Human Health and Ecological Risk Assessment for the Use of Wildlife Damage Management Methods by USDA-APHIS-Wildlife Services

Chapter XIX

The Use of Strychnine in Wildlife Damage Management

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THE USE OF STRYCHNINE IN WILDLIFE DAMAGE MANAGEMENT

EXECUTIVE SUMMARY

Strychnine is a rodenticide used by USDA-APHIS-Wildlife Services (WS) to control pocket gophers belowground. APHIS evaluated the potential human health and ecological risks from the proposed use of strychnine to control pocket gopher damage. Pocket gophers are small, burrowing rodents that feed on a variety of vegetation, including crops, shrubs, and trees, and can cause serious damage in a short time. WS applicators used strychnine to take an annual average of 3,535 pocket gophers of four species in ten states between FY16 and FY20 using 99 pounds of strychnine baits (0.5 pounds of the active ingredient strychnine).

Strychnine is highly toxic to humans and other vertebrates. Strychnine is a neurotoxin and inhibits glycine, a neurotransmitter essential to the nervous system in vertebrates. Although the hazard potentially could be high, the anticipated minimal exposure to this restricted-use pesticide results in low risk. Exposure is greatest for workers who apply the product but using the required personnel protective equipment results in a low potential for exposure. The potential exposure and risk to the public is negligible given the use pattern and label restrictions, as well as lack of dietary exposure through food or drinking water.

Rodents and other small mammals that share burrows with pocket gophers and eat strychnine bait may die, and any animals that find spillage aboveground. Secondary exposure of predators and scavengers feeding on pocket gophers poisoned by strychnine is possible, but several studies indicate most pocket gophers and any nontarget rodents die belowground and are inaccessible. However, secondary hazards could occur if animals that eat bait die above ground. Several studies did not find long-term population impacts to nontarget species from primary and secondary exposure. Direct access to treated bait inside the burrow is negligible for most bird species. Insectivorous bird species and terrestrial reptiles and amphibians are unlikely to receive lethal tertiary exposure by eating insects exposed to strychnine. Exposure of surface and groundwater is unlikely; therefore, the risk to aquatic species is negligible. Exposure of terrestrial vertebrates and invertebrates through the intake of strychnine-contaminated surface water is also negligible. WS's use of strychnine to control pocket gophers was determined to be a minimal risk to human health and safety and the environment.

The USEPA Office of Pesticide Programs is completing registration review for all registered pesticides. This process includes the publication of a Proposed Interim Registration Review Decision (PID) that provides information about the use and risks of each pesticide and new measures to reduce risks to human health and the environment. USEPA published in the Federal Register PIDs for public comment for all registered rodenticides in November 2022. USEPA is proposing pesticide label language changes for rodenticides in the PIDs. The proposed new label language is not discussed in this risk assessment since the changes have not been finalized by USEPA. APHIS-WS will update this risk assessment to reflect the human health and ecological risks related to the new label language once approved by USEPA. USEPA proposed label language changes in the PIDs are generally more restrictive than the current label language for rodenticides. Therefore, the following risk assessment likely overestimates the risks that would be associated with use under any future label language changes required by USEPA.

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1 INTRODUCTION

Pocket gophers (*Cratogeomys* sp., *Geomys* spp. and *Thomomys* spp.)[1] are small, burrowing rodents that feed on a variety of vegetation, including crops, trees, and shrubs, and can cause serious damage in a short time. The United States Department of Agriculture's (USDA) Animal and Plant Health Inspection Service's (APHIS) Wildlife Services (WS) may manage pocket gopher populations and their damage by placing strychnine bait inside pocket gopher burrows.

Strychnine baits are applied underground in pocket gopher burrows either by hand with a probe or mechanically with a burrow builder. Typically, WS uses hand baiting with a probe for small areas, and if a burrow builder is not available, for larger areas as well. Hand applicators find burrow runways by pressing the probe into the ground about a foot from gopher mounds to find the main runway (the probe easily drops when it hits a burrow). The probes are hollow tubes with a bait dispenser or side funnel that allows a teaspoon of bait to be inserted into the burrow through the tube. Solid probes can be used, and the hole into the burrow from the probe is widened so a teaspoon of bait can be deposited into the burrow system. The holes created by probes are then covered with dirt and debris, being careful not to cover the bait with dirt to discourage pocket gophers from plugging the area with dirt. Burrow builders are tractor-drawn implements that create tunnels in the soil and drop a measured amount of strychnine baits in the burrow runs it creates. They are used for larger areas with high densities of gophers (e.g., pastures, alfalfa (*Medicago sativa*) fields, parks, playing fields, golf courses, orchards, roadsides, and windbreaks where a burrow builder can be dragged without hitting obstructions). In rough terrain or areas with obstructions such as rocks, a free-floating hitch is used, and shorter burrow runs are made, especially in orchards where root systems could be damaged. Where obstructions are expected, such as underground boulders, short runs of tunnels can be made to avoid damaging the burrow builder. Burrow builder tunnels are run through fields and expected to intersect gopher burrows. Gophers find the tunnels and will use them where they find the bait.

This human health and ecological risk assessment evaluates potential risks and hazards to human health and the environment, including nontarget fish and wildlife, as a result of exposure to strychnine from its proposed use by WS. The methods used to assess potential human health effects follow standard regulatory guidance and methodologies (National Research Council 1983) and generally conform to other Federal agencies such as the U.S. Environmental Protection Agency (USEPA 2019). The methods used to assess potential ecological risk to nontarget fish and wildlife generally follow USEPA (2019) methodologies.

This risk assessment starts with problem formulation (identifying hazard) and then evaluates toxicity (dose-response assessment) and exposure (identifying potentially exposed populations and determining potential exposure pathways for these populations). Lastly, the integration of the toxicity and exposure assessments provides a characterization of risks (determining if adverse human health or ecological risks are present and their significance). A discussion of the uncertainties associated with the risk assessment and cumulative effects is also included in this risk assessment.

[1] Scientific names are given in *Chapter 1: Introduction to Risk Assessments for Methods Used in Wildlife Damage Management* and not in this document except for species not in that chapter.

1.1 Strychnine Formulations

Strychnine baits come in several APHIS and commercial formulations. Each formulation with its label and instructions must be followed when applying the baits. The primary formulations that WS uses are the APHIS registrations for milo (*Sorghum bicolor*) and oat (*Avena sativa*) baits delivered by burrow builders or hand baiting. Table 1 gives the formulations used by WS personnel during FY16[2]-FY20, the USEPA registration number, the amount of active ingredient (a.i.), treatment rates, and target species.

Table 1. Strychnine formulations available for USDA-APHIS WS use.

Trade Name (Registrant)	EPA Reg. No. (label date)	Formulation (% a.i.)	Application Rate lb. formulation per acre (lb. a.i./acre)	Target Pocket Gophers
Strychnine milo - burrow builders (APHIS)	56228-11 (30 Aug. 2019)	Strychnine (0.5%) Inert ingredients: (99.5%)	1.0 (0.45 kg) to 2.5 lb (1.13 kg) of bait per acre (0.405 ha) (0.005 to 0.0125 lb. a.i./ac)	*Cratogeomys* spp., *Geomys* spp. and *Thomomys* spp., excluding Mazama pocket gopher (*T. mazama*) in Thurston and Pierce Counties, WA
Strychnine oat - burrow builders (APHIS)	56228-12 (30 Aug. 2019)			
Strychnine milo - hand-baiting (APHIS)	56228-19 (3 Jan. 2020)		1.0 lb (0.45 kg) bait will treat 1 to 8 acres (0.41 to 3.24 ha)	
Strychnine oats - hand-baiting (APHIS)	56228-20 (3 Jan. 2020)			
RCO Omega Gopher Grain Bait, 0.5% strychnine grain bait for pocket gophers (RCO International, Inc.)	5042-32 (3 Jan. 2020)		1.0 lb. (0.45 kg) bait/ 1 to 8 acres	Northern (*T. talpiodes*), Southern (*T. umbrinus*), Camas (*T. bulbivorus*), Botta's (*T. bottae*), Mazama (*T. mazama*), plains (*G. bursarius*), mountain (*T. monticola*), and Townsend's pocket gophers (*T. townsendii*)

Other commercial strychnine formulations are available with the percentage of active ingredients that WS could potentially use. Other products are typically used for small projects because they are available in local areas at some distributors in small quantity buckets. However, some previously available gopher formulations have replaced strychnine with diphacinone or other toxicants in their products. In general, the APHIS formulations (Table 1) will be used, with minimal use of other products.

1.2 Use Pattern

WS used strychnine in ten states to take an estimated annual average of 3,535 pocket gophers of four species during FY16-FY20 (Table 2). All of these species are common and abundant. Plains pocket gophers (36%) and northern pocket gophers (32%) were the primary target species. Burrow builder formulations with milo (37%) and oat (34%) baits were used the most, followed by hand baiting formulations with oat (16%) and milo (12%) baits. WS applied strychnine under four labels; three APHIS labels and one commercial label (Table 2). Additionally, WS distributed or sold 736 pounds of bait annually to certified pesticide applicators, as necessary, for use on their properties, which included an additional label and species (Table 2). WS primarily used APHIS

[2] FY16 equals the federal Fiscal Year 2016, which is October 1 2015-September 30 2016 (the year is denoted by FY17, FY18, …).

products (99.8%) (Table 2). Use decreased from a 266-pound annual average for FY11-FY15 (Appendix 1) to a 99-pound average from FY16-FY20.

Because applications of strychnine are belowground and most pocket gophers that ingest bait die underground (Nolte and Wagner 2001, Ramey et al. 2002), it is not possible to count the exact number of pocket gophers taken with strychnine treatments nor any nontarget species taken. Since WS personnel did not dig up burrows to determine the actual take of target or nontarget species, numbers were estimated from the expected number of target animals taken per ounce of bait applied based on consumption. In the MIS[3], WS personnel record the number of target species taken with treatments or the acreage or burrows treated. With that said, they often record bait placements rather than burrows treated. Therefore, take based on consumption makes a better estimate of take. Additionally, it is often difficult to determine where one burrow system ends and the next one starts or the amount of bait put into a burrow (4 tsp of oats = 0.30 oz whereas milo = 0.54 oz), making estimates more difficult in the field.

Table 2. The annual average number of target pocket gophers killed with strychnine by APHIS-WS in WDM activities for FY16 to FY20 throughout the United States and the pounds of strychnine used. No known nontarget take occurred during this time.

ANNUAL AVERAGE SPECIES KILLED WITH STRYCHNINE AND FORMULATIONS USED					
SPECIES TARGETED					
Species	**States Used**	**Take[1]**	**Lb. Bait**	**States Sold**	**Lb. Sold**
Northern Pocket Gopher	ND OR WA	1,130	12.2	ND NM	33
Botta's Pocket Gopher	NM UT	560	14.0	NM UT	593
Desert Pocket Gopher	NM	574	17.5	NM	64
Plains Pocket Gopher	CO KS MN NE TX	1,272	55.1	NE	10
Yellow-faced Pocket Gopher	-	-	-	NM	37
FORMULATION USE					
Formulation	**States Used**	**Take[1]**	**Lb. Bait**	**States Sold**	**Lb. Sold**
Omega Gopher in Bait	OR	6	0.2	-	-
Strychnine Milo – Burrow Builder	NE NM	297	42.0	NM UT	325
Strychnine Milo – Hand Bait	CO KS MN ND NE NM TX UT WA	2,148	44.7	ND NE NM	311
Strychnine Oats – Burrow Builder	-	-	-	UT	100
Strychnine Oats – Hand Bait	MN OR WA	1,084	12.0	-	-
Annual Average Take and Use	**10 States**	**3,535**	**98.9**	**4 States**	**736**

[1]If the take was not estimated, the number of target animals taken was estimated at 8 per pound of bait for burrow builders or 1 per ounce for hand baiting.

