APPENDIX B

GLEAMS MODELING FOR THE ECOLOGICAL RISK ASSESSMENT

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

^{o}F	-	Degrees Fahrenheit
CREAMS	-	Chemical Runoff Erosion Management System
EEC	-	Estimated Exposure Concentration
ERA	-	Ecological Risk Assessment
ft	-	foot (feet)
GLEAMS	-	Groundwater Loading Effects of Agricultural Management Systems
hr	-	hour
in	-	inches
kg	-	kilogram
L	-	Liter
LAI	-	Leaf Area Index
mg	-	milligrams
SCS	-	Soil Conservation Service
sec	-	second
SERA	-	Syracuse Environmental Research Associates, Inc.
USLE	-	Universal Soil Loss Equation

1.0 GLEAMS MODELING FOR THE ECOLOGICAL RISK ASSESSMENT

GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) is a modified version of the CREAMS (Chemical Runoff Erosion Assessment Management System) model that was originally developed to evaluate non-point source pollution from field-sized areas. The disadvantage of the CREAMS model was that it only considered surface processes, and any pesticide below the surface 1-cm of the soil was not considered. Specifically, the hydrology, plant nutrient, and pesticide components of the CREAMS model were modified to consider movement of water and chemicals within and through the root zone. The GLEAMS model was developed for field-sized areas to evaluate the effects of agricultural management systems on the movement of agricultural chemicals within and through the plant root zone (Leonard et al. 1987). The model simulates edge-of-field and bottom-of-root-zone loadings of water, sediment, pesticides, and plant nutrients from climate-soil-management interactions. Agricultural pesticides are simulated by the GLEAMS model using three major components:

- *Hydrology* – The hydrology component of the GLEAMS model simulates the movement of water through an agricultural system by considering the effects of precipitation, surface runoff, and percolation through the unsaturated zone of the soil. The model simulates runoff using the Soil Conservation Service (SCS) curve number method, simulates evapotranspiration using the Priestly-Taylor or Penman-Monteith methods, and simulates the percolation of water through a multi-layered soil system. The hydrology component of the GLEAMS model also simulates the effect of vegetation on surface water runoff, infiltration, and evapotranspiration.

- *Erosion* – The erosion component of GLEAMS simulates the movement of sediment over the land surface using the USLE (Universal Soil Loss Equation). The GLEAMS model also calculates pesticide loss associated with the erosion of soil particles.

- *Pesticide* – The pesticide component of the GLEAMS model simulates the movement of pesticides through an agricultural system by associating the pesticides with both water and sediment. Pesticides are aerially applied and may be intercepted by foliage. The chemical characteristics of the pesticide are used to determine whether the pesticide will be held or released by soil organic carbon, or adsorbed to or washed off from living and dead plant tissue, and to predict the rate of pesticide degradation. The concentration of pesticide at the soil surface determines the amount that is available for extraction into surface runoff and/or movement into the soil profile.

The GLEAMS model has evolved through several versions from its inception in 1984 to the present, and has been evaluated in numerous climatic and soil regions around the world. The model was selected for use in this investigation because of its widespread acceptance, its suitability to this particular application, and the previous use of the model to support similar risk assessments for the U.S. Department of Agriculture (USDA) Forest Service (Forest Service; Syracuse Environmental Research Associates, Inc. [SERA] 2001).

1.1 Application of GLEAMS to an Application Area

The GLEAMS model can be applied to simulate the short-term and long-term loads of pesticides from an application area over a wide range of hydrologic and soils conditions. In this application, the model was used to represent herbicides instead of insecticides. However, it was assumed that vegetation density is not altered by the application of an herbicide. Since the herbicides in the model are selective and new native growth is expected to repopulate the treated areas, the general vegetative characteristics of the application area are not expected to change dramatically. This application is consistent with previous risk assessments conducted for the Forest Service (SERA 2001) and provides an adequate representation of the fate and transport of herbicide in field-sized application areas.

Hydrologic predictions are developed in GLEAMS using an array of standard equations, including erosion and pesticide characteristics, to predict the fate and transport of specific pesticides in a field-sized area. In addition to considering characteristics of precipitation, the soil, and the pesticide applied, the GLEAMS model estimates plant coverage over the agricultural field and the resultant effect on the Leaf Area Index[1] (LAI) as it changes throughout the year. By incorporating the effect of vegetation on the hydrologic cycle, the GLEAMS model is able to effectively capture the temporal distribution of pesticides both exported from the agricultural site and retained within the site. The model predicts the loads of pesticides in surface runoff and in percolated groundwater.

The data required for a GLEAMS simulation include a wide variety of descriptions of the climate, surficial topography, subsurface soils, vegetation type, and growing potential, as well as herbicide-specific information (i.e., chemical properties that may affect the behavior of the herbicide in the model). The following briefly describes a subset of the data required to successfully simulate the effects of an herbicide on an application area using GLEAMS:

- *Precipitation* – Daily rainfall records for the entire simulation period are required to provide input to the hydrologic simulation. The volume of precipitation strongly controls the amount of runoff and percolation of associated herbicides.

