Relative Aquifer Vulnerability Evaluation for the Gallatin National Forest

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INTRODUCTION

Pesticide applicators of today are faced with growing concern over the potential for pesticide contamination of ground water. Over 50% of all Montanan's and 95% of the agricultural community consume ground water as their source of drinking water. Protecting this fragile resource from pesticide contamination is imperative, because some pesticides may be harmful to humans at very low concentrations and clean-up of ground water is extremely difficult. Pesticide residues in ground water may also adversely affect sensitive crops and wildlife (Montana State University, Extension Service, 1990.)

There are several ways for herbicides to damage resources. These include buildup in the soil, and contamination of groundwater through infiltration, and surface runoff to streams. This paper deals only with groundwater contamination and buildup. Other models are used to predict surface water contamination by runoff.

Caution must be taken to avoid long-term buildup of herbicides in soils. Not only could they approach toxic levels, but they may become more susceptible to movement and contamination as concentrations increase. Several processes affect persistence in soils (Vighi and Funari, 1995, pages 78-79). These include transport (volatilization, leaching, runoff, and erosion), sorption and partition (immobilization by soil components), transformation (degradation by biological, photochemical, or other chemical processes), and plant processes (uptake, metabolization, immobilization.) Herbicides vary in their persistence, but generally have short "half-lives" (that period of time to degrade ½ of a given addition in or near the surface of the soil.) This measure is a result of those processes described above with the exception of removal.

Groundwater vulnerability is a general concept that deals with the susceptibility of underground water bodies to contamination by a surface addition of polluting material, in this case herbicides (Vighi and Funari, 1995, pages 102-104.) There are numerous models of herbicide movement in soils (Macur, et al, 2000.) We selected the RAVE (Relative Aquifer Vulnerability Evaluation) because it is localized to Montana soils, it has a straightforward, relatively simple system, and is a published operational method (Montana State University, Extension Service, 1990.) This model evaluates only the groundwater contamination path and indirectly the buildup in soil. The National Forests are primary sources for many ground water systems. It was designed to help farmers and other pesticide applicators reduce the potential for contaminating ground water with pesticides. This numeric scoring system helps individuals evaluate pesticide selection for on-site ground water contamination potential. RAVE is designed only as a guidance system and does not replace the need for safe and judicious pesticide application required in all situations. Though this rating scheme was developed primarily for farmlands, we judged the Gallatin Forest is similar enough in climate, soils, and application methods to warrant application of this model.

In most cases pesticide contamination of ground water can be avoided by using common sense and following label instructions. However, on a planning basis, some landscapes are particularly vulnerable to pesticide contamination and thus require special consideration prior to making an application. Therefore, a spatial model of the RAVE system was developed for use over the entire National Forest. This is not meant for on-site use, because many of the parameters are only meaningful over an area greater then 100 acres. However, results can be used to focus mitigation in potentially hazardous areas, alert pesticide users of important factors on a Forest basis, and help put the potential problem of groundwater contamination in a scientific perspective. The use of this score card may indicate whether an alternative pesticide should be used within a given area or if the area is not suited to pesticide applications.

Several major factors in a particular area determine the relative vulnerability of ground water to pesticide contamination. Nine of these factors have been incorporated into the RAVE score card and are defined below. Values for these factors were developed on a landscape basis, as defined below. Pesticide leaching potential is based on the soil persistence and mobility of a pesticide. For this planning effort, a highly leachable herbicide was used. This was done to give a "worst case" scenario.

The herbicide picloram (Tordon) is considered a highly leachable chemical (Montana State University, Extension Service. 1990), (Kamrin, 1997, pages 8, 506-510), since it is quite soluble in water, it is poorly bound to soils. It is also moderately persistent (average of 90 days ½ life.) Degradation by microorganisms is mainly aerobic. Volatilization is low and photochemical degradation occurs only at the soil surface. For these reasons, picloram is used as an index in this evaluation. Because of its moderate ½ life, and high leachability it is not considered a candidate for long term buildup in soils. However, traces of it can remain in the soil for up to eleven years, so it is important to carefully consider application rates (Rew, Lisa, PhD, Montana State University, personal communication 2003)

Factor Definitions

Irrigation Practice: A rating based on whether a field is flood, sprinkler or non-irrigated.