If take numbers were estimated by field personnel, the number of pocket gophers taken was used. If no take was estimated for an application, the take was estimated based on the acres treated or the pounds of bait used. Consumption was based on an estimate that pocket gophers likely consume about 8% of body weight (bw) per day. The amount of feed an adult gopher would consume can be calculated given the average weight of a pocket gopher by species (males tend to be larger than females, and average weights vary by species (Table 3). Given that amount, and an assumption that they consume all the bait in their burrow system except 10% wastage (e.g., baits inaccessible, covered by dirt, or taken by the gopher back to the food chamber in its cheek pouches, "pockets"), and that all pocket gophers die from eating a lethal dose of bait, provide the parameters for an estimate of take for the pounds used. If acreage is recorded, typical pocket gopher density/ha or acre can be used. Finally, if the number of burrows treated is

[3] MIS - Computer-based Management Information System used for tracking WDM activities. Throughout the text, data for a year (e.g., FY16 to FY20) will be given and is from the MIS. MIS reports will not be referenced in the text or Literature Cited Section because MIS reports are not kept on file. A database is kept that allows queries to be made to retrieve the information needed.

recorded, an estimate can be made for how many gophers will be in a burrow system. The male is solitary except for breeding, and the female weans the pups in relatively few weeks. Within two months, they are usually in their own burrow. Most pocket gophers have two litters per year, so being conservative, an estimate of the number per burrow would be for 6 months. Table 3 gives the parameters used to make estimates.

Table 3. The estimated annual average number of target pocket gophers killed with an ounce of strychnine bait for burrows treated or per acre treated when it was not estimated. It is assumed that pocket gophers consume 8% of their body weight per day, 4 tsp. are used per burrow, and that 10% of the strychnine baits are waste (e.g., bait lost to being unconsumed or buried and unavailable).

ANNUAL AVERAGE NUMBER OF POCKET GOPHERS KILLED PER OUNCE OF BAIT						
Species	**Weight (oz.)**	**Feed (oz./day)**	**#/oz. Bait[1]**	**#/Litter**	**#/Burrow**	**#/Acre**
Northern Pocket Gopher	11.6	0.3	2.9	5.5	3	14
Botta's Pocket Gopher	5.5	0.4	2.0	5.5	3	9
Desert Pocket Gopher	6.8	0.6	1.6	4	2	6
Plains Pocket Gopher	6.5	0.5	1.7	4	2	7
Yellow-faced Pocket Gopher	9.5	0.8	1.2	2	2	5

[1] 10% of the strychnine baits applied are lost to going unconsumed, being buried by gophers, or being unavailable. Pocket gophers live solitary lives except for breeding and mothers with young. Most female gophers have young in burrow systems about 50% of the year. It is also expected that four teaspoons treat each burrow system (2-7 tsp/burrow system is the label suggestion). Also, 4 tsp weighs for milo 0.54 oz. and for oats 0.30 oz. Thus, for 1 gopher some could be left over if milo used whereas it is likely to be consumed by a gopher if oats are used. For the yellow-faced pocket gopher (e.g., larger pocket gophers), generally more bait is applied. Larger gophers tend to build longer burrow systems, and one gopher can maintain 100 m or more of burrow; it is often hard to tell if treating one burrow or another in the field, especially from mounds, since one burrow system can have many. The average density of burrows in alfalfa, a desirable gopher habitat, was 14/ha or about 6/acre (Smallwood et al. 2001).

Table 4. The annual average number of target pocket gophers killed[1] with strychnine and ounces used in each State by APHIS-WS in WDM activities for FY16 to FY20. No known nontarget take was recorded.

ANNUAL AVERAGE STRYCHNINE USED WITH TARGET TAKE[1] BY STATE FOR FY16-FY20								
	Burrow Builder Baits		**Hand Baits**				**Omega Baits**	
State	**Milo**		**Milo**		**Oats**		**Grain**	
	Take	**Oz.**	**Take**	**Oz.**	**Take**	**Oz.**	**Take**	**Oz.**
Colorado	-	-	520	172.8	-	-	-	-
Kansas	-	-	397	32.9	-	-	-	-
Minnesota	-	-	1	6.4	13	12.8	-	-
Nebraska	270	640.0	14	2.4	-	-	-	-
New Mexico	27	32.0	714	360.4	-	-	-	-
North Dakota	-	-	8	0.7	-	-	-	-
Oregon	-	-	-	-	2	2.4	6	2.8
Texas	-	-	68	14.4	-	-	-	-
Utah	-	-	393	111.1	-	-	-	-
Washington	-	-	33	13.6	1,081	176.3	-	-
Total	**297**	**672.0**	**2,148**	**714.7**	**1,096**	**191.5**	**6**	**2.8**
States	**2**		**9**		**3**		**1**	

[1]If take was not estimated, the number of pocket gophers taken was estimated based on parameters from Table 3.

WS mostly used the strychnine formulations registered for use by USDA-APHIS 99.7% of the time (Table 4). WS applicators applied an annual average of 1,581 ounces (98.9 pounds) of strychnine baits. Utah (70%), Washington (12%), Texas (6%), and Oregon (5%) used the most strychnine baits. The primary use of strychnine baits was at airports to reduce the attractiveness of airfields to raptors hunting pocket gophers. WS also used baits to minimize damage to pastures, alfalfa, orchards, property, and parks. Some areas are retreated in subsequent years, especially airfields, because pocket gophers reproduce annually and may recolonize areas.

2.0 PROBLEM FORMULATION

Strychnine is a nonselective rodenticide first registered in the U.S. in 1947 (USEPA 1996b). Strychnine was registered to control rodents such as ground squirrels and pocket gophers, birds such as feral pigeons, and predators such as skunks and coyotes in both aboveground and belowground applications. In 1988, aboveground uses were suspended and, since, can only be used belowground for pocket gophers. The following sections discuss the chemical description, product use, physical and chemical properties, environmental fate, and hazard identification for strychnine.

2.1 Chemical Description and Product Use

Strychnine (CAS Number 57-24-9) is a toxic alkaloid extracted from seeds of the strychnine tree (*Strychnos nux-vomica*), Ignatius tree (*S. ignatii* (*S. sancta ingnatius*)), and upas tree (*S. tiente*), all native to the Asia-Pacific region including India, Sri Lanka, Vietnam, Indonesia, the Philippines, and northern Australia with some being introduced in the U.S. (USEPA 1996b, Centers for Disease Control 2018). It is a competitive antagonist at glycine receptors, making it a convulsant. Strychnine has been used as an analeptic in the treatment of hyperglycinemia and sleep apnea, as well as a rodenticide.

WS applicators apply strychnine bait directly into subterranean burrow systems of pocket gophers with a machine-drawn mechanical burrow builder or by hand-baiting. The mechanical burrow builder is a device that digs an artificial burrow and places the bait into the burrow. During hand-baiting, applicators use a bait dispensing probe, a hollow tube, or a metal rod to locate a burrow and release bait into the burrow. The applicator typically applies bait at up to seven locations per burrow system; the number of applications per burrow system often depends on the number of mounds because baits are placed a foot to a yard away from each mound.

APHIS is the registrant for four USEPA-registered strychnine formulations that WS uses to control pocket gopher populations (Table 1). Two formulations are burrow builder products, and two are hand-bait products. WS has also used Omega Gopher Grain Bait, a hand-bait product. These products all contain 0.5% strychnine pre-mixed with oats or milo. The products are restricted to underground use to control pocket gophers in rangelands, pastures, croplands, forests, and non-agricultural areas. The labels for the two burrow builder products specify a higher application rate than the hand-bait products. Application rates vary with the density of gopher populations.

The use of this product may pose a hazard to federally threatened and endangered species. The label identifies several species that must be considered prior to use. Strychnine baits cannot be used within the ranges of threatened and endangered (T&E) species that would eat the baits (belowground) or prey or scavenge on dead or dying pocket gophers including the Olympia (*Thomomys mazama pugetensis*), Roy Prairie (*T. m. glacialis*), Tenino (*T. m. tumuli*), and Yelm (*T. m. yelmensis*) pocket gophers; Point Arena mountain beaver (*Aplodontia rufa nigra*); Utah prairie dog (*Cynomys parvidens*); northern Idaho ground squirrel (*Urocitellus brunneus brunneus*); giant (*Dipodomys ingens*), Morro Bay (*D. heermanni morroensis*), Fresno (*D. nitratoides exilis*), Tipton (*D. n. nitratoides*), and Stephen's (*D. stephensi*) kangaroo rats; Pacific little pocket mouse (*Perognathus longimembris pacificus*); Preble's (*Zapus husonius preblei*) and New Mexico (*Z. h. luteus*) meadow jumping mice; Amargos vole (*Microtus californicus scirpensis*); riparian woodrat (*Neotoma fuscipes riparia*); salt marsh harvest mouse (*Reithrodontomys raviventris*); Columbia Basin pygmy rabbit (*Brachylagus idahoensis* distinct population segment); riparian brush rabbit (*Sylvilagus bachmani riparia*); San Joaquin kit fox (*Vulpes macrotis mutica*); gray wolf; grizzly bear (*Ursus horribilis horribilis* Continental U.S. distinct population segment); black-footed ferret (*Mustela nigripes*); California condor (*Gymnogyps californianus*); and northern (*Strix occidentalis caurina*) and Mexican (*S. o. lucida*) spotted owls. It is a federal offense to use any pesticide in a manner that results in the death of a T&E species. The label requires that the U.S. Fish and Wildlife Service be consulted on local species that could be impacted by use of strychnine. WS conducts Section 7 consultations with USFWS to ensure that T&E species are not impacted.

2.2 Physical and Chemical Properties

Strychnine (C21H22N2O2, Figure 1) is a white, odorless, and stable solid crystalline powder with a bitter taste (USEPA 1996b; Centers for Disease Control 2018). It has a high melting point (273°C) and very low vapor pressure (2.93X10-9 mm Hg at 25 °C (est)) (NIH 2022). It's Henry's Law Constant is 7.56 x 10^{-14} atm m^3/mol (NIH, 2018), suggesting it does not volatilize into the atmosphere from water.

Strychnine is not soluble in water (0.0115 g/100ml) (USEPA 1996b). It has a dissociation constant of 8.26 at 25°C (NIH, 2022). Strychnine's log of the octanol-water partition coefficient, K_{ow} is 1.93 (NIH 2022).

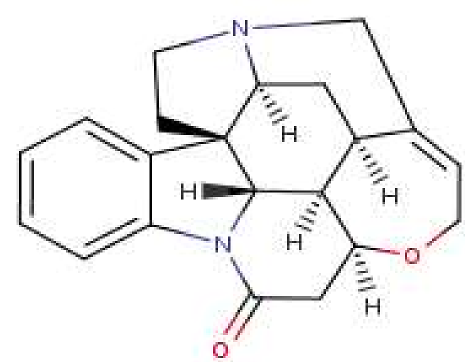

Figure 1. Chemical structure of strychnine (C21-H22-N2-O2) (NIH 2020).

2.3 Environmental Fate

Environmental fate describes the processes by which strychnine moves and transforms in the environment. The environmental fate processes include mobility, persistence, and degradation in soil, movement to air, migration potential to groundwater and surface water, and plant uptake.