- *Climate* – Daily averages of standard meteorological data are necessary to characterize precipitation as either rain or snow and to calculate variations in monthly evapotranspiration. Since evapotranspiration is a large component of the hydrologic cycle, the climate (e.g., temperature and humidity) can affect the volume of water leaving the application area as runoff or subsurface flow.

- *Soil Characteristics* – Soil characteristics (as identified by soil type) are applied to the GLEAMS model to facilitate the calculation of runoff and percolation from the application area.

- *Vegetation/Ground Cover* – Plant growth on agricultural fields controls the partitioning of pesticide to either the soil or foliar surfaces and controls the rate of evapotranspiration, which can be a significant component of the hydrologic balance.

- *Herbicide Properties* – The varying distribution of pesticide concentrations predicted by GLEAMS in an agricultural system is largely dependent on the chemical-specific properties used in the model, such as sorption coefficients and decay rates. These values are herbicide-specific and can vary significantly. Export rates predicted by GLEAMS, therefore, can be quite different between herbicides.

Given the many parameters associated with a GLEAMS simulation, the potential range of values for each parameter, and the variation of these parameters on public lands, a large number of application scenarios are possible. This summary identifies the most important parameters and provided a review of the impacts of their variation on the loading and concentration of the predicted herbicides.

1.2 GLEAMS Model Scenarios

The GLEAMS model was applied using a variety of model inputs to investigate the variability in the predicted export of a specific herbicide in response to a variety of realistic environmental conditions. The effect of changing environmental conditions on the export of herbicide from an application area was assessed in two distinct phases:

- ***Phase I:*** *Variable soil type and annual precipitation* – The effects of soil type and cumulative annual precipitation were investigated by developing a single realistic GLEAMS scenario and then varying these two components. Three soil types—sand, loam, and clay—and their respective soil characteristics were applied to the model. The model was then used to calculate herbicide export in environments with an annual

[1] Leaf Area Index (LAI) refers to the amount of land in a given area covered by leafy vegetation when viewed from directly overhead. An LAI of 1, for example, would indicate the entire area is covered by leafy vegetation.

precipitation of 5, 10, 25, 50, 100, 150, 200, and 250 inches. In total, there were **24 simulation** combinations in this first phase of the modeling application.

- ***Phase II:*** *Variable physical characteristics* – The effect of varying six physical parameters (soil type, soil erodibility factor, size of application area, hydraulic slope, surface roughness, and vegetation type) was investigated by changing each of the parameters individually and then recording the results. Precipitation was held constant at 50 inches. There were three variations for each of the six parameters, resulting in **18 simulations** in this second phase of the modeling application.

The combination of scenarios included in each of the two phases of GLEAMS modeling produced results for **42 simulations**. These simulations provide an indication of the effects of a variety of environmental conditions on the export of herbicide to offsite receptors. Each GLEAMS simulation was used to provide estimated exposure concentrations (EECs) for several exposures scenarios (e.g., pond, stream, off-site soil). A summary of the input characteristics used in Phase I and Phase II of the GLEAMS modeling is presented in Table B-1.

1.2.1 Scenario Identification Phase I

As discussed above, soil type and precipitation were varied in Phase I of the modeling. Each scenario was labeled indicating the soil type and precipitation level. For example, in the label "G_BASE_SAND_005" (Table B-1), "G" refers to the GLEAMS model, and "BASE" indicates that it is a Phase I (or base level) scenario. "SAND" refers to the soil type (other labels may be "LOAM" or "CLAY"), and the number "005" indicates the amount of precipitation (5 inches). The application area, hydraulic slope, surface roughness, USLE soil erodibility factor, and vegetation type remained constant. Eight levels of precipitation were used, ranging from 5 to 250 inches.

1.2.2 Scenario Identification Phase II

In Phase II of the modeling, the precipitation rate remained constant, while each of the other six parameters were varied, using three different values. The labels for Phase II (e.g., G_VGV1_050, Table B-1) identify the data as a GLEAMS run ("G"), indicate the amount of precipitation (e.g., 050 for 50 inches), and identify which parameter was varied (application area [ARV], hydraulic slope [SLV], surface roughness [RGV], USLE soil erodibility factor [ERV], vegetation type [VGV], or soil type [STV]) and at which interval (i.e., 1, 2, or 3).

1.3 Sources of Data Used in GLEAMS Simulations

Several model-input scenarios were developed to simulate the effect of a variety of soil conditions and annual rainfall totals on multimedia herbicide concentrations in a hypothetical watershed. Toward this end, a simple watershed was described in the GLEAMS model using climatic characteristics typical of a site in Medford, Oregon. Physical characteristics of the watershed were not based on any particular characteristics of watersheds in the vicinity of Medford, but were instead representative of a typical watershed in a temperate climate. Medford was selected as a representative site because of its inclusion in the dust transport modeling (ENSR 2004) completed as part of the ecological risk assessment (ERA)for the PEIS.