Depth to Ground Water: The distance, in vertical feet, below the soil surface to the water table.

Distance to Surface Water: The distance, in feet, from the application site to the nearest flowing or stationary surface water.

Percent Organic Matter: The relative amount of decayed plant residue in the soil (most Montana soils are < 3 %).

Pesticide Application Frequency: The number of times the particular pesticide is applied during one growing season.

Pesticide Application Method: A rating based on whether the pesticide is applied above or below ground.

Pesticide Leachability: A relative ranking of the potential for a pesticide to move downward in soil and ultimately contaminate ground water based upon the persistence, sorptive potential and solubility of the pesticide.

Topographic Position: Physical surroundings of the field to which the pesticide application is to be made. Flood plain = within a river or lake valley, Alluvial Bench = lands immediately above a river or lake valley, Foot Hills = rolling up-lands near mountains, Upland Plains = high plains not immediately affected by open water or mountains.

Sources of Information

Soils Information: USDA-SCS Gallatin National Forest soil survey

Ground Water Information: USDA-SCS Gallatin National Forest soil survey, and professional experience of the Gallatin National Forest Soil Scientist.

Pesticide Information: Leachability table included with the RAVE method.

THE RAVE SCORE CARD FACTORS

Factor One: DEPTH TO GROUND WATER:

2-10 ft	20
10-25 ft	12
25-50 ft	5
> 50 ft	0

This factor was estimated using the Gallatin National Forest Soil Survey, which has an interpretation in its draft 1984 version for "occurrence of wet areas" (Davis and Shovic, 1984, Table One: Map Unit Features Affecting Road Location and Construction.) In this semi-arid environment these areas are generally surface indications of high groundwater tables and not from precipitation (except for a short period of snowmelt in June.) A "high" rating for a map unit is interpreted as indicating water tables are consistently near the surface, generally within 2 – 10 feet. One additional map unit was included that rated only "moderate." This is because of its topographic location as a higher-elevation flood plain (Map Unit 64-2C.) where landform-based hydrology and vegetation types indicate a near-surface groundwater table.

All "moderate" ratings for wet areas indicate ground water depths of 10-25 feet. Wet areas are often at the base of slopes in these units, indicating groundwater is present, but not commonly near the surface. All other ratings indicate relatively deep groundwater levels (25-50 feet.)

Factor Two: DISTANCE TO SURFACE WATER:

1-100 ft	5
100-500 ft	3
> 500 ft	2

This factor was evaluated using digital versions of lakes and major stream maps. Buffers of 100 ft (30m) and 500 ft (152m) were created around each water body.

Factor Three: TOPOGRAPHIC POSITION:

Floodplain	15
Alluvial bench	10
Rolling foothill	5
Upland plain	2

This factor was estimated using the landform descriptions in the soil survey. Landforms on the Gallatin Forest are classified primarily as rolling foothills with a few floodplains and alluvial benches.

Factor Four: SOIL TEXTURE:		Gallatin National Forest Texture Classes
Gravelly	15	Moderately-Coarse, Coarse
Sandy	15	Moderately-Coarse, Coarse
Loamy	10	Medium, Medium to Moderately Fine
Clayey	5	Moderately-Fine or Fine

A generalized textural rating given in map unit descriptions (Davis and Shovic, 1996) was used to class soil texture. See above for classification.

Factor Five: PERCENT SOIL ORGANIC MATTER:

0-1%	5
1-3%	3
> 3%	2

All Gallatin Forest soils are rated at 1-3% organic matter based on laboratory data on file at the Gallatin National Forest.

Factor Six: IRRIGATION PRACTICE:

Flood irrigated	10
Sprinkler irrigated	7
Non-irrigated	2

Based on the semi-arid nature of the surrounding areas, all soils were rated non-irrigated.