Strychnine in the soil is stable to photolysis (Timm et al. 1993). Batch adsorption/desorption data show that strychnine binds strongly to various soils with Freundlich Kd-adsorption/desorption values of 39-168 mL/g (USEPA 2015a). The mean sorption (Kf), desorption (Kfdes), and sorption coefficient (Kfoc) for strychnine technical are 105.9, 101.3, and 13823, respectively, which indicates strychnine is strongly sorbed to soil and likely immobile in the environment (Timm et al. 1992); particularly in soils with moderate to high cation exchange capacities (Starr et al. 1996, USEPA 1996b; Kookana et al. 1997). In one laboratory study, strychnine sorption to soil particles was rapid, with 90% sorption occurring within 15 minutes to a couple of hours in experiments combining 1 gram of soil mixed with a strychnine solution of 10 mg/L (Kookana et al. 1997). Strychnine is not likely to accumulate in soil because it is biodegradable (Starr et al. 1996, Rogers et al. 1998). Approximately 50% of the 10 ppm (ug/g) of strychnine in soil was lost through soil sorption and degradation by microorganisms within 24 days for sandy loam soil and 27 days for sandy-clay loam soil (Starr et al. 1995, Starr et al. 1996). Similar degradation rates occurred in another study on two alkaline soils despite the higher starting concentration of 50 mg/kg strychnine (Rogers et al. 1998). In sandy loam and sandy-clay soils, the time for 50% of the strychnine to dissipate (DT50) under aerobic conditions was 24 and 27 days, respectively. About 90% of the strychnine dissipated within 33 to 40 days in both soil types (Starr et al. 1996). In one laboratory study, when strychnine strongly adsorbed to soil with a pH of 5.5, degradation did not occur during the 98-day incubation period (Rogers et al. 1998). The authors attribute this to the low bioavailability of strychnine due to the strong adsorption (Rogers et al. 1998). This may indicate that in some environments, strychnine may persist in soil; however, this observation was made in a laboratory study, and field conditions may be different.

In a study looking at the release of strychnine from treated grain to soil, strychnine took approximately 2 months to move from treated grains placed on the soil surface to the soil; however, 90% of strychnine transferred within 7 days when treated grain was buried (Kookana et al. 1997). Strychnine is not expected to leach based on its high soil-water partition coefficient for organic compounds (Koc), sorption to soil, particularly with higher clay content, and its insolubility in water (Starr et al. 1996, Kookana et al. 1997, Ghadiri et al. 1999). In laboratory studies, clay soil retained higher amounts of strychnine. It resisted releasing strychnine during desorption studies with strychnine concentrations higher than those used in mouse bait or treated grains in Australia (Ghadiri et al. 1999). The binding capacity of strychnine to soils decreased as clay content decreased (Ghadiri et al. 1999).

Off-site movement of strychnine formulations is unlikely to occur in surface and ground water runoff because strychnine application is within the gopher burrows, and strychnine is essentially immobile. In one atypical finding, the U.S. Forest Service (USFS 2010) detected strychnine in stream water following strychnine bait applications. The USFS applied 0.5% strychnine bait belowground at 42 sites between 1996 and 1997. USFS (2010) detected concentrations of strychnine (13-23ppb) in stream water at two sites; both streams were located below treatment areas that received heavy rains following strychnine application. In subsequent years, there were no reports of detectable concentrations of strychnine in surface water, indicating the off-site movement of strychnine was atypical. The estimated half-life for strychnine is seven to 28 days in surface water based on unacclimated aqueous aerobic biodegradation half-life (Howard 1991). Strychnine does not hydrolyze at pH 5, 7, or 9 (Mishalanie et al. 1989).

Strychnine is not likely to be present in the air, except as a particulate, because of its low vapor pressure. The photolysis process does not appear to degrade strychnine significantly (USEPA 1996b).

Laboratory studies indicate plants can uptake strychnine from the soil, but plants in the field do not appear to uptake measurable amounts of strychnine. In a greenhouse study, fava bean (*Vicia faba*), pea (*Pisum sativum*), and lupine plants (*Lupinus angustifolius*) took up strychnine from bait applied approximately 10 to 30 times the recommended application rate (Oliver et al. 2000), indicating that plants can take up strychnine. However, when field tested, crops did not have measurable uptake of strychnine from surface-applied strychnine bait applied at 8 times the recommended rate (Oliver et al. 2000). The authors speculated that the recommended field application rates would result in no detectible limits of strychnine in plants. A study on the strychnine uptake from subsurface bait (up to 5.26% strychnine-treated grain bait) did not show evidence that alfalfa and apple (*Malus domestica*) trees took up strychnine from the soil (Smith 1982).

2.4 Hazard Identification

Strychnine is highly toxic to humans and other vertebrates. Strychnine is a neurotoxin and inhibits glycine, a neurotransmitter essential to the nervous system in vertebrates. The inhibition of glycine in the spinal cord causes excessive motor neuron activity and muscle spasms (convulsions) (Borges et al. 1989, USEPA 1996b, USFS 2010). Muscular hyperactivity and convulsions can quickly lead to respiratory failure and death (Borges et al. 1989). Symptoms may appear within 15 to 60 minutes, with respiratory failure and brain death occurring within 30 minutes of exposure to high doses (Borges et al. 1989, Centers for Disease Control 2018).

The formulations used by WS contain 0.5% strychnine. In these products, the other ingredients are primarily grains (oats or milo), which are not hazardous to humans or nontarget animals. The other additives used in these formulations occur in minor amounts. They are typically dyed to mark toxic bait and other materials intended to make the formulation more palatable to pocket gophers. The following section summarizes available acute and chronic toxicity data for humans and mammals that are used to evaluate the hazards of strychnine to human health and nontarget animals.

2.4.1 Toxicokinetics

Strychnine is absorbed through the gastrointestinal tract and nasal passages (Borges et al. 1989). Studies on dermal absorption of strychnine are limited. One report summarized nonlethal exposure in a woman whose left hand contacted a solution of strychnine with an assumed concentration of 2% and did not wash her hand until 30 minutes after exposure (Greene and Meatherall 2001). She spilled strychnine and cleaned it with a cloth, using sodium hypochlorite (bleach). Bleach is strongly alkaline and converts the strychnine to a free base, more easily absorbed through the skin. About 22 hours after exposure, she experienced progressive muscle spasms, pain in her lower limbs, and jaw stiffness. After 24 hours, she experienced dermal hypersensitivity. Two days after medical treatment, the woman had some muscle discomfort but had no symptoms within a month.

Strychnine does not accumulate in the body; instead, the liver metabolizes and detoxifies nonlethal doses of strychnine, and the body excretes it in urine (Borges et al. 1989). Survival from strychnine poisoning is unlikely to cause long-term health effects unless damage from poisoning occurs, such as kidney failure or brain damage from low oxygen levels (Centers for Disease Control 2018).

2.4.2 Acute Toxicity

The USEPA (2015a) Office of Pesticide Programs (OPP) classifies strychnine as a toxicity category I (indicating the greatest degree of acute toxicity) for oral and inhalation effects (presumed inhalation toxicity) (Table 5). The inhalation toxicity category I was assigned based on the acute oral toxicity. This protective assumption to human health is conservative because strychnine has a low vapor pressure, and only particulates pose potential hazards. Mammalian strychnine toxicity studies found that females appeared more sensitive than males, and young animals appeared more sensitive than mature animals.

USEPA (1996b) classified strychnine as a toxicity category I eye irritant because of rabbit mortality in the eye irritation study, which indicated rapid absorption of strychnine through the eye.

For dermal contact, USEPA (1996b) classified acute dermal toxicity as category III and dermal irritancy as category IV. These classifications are due to strychnine's poor absorption through the skin based on the dermal toxicity study in rabbits in which neither mortality nor signs of toxicity were noted at a limit dose of 2,000 mg/kg body weight (USEPA 1996b; Glaza 1997a). In addition, after direct dermal contact with a strychnine solution (estimated at 2% strychnine), one woman did not show evidence of dermal irritation (Greene and Meatherall 2001). The woman was asymptomatic for about 12 hours. After which, she experienced shaking and spasms of the arms and legs, muscular pain, and hypersensitivity to touch, the same strychnine symptoms of oral systemic toxicity. Strychnine is a fast-acting toxin through the oral route of exposure, and the delayed toxic effects from dermal exposure indicate a slower rate of absorption (USFS 2010). A comparison of acute mammalian oral toxicity data between the technical active ingredient and formulations shows that the formulations are less toxic than the technical active ingredient (Table 5). Other available comparable acute endpoints show similar or less hazard between the technical a.i. and formulated product, with the exception of the primary dermal irritation study in rabbits.

Table 5. Acute mammal toxicity data for strychnine alkaloid technical (purity = 99.42%) and grain oat baits containing 0.5% strychnine.

Test	Results (99.42%)	Toxicity Category	Grain baits (0.5% strychnine)	Toxicity Category
Acute oral LD_{50}[1], lab rat	6.4 mg/kg males 2.2 mg/kg females Death within 1 hour	I	440-541 mg/kg[2]	IV [2]
Acute dermal LD_{50}, lab rabbit	2000 mg/kg, No signs of toxicity	III	>2,000 mg/kg [3]	III
Acute LD_{50} inhalation	N/A	I*	>2.11 mg/L [4]	I [2]
Primary eye irritation, rabbit	Irritation and mortality	I	Temporary [5]	IIB [2]
Primary dermal irritation, rabbit	No irritation, mortality, or signs of toxicity	IV	Slight irritation to skin [6]	II [2]
Skin sensitization – Guinea pig	Not a sensitizer[7]	N/A		IB [2]

* Based on high acute toxicity of oral exposure route N/A = Not Available

[1] LD50 – Lethal dose 50% = amount of a chemical sufficient to kill 50% of a population; [2] USDA (2019); [3] (Glaza 1997a); [4] MRID 44708001: Wnorowski (1998); [5] MRID 44708002: Moore (1998); [6] Glaza (1997b); 7 USEPA (2015a)

2.4.3 Subchronic and Chronic Toxicities

Chronic and subchronic strychnine toxicity studies are limited. In a subchronic study, rats were exposed to a 0.2% solution of strychnine hydrochloride intubated into the stomach at a daily dose of 5 mg/kg and 10 mg/kg in males and 2.5 mg/kg in females over 28 days (Seidl and Zbinden 1982). After each treatment, animals exhibited slight tremors, which subsided within the first hour. Treated rats did not differ from control rats in weight gain, food or water consumption, hematological values, urinalysis, eye examination, electrocardiogram test, organ weight, behavior, or coordination. No other symptoms were observed. Based on this study, the lowest-observed-adverse-effect level (LOAEL) for rats is 2.5 mg/kg/day (USEPA 2002).

2.4.4 Effects on Nervous, Immune, and Endocrine Systems and Reproduction and Development

Strychnine is a neurotoxin. Acute toxic doses of strychnine cause muscular hyperactivity, convulsions, respiratory failure, and death. Studies on the immunological effects of strychnine exposure are lacking in the literature.

Studies on the effects of strychnine on the endocrine system are limited, and multigenerational exposure studies are not available. In the 28-day oral toxicity rat study summarized above, no histological changes occurred in the adrenal gland, pancreas, pituitary gland, ovary, testicle, and thyroid gland, and no significant weight changes occurred in the adrenals or testes (Seidl and Zbinden 1982).

Multigenerational studies and reproductive toxicity studies are mostly lacking in the literature. In a developmental study, García-Alcocer et al. (2005) found the embryos of pregnant rats given a single oral dose of 2.5, 5.0, or 8.0 mg/kg strychnine on day 8 developed neural tube defects.