1.3.1 Precipitation

Rainfall distribution was described in the GLEAMS model using a daily hyetograph (i.e., a chart that shows the average distribution of rainfall in a given area) from Medford, Oregon, from 1990, when a total of approximately 13.5 inches of precipitation was recorded. The GLEAMS model used the hyetograph to describe the annual distribution of

TABLE B-1
Parameters Used in GLEAMS Modeling

Scenario Name from GLEAMS	Annual Precipitation (inches/year)	Application Area (acres)	Hydraulic Slope (feet/feet)	Surface Roughness	USLE Soil Erodibility Factor (ton/acre)	Vegetation Type	Soil Type
Phase I							
G_BASE_SAND_005	**5**	10	0.05	0.015	0.401	Weeds (78)	**Sand**
G_BASE_CLAY_005	**5**	10	0.05	0.015	0.401	Weeds (78)	**Clay**
G_BASE_LOAM_005	**5**	10	0.05	0.015	0.401	Weeds (78)	**Loam**
G_BASE_SAND_010	**10**	10	0.05	0.015	0.401	Weeds (78)	**Sand**
G_BASE_CLAY_010	**10**	10	0.05	0.015	0.401	Weeds (78)	**Clay**
G_BASE_LOAM_010	**10**	10	0.05	0.015	0.401	Weeds (78)	**Loam**
G_BASE_SAND_025	**25**	10	0.05	0.015	0.401	Weeds (78)	**Sand**
G_BASE_CLAY_025	**25**	10	0.05	0.015	0.401	Weeds (78)	**Clay**
G_BASE_LOAM_025	**25**	10	0.05	0.015	0.401	Weeds (78)	**Loam**
G_BASE_SAND_050	**50**	10	0.05	0.015	0.401	Weeds (78)	**Sand**
G_BASE_CLAY_050	**50**	10	0.05	0.015	0.401	Weeds (78)	**Clay**
G_BASE_LOAM_050	**50**	10	0.05	0.015	0.401	Weeds (78)	**Loam**
G_BASE_SAND_100	**100**	10	0.05	0.015	0.401	Weeds (78)	**Sand**
G_BASE_CLAY_100	**100**	10	0.05	0.015	0.401	Weeds (78)	**Clay**
G_BASE_LOAM_100	**100**	10	0.05	0.015	0.401	Weeds (78)	**Loam**
G_BASE_SAND_150	**150**	10	0.05	0.015	0.401	Weeds (78)	**Sand**
G_BASE_CLAY_150	**150**	10	0.05	0.015	0.401	Weeds (78)	**Clay**
G_BASE_LOAM_150	**150**	10	0.05	0.015	0.401	Weeds (78)	**Loam**
G_BASE_SAND_200	**200**	10	0.05	0.015	0.401	Weeds (78)	**Sand**
G_BASE_CLAY_200	**200**	10	0.05	0.015	0.401	Weeds (78)	**Clay**
G_BASE_LOAM_200	**200**	10	0.05	0.015	0.401	Weeds (78)	**Loam**
G_BASE_SAND_250	**250**	10	0.05	0.015	0.401	Weeds (78)	**Sand**
G_BASE_CLAY_250	**250**	10	0.05	0.015	0.401	Weeds (78)	**Clay**
G_BASE_LOAM_250	**250**	10	0.05	0.015	0.401	Weeds (78)	**Loam**
Phase II							
G_ARV1_025	50	**1**	0.05	0.015	0.401	Weeds	Loam
G_ARV2_025	50	**100**	0.05	0.015	0.401	Weeds	Loam
G_ARV3_025	50	**1000**	0.05	0.015	0.401	Weeds	Loam
G_SLV1_025	50	10	**0.005**	0.015	0.401	Weeds	Loam
G_SLV2_025	50	10	**0.01**	0.015	0.401	Weeds	Loam
G_SLV3_025	50	10	**0.1**	0.015	0.401	Weeds	Loam
G_RGV1_025	50	10	0.05	**0.023**	0.401	Weeds	Loam
G_RGV2_025	50	10	0.05	**0.046**	0.401	Weeds	Loam