Factor Seven: PESTICIDE APPLICATION FREQUENCY:

> 1/year	5
1/year	2

The usual application is less than once per year.

Factor Eight: PESTICIDE APPLICATION METHOD:

Soil applied	5
Foliar applied	2

All pesticides are applied on plant leaves.

Factor Nine: PESTICIDE LEACHING INDEX:

High	20
Moderate	10
Low	5

A leaching index of "high" was used. This was based on application of Tordon (picloram) which is sometimes used on the Forest (Table 1.) This was used to account for the probable "worst-case" scenario in terms of contamination potential.

Table 1. Commonly used herbicides, an example trade name and relative herbicide leaching potentials. Chemicals bolded have been found in ground water in Montana (Montana State University, Extension Service. 1990.)

Herbicide	**Leachability**
paraquat (Gramoxone Extra, Cyclone)	low
pendimethalin (Prowl)	low
phenmedipham (Betamix)	low
picloram (Tordon)	high
prometon (Pramitol)	high
pronamide (Kerb)	low
propachlor (Ramrod)	low
propanil (Stampede)	low
pyrazon (Pyramin)	low
sethoxydim (Poast)	low
simazine (Princep)	high
sulfometuron methyl (Oust)	med
tebuthiuron (Spike)	high
terbacil (Sinbar)	high
thifensulfuron (Harmony)	high
tralkoxydim (Achieve)	low
triasulfuron (Amber)	low
triallate (Far-Go)	low
tribenuron (Express)	high
triclopyr (Garlon)	med
trifluralin (Treflan)	low
triflusulfuron methyl (Upbeet)	med
vernolate (Vernam, Surpass)	med
2,4-D	**high**
2,4-D amine (Curtail)	**high**
2,4-D ester (Curtail M)	**high**
2,4-DB (Butyrac)	**high**
2,4-DP (Weedone)	**high**

All spatial layers were co-located in a geodatabase. Ratings for factors 1, 3, 4, 5, 6, 7, 8, and 9 were assigned to soil survey map units. These were spatially joined to the buffered stream and lake layers to rate factor 2. All rankings were totaled and classed in ACCESS as described below for risk categories. The resulting layer was clipped by the Gallatin National Forest boundary. This was joined to a HUC6 watershed layer and the layer showing existing weed infestations for the Forest. The resulting tables were queried to provide risk classification summaries by watershed and presence of weeds. District-level maps are provided to show high-risk areas. All spatial data and analytical procedures are on file at the Gallatin National Forest.

Interpretation of RAVE Scores

The RAVE score card rates aquifer vulnerability on a scale of 30 to 100 for individual application sites and pesticides. Higher values indicate high vulnerability of ground water to contamination by the pesticide used in the evaluation. Those values greater than or equal to 65 indicate a potential for ground water contamination. In such instances alternative pesticides should be sought which have a lower leaching potential. Scores of 80 or greater indicate that pesticide applications should not be made at this location unless an alternative product greatly reduces the score. Scores between 45 and 64 indicate a moderate to low potential for ground water contamination and scores less than 45 indicate a low potential for ground water contamination by the pesticide in question. Even in such cases, careful use of pesticides and following label instructions is imperative to protect ground water (Table 2 describes risk classes.)

Table 2. Risk classes for herbicide/groundwater aquifer contamination

RAVE Rating Score	Risk Class
< 45	Low
45-64	Low to moderate
65-79	High
80-100	Unacceptable

RESULTS

For this study, total area for the Gallatin Forest and each Ranger District was calculated from GIS layers (Table 4.) Small differences between totals in the following tables are due to this variation and small numbers of missing data in the modeling process.

