment Worksheet
	Typical	Lower	Upper	
General Exposures				
Directed ground spray (Backpack)	3.29e-12	6.76e-14	6.01e-11	WSC01
Broadcast ground spray (Boom spray)	5.61e-12	9.92e-14	1.14e-10	WSC02a
Aerial	3.68e-12	6.01e-14	2.00e-11	WSC02b
Accidental/Incidental Exposures				
Immersion of Hands, 1 minute	5.88e-11	1.83e-11	1.89e-10	WSC03
Contaminated Gloves, 1 hour	3.53e-09	1.10e-09	1.13e-08	WSC03
Spill on hands, 1 hour	7.86e-13	1.69e-13	3.67e-12	WSC04
Spill on lower legs, 1 hour	1.94e-12	4.15e-13	9.04e-12	WSC04
Forest Service Reference Cancer Risk Level	1.00e-06	one in one million		

¹ Based on the cancer potency factor of 1.6 (mg/kg/day)⁻¹ for lifetime exposure. To get an estimate of daily cancer risk, this factor is divided by the number of days in the reference human life span of 70 years - i.e., 365 days/year × 70 years = 25,550 days. Thus, the adjusted potency is 1.6 (mg/kg/day)⁻¹ ÷ 25,550 days or 0.000062622 (mg/kg)⁻¹.

Worksheet E02c: Summary of risk characterization for cancer risk assessment for workers relative to risk level of 1 in 1 million.¹

Adjusted Cancer potency parameter	6.26e-05	(mg/kg/day) ⁻¹	see note below ²	
Scenario	Cancer risk divided one in one-million			Exposure Assessment Worksheet
	Typical	Lower	Upper	
General Exposures				
Directed ground spray (Backpack)	3.29e-06	6.76e-08	6.01e-05	WSC01
Broadcast ground spray (Boom spray)	5.61e-06	9.92e-08	1.14e-04	WSC02a
Aerial	3.68e-06	6.01e-08	2.00e-05	WSC02b
Accidental/Incidental Exposures				
Immersion of Hands, 1 minute	5.88e-05	1.83e-05	1.89e-04	WSC03
Contaminated Gloves, 1 hour	3.53e-03	1.10e-03	1.13e-02	WSC03
Spill on hands, 1 hour	7.86e-07	1.69e-07	3.67e-06	WSC04
Spill on lower legs, 1 hour	1.94e-06	4.15e-07	9.04e-06	WSC04
Forest Service Reference Cancer Risk Level	1.00e-06	one in one million		

¹ Cancer risk from Table E02a divided by the reference cancer risk level used by the Forest Service.

² Estimated daily cancer potency factor based on the cancer potency factor of 1.6 (mg/kg/day)⁻¹ for lifetime exposure. See Worksheet E02a for details.

Worksheet E03: Summary of Exposure Scenarios for the General Public

Scenario	Target	Dose (mg/kg/day)			Worksheet
		Typical	Lower	Upper	
Acute/Accidental Exposures					
Direct spray, entire body	Child	4.75e-07	1.02e-07	2.21e-06	WSD01
Direct spray, lower legs	Woman	4.77e-08	1.02e-08	2.22e-07	WSD02
Dermal, contaminated vegetation	Woman	8.85e-07	1.09e-07	1.37e-05	WSD03
Contaminated fruit, acute exposure	Woman	4.26e-08	2.55e-08	5.96e-07	WSD04
Contaminated water, acute exposure	Child	9.09e-07	2.50e-07	1.28e-05	WSD06
Consumption of fish, general public	Man	2.73e-04	1.23e-04	1.23e-03	WSD07
Consumption of fish, subsistence populations	Man	1.33e-03	5.99e-04	5.99e-03	WSD07
Chronic/Longer Term Exposures					
Contaminated fruit	Woman	7.15e-10	7.66e-13	4.99e-09	WSD05
Consumption of water	Man	1.46e-12	0.00e+00	1.10e-10	WSD08
Consumption of fish, general public	Man	7.29e-11	0.00e+00	7.22e-08	WSD09
Consumption of fish, subsistence populations	Man	5.90e-10	0.00e+00	3.52e-07	WSD09

Worksheet E04a: Summary of risk characterization for the general public ¹.

ATSDR Acute MRL					
		0.008	mg/kg/day	Sect. 3.3.3.	
U.S. EPA RfD					
		0.0008	mg/kg/day	Sect. 3.3.3.	
Scenario	Target	Hazard Quotient			Worksheet
	Typical	Lower	Upper		
Acute/Accidental Exposures					
Direct spray, entire body	Child	5.93e-05	1.27e-05	2.77e-04	WSD01
Direct spray, lower legs	Woman	5.96e-06	1.28e-06	2.78e-05	WSD02
Dermal, contaminated vegetation	Woman	1.11e-04	1.36e-05	1.71e-03	WSD03
Contaminated fruit, acute exposure	Woman	5.32e-06	3.19e-06	7.45e-05	WSD04
Contaminated water, acute exposure	Child	1.14e-04	3.12e-05	1.60e-03	WSD06
Consumption of fish, general public	Man	3.41e-02	1.54e-02	1.54e-01	WSD07
Consumption of fish, subsistence populations	Man	1.66e-01	7.48e-02	7.48e-01	WSD07
Chronic/Longer Term Exposures					
Contaminated fruit	Woman	8.94e-07	9.58e-10	6.23e-06	WSD05
Consumption of water	Man	1.82e-09	0.00e+00	1.37e-07	WSD08
Consumption of fish, general public	Man	9.11e-08	0.00e+00	9.03e-05	WSD09
Consumption of fish, subsistence populations	Man	7.38e-07	0.00e+00	4.40e-04	WSD09