TABLE B-1 (Cont.)
Parameters Used in GLEAMS Modeling

Scenario Name from GLEAMS	Annual Precipitation (inches/year)	Application Area (acres)	Hydraulic Slope (feet/feet)	Surface Roughness	USLE Soil Erodibility Factor (ton/acre)	Vegetation Type	Soil Type
Phase II (Cont.)							
G_RGV3_025	50	10	0.05	**0.15**	0.401	Weeds	Loam
G_ERV1_025	50	10	0.05	0.015	**0.05**	Weeds	Loam
G_ERV2_025	50	10	0.05	0.015	**0.2**	Weeds	Loam
G_ERV3_025	50	10	0.05	0.015	**0.5**	Weeds	Loam
G_VGV1_025	50	10	0.05	0.015	0.401	**Shrubs**	Loam
G_VGV2_025	50	10	0.05	0.015	0.401	**Rye Grass**	Loam
G_VGV3_025	50	10	0.05	0.015	0.401	**Conifer + Hardwood**	Loam
G_STV1_025	50	10	0.05	0.015	0.401	Weeds	**Silt Loam**
G_STV2_025	50	10	0.05	0.015	0.401	Weeds	**Silt**
G_STV3_025	50	10	0.05	0.015	0.401	Weeds	**Clay Loam**
Note: Parameters changed in each scenario are presented in boldface text.							

precipitation during the model simulations and eight different precipitation totals: **5**, **10**, **25**, **50**, **100**, **150**, **200**, and **250** inches per year (in/yr). The annual distribution of rainfall (Figure B-1) was scaled using the eight hypothetical precipitation totals. During Phase II of the GLEAMS modeling, precipitation was held constant (50 in/yr), and some of the watershed characteristics and erosion properties were varied.

1.3.2 Climate Information

The meteorological information used to support the GLEAMS simulations was derived from a station in Medford, Oregon. This site was selected to provide climatic data because it was also used in the dust modeling completed for this risk assessment, and because it does not receive very much precipitation in the form of snowfall. Use of snowfall in GLEAMS simulations affects model outputs by predicting a large pulse of runoff and percolation, which is caused by the melting of a substantial snow pack that develops during the winter months. The timing and magnitude of such events is highly variable and difficult to generalize across sites. The omission of this scenario should not result in under-prediction of risk because of the inclusion of high precipitation scenarios among the simulations. Such high precipitation events yield high runoff similar to hypothetical snowmelt events.

Climate data included maximum and minimum daily average temperatures, daily average solar radiation, wind movement, and dew point temperature for each month (Table B-2). This information was used primarily to calculate monthly average evapotranspiration rates, which have a strong effect on the overall hydrologic budget. High evapotranspiration rates result in a net loss of water to the application area. Percolation rates are low because minimal water migrates vertically through the unsaturated soil zone, and runoff is also low because of the reduced moisture conditions in the unsaturated soil zone. Climate data did not vary during any of the Phase I or Phase II simulations.

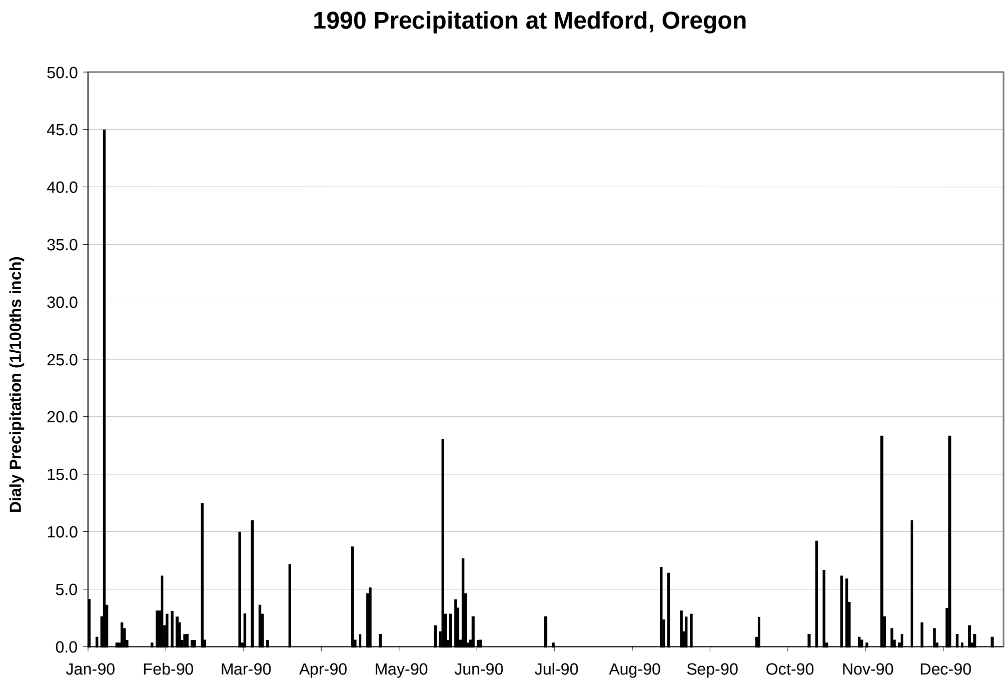

Figure B-1 Daily Rainfall Totals for 1990 at Medford, Oregon

TABLE B-2
Meteorological Values Used to Represent the Climate in Medford, Oregon

Input	Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum temperature	^oF	45.17	52.78	58.16	64.85	72.84	80.62	89.80	89.19	82.44	69.03	53.20	45.03
Minimum temperature	^oF	30.03	32.13	34.82	38.09	43.48	49.77	54.50	53.69	47.40	40.06	34.23	31.66
Solar radiation	Langley	114	210	333	477	588	647	697	602	444	276	149	92
Wind movement	Miles per day	272	272	291	294	290	301	300	285	256	240	245	252
Dew point	^oF	32	34	35	38	42	46	49	49	45	43	37	34