Table 4. Ranger District Areas

DISTRICT	TotalAcres
Big Timber RD	386,472
Bozeman RD	558,528
Gardiner RD	418,270
Hebgen Lake RD	355,443
Livingston RD	406,078
Total	2,124,790

Table 5 shows RAVE risk classes for the entire Forest, and Table 6 proportions classes by Ranger District. Figure 1 shows risk for the entire Gallatin Forest. Table 7 depicts area of existing weeds (from the Gallatin National Forest Invasive Species Inventory (weeds_gnf)) intersected with the “High” risk areas from the RAVE model. Table 8 shows total “High” risk by watershed and total area of existing weeds intersected with those “High” areas. Highlighted watersheds are those having greater than 640 acres of “High” areas. Watersheds with an asterisk (*) have more than 20 acres of existing weeds within those “High” areas. Figure 2 shows risk areas and “High” risk weed infestations displayed by watershed.

Table 5. RAVE Risk Classes for the Entire Forest

RAVEScoreClass	Acres
Low to Moderate	1,994,893
High	105,353
Total	2,100,246

Table 6. RAVE Risk Classes by Ranger District

DISTRICT	RAVEScoreClass	Acres
Big Timber RD	Low to Moderate	378,334
	High	7,868
Bozeman RD	Low to Moderate	538,327
	High	17,065
Gardiner RD	Low to Moderate	351,429
	High	64,016
Hebgen Lake RD	Low to Moderate	324,604
	High	13,143
Livingston RD	Low to Moderate	402,185
	High	3,261
Total		2,100,232

Table 7. Percentage of Existing Weed Area by Risk Class for the Forest

RAVEScoreClass	Acres	Percentage of Total Existing Weed Area
	69	
Low to Moderate	4,555	92
High	394	8
Total	4,949	100

Table 8. High RAVE Risk Class by HUC6 Watershed (Acres in Risk Class and Acres of Risk Class In Weed Areas

HUC6	HUC6 Name	Acres rated as "HIGH" RAVE Class	Acres rated "HIGH" in existing weed areas	High Risk Areas (gt 640 acres of "High" RAVE risk)	High Weed Occurrence in High Risk Area (gt than 20 acres)
100700060101	Broadwater Fisher	16,769		x	
100700060104	Russell	16,184		x	
100700060105	Beartooth	13,564		x	
100700010705	Upper Slough	5,128		x	
100200071601	Cherry	2,987		x	
100700020801	Rainbow	2,677	0	x	
100200070205 *	Denny	2,674	25	x	x
100700060103	Clarks Fork	2,496		x	
100200070306	Tepee	2,133		x	
100700010706	Lower Slough	1,851		x	
100200071401	Bear Trap	1,786		x	
100200080104	Bacon Rind	1,438		x	
100700010806	Crevice	1,331		x	
100700010702	Soda Butte	1,185		x	
100200080504	Twin	1,180	0	x	
100700010805	Lower Hellroaring	1,114		x	
100200070505	Hebgan Lake	1,076	19	x	

100700020804	Upsidedown Bridge	1,053	8	x	
100700030201	Shields Headwaters	899		x	
100700060107	Beartooth Lake	867		x	
100700010708	Buffalo	862		x	
100700020809	Upper East Boulder	858	2	x	
100200080604	Squaw	842	8	x	
100200080502	NF Spanish	807		x	
100700020808	Middle Boulder	782	2	x	
100200080107 *	Upper Taylor	752	25	x	x
100200080901	Hyalite	712	11	x	
100200070603	Lower Beaver	661	6	x	
100700020905	Lower West Boulder	658	1	x	
100700010802	Upper Hellroaring	648		x	
100200070304	Duck Red Canyon	642	14	x	
100200070202	Upper Madison	620	10		
100200070204 *	S. Fk.Madison	619	29		x
100700020102	Mulherin	544			
100200081102	Boswick M Cottonwood	529			
100700030202	Smith	496	1		
100200080406	Dudley Levinski	495			
100200070305	Greyling	479	11		
100700021101	Upper Lower Deer	444			
100200080605	Cascade	436	5		
100200080103	Headwaters Gallatin	427			
100200080108	Wapiti	423	3		
100200080703	S Cottonwood	412			
100700020101	Cinnebar	405	0		
100200080302	Middle FK West Gallatin	398			
100700010803	Middle Hellroaring	352			
100200080803	Bozeman	346	18		
100700030301	Brackett	335	1		
100200070601	Upper Beaver	335	3		
100200080601	Portal	319	4		
100700020105	Upper Tom Miner	317	8		
100700020305a *	Lower Mill	305	29		x
100700020301b	Rockb	295			
100700020301a	Upper Mill	294			
100200080501	SF Spanish	272	4		
100700020904 *	Middle West Boulder	256	52		x
100200081003	Reese	252			
100200080407	Deer Aspestos	236	0		
100700020302b	Passage	226			
100700010804	Horse	216			
100200080405	Porcupine	204	0		