2.4.5. Human Incidents

USEPA (2015b) evaluated human incidents and epidemiology studies related to strychnine using the USEPA/OPP Incident Data System (IDS), the Centers for Disease Control, National Institute for Occupational Safety and Health Sentinel Event Notification System for Occupational Risk-Pesticides (SENSOR), and the National Pesticide Information Center (NPIC) databases between 1998 and 2011. The incidents reported in IDS and SENSOR during this period following the implementation of the mitigation measures recommended in the 1996 reregistration eligibility decision were of low frequency and severity. Mitigation measures included only allowing ready-to-use grain baits at levels of no greater than 0.5% strychnine concentration for manual baiting by homeowners and child-resistant packaging, as well as label modifications on personal protective equipment (PPE). Strychnine is not included in the Agricultural Health Study, so no reporting data is available.

3.0 DOSE-RESPONSE ASSESSMENT

3.1 Human Health

A dose-response assessment evaluates the dose levels (toxicity criteria) for potential effects on human health. The lethal dose in humans varies. Human poisoning incidents include both accidental and intentional exposures. Fatal doses (acute oral toxicity) measured from individuals under medical intervention ranged between 1.4 and 80 mg/kg bw, and non-fatal doses ranged between 1 to 25 mg/kg bw (U.S. Forest Service (USFS) 2010). The oral lethal dose for humans ranges from 30 to 120 mg (Borges et al. 1989). Most incidents involving young children are associated with accidental ingestion of strychnine medicine tablets. Children are more sensitive to strychnine with lethal doses possibly as low as 15 mg (Goodman and Gilman 1985).

The USEPA (1996b) estimated a single strychnine bait (0.5% strychnine) would be lethal to a 10 kg child based on a calculated dose of 1.1-1.8 mg/kg of strychnine. Because of strychnine’s high acute oral toxicity, the USEPA (1996b) did not calculate an acute oral reference dose (RfD).

The USEPA Office of Research and Development (USEPA 1987) derived a chronic oral exposure RfD of 0.0003 mg/kg bw/day based on a LOAEL of 2.5 mg/kg/day from the 28-day gavage rat study (Seidl and Zbinden 1982). An uncertainty factor of 10,000 was applied to account for a) extrapolation from a less-than-chronic to a chronic exposure study, b) extrapolation from animals to humans, c) differences in sensitivity among the human population, and d) using a LOAEL instead of a no-observable-adverse-effect level (NOAEL) to derive the RfD. The RfD is not used in this human health risk assessment because very few animals were involved, no NOAEL was identified in the study, and no human toxicity data was considered. The USFS (U.S. Forest Service (USFS) 2010) used a surrogate RfD of 0.02 mg/kg bw for their risk assessment based on the threshold limit value recommended by the American Conference of Governmental Industrial Hygienists. This threshold limit value is intended to be protective in both acute and longer-term exposures based on human data. USDA-APHIS uses this surrogate RfD for this risk assessment.

The National Institute for Occupational Safety and Health (NIOSH) set a recommended exposure limit (REL) time-weighted average (TWA) of 0.15 mg/m3 for occupational exposure (exposure routes of inhalation, ingestion, skin, or eye contact) for a 10-hour workday during a 40-hour workweek (Centers for Disease Control 2019). This value is used to minimize the potential for neurotoxic and central nervous system effects.

3.2 Ecological

A dose-response assessment evaluates the dose levels (toxicity criteria) for potential ecological effects, including acute and chronic toxicity. Many toxicity studies have been conducted on species to determine the relative toxicity of strychnine to them and their potential to others as surrogate species (Table 6). In general, strychnine is highly toxic to vertebrates and invertebrates.

3.2.1 Terrestrial Dose-Response Assessment

Mammals

Strychnine has high acute toxicity in mammals (Table 6). Strychnine sensitivity varied from mink with an LD50 of 0.6 mg/kg to the California ground squirrel with an LD50 of 38 mg/kg (Table 6). Strychnine (99.9% a.i.) has median lethal concentration (LC50) values of 70 ppm and 198 ppm for red fox and European ferret, respectively (USEPA 1996b) (Table 4). In acute oral studies using the domestic brown (Norway) rat, females (LD50 = 2.2 mg/kg) were more sensitive than males (LD50 = 6.4 mg/kg) (USEPA 1996b). In these studies, death occurred within one hour.

In a field study, exposure of plains pocket gophers to strychnine bait at 0.35%, 0.75%, and 1.30% caused mortality in 66.7%, 96.3%, and 89.7% of the animals, respectively (Ramey et al. 2002). Pocket gophers can absorb strychnine through their cheek pouches, where they may store treated bait, and through their stomach and intestinal tract (Record and Marsh 1988).

In a subchronic study, brown rats treated by gavage with 0 to 10 mg/kg strychnine over 28 days did not display differences from the control rats in weight gain, food or water consumption, hematological endpoints, urinalysis, eye examination, electrocardiogram test, organ weight, behavior, or coordination (Seidl and Zbinden 1982). After each treatment, animals exhibited a slight tremor, which subsided within the first hour.

Birds

As with other animal species, there is variability in strychnine sensitivity in bird species, but it shows its high toxicity. Strychnine is acutely toxic to avian species (USEPA 1996b) (Table 6) with mortality occurring between one and five hours after poisoning (Hudson et al. 1984). In acute toxicity studies, signs of poisoning appeared about 10 minutes after dosing and include ataxia, salivation, tremors, convulsions, and immobility (Tucker and Crabtree 1970, Hudson et al. 1984).

In subacute dietary toxicity studies, strychnine (technical grade) is slightly toxic in northern bobwhite, a quail species, with an LC50 of 3,536 ppm and no-observable-effect-concentration (NOEC) of 1,250 ppm. Strychnine is highly toxic in mallard, black-billed magpie, and American kestrel, with LC50 values of 212 ppm, 99 ppm, and 234 ppm, respectively, and a NOEC of 78 ppm in the mallard (USEPA 1996a).

Table 6. Strychnine acute oral and dietary toxicity values for vertebrates and invertebrates.

Strychnine Acute Oral and Dietary Toxicity Values for Mammals and Birds			
Species (Age)	**Test**	**Result (Age)**	**Reference**
Mammals			
Golden-mantled Ground Squirrel	LD_{50}	3.6 mg/kg	Anthony et al. 1984
California Ground Squirrel	LD_{50}	38 mg/kg	Schafer and Bowles 2004
Hispid Cotton Rat (*Sigmodon hispidus*)	LD_{50}	32 mg/kg	
Meadow Vole	LD_{50}	22 mg/kg	
House Mouse ♀	LD_{50}	10 mg/kg	
Ricefield Rat (*Rattus argentiventer*)	LD_{50}	5.9 mg/kg	
Brown (Norway) Rat	LD_{50}	14 mg/kg	
Brown (Norway) Rat	LD_{50}	5.8 mg/kg	
Marsh Rice Rat	LD_{50}	5.8 mg/kg	
Nutria	LD_{50}	27 mg/kg	
Black-tailed Jackrabbit	LD_{50}	4.4 mg/kg	
Mule deer ♀ (8-11 months old)	LD_{50}	17-24 mg/kg	
Mink ♀	LD_{50}	0.6 mg/kg	Anthony et al. 1984
European Ferret	LC_{50}	198 ppm	USEPA 1996b
Red fox	LC_{50}	70 ppm	
Birds			
Mallard	LD_{50}	2.9 (♂ & ♀, 6 mos.)	Tucker and Crabtree 1970, Tucker and Haegele 1971
		2.62 (36 hrs.) 2.0 (1 week) 5.88 (1 mo.) 2.27 9 (♂ & ♀, 6 mo.)	Hudson et al. 1984
Japanese Quail (*Coturnix japonica*)	LD_{50}	12	Schafer and Bowles 2004
		22.6 (♀ 2 mos.)	Tucker and Crabtree 1970, Tucker and Haegele 1971
California Quail (5-6 mos.)	LD_{50}	112	Hudson et al. 1984
Chukar Partridge ♂ & ♀ (5-7 mos.)	LD_{50}	16	Tucker and Crabtree 1970, Tucker and Haegele 1971
Ring-necked Pheasant ♂ (10-23 mos.)	LD_{50}	24.7	
Rock Pigeon ♂ & ♀	LD_{50}	21.3	
Golden Eagle	LD_{50}	5.0 (approximate)	Tucker and Crabtree 1970
House Sparrow ♂	LD_{50}	4.18	
European Starling	LD_{50}	<5.0	Schafer and Bowles 2004
Red-winged Blackbird	LD_{50}	6.0	
Fish			
Bluegill	96-hr LC_{50}	0.76 mg/L	Bowman 1989a
Rainbow Trout	96-hr LC_{50}	2.3 mg/L	Bowman 1989b
Japanese Rice Fish (*Oryzias latipes*)	48-hr LC_{50}	5.7 mg/L	Rice et al. 1997
Invertebrates			
Water Flea (*Daphnia magna*)	96-hr LC_{50} 48-hr EC_{50}	10 ppm 11 mg/L	USEPA 1996b, Forbis 1989

In 28-day subchronic dietary studies, northern bobwhite had a NOEC of 972 µg/g and mallards had a NOEC of 91 µg/g (Sterner et al. 1998). Bobwhites fed more than 1,870 µg/g strychnine displayed ataxia, wing-beat convulsions, tremors, muscle spasms, and sitting posture, but of bobwhites displaying signs of toxicosis only one died (Sterner et al. 1998). Intestinal hemorrhage was found in post-exposure necropsies of one exposed to 972.6 µg/g and one exposed to 6,083.3 µg/g (Sterner et al. 1998). Ducks were more sensitive to strychnine than quail. In ducks, signs of toxicosis occurred at 235, 484, and 972 µg/g strychnine diets. In addition to the signs observed in quail, ducks exhibited unkemptness, unsteady gait, falling, and other mobility problems (Sterner et al. 1998). Post-exposure necropsies of three ducks fed diets with strychnine levels between 75 µg/g and 250 µg/g had hemorrhagic testes and four ducks had gaseous intestines (Sterner et al. 1998).

In chronic studies, reproductive effects in mallards included smaller testes at the lowest observable effect level of 33 ppm (USEPA 1996b). A reduction in chick body weight occurred on day one in the 68.9ppm dose group. At the 140.9ppm dose group, chicks had reduced body weight, and adult females had reduced egg production and body weight (USEPA 1996b).

In chronic dietary reproductive toxicity studies, 140-day exposure of mallard hens to 140.9 µg/g strychnine diets (highest dose) caused a statistically significant decrease in egg production, normal egg formation, and hatching success as well as observed mortality of some ducklings that was not statistically significant (Pedersen et al. 2000). Clinical signs of toxicosis without mortality included loss of righting reflex, tremors, spasms, and wing-beat convulsions occurred between weeks 6 and 16 for ducks exposed to 68.9 and 140.9 µg/g (Pedersen et al. 2000). Female ducks fed a 140.9 µg/g strychnine diet significantly gained less body weight (99 g less) compared to the control females at week 20 (Pedersen et al. 2000). Based on this study, a no observed adverse effect level (NOAEL) on reproduction for subchronic strychnine-dietary exposure in mallard duck was 33.2 µg/g. Northern bobwhite did not display any reproductive effects from diets containing between zero and 1,113.6 µg/g strychnine (Pedersen et al. 2000). A NOAEL on reproduction for subchronic strychnine-dietary exposure in bobwhites was 1,113.6 µg/g (Pedersen et al. 2000).