1.3.3 General Hydrology

The hydrology and erosion components of the GLEAMS model require a basic description of the field application area for calculation of runoff intensity, evapotranspiration, and sediment erosion and export. The values selected for the Phase I GLEAMS simulations are representative of the size and shape of a typical application area with a moderate slope in the vicinity of Medford, Oregon. None of the general hydrology components were altered during the Phase I GLEAMS simulations, but some were included in the Phase II variation (Table B-3).

TABLE B-3
General Characteristics of Watershed Used in Phase I GLEAMS Simulations

Description	Units	Phase I	Phase II		
		Value	Value Variable 1	Value Variable 2	Value Variable 3
Drainage area of field	acres	10	1	100	1,000
Hydraulic slope of field	ft/ft	0.050	0.005	0.01	0.1
Watershed length to average width ratio	ft/ft	1 (square)	1 (square)	1 (square)	1 (square)
Mean sea level elevation	ft	1,300	1,300	1,300	1,300
Latitude	degrees	42.37	42.37	42.37	42.37

1.3.4 Soil Characteristics

To quantify the effects of variable soil characteristics on herbicide export rates, the GLEAMS model was applied to application areas described by three different soil types in Phase I: sand, loam, and clay (Table B-4). These three categories are reflective of a wide range of expected runoff characteristics, which directly affect the export of water, via both overland flow and percolation, and associated herbicide. For example, sandy soils tend to favor percolation instead of overland flow, and relatively little water is held in the soil matrix and available for evapotranspiration. Since a large portion of the residual herbicide is exported from the application area via subsurface flow, the export rate is more constant with time from sandy soils than under the conditions of clay soils. In contrast to the sandy soils, clay soils tend to favor overland flow instead of percolation, and export rates are more storm-dependent and therefore more variable. Furthermore, clay soils do not facilitate a high degree of evapotranspiration because of the relatively low field capacity and tendency of the soil matrix to store water. Loam soils tend to facilitate the percolation of water, but then act as a reservoir that supports high rates of evapotranspiration. Therefore, the total export rate of water from a loam soil is less than that from either a sand or clay soil. In Phase II, three new soil types were evaluated: silt loam, clay, and clay loam (Table B-4).

1.3.5 Erosion

The erosion of sediment from the soil surface can provide a major source of offsite transport of herbicide and sediment. The erosion of sediment from a watershed is dependent on both the volume and intensity of rainfall and on the relative vulnerability of the soil surface to erosion induced by rainfall and associated runoff. The GLEAMS model uses the USLE to predict sediment export from a field with applied herbicide. The USLE incorporates several factors to consider the effects of storm intensity, soil erodibility, and erosion vulnerability, and to calculate a mass of material that is dislodged and moved within a representative watershed. The determination of how much sediment is actually exported from the watershed, presumably into an adjacent stream or pond, is determined using a watershed delivery ratio. These properties are summarized in Table B-5.

1.3.6 Herbicide

The GLEAMS model predictions of herbicide export rates and concentrations are dependent on the physical and chemical characteristics associated with each specific herbicide (Table B-6). The parameters that most strongly control the model predictions include coefficients that describe the equilibrium partitioning between the dissolved and particulate phase of the herbicide and the decay rate of the herbicide due to environmental conditions.

TABLE B-4
Physical Characteristics of Soil Types Considered for GLEAMS Simulations

Soil Type Parameters	Units	Sand	Loam	Clay	Silt Loam	Silt	Clay Loam
Soil evaporation parameter	-----	3.3	4.5	3.5	4.5	4.0	4.0
Porosity	in^3/in^3	0.40	0.40	0.47	0.43	0.47	0.40
Field capacity	in/in	0.16	0.26	0.39	0.32	0.27	0.35
Wilting point	in/in	0.03	0.11	0.28	0.12	0.03	0.22
Saturated conductivity	in/hr	0.40	0.15	0.01	0.20	0.20	0.10
Organic matter content	%	0.5	2.5	5.0	3.5	4.0	4.5
Percent clay	%	5	20	50	20	10	35
Percent silt	%	5	35	30	60	85	30
Curve number	-----	49	69	84	79	79	84