100200080303	West FK West Gallatin	195			
100200080603	Swan	194	2		
100200080602 *	Moose Tamphry	194	60		x
100200080106	Sage	180			
100200080404	Beaver	179	0		
100200080804	Bridger Canyon	177			
100700020803	Meatrack	172	15		
100402010601	American Fork	169			
100700030101	Fairy Carrol	165	1		
100700020810	Lower East Boulder	163			
100200081004	Quagle	162			
100200080802	Bear Canyon	137			
100301010302	S FK Sixteenmile	123	0		
100200080606	Hellroaring	116			
100200080801	Jackson Meadow	116	0		
100700020712	Swamp	114			
100200080402	Elkhorn	113			
100700030402	Cottonwood	108			
100700020302a	Upper Big	107			
100200081002	Pass Mill	105	0		
100200070203	Dry Canyon	105	1		
100700021202	Lower Sweetgrass	104			
100700020303a	Lower Big	101	1		
100700021302	West Bridger	96			
100200080701	Yankee Wilson	90			
100700030408	Willow	75	11		
100700030403	Rock	74			
100700020714	Big Timber	73			
100700020304a	Donahue Daily	62	0		
100200080401	Buffalo Horn	60			
100700020406	Suce Strickland	58	0		
100700020713	M FK Big Timber	57			
100700030406	Bangtail	57			
100700020306	Emigrant	53			
100200070602	Cabin	52			
100200080505	Wilson Draw	51			
100700020807	Shorty	49	0		
100200080702	Big Bear	44			
100700020711	Little Timber	43			
100700021001	Otter	37			
100700020402	Trail	36			
100200080403	Buck	35			
100700020108	Sphinx Slip and Slide	35	0		
100700020906	Boulder	35	0		
100700020307	Fridley	31			

100700030104	Lower Flathead	29			
100700020309	Pole Conlin	28			
100700020305b	Sixmile	25			
100700030405	Canyon	25			
100200081103	Sypes	23			
100700020106	Horse	21			
100700020903	Blacktail	19			
100700020403	Pine West	13	2		
100700020303b	West Fork Mill	13			
100700020505	Mission	13			
100700020308	Eightmile	12			
100700030204	Porcupine1	8			
100700030102	Upper Flathead	6			
100700030205	Elk	4			
100700021201	Upper Sweetgrass	3			
100700020811	Lower Boulder	2			
100700030103	Dry				
100700020805	Speculator				
100700030105	Muddy				
100700030203	Middle Shields				
100700021104	Lower Lower Deer				
100200070703	Raynolds				
100200070801	Sheep				
100700030207	Horse				
100200070802	Mile				
100700021103	Upper Deer				
100700021102	E FK Upper Deer				
100700030208	Daisy				
100700020902	Falls				
100700021301	Blind Bridger				
100700020401	Elbow				
100200081001	Rocky				
100301010301	Timber				
100200080607	Logger				
100301010303	Sixteenmile				
100700010901	Bear				
100700010902	Eagle Reese				
100700020103	Basset				
100700020806	West Chippy				
100700020304b	East Fork Mill				
100700020901	Upper West Boulder				
100700020404	Pine East				
100700020405	Deep				
100700020502	Dry1				
100700020602	East Fork Duck				