¹ Hazard quotient is the level of exposure divided by the provisional RfD then rounded to one significant decimal place or digit. See Worksheet E02 for summary of exposure assessments.

Worksheet E04b: Summary of cancer risk assessment for the general public ¹.

Adjusted Cancer Potency parameter					
		6.26e-05	(mg/kg/day) ⁻¹	Sect. 3.3.3.	
Scenario	Target	Cancer risk			Worksheet
		Typical	Lower	Upper	
Acute/Accidental Exposures					
Direct spray, entire body	Child	2.97e-11	6.37e-12	1.39e-10	WSD01
Direct spray, lower legs	Woman	2.99e-12	6.40e-13	1.39e-11	WSD02
Dermal, contaminated vegetation	Woman	5.54e-11	6.82e-12	8.56e-10	WSD03
Contaminated fruit, acute exposure	Woman	2.67e-12	1.60e-12	3.73e-11	WSD04
Contaminated water, acute exposure	Child	5.69e-11	1.56e-11	8.02e-10	WSD06
Consumption of fish, general public	Man	1.71e-08	7.69e-09	7.69e-08	WSD07
Consumption of fish, subsistence populations	Man	8.33e-08	3.75e-08	3.75e-07	WSD07
Longer Term Exposures					
Contaminated fruit ²	Woman	1.14e-09	1.23e-12	7.98e-09	WSD05
Consumption of water	Man	2.33e-12	0.00e+00	1.76e-10	WSD08
Consumption of fish, general public	Man	1.17e-10	0.00e+00	1.16e-07	WSD09
Consumption of fish, subsistence populations	Man	9.44e-10	0.00e+00	5.63e-07	WSD09

¹ Based on the cancer potency factor of 1.6 (mg/kg/day)⁻¹ for lifetime exposure. To get an estimate of daily cancer risk, this factor is divided by the number of days in the reference human life span of 70 years - i.e., 365 days/year × 70 years = 25,550 days. Thus, the adjusted potency is 1.6 (mg/kg/day)⁻¹ ÷ 25,550 days or 0.000062622 (mg/kg)⁻¹.

² Based on the cancer potency factor of 1.6 (mg/kg/day)⁻¹ for lifetime exposure and the assumption of daily lifetime exposure.

Worksheet E04c: Summary of risk characterization of cancer risk assessment for the general public relative to a risk level of 1 in 1 million ¹.

Acute Cancer Potency Parameter		6.26e-05	(mg/kg/day) ⁻¹		see note ¹ below
Scenario	Target	Cancer risk divided by one in one-million			Worksheet
		Typical	Lower	Upper	
Acute/Accidental Exposures ²					
Direct spray, entire body	Child	2.97e-05	6.37e-06	1.39e-04	WSD01
Direct spray, lower legs	Woman	2.99e-06	6.40e-07	1.39e-05	WSD02
Dermal, contaminated vegetation	Woman	5.54e-05	6.82e-06	8.56e-04	WSD03
Contaminated fruit, acute exposure	Woman	2.67e-06	1.60e-06	3.73e-05	WSD04
Contaminated water, acute exposure	Child	5.69e-05	1.56e-05	8.02e-04	WSD06
Consumption of fish, general public	Man	1.71e-02	7.69e-03	7.69e-02	WSD07
Consumption of fish, subsistence populations	Man	8.33e-02	3.75e-02	3.75e-01	WSD07
Longer Term Exposures ³					
Contaminated fruit	Woman	1.14e-03	1.23e-06	7.98e-03	WSD05
Consumption of water	Man	2.33e-06	0.00e+00	1.76e-04	WSD08
Consumption of fish, general public	Man	1.17e-04	0.00e+00	1.16e-01	WSD09
Consumption of fish, subsistence populations	Man	9.44e-04	0.00e+00	5.63e-01	WSD09
Forest Service Reference Cancer Risk Level	1.00e-06	one in one million			

¹ Cancer risk from Worksheet E04a divided by the reference cancer risk level used by the Forest Service.

² Estimated daily cancer potency factor based on the cancer potency factor of 1.6 (mg/kg/day)⁻¹ for lifetime exposure. See Worksheet E04a for details.

³ Based on the cancer potency factor of 1.6 (mg/kg/day)⁻¹ for lifetime exposure and the assumption of daily lifetime exposure.