TABLE B-5
Erosion Properties Applied to GLEAMS Simulations

Description	Units	Phase I	Phase II		
		Value	Value Variable 1	Value Variable 2	Value Variable 3
Drainage area represented by profile	acres	10	1	1000	1,000
Length of overland profile	ft	2,087	2,087	2,087	2,087
Slope of overland profile	ft/ft	0.050	0.050	0.050	0.050
Soil erodibility factor	ton/acre	0.401	0.05	0.2	0.5
Soil loss ratio for overland profile	-----	0.1	0.1	0.1	0.1
Contouring factor for overland profile	-----	0.5	0.5	0.5	0.5
Manning's roughness for overland profile	-----	0.015	0.023	0.046	0.15

TABLE B-6
Herbicide Characteristics Applied to GLEAMS Simulations

Description	Units	Diflufenzopyr	Imazapic	Sulfometuron Methyl	Tebuthiuron	Diuron	Bromacil	Chlorosulfuron
Water solubility	mg/L	5,850	36,000	244	2,500	42	815	7,000
Foliar half life	days	30	30	10	30	30	20	30
Soil-water partitioning coefficient	(mg/kg)/(mg/L)	87	160	99	71	389	75	40
Fraction on foliage available for washoff	-----	0.71	0.62	0.65	0.90	0.45	0.75	0.75
Soil half life	days	9	116	30	1,077	372	275	30

1.4 Summary

The GLEAMS model has been used to predict the rate of herbicide loading from application areas to nearby potential ecological receptors. Potential application areas in public lands include a variety of different site-specific conditions. While it is not possible to model each of these conditions separately, an effort was made to identify important model inputs and then to vary them over a meaningful range. Varying model inputs has been done to support the evaluation of model uncertainty (i.e., to highlight the potential range in estimated exposure concentration with site conditions), as well as to help the BLM land manager understand those conditions that are likely to result in significant changes in exposure and potentially evaluate those conditions on a site-specific basis.

From this general evaluation, it is clear that the annual precipitation amount and soil type are important predictors of herbicide loading. At very low annual precipitation rates, the amount of off-site herbicide loading is very low as most or all of precipitation is lost to evapotranspiration and none is available to carry herbicide offsite. As the annual precipitation amount increases beyond the annual evapotranspiration amount, both surface and groundwater runoff and associated herbicide loading increase. Similar trends are seen with soil type. Soils that allow infiltration, but hold water in the root zone tend to yield less herbicide to off-site receptors. On the other hand, soils that yield high surface runoff (i.e., clays) or sub-surface runoff (i.e., sands) are predicted to have higher off-site loadings of herbicide. Other model input parameters also affect the amount of herbicide predicted to leave the application area in runoff. These include land slope, vegetation type, etc. The following section describes the process used to summarize the effects of these variables on predicted exposure. The results of this “sensitivity analysis” are presented in the ERAs for the various herbicides.

2.0 SENSITIVITY ANALYSIS

The variability and uncertainty associated with the GLEAMS model predictions was evaluated through a sensitivity analysis of several key model input parameters. The goal of the sensitivity analysis was to investigate the influence that model input parameters (and the characteristics of the watershed that they represent) have on the exposure concentrations predicted by GLEAMS.

The sensitivity analysis consists of changing given variables within the range of feasible values while holding all other input parameters constant, and then calculating the change in the estimated exposure concentration. For insensitive parameters, a significant change in the input value (e.g., factor of 10 or, alternatively, across the entire range of feasible values) might result in little or no change in the estimated exposure concentration. On the other hand, a factor of 10 change in a sensitive parameter might result in a greater than 10-fold increase in the estimated concentration. For example, as annual precipitation begins to exceed evapotranspiration and runoff is generated, the offsite transport of herbicide is predicted to increase substantially.

Variables for evaluating sensitivity (soil type, soil erodibility factor, size of application area, hydraulic slope, surface roughness, and vegetation type) were selected based on their likelihood of influencing model predictions, and their ease of determination in a typical field application. The base case for the sensitivity analysis used the annual precipitation rate of 50 inches and a loam soil type. The only scenarios that deviated from this arrangement were those that investigated the importance of soil type.

The presentation of parameter sensitivity is intended to support the assessment of uncertainty in the ERA process. As importantly, it highlights the importance of certain site characteristics so that land managers may consider the need to evaluate risks on a site-specific basis.

2.1 Sensitivity Variables

A sensitivity analysis of the GLEAMS model was performed for each of the terrestrial herbicides (bromacil, chlorsulfuron, diflufenzopyr, diuron, imazapic, sulfometuron methyl, and tebuthiuron). The results of these analyses are presented in the herbicide-specific ecological risk assessments. As discussed above, a total of six variables were selected for the sensitivity analysis of the GLEAMS model, based on their potential to affect the outcome of a simulation, and the likelihood that these variables would change from site to site:

1. *Annual Precipitation* **-** The effect of variation in annual precipitation on herbicide export rates was investigated to determine the effect of precipitation, or more specifically runoff, on predicted stream and pond concentrations. It is expected that the greater the amount of precipitation, the greater the expected exposure concentration. However, this relationship is not linear because it is influenced by additional factors, such as soil porosity. The lowest and highest precipitation values evaluated were 25 and 100 inches per year, respectively.