100700020802	Upper Boulder				
100200080805	Beasley M				
100200080301	SF West FK Gallatin				
100700020107	Lower Tom Minor				
100700020104	Cedar				
Total		102,649	392		

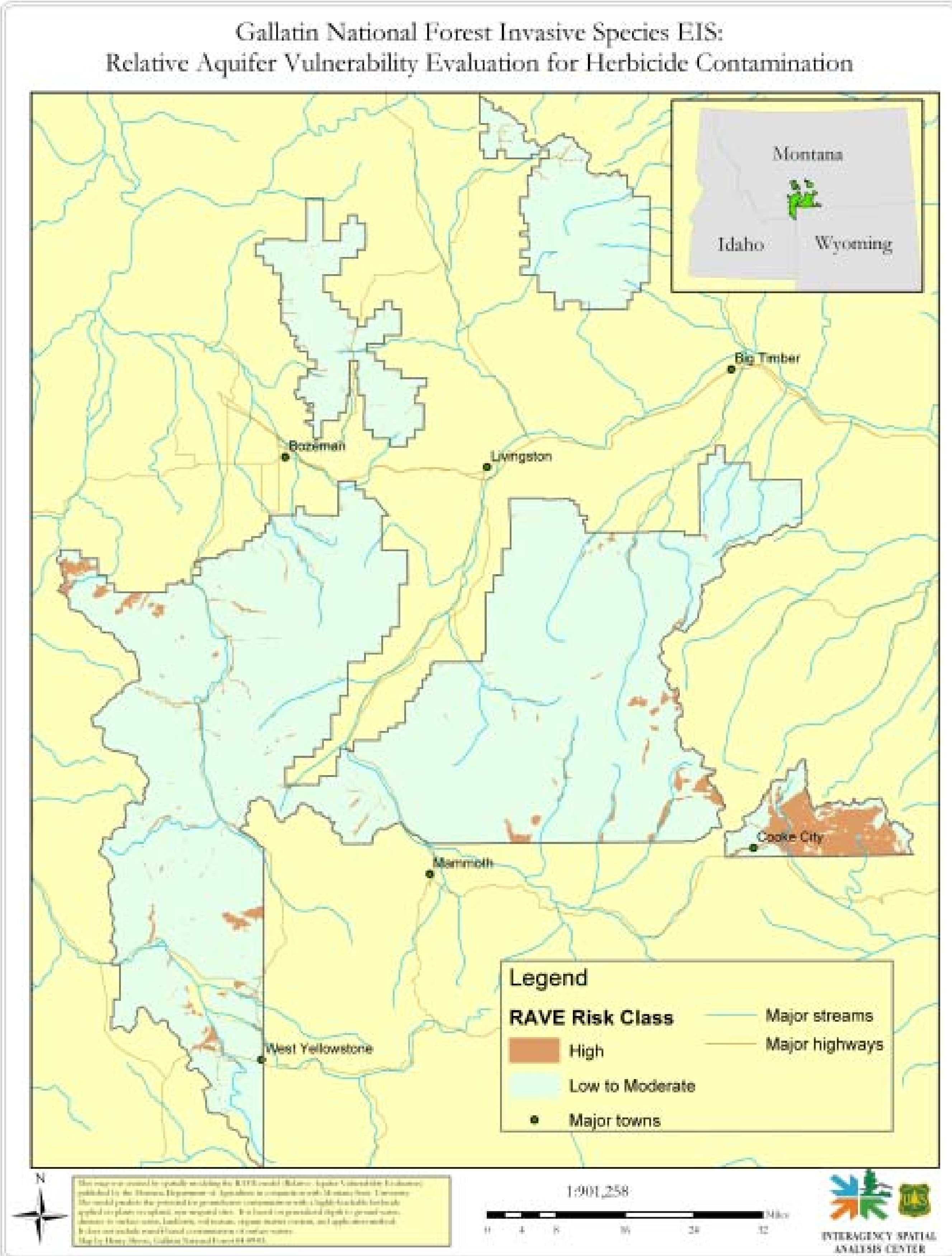

Figure One. Relative Aquifer Vulnerability Evaluation for Herbicide Contamination