Surface-applied strychnine bait to control mice in an agricultural field resulted in direct and secondary poisoning of birds (WS applications are belowground only) (Brown and Lundie-Jenkins 1999). Carnivorous birds gathered during the study likely died from eating poisoned mice, as one or two mouse carcasses were in their crop or gizzard. The recovery of a low number of mice from the crop or gizzard indicates a potential low level of strychnine is enough to cause death or the birds regurgitated mice when they became ill (Brown and Lundie-Jenkins 1999). Estimated lethal doses in raptors range from 0.94 mg/kg bw for snowy owls (Redig et al. 1982) to 10.75 mg/kg bw for red-tailed hawks (Anthony et al. 1984). Exposure of great horned owls to 2.1 mg/kg bw caused convulsions (Anthony et al. 1984), and exposure of one red-tailed hawk to strychnine by feeding it a mouse dosed with 2.3 mg/kg strychnine caused incoordination and agitation (Cheney et al. 1987). In a secondary exposure study, researchers fed mice dosed with strychnine to two great horned owls (Cheney et al. 1987). Both owls displayed loss of motor coordination, including difficulty balancing on a perch, falling to the ground, extended flapping of the wings, and body trembling after eating a mouse dosed with 1.0 mg/kg and 1.5 mg/kg strychnine (Cheney et al. 1987). In the wild, birds falling from their perch could be fatal, and motor coordination problems could make birds vulnerable to predation or affect foraging behavior.

Reptiles and Terrestrial Phase Amphibians

Studies on the effects of strychnine on reptiles and amphibians are limited. Research was conducted that involved feeding a strychnine-poisoned rodent every day for 14 days to 12 gopher snakes (Brock 1965, Pauli et al. 2000). The amount of strychnine ingested by the snakes was unknown, but the estimated average amount of strychnine consumed by the rodents was 1.64 mg (range 0.03 – 11.70 mg) (Brock 1965). The snakes showed signs of toxicity, including tremors and irritability. Five snakes died, likely from strychnine poisoning. The average dose of 3.6 mg/kg bw for gopher snakes used in the study was based on the average body weight of the gopher snakes and the average amount of strychnine fed to the mice (Brock 1965, Pauli et al. 2000, USFS 2010). USFS (2010) estimated a fatal dose of 7 to 18 mg/kg bw for a prairie rattlesnake based on calculations of strychnine residues in pocket gophers (Evans et al. 1990) and collection of a prairie rattlesnake with signs of toxicity (Campbell 1953).

For amphibians, the acute oral LD50 for the terrestrial-phase bullfrog is 2.21 mg/kg bw (Tucker and Crabtree 1970). Data is limited on the effects of strychnine on aquatic phase amphibians. Common toads (*Bufo vulgaris*) were immobilized at strychnine concentrations of 50 mg/L, and at 5 mg/L, toads developed abnormalities of the digestive tract and eyes (Cuomo et al. 1978). Common toads were considered possibly a strychnine-tolerant species.

Terrestrial Invertebrates

Toxicity values for terrestrial invertebrates are limited. Field observations indicated toxicity to insects would not be significant (Nolte and Wagner 2001). Ants given strychnine orally (0.1 to 0.5 mg/kg) displayed motor coordination problems but no mortality (Kostowski et al., 1965). In one controlled field study, Hymenoptera (ants, wasps, and others), Coleoptera (beetles and weevils), and Diptera (true flies) insects, which fed on pocket gopher carcasses that had died from eating strychnine bait, had detectable levels of strychnine (Stahl et al. 2004). Based on calculated exposure scenarios for pigeons, mice, and bullfrogs, the detected levels were not expected to pose a risk to insectivores. The study did not report any insect mortalities.

Terrestrial Plants and Terrestrial Microorganisms

No dose-response assessment is estimated for plants and microorganisms, given the lack of a hazard as well as a lack of toxicity data.

3.2.2 Aquatic Dose-Response Assessment

Aquatic Vertebrates and Invertebrates

In freshwater fish, strychnine (99.9% a.i.) is moderately toxic to rainbow trout with a 96-hour LC50 of 2.3 mg/L (Bowman 1989b) and is highly toxic to bluegill (*Lepomis macrochirus*) with a 96-hour LC50 of 0.76 mg/L (Bowman 1989a) (Table 6). Strychnine is moderately toxic to freshwater invertebrates; the freshwater cladoceran, *Daphnia magna*, has a LC50 value of 10 ppm (USEPA 1996b) and a 48-hour EC50 of 11 mg/L (Forbis 1989).

Japanese rice fish (also known as medaka) (*Oryzias latipes*) had a 48-hour (static) LC50 of 5.7 mg/L (Rice et al. 1997). Fish experienced a loss of equilibrium and convulsions. Fish with severe strychnine intoxication stopped swimming or responding to external stimuli, including the failure to display a startle response. Stress symptoms appeared 2 hours after receiving 10 mg/L or more strychnine and 24 hours after receiving 1 mg/L or more strychnine (Rice et al. 1997). In a laboratory study, 96-hour exposure of zebrafish (*Dania rerio*) embryos to strychnine caused a reduction in hatching in response to doses greater than 50 micromolar (μmol)/L (Yu et al. 2014). Embryo development abnormalities occurred at 200 μmol/L strychnine, including curved spines and pericardial edema.

In laboratory experiments, short exposure (18 and 29-hours) of zebrafish embryos to a concentration of 1.5 millimolar (mM) strychnine caused changes later in adulthood in swimming speed and diving behavior (a predatory avoidance response) (Roy et al. 2012). These long-term changes in behavior would place fish at risk of predation.

Aquatic Phase Amphibians

Research on the effects of strychnine on the aquatic phase of amphibians and aquatic reptiles is limited or not available. Common toad embryos exposed to a strychnine concentration of 50 mg/L were immediately immobilized (Cuomo et al. 1978). At the 5 mg/L concentration, the embryos developed abnormal digestive tracts and eyes.

Aquatic Plants

Information is unavailable on the toxicity of strychnine to aquatic plants. Based on strychnine's mode of action, the toxicity to aquatic plants is expected to be low.

4 EXPOSURE ASSESSMENT

4.1 Human Health

Exposure assessment estimates the potential exposure of humans to strychnine. The exposure assessment begins with the use and application methods of strychnine products. A complete exposure pathway for strychnine includes (1) a release from a strychnine source, (2) an exposure point where contact could occur, and (3) an exposure route such as ingestion, inhalation, or dermal contact by which contact can occur. In this way, the potentially exposed human populations and complete exposure pathways are identified. Finally, exposures for the identified human populations are evaluated qualitatively or quantitatively for each identified exposure pathway.

4.1.1 Potentially Exposed Human Populations and Complete Exposure Pathways

All strychnine formulations are restricted to belowground uses in rangelands, pastures, croplands, forests, and non-agricultural areas. Baits made under the various formulations are for application by burrow builders or hand-baiting with a probe that has a bait dispenser or through the use of a long-handled spoon. Based on the registered uses and specific application methods of strychnine, workers (i.e., handlers including loaders and applicators) in the program are the most likely human population group to be exposed to strychnine; mixing is not required by applicators. Applicators handle pre-mixed bait in either manual or mechanical applications. The complete exposure pathways for these workers include direct contact (i.e., incidental ingestion, inhalation, and dermal contact) to strychnine baits during normal belowground applications of each bait formulation.

The general public is not identified as a potentially exposed human population because their exposure to strychnine mixed in bait formulations is extremely unlikely since they would have to dig up the gopher burrows. Therefore, an exposure pathway for the general public is not evaluated.

Similarly, a complete exposure pathway is not identified for dermal contact with contaminated vegetation because this scenario does not apply to strychnine subsurface applications. A complete exposure pathway is also not identified for strychnine residues on dietary items. This is because of its nonfood and belowground use pattern, where strychnine residues in soil are not likely to be taken up by plants and therefore consumed in vegetables or fruits (see Section 2.3). A complete exposure pathway is not identified for drinking water. Strychnine is immobile in the soil and has low water solubility resulting in a negligible leaching potential from subsurface soil to groundwater (see Section 2.3). Surface runoff is not expected to occur due to the belowground use pattern (see Section 2.3). The use pattern and properties of strychnine indicate contamination of water sources is unlikely.

4.1.2 Exposure Evaluation

This section qualitatively evaluates the worker exposures in direct contact pathways associated with handling and applying the strychnine belowground formulations. It also quantifies worker inhalation exposure for the burrow builder and hand baiting applications.

As discussed in Sections 2.4 and 3.1, strychnine has high acute toxicity via oral and ocular routes and probably the inhalation route of exposure. The direct contact exposures via incidental ingestion, inhalation, and dermal contact to workers (i.e., handlers, particularly applicators) are minimized with proper worker hygiene and properly functioning personal protective equipment (PPE) as required by the label.

Accidental exposures may occur should PPE not function properly or for those who do not follow label directions regarding the use of PPE or washing shortly after strychnine applications are completed. WS personnel are responsible for stringently following label directions to ensure their safety.

Inhalation exposure doses to strychnine for workers making applications using hand baiting with a probe or the use of a burrow builder were estimated using a PF10 safety factor for a respirator (Table 7). These values were estimated to determine the potential for risk to workers, which is discussed further in the risk characterization, Section 5.

An inhalation exposure dose was quantified for the following exposure scenarios:

1) a burrow builder label application rate of 0.005 lb a.i./acre treating 200 acres, and
2) a hand baiting label application rate of 0.005 lb a.i./acre treating 1 to 8 acres daily.

An inhalation dose is calculated using the following equation:

Inhalation Dose = (Application Rate x Area Treated Daily x Inhalation Unit Exposure x Conversion Factor)/Body Weight

PPE levels with a respirator of PF10 are used for an inhalation unit exposure. A PF10 respirator is assumed to reduce inhalation exposure by 90% (USEPA 2020). The inhalation doses for these exposure scenarios are summarized in Table 7, and detailed calculations are given in Table 8.

Table 7. Inhalation doses for workers using a burrow builder and hand baiting applications.

Worker Activity	Formul-ation	Application Method	Application Rate (lb a.i./acre)	Area Treated Daily (acre)	Inhalation Unit Exposure (µg/lb)	Inhalation Dose (mg/kg/day)
Application	Bait	Hand Baiting	0.005	1/8	38 (PF10)	2.4E-06/ 1.9E-05
Loading	Granule	Burrow Builder	0.005	200	0.825 (PF10)	1.0E-05

4.2 Exposure Assessment for Nontarget Species

WS personnel did not report any nontarget impacts to species other than the target species between FY16-FY20. However, it is acknowledged that nontarget species take likely occurred, as discussed below.

Table 8. Inhalation margin of exposures for hand baiting and burrow builder applications using the inhalation dose equation[1]. A PE10 is a PF10 respirator, which reduces inhalation exposure by an assumed 90%.

Parameters	Units	Hand Baiting		Burrow Builder
		PF 10	PF 10	PF 10
Application rate	lb a.i./acre	0.005	0.005	0.005
Area treated daily	acre	1	8	200
Inhalation unit exposure[2]	ug/lb	38	38	0.825
Conversion factor	mg/ug	0.001	0.001	0.001
Body weight	kg	80	80	80
Inhalation doses	mg/kg/day	2.4E-06	1.9E-05	1.0E-05
Surrogate RfD	mg/kg/day	0.02	0.02	0.02
Inhalation MOE	mg/L	8421	1052	1939

[1] Inhalation Dose = (application rate * area treated daily * inhalation unit exposure * conversion factor)/ body weight
[2] Source for inhalation unit exposure is USEPA (2020)

4.2.1 Direct Exposure

Direct or primary exposure of nontarget species to strychnine could occur if a nontarget species ingests strychnine baits. Strychnine baits could be available from accidental spills, misapplications, or nontarget species accessing a treated burrow. The belowground application reduces direct exposure to mammals, birds, and other species living aboveground.