2. *Application Area* – The effect of variation in field size on herbicide export rates was investigated to determine the effect of application area on predicted stream and pond concentrations. The lowest and highest values for application areas evaluated were 1 to 1,000 acres, respectively.

3. *Field Slope* – The effect of variation in field slope was investigated during the sensitivity analysis to determine the degree to which application areas with steep slopes either diminished or enhanced runoff and herbicide export. The slope of the application field affects both the predicted runoff and percolation and the degree of sediment erosion resulting from rainfall events. The lowest and highest values for slope evaluated were 0.005 to 0.1 (unitless), respectively.

4. *Surface Roughness* – The effect of variability in the roughness of the application area was investigated during the sensitivity analysis by adjusting the Manning Roughness value. This parameter is a measure of surface roughness and is used in the GLEAMS model to predict runoff intensity and erosion of sediment. The Manning Roughness

value is not measured directly, but can be estimated using the general surficial characteristics of the application area. The lowest and highest values for surface roughness evaluated were 0.015 to 0.15 (unitless), respectively.

5. *Erodibility* – The effect of variation in soil erodibility was investigated during the sensitivity analysis to determine the effect of soil erodibility on predicted river and pond concentrations. The soil erodibility factor is the average long-term soil and soil-profile response to the erosive powers of rainstorms. This is a lumped parameter representing an integrated average annual value of the total soil and soil profile reaction to a large number of erosion and hydrologic processes. These processes consist of soil detachment and transport by raindrop impact and surface flow, localized redeposition due to topography and tillage-induced roughness, and rainwater infiltration into the soil profile. The lowest and highest values for erodibility evaluated were 0.05 to 0.5 tons per acre, respectively.

6. *Pond Volume or Stream Flow Rate* – The effect of variability from pond volume and stream flow on herbicide concentrations was evaluated as part of this sensitivity analysis. The lowest and highest pond volumes evaluated were 0.41 and 1,640 cubic meters (0.54 and 2,145 cubic yards), respectively. The lowest and highest stream flow values evaluated were 0.05 to 100 cubic meters per second (cms; 0.07 to 131 cubic yards per second), respectively.

7. *Soil Type* – The significant influence that soil characteristics have on predicted herbicide export rates and concentration was investigated by simulating different soil types within the application. In this sensitivity analysis, clay, loam, and sand were evaluated.

8. *Vegetation Type* – The effect of variability in the type of vegetation cover on the application area was investigated. Since the type of vegetation cover strongly affects the evapotranspiration rate, this parameter was expected to have a large influence on the hydrologic budget. Plants that cover a greater proportion of the application area for longer periods of the growing season will remove more water from the subsurface, and will therefore result in diminished percolation rates through the soil. Vegetation types included in this sensitivity analysis were weeds, shrubs, rye grass, and conifer and hardwood trees.

The effects of the eight different input model variables were evaluated to determine the relative effect of each variable on model output concentrations. A base case was established using the following values:

- Annual precipitation rate of 50 in/yr,
- Application area of 10 acres,
- Slope of 0.05 ft/ft,
- Roughness of 0.015,
- Erodibility of 0.401 tons/acre,
- Vegetation type of weeds, and
- Loam soils.

Once the base case was established, one input variable was adjusted. The difference between the result obtained from the base case and the new case, with one adjusted input variable (+/- a factor of 10 from the base case), provides a measure of sensitivity of output concentrations from that variable.

2.2 Summary

The sensitivity analysis was conducted to investigate the effect of changing general physical parameters on the predicted export loads of herbicide from the application area. Variables not included in the sensitivity analysis were those considered to have to greatest uncertainty in field application areas and for the most part cannot be measured or are at least difficult to measure. The results of the herbicide-specific sensitivity analyses are presented in each herbicide-specific ERA report.

3.0 COMPARISON TO MEASURED DATA

The ERAs rely on different models to predict the off-site impacts of herbicide use. For example, the GLEAMS model is used to predict the loading of herbicide to nearby soils, ponds, and streams from overland runoff, erosion, and groundwater runoff. The models have been developed and applied in order to develop a conservative estimate (i.e., an over-estimate) of herbicide loss from the application area to the off-site locations.

The conservative nature of GLEAMS model predictions can be illustrated by comparing these predictions to the recent work by Lerch and Blanchard (2003). These authors evaluated the rate of loading of six herbicides from several watersheds and found that the median rate of loading ranged from 0.33 to 3.9% of the mass applied. Lerch and Blanchard found that these rates of loss were "considerably higher" than those observed in other parts of the country. While the herbicides monitored by these authors were different than those assessed in the ERA, they have similar physical-chemical properties[2].