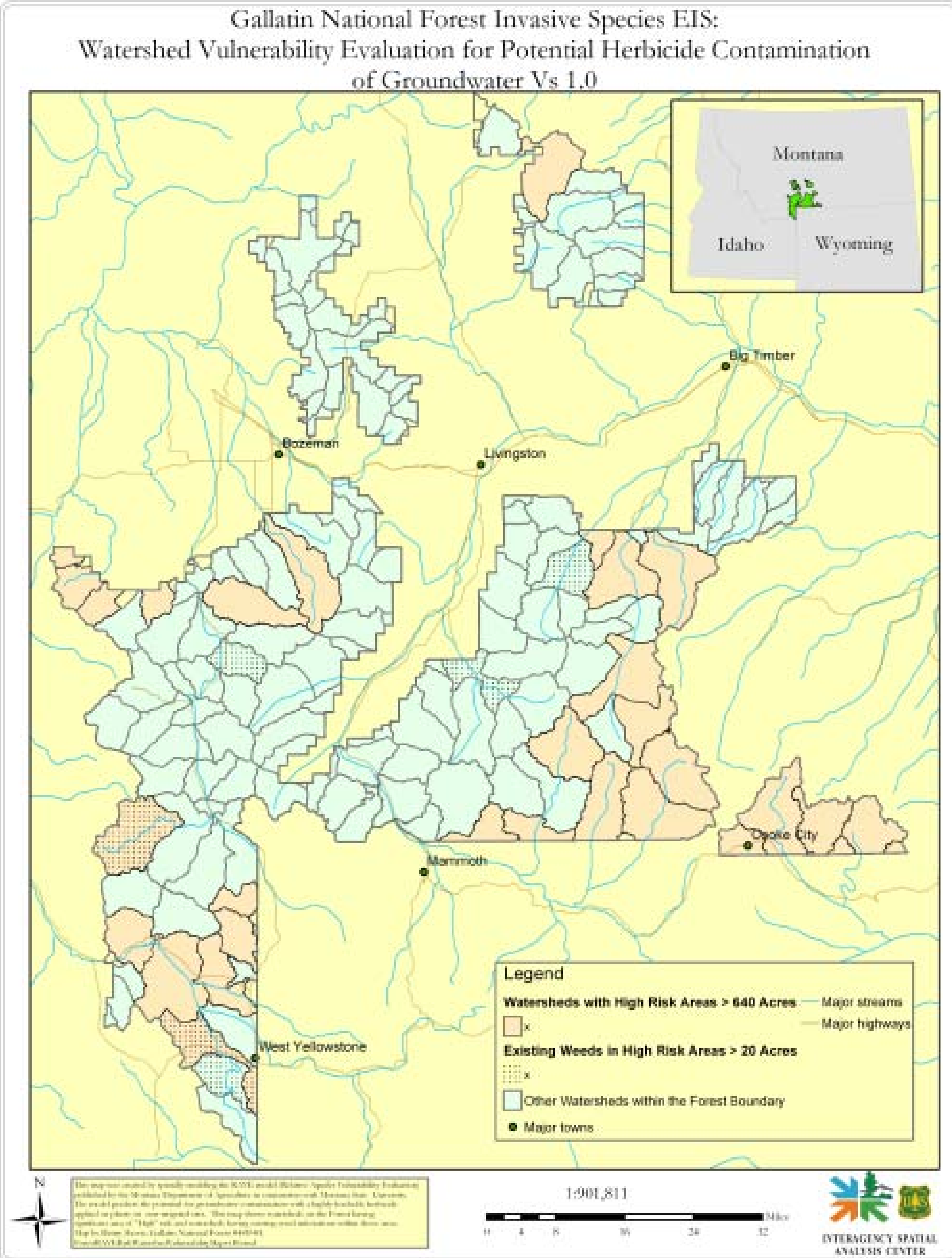

Figure Two