Spillage on the ground surface could occur during application with the burrow builder. Spillage during hand baiting is less likely to occur. Bait could fall out of the burrow builder if the bait clogs the nozzle or the builder is removed from the burrow before all the bait is dispensed. The strychnine labels state that bait should not be left exposed on the soil surface; thus, applicators must pick up any spilled material to reduce exposure. Hegdal and Gatz (1977) found a mourning dove that apparently died from strychnine milo spillage during a burrow builder application, which shows that it is a potential hazard. However, this is a rare occurrence, especially if the application process is monitored closely.

The application of strychnine bait to inactive pocket gopher burrows is generally unlikely because applicators look for evidence of activity, such as fresh gopher mounds prior to treatment. Pocket gophers are highly territorial and do not typically share their burrow systems with other species (Fagerstone et al. 1980). WS personnel do not treat in areas where threatened or endangered species could be affected; thus, their take should not be a big concern. More nontarget species are expected to be taken with burrow builder applications than hand baiting because the runways produced with burrow builders are more likely to have nontarget use than existing pocket gopher burrows (Hegdal and Gatz 1977, Fagerstone et al. 1980).

Other animal species, including small mammals, lizards, snakes, and insects, may enter active gopher burrows, and exposure to strychnine could occur if they eat the bait (Howard and Childs, 1959, Fagerstone et al. 1980, El Hani et al. 2002). Aboveground searches for nontarget carcasses found strychnine residues in meadow and montane voles, North American deer mice, golden-mantled ground squirrels, yellow pine chipmunks (*Neotamias amoenus*), and western harvest mice (*Reithrodontomys megalotis*) from the application of strychnine bait to pocket gopher burrows (Arjo et al. 2006 cites several studies; Fagerstone et al. 1980, El Hani et al. 2002). The presence and population size of nontarget species will change depending on the habitat. In one study, daily aboveground searches did not find nontarget animal carcasses after applying hand-applied strychnine baits to pocket gopher burrows (Ramey et al. 2002).

4.2.2 Secondary and Tertiary Exposure

Secondary exposure to nontarget species occurs if predators or scavengers consume species that have consumed strychnine. Field studies on secondary exposure from belowground baiting of strychnine are limited, but it is possible that mammalian predators of pocket gophers could be at risk of exposure (Fagerstone et al. 1980, El Hani et al. 2002, Anthony et al. 1984, Nolte and Wagner 2001). Strychnine-poisoned pocket gophers are more likely to die underground (Nolte and Wagner 2001; Ramey et al. 2002), which reduces secondary exposure to predatory or scavenger species that do not or cannot access burrows, except for species that dig, such as badgers and bears. However, a few small animals that access the burrows and consume the bait may be more likely to die aboveground, where they are available to avian and mammalian predators, scavengers, and decomposers such as insects (Anthony et al. 1984, El Hani et al. 2002, Arjo et al. 2006). In one study, aboveground carcasses of ground squirrels and chipmunks were mostly gone within 48 hours through decomposition and consumption by insects (El Hani et al. 2002). This reduces the availability of the carcasses to scavengers.

Animals can rapidly excrete strychnine; however, death is rapid, indicating toxic levels of strychnine can remain in the body (Record and Marsh 1988). Strychnine is mostly concentrated in the gut, given the limited time for distribution in the body as a result of a rapid time to death (Anthony et al. 1984). Predators, including raptors and scavengers that do not consume the gastrointestinal tract when feeding, are unlikely to experience impacts from strychnine (Howard and Childs, 1959, Record and Marsh 1988, James et al. 1990). One laboratory study found toxicity in owls and red-tailed hawks from secondary exposure to be minimal due to avoidance of gastrointestinal portions and regurgitation (Anthony et al. 1984). Another study found that Swainson's hawk nestlings and adults fed Richardson's ground squirrels killed with strychnine did not impact their survival as a result of the evisceration of the ground squirrels before feeding them to the nestlings (Schmutz et al. 1989). In a field study, a burrowing owl fed on a strychnine-poisoned ground squirrel avoided the gastrointestinal tract and did not show toxicity after feeding on them (James et al. 1990). In another field study, 662 hectares were treated with 0.5% strychnine-treated bait using a burrow builder. Populations of small rodents (other than pocket gophers) declined in the treated area but increased in the control area (Hegdal and Gatz 1977); the researchers using radio-telemetry monitored red-tailed hawks, American kestrels, great horned owls, badgers, striped skunks, red foxes, and coyotes on treated fields found that all survived. They also monitored red-winged blackbirds and did not detect any effects on this seed-eating species. A mourning dove was found that apparently died from eating spillage from the burrow builder. Marsh et al. (1987) studied the effects of secondary exposure in coyotes fed poisoned ground squirrels in controlled experiments. The squirrels were fed lethal doses of 1.0–2.7 g (low dose) or 5.0-7.5 g (high dose) of strychnine bait. The estimated strychnine amount in the dosed squirrels ranged from 0.275 to 1.059 mg/kg at the low dose and 1.321 to 2.860 mg/kg at the high dose. The amount of strychnine coyotes ingested was likely lower due to their metabolism of strychnine and the tendency of coyotes to reject portions of the gastrointestinal tract when they contained strychnine. The four coyotes fed the low dose survived, and three of the four coyotes fed the high dose survived.

Pocket gophers, ground squirrels, and other animals may store bait in their cheek pouches, which may expose predators or scavengers to strychnine bait (Anthony et al. 1984, Arjo et al. 2006). Scavengers that store carcasses may increase their exposure should they store a large number of carcasses containing strychnine (Arjo et al. 2006). Many factors influence the availability of strychnine-killed animals aboveground, including the rate of decomposition and the ability of a scavenger to find the carcass, as smaller carcasses are more difficult to detect (Arjo et al. 2006, Sullivan 1988).

Insectivore species (e.g., insect-eating birds, terrestrial amphibians, etc.) exposure could occur if insects scavenge on animal carcasses killed by strychnine (El Hani et al. 2002, Arjo et al. 2006). In field experiments, measured strychnine concentrations in insects that fed upon strychnine-poisoned small mammal carcasses were below the threshold level considered harmful to animals, including birds and amphibians that may feed on the insects (Stahl et al. 2004, Arjo et al. 2006). Ants exposed to strychnine-baited pocket gophers had a mean and maximum strychnine concentration of 0.130 and 0.338 µg/g. However, as a source of tertiary exposure to insectivores, the level of strychnine does not appear to be a significant risk (Stahl et al. 2004).

5 RISK CHARACTERIZATION

This section characterizes risks associated with adverse human health and nontarget species qualitatively and quantitatively, where appropriate. Under the WS use patterns, strychnine in belowground applications for controlling pocket gophers in rangelands, pastures, croplands, forests, and non-agricultural areas poses minimal risks to human health.

5.1 Human Health

Exposure will be limited to WS applicators and handlers since strychnine baits are placed directly belowground into burrows that are not accessible to the public. Adherence to required PPE and other label directions will minimize exposure and risk to applicators. Inhalation and ocular exposure to dust when loading a bait-dispensing probe or a burrow builder hopper could potentially occur. However, using goggles or a face shield and a label-approved respirator will reduce this exposure pathway and minimize risk.

Inhalation margin of exposures (MOEs) were calculated by comparing an estimated inhalation dose for each exposure scenario to a benchmark toxicity value or reference dose. USEPA (2016) uses a MOE of 1,000, below which there is a presumption of risk. Table 9 summarizes the inhalation MOEs for the hand baiting and burrow builder applications. As shown in Table 9, the inhalation MOEs for an applicator hand baiting a low range (1 acre) and a high range (8 acres) with a PF10 respirator, and for an applicator using a burrow builder for a loading activity with a PF10 respirator are higher than the MOE of 1,000 with the protection of label-required respirator. A surrogate RfD of 0.02 mg/kg/day based on the threshold limit value recommended by the American Conference of Governmental Industrial Hygienists is used for the MOE calculation. This is a conservative approach because the acute inhalation LC50 of >2.11 mg/L from an acute inhalation exposure limit study (MRID 44708001) is more than 100x higher than the surrogate RfD.

Table 9. Inhalation MOEs for workers under the hand baiting and burrow builder applications.

Worker Activity	Formul-ation	Application Equipment	Application Rate (lb a.i./acre)	Area Treated Daily (acre)	Inhalation Dose (mg/kg/day)	Inhalation MOE
Application	Bait	Hand Baiting	0.005	1/8	2.9E-06/ 2.4E-05 (PF10)	6809/851
Loading	Granule	Burrow Builder	0.005	200	1.0E-05 (PF10)	1939

Although strychnine is highly toxic to humans due to its high acute toxicity via the oral, ocular, and inhalation routes, there is a low potential for exposure and risk to applicators due to the belowground use of strychnine baits and the use of appropriate PPE described on each strychnine label. WS maintains records on exposure incidents of WS personnel that conduct WDM activities and has no incident reports of workers exposed during strychnine applications.

Accidental exposures may occur should PPE not function properly; the potential for accidental exposure during belowground hand baiting and burrow builder applications is limited and minimal. The baits are premixed, so no accidental exposure will occur during applications from mixing or preparing baits. Accidental inhalation and ocular exposure from dust for loaders are unlikely because each bait formulation will generate minimal dust. If accidental exposure occurs for applicators, the exposure route is most likely to be dermal contact. Acute dermal toxicity (Category III – 2,000 mg/kg through 5,000 mg/kg) is at least two orders of magnitude less toxic than acute oral toxicity (Category I – up to and including 50 mg/kg). The strychnine labels require applicators to wear gloves, long sleeves and pants, shoes plus socks, and goggles or a face shield to reduce dermal exposure. In addition, the labels require waterproof gloves when loading a bait-dispensing probe, disposing of non-rigid containers (e.g., bags), and loading more than 3 lbs. of bait into mechanical equipment. USEPA 6(a)(2) reports show two adverse effects incidents between 1994 through 2013 related to strychnine use. Still, neither of these incidents was associated with occupational exposure to WS personnel or exposure during application from WS use.

5.2 Ecological

5.2.1 Terrestrial Risk Characterization

Adverse effects are likely and documented in the scientific literature for rodents that share burrows with pocket gophers. One field study demonstrated a reduction in a golden-mantled ground squirrel population shortly after hand-baiting western pocket gopher burrows with 0.5% strychnine-treated oats. However, the population recovered within a month or two, indicating a lack of long-term effects (Anthony et al. 1984). Deisch et al. (1990) conducted an experimental use of strychnine baits for black-tailed prairie dogs. They reported no adverse impacts to North American deer mice after making field applications with 0.5% strychnine-treated oats. Deer mice populations were variable but increased after treatment, possibly due to the low efficacy of strychnine treatments in black-tailed prairie dogs. Prairie dogs provide habitat for deer mice, and the lack of impacts on prairie dogs allowed mouse populations to increase over time. Deisch et al. (1990) did not follow other small rodent populations, such as Ord's kangaroo rats or pocket mice (*Perognathus* spp.), and suggested these species should be monitored.