Using the GLEAMS model, the BLM has predicted median loss rates of 0.27 to 36% (median loss rates for each herbicide are presented in the herbicide-specific ERAs), which is similar to or greater than the rates observed by Lerch and Blanchard. This finding confirms that the GLEAMS modeling approach either approximates or over-estimates the rate of loadings observed in the field.

[2] Both sets of herbicides exhibit a range of properties that generally overlap one other. For example, the set evaluated by Lerch and Blanchard exhibit a range of log octanol-water partition coefficients of 1.7 to 3.5, while the set subject to the ecological risk assessment have a range of 1.1 to 2.9. Other properties that drive watershed fate and transport are also likely to vary as much within the two sets as between them.

4.0 CHRONIC AND ACUTE AMBIENT WATER CONCENTRATIONS

The GLEAMS model daily predictions of herbicide export rates were used to calculate ambient water concentrations of herbicide for both acute and chronic conditions. Ambient water concentrations were calculated for both a river and a pond immediately adjacent to the application field, using runoff and percolation rates predicted by the model and the mass of herbicide associated with each of these exports. Concentrations were calculated using an entire year of predicted results that were extracted once the model had reached a quasi-steady state. Chronic concentrations were calculated as the annual daily average from the last year of the simulation. Acute concentrations were calculated as the maximum 3-day average from the last year of the simulation.

4.1 River Concentrations

Chronic and acute herbicide concentrations in river water were calculated by diluting the predicted daily runoff and herbicide export into a stream flowing at 4.23 ft^3/second (sec) (0.12 m^3/sec).[3] The following equation was used to calculate river concentrations during a 1-year quasi-steady period:

$$\text{River Concentration}_{(i)} = \frac{\text{Runoff} + \text{Perc. Mass Rate}_{(i)}}{\text{Runoff} + \text{Perc. Flow}_{(i)} + \text{River Flow}_{(i)}}$$

4.2 Pond Concentrations

Ambient water concentrations of herbicide for a representative pond were calculated using an approach similar to that used to calculate river concentrations. Pond concentrations were calculated by assuming a fixed pond volume and a daily inflow of mass and water to the pond, dependent on recent precipitation, runoff, and percolation characteristics. Because the pond has a fixed volume, the concentration resulting from an influx of runoff and percolation water replaces an equal volume of pond water. Therefore, there are three unique possibilities that can occur as a daily volume of runoff and percolation enters the pond. In addition to the effect of runoff and percolation water, there are natural decay processes that influence the ambient water concentrations of herbicide in the pond.

1. **Pond Concentration (if export volume is zero):** If there is no predicted export of water and associated herbicide to the adjacent pond, then the pond concentration is simply the decayed concentration from the previous day. The following equation was used to calculate pond concentrations on days when there was no predicted runoff or percolation to the pond:

$$\text{Pond Conc}_{(i)} = \text{Conc}_{(i-1)} * e^{-kt}$$

2. **Pond Concentration (if export volume is greater than zero and less than the pond volume):** If there is some export of water and associated herbicide to the adjacent pond, but the volume of water exported is less than the volume of the pond, then the resulting pond concentration is a volume weighting of the previous day's pond concentration and the runoff concentration. The following equation was used to calculate pond concentrations on

[3] As described in the main document, the stream size was established at 2 meters (6.6 feet [ft]) wide and 0.2 meters (8 inches) deep with a mean water velocity of approximately 0.3 meters (12 inches) per second, resulting in a base flow discharge of 0.12 cubic meters per second (cms; 0.16 cubic yards).

days when runoff and/or percolation was predicted to enter the pond at a volume less than the pond maximum volume:

$$\text{Pond Conc}_{(i)} = \frac{\text{Runoff} + \text{Perc Mass Rate}_{(i)}}{\text{Runoff} + \text{Perc Flow}_{(i)}} * \left(\frac{\text{Runoff} + \text{Perc Vol}_{(i)}}{\text{Pond Vol}_{(i)}} \right) + \text{Conc}_{(i-1)} * e^{-kt} * \left(1 - \frac{\text{Runoff} + \text{Perc Vol}_{(i)}}{\text{Pond Vol}_{(i)}} \right)$$

3. **Pond Concentration (if export volume is greater than the pond volume):** If the volume of water in the export is greater than the volume of the pond, than the pond concentration is simply the concentration of the water entering the pond. The following equation was used to calculate pond concentrations on days when the predicted runoff and percolation volume exceeded the volume of the pond:

$$\text{Pond Conc}_{(i)} = \frac{\text{Runoff} + \text{Perc Mass Rate}_{(i)}}{\text{Runoff} + \text{Perc Flow}_{(i)}}$$

5.0 REFERENCES

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