Other terrestrial vertebrates and invertebrates that use the burrows or feed upon treated pocket gophers or pocket gopher food caches are also at risk. For example, golden-mantled ground squirrels and yellow pine chipmunks, which can access burrows, would be at risk if they feed on strychnine bait (Anthony et al. 1984). Canid and raptor predators and scavengers could also be at risk from secondary exposures. However, the belowground applications would limit their exposure to poisoned pocket gophers making the risk of adverse effects low. In one study, pocket gophers that died after their burrows were hand-baited with strychnine bait died at least 15 cm underground (Ramey et al. 2002). Similarly, another field study found that all pocket gophers killed with strychnine died underground in their burrows (Nolte and Wagner 2001). In addition, the preference of not eating the gastrointestinal tract of prey, where strychnine and treated bait may be concentrated, reduces the risk of exposure to certain canid (Marsh et al. 1987) and raptor species (Anthony et al. 1984). Other nontarget animals directly poisoned by strychnine may commonly die aboveground, as was the case in one study looking at the effects on golden-mantled ground squirrels after treatment of gopher burrows (Anthony et al. 1984). Anthony et al. (1984) noted badgers killed two treated squirrels with no apparent secondary exposure effects.

The treatment of ground squirrels with colocated burrowing owls did not cause death or reproductive effects to the owls, but adults did have reduced body weight, possibly from a reduction in available squirrels as a food source (James et al. 1990).

Direct access to treated bait inside the burrow is negligible for most bird species. Insectivorous bird species and terrestrial amphibians are unlikely to receive significant exposure by eating insects exposed to strychnine (Stahl et al. 2004, Arjo et al. 2006).

5.2.2 Aquatic Risk Characterization

Aquatic risk to strychnine exposure is not expected based on the application method for strychnine and its environmental fate profile. Strychnine applications are made belowground eliminating drift and reducing the probability of significant runoff into water bodies containing aquatic vertebrates, invertebrates, and plants. The label states that the product should not be used in areas where surface water is present and applicators should also use caution if rain events around the time of baiting could cause runoff. In addition, strychnine solubility in water is below the range of effect concentrations for aquatic vertebrates and invertebrates. Strychnine also degrades and binds tightly to soil and sediment, reducing the potential for significant residues that would be available to most aquatic organisms.

6 UNCERTAINTIES AND CUMULATIVE EFFECTS

Uncertainties associated with the risk evaluation are discussed qualitatively in this section. Toxicity data is unavailable for all possible species that could be exposed to strychnine bait treatments. The use of a few species to represent the toxicity for an entire group of species has inherent uncertainties. Strychnine is highly toxic to numerous mammals, birds, and aquatic vertebrates, and our risk evaluation assumes high toxicity to all species within these animal groups. This section qualitatively evaluates the potential cumulative effects associated with 1) repeated worker exposures to strychnine, 2) co-exposures to other pesticides within the program with respect to their toxicity, and 3) exposures to other chemicals impacting the toxicity of strychnine.

Repeated exposure to strychnine is not expected in the WS program because, with PPE, worker exposure to strychnine is not expected. The improper use of PPE could lead to accidental exposure, as described earlier. Exposure to a non-lethal dose of strychnine will not lead to a substantial accumulation in the body since strychnine is rapidly excreted (See Section 2.4.1 and 3.1 for toxicokinetics and dose-response information). WS has not reported any accidental exposures for more than 20 years, suggesting a low probability of risk to workers.

Strychnine inhibits glycine and causes convulsions. The WS Program does not use chemicals with the same mode of action, so the potential for co-exposure is negligible. The other rodenticides used in the WS Program, not necessarily for control of pocket gophers, are mostly zinc phosphide, anticoagulants, and aluminum phosphide fumigants.

Cumulative effects involving other chemicals that impact strychnine toxicity are unlikely. WS does not mix strychnine with other chemicals or apply other chemicals during the same treatment period. Strychnine degrades in the environment and is not expected to persist. Zinc phosphide is also a labeled toxicant available to WS for the control of pocket gophers, but WS does not use both at the same location. The application of strychnine baits belowground also reduces its potential interaction with chemicals that may be applied above ground by other land managers for other purposes. Other land management agencies, such as USFS, may conduct pocket gopher control; however, this would not occur on the same lands treated by WS during the same treatment period. WS does not knowingly conduct treatments of species where others are conducting WDM using toxicants.

In California, an average of 506 lbs. a.i. of strychnine was used for calendar years 2016-2018 by the public and agencies including WS (California Department of Pesticide Regulation 2021). Most of the applications made in California involved crops, landscaping, and turf. Applications to timberland and rangelands were minimal in comparison. WS also assists a lot with crops and landscaping, but additionally, WS works on lands surrounding runways at airports to reduce the gopher population that attracts predators that could become wildlife strike hazards for aircraft and damage underground electrical cables for runway and taxiway lighting. However, from FY16-FY20 nationally, WS annually averaged the use of 0.5 pounds a.i. (0.1% of California use), which suggests that WS would not add significantly to the cumulative take of pocket gophers in California or nationally.

7 SUMMARY

Strychnine baits are used by WS to control pocket gophers. WS personnel either hand-bait pocket gopher burrows or use burrow builders to treat areas. Strychnine is a highly lethal acute toxicant for pocket gophers. Formulations contain 0.5% of strychnine a.i. WS personnel have not had any known exposures or exposed the public or pets to strychnine. Thus, it is assumed that the risk to human health from strychnine baits used by WS in WDM has been at the most minimal. WS applicators used an annual average of 98.9 pounds of baits (0.5 pounds a.i.) of five formulations of strychnine in 10 states to take 3,535 pocket gophers of four species from FY16 to FY20. Plains and northern pocket gophers were the two species (68%) taken most. WS applicators attempt to minimize nontarget take by treating burrows with recent mounds. WS did not record any nontarget species taken but believes that it has occurred, especially for other small rodents that use pocket gopher burrows or tunnels.

This risk assessment evaluated the human health and ecological risk of strychnine under the WS use pattern for pocket gopher control. Although strychnine is highly toxic to humans, the risk to human health is low because ingestion, inhalation, and dermal exposure risks are slight for underground applications. WS applicators wear proper PPE according to the pesticide label requirements, reducing exposure to strychnine poisoning and lowering the risk of adverse effects. Label restrictions protect the public from exposure to the toxicant when used accordingly.

Label restrictions, use patterns, environmental fate, and aquatic toxicity data for strychnine suggest low risk to aquatic species and their habitats. Strychnine uptake risks to terrestrial plants are also low. The highest risk is to nontarget small mammals that will consume the baits. Nontarget terrestrial vertebrates and invertebrates that consume treated pocket gophers or nontarget species taken could be killed from secondary exposure but are considered low risk. Target and nontarget species killed by strychnine typically die within the treated burrows reducing the chance for secondary risk. Tertiary risks, primarily from species that consume insects that scavenge animals that have succumbed to strychnine poisoning, appear to be minimal. Restrictions on all labels lower the chance of exposure and risks to humans and nontarget terrestrial species.

It should be noted that WS has been using strychnine since all uses went belowground and have not had any known impacts on people or pets. WS acknowledges that nontargets have been taken, but this would be relatively few compared to targets. WS also does not use strychnine where a sensitive species may be taken and, therefore, believes that WS personnel have not impacted these species.

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9 PREPARERS

9.1 APHIS-WS Methods Risk Assessment Committee

Writers for "Use of Strychnine in Wildlife Damage Management Risk Assessment":

Primary Writer: Andrea Lemay
Position: USDA-APHIS-Policy and Program Development (PPD), Environmental and Risk Analysis Services (ERAS), Biological Scientist, Raleigh, NC
Education: BS Plant and Soil Science (Biotechnology) - University of Massachusetts; MS Plant Pathology -North Carolina State University
Experience: Thirteen years of service in APHIS conducting risk analysis. Four years of experience in preparing environmental analyses in compliance with the National Environmental Policy Act.

Writer: Thomas C. Hall
Position: USDA-APHIS-WS, Operational Support Staff, Staff Wildlife Biologist, Fort Collins, CO
Education: BS Biology (Natural History) and BA Psychology – Fort Lewis College; MS Wildlife Ecology – Oklahoma State University
Experience: Special expertise in wildlife biology, identification, ecology, and damage management. Thirty-two years of service in APHIS Wildlife Services, including wildlife damage management operations and research. Expert in preparing environmental documents for WS programs to comply with the National Environmental Policy Act and the Endangered Species Act. For strychnine specifically, I have used strychnine in WDM and supervised employees that used it in their duties.

Writer: Fan Wang-Cahill
Position: USDA-APHIS-Policy and Program Development (PPD), Environmental and Risk Analysis Services (ERAS), Environmental Health Specialist, Riverdale, MD
Education: B.S. Biology and M.S. Hydrobiology - Jinan University, Guangzhou, China; Ph.D. Botany (Ultrastructure/Cell Biology) – Miami University
Experience: Joined APHIS in 2012, preparing human health risk assessments and providing assistance on environmental compliance. Prior experience before joining APHIS includes 18 years environmental consulting experience specializing in human health risk assessments for environmental contaminants at Superfund, Resource Conservation and Recovery Act (RCRA), and state-regulated contaminated facilities.

Writer: Jim Warren
Position: USDA-APHIS-Policy and Program Development (PPD), Environmental and Risk Analysis Services (ERAS), Environmental Toxicologist, Little Rock, AR
Education: B.S. Forest Ecology and M.S. Entomology – University of Missouri; Ph.D. Environmental Toxicology – Clemson University

Experience: Eight years of experience working for APHIS preparing ecological risk assessments and providing assistance on environmental compliance. Prior experience before joining APHIS includes other government and private sector work regarding ecological risk assessments related to various environmental regulations.

Editors/Contributors for "Use of Strychnine in Wildlife Damage Management Risk Assessment":

Editor/Contributor: Ryan Wimberly
Position: USDA-APHIS-WS, Operational Support Staff, Staff Wildlife Biologist, Madison, TN
Education: BS Wildlife Management and Ecology – Northwest Missouri State University
Experience: Special expertise in wildlife biology, ecology, and damage management. Seventeen years of service with APHIS Wildlife Services, including operations and research, conducting a wide variety of programs, including bird damage research and management, livestock protection, invasive species management, wildlife hazard management at airports, property, and natural resource protection. Expert in preparing environmental documents for WS programs to comply with the National Environmental Policy Act and the Endangered Species Act.

Data Contributor: Joey Millison
Position: USDA-APHIS-WS Information and Technology (IT), Junior Applications Developer
Education: Information and Technology coursework from various sources
Experience: Eleven years of experience in APHIS, WS Management Information System (MIS) Group. Retrieves WS field data from the MIS for writers, reviewers, and editors.

9.2 Internal Reviewers

USDA APHIS Wildlife Services

Reviewer: Emily Ruell
Position: USDA-APHIS-WS, NWRC: Registration Specialist, Fort Collins, CO
Education: B.S. Zoology and Biological Aspects of Conservation – University of Wisconsin – Madison; M.S. Ecology – Colorado State University (CSU); M.A. Political Science -- CSU MS Biology, University of Nevada, PhD Botany/Ecology University of Hawaii
Experience: Five years of experience with WS NWRC preparing and reviewing vertebrate pesticide registration data submissions and other registration materials, and providing pesticide regulatory guidance to WS, WS NWRC, and collaborators. Prior experience before joining APHIS includes seven years of conducting field and laboratory wildlife research at CSU, and environmental policy research for the U.S. Geological Survey.

Reviewer: Shelagh DeLiberto
Position: USDA-APHIS-WS Operational Support Staff, Environmental Management Coordinator, Fort Collins, CO
Education: BA Biology and Environmental Science – Ithaca College; MS Wildlife Biology – Colorado State University
Experience: Nineteen years of service in APHIS conducting wildlife research. Six years of experience in preparing categorical exclusions and environmental analyses in compliance with the National Environmental Policy Act.

9.3 Peer Review

The Office of Management and Budget requires agencies to have peer review guidelines for scientific documents. The APHIS guidelines were followed to have "Use of Strychnine in Wildlife Damage Management" peer reviewed. WS worked with the Association of Fish and Wildlife Agencies to have experts review the documents.

9.3.1 Peer Reviewers Selected by the Association of Fish and Wildlife Agencies

University of Tennessee/Tennessee Wildlife Resources
Louisiana Department of Wildlife and Fisheries
Wildlife Veterinarian, Arizona Game and Fish Department

9.3.2 Comments

1. **Comment:** Louisiana black bears are no longer federally protected as a T&E species but are protected by the state.

   Response: Louisiana black bears are a protected species in southeastern states and within the range of the plains pocket gopher in eastern Texas, western Louisiana, and southern Arkansas, recently delisted as a federal T&E species. Protected species are considered when putting out bait. The maximum rate, 2.5 pounds of bait per acre (5,670 mg active ingredient) underground, minimizes the opportunity for nontarget animals such as bears to get a lethal dose. Bears are omnivores and would eat bait or dead pocket gophers and can dig easily to get to either. However, it would take more strychnine than is somewhat available. To extrapolate, a yearling cub weighing 50 pounds (23 kg) with an $LD_{50,}$ possibly similar to a red fox (70 mg/kg), would require 1,610 mg or eating 0.7 pounds of bait to reach the point where it is lethal for 50%. The method of broadcast (probes or burrow builders) would make that very difficult to achieve. These are always a concern for WS personnel, and they consider the potential for taking nontarget species. With that said, WS did not apply strychnine baits within the range of the Louisiana black bear from FY11-FY20.

2. **Comment:** I found, at least to my understanding, a notable discrepancy in the amount of bait applied by WS. In the executive summary it stated that WS applied 99 lbs. of bait between FY 16 and FY 20 but page 4 states that WS applied 266 lbs. annually. Also, on page 4 it states 1,41 oz., an obvious typographical error.

   Response: While updating data from FY11-FY15 to FY16-FY20, some data was overlooked. All data in the text and tables has been verified to be accurate for the updated FY16-20 time period.

3. **Comment:** Although mentioned, one concern would be the incidental take of predatory snakes. In areas where there are endangered snake species that would prey upon the target species, I would avoid use since it is difficult to quantify the incidental take.

   Response: We have included language in Section 2.1 regarding the potential hazard of strychnine to all T&E species (including snakes). Label restrictions require applicators to contact the USFWS to determine if strychnine can be used in a given area where T&E species are present. WS personnel contact the USFWS to identify sensitive species within any potential application area. We believe these requirements will prevent exposure to sensitive species, including snakes.

4. **Comment:** Given that there is some evidence of stream contamination during rains, I would recommend avoiding application during known "wet" seasons to avoid immediate flooding of tunnels and possible movement of baits out of the tunnels prior to consumption. Along these lines avoid applying before rainstorms etc. that may lead to flash flooding before baits are fully consumed.

   Response: We have included language in Section 5.2.2, "Aquatic risk characterization," referencing the label restrictions about using where surface water is present and limiting application when rain events could cause runoff at the treatment site. However, rain makes treatments less effective; therefore, WS personnel will wait for the appropriate days to treat a site.

5. **Comment:** The individual components of the MRA appear complete with the exception of the lack of consideration of the risks to non-targets species and human health should product sold by USDA-WS be applied or used incorrectly. While the product is reported to have been sold to certified pesticide applicators, no mention is made of any monitoring or accountability for those applicators. Since the most effective method for reducing risk is application underground, and applicators distribute more than seven times the amount of strychnine that WS did, this could be a significant error in the risk calculation for public and non-target species exposure. In the past 2 years, I have identified strychnine as a cause of avian mortality in 5 events with more than 75 total individuals affected. Most were doves however red-winged blackbirds were affected in one event. An additional 5 events were identified between 2014 and 2020 (a cottontail and ground squirrel, a javelina, a killdeer, multiple bird species, and doves). The event with multiple bird species included a great-horned owl and a kestrel and it occurred a city park. The killdeer was found dead in association with a spill event. These event suggest that some licensed pesticide applicators do not follow label directions.

   Response: When WS sells products to the public and certified pesticide applicators, it is considered technical assistance and outside the scope of this Risk Assessment. Certified Pesticide Applicators and the public are required to abide by the product labels without monitoring or supervision by WS. They can face consequences if they use the products illegally. Since strychnine baits are required by the label to be applied underground, the bait is likely illegally applied if birds are found dead due to strychnine. WS is not a regulatory agency. Any suspected violations of the Federal Insecticide, Fungicide, and Rodenticide Act by private applicators should be reported to the State Department of Agriculture. New labels for strychnine will likely make all strychnine baits Restricted-Use, including hand-baiting labels, which are not currently restricted use.

6. **Comment:** While I agree the impact to non-target species is likely minimal, it is not appropriate to assume that avoiding consumption of the gastrointestinal tract occurs in all predation and scavenging events.

   Response: We reference several studies in Section 5.2.1 that indicate species avoid gastrointestinal tracts when consuming prey. We identify that these preferences reduce the risk of exposure but do not assume it does not occur. It should be noted that pocket gophers most always die belowground, minimizing risks to terrestrial species. Fossorial (underground dwelling) or semi-fossorial scavengers, such as weasels that use gopher tunnels for preying on gophers, have the highest possibility of being taken as nontarget species. These scavengers would have direct access to pocket gophers that died from strychnine baiting. Weasels would have to consume the gut contents to get a high dose of strychnine toxicant, and the gopher would have had to consume enough bait to have enough remaining. A northern pocket gopher (average weight 110 g) that consumed 8% of its body weight (9 g) would have 45 mg a.i. This likely would be enough to kill a long-tailed weasel (average weight 7.5 oz.). It should be noted that pocket gophers are highly territorial and often do not tolerate other species in their tunnels except young. Therefore, it Is unlikely for several gophers to be found in a single burrow. Most scavengers would likely have to dig up many pocket gophers to scavenge a lethal dose of strychnine.

7. **Comment:** The methodology of estimating the take of pocket gophers based on estimated consumption seems as though it has the potential to be grossly inaccurate although I do not have a better method. Ultimately, as long as the estimate corresponds with an appropriate decline in sightings/new burrows/damage I suppose it is accurate enough. Other methodologies in the document seem appropriate to arrive at the desired conclusions.

   Response: This method of estimating take is standard practice. USEPA lays out a framework for this type of analysis in their Wildlife Exposure Factors Handbook (USEPA 1993; EPA/600/R-93/187). Although gophers are not a species discussed in this handbook, a goal of the handbook is to "foster a consistent approach to wildlife exposure and risk assessments." This handbook identifies body weight, food ingestion rate, and home range size, among other factors for each species, similar to what has been done in this risk assessment.

8. **Comment:** See Warnock and Schwarzbach 1995 Incidental kill of Dunlin and Killdeer by Strychnine, J Wildlife Dis 31:566-569.

   Response: This reference indicates that shorebirds were exposed to strychnine baits due to "strychnine-laced wheat seeds broadcast on a field for rodent control" prior to 1995. Broadcast and aboveground application of strychnine baits are no longer label-approved application methods. This reference is not within the scope of our current use patterns.

Comments received not requiring a response.

1. **Comment:** The document was thorough and incorporated all of the pertinent information to assess delivery methods, efficacy estimates, by-kill data, and human and animal safety.

2. **Comment:** All of the components/ subjects of the document are complete to my satisfaction.

3. **Comment:** Common sense methodologies are used to reduce non-target impacts and I am satisfied with the extent of the methodologies used to protect humans and other animals for unintended strychnine exposure.

4. **Comment:** The references look appropriate to support the statements in the document.

5. **Comment:** Overall a good document with noted exceptions. I support this risk assessment.

Peer reviewers provided editorial comments on the manuscript. These were appreciated and incorporated into the final document.

APPENDIX 1. WS Strychnine Use for Pocket Gophers for FY11-FY15.

For comparison, take tables and strychnine used for FY11-FY15 are given for comparison. These compare with Tables 2 and 4 in Section 1.

Table 1a. The annual average number of target pocket gophers killed with strychnine by APHIS-WS in WDM activities for FY11 to FY15 throughout the United States and the pounds of strychnine used. No known nontarget take occurred in this time.

ANNUAL AVERAGE SPECIES KILLED WITH STRYCHNINE AND FORMULATIONS USED				
Species	**Target**	**Lbs. Used**	**% of Spp. Take**	**States Used**
Yellow-faced Pocket Gopher	349	17	4%	TX
Plains Pocket Gopher	447	12	5%	CO KS MN NE TX
Botta's Pocket Gopher	4,887	185	56%	AZ UT
Camas Pocket Gopher	172	6	2%	OR
Northern Pocket Gopher	2,828	47	33%	CO ND OR UT WA
Avg. Ann. Take (5T – 5 spp.)	**8,683***	**267***		
Formulation	**Target**	**Lbs. Used**	**% of Pounds**	**States Used**
Omega Gopher Grain Bait	44	1	0.4%	OR
Strychnine Milo – Burrow Builder	3,033	98	42%	AZ UT WA
Strychnine Milo – Hand Bait	1,658	33	14%	CO KS MN NE ND OR TX UT
Strychnine Oats – Burrow Builder	2,036	91	26%	TX UT
Strychnine Oats – Hand Bait	1,909	43	18%	MN OR TX WA
Avg. Annual Take and Use	**8,680***	**266***		

If take was not estimated, numbers of targets taken was estimated at about 8 per pound of bait for burrow builders or 1 per ounce for hand baiting.
* Rounding errors gave different numbers for summing data.

Table 1b. The annual average number of target pocket gophers killed with strychnine and ounces used in each State by APHIS-WS in WDM activities for FY11 to FY15. No known nontarget take occurred in this time.

ANNUAL AVERAGE STRYCHNINE USED WITH TAKE BY STATE FOR FY11-FY15										
State	**Strychnine Burrow Builder Baits**				**Strychnine Hand Baits**				**Omega Baits**	
	Milo		**Oats**		**Milo**		**Oats**		**Grain**	
	Target	**Oz.**	**Target**	**Oz.**	**Target**	**Oz.**	**Target**	**Oz.**	**Target**	**Oz.**
Arizona	130	48	0	0	0	0	0	0	0	0
Colorado	0	0	0	0	342	100	0	0	0	0
Kansas	0	0	0	0	19	8	0	0	0	0
Minnesota	0	0	0	0	15	6	7	3	0	0
Nebraska	0	0	0	0	329	143	0	0	0	0
North Dakota	0	0	0	0	2	0.4	0	0	0	0
Oregon	0	0	0	0	347	91	175	102	44	12
Texas	0	0	105	80	18	8	244	188	0	0
Utah	2,595	1,440	1,931	1,383	213	79	236	64	0	0
Washington	309	81	0	0	374	98	1,247	328	0	0
Total	**3,034**	**1,569**	**2,036**	**1,463**	**1,659**	**533**	**1,909**	**685**	**44**	**12**
States	**3**		**2**		**9**		**5**		**1**	

If take was not estimated, numbers of targets taken was estimated based on parameters from Table 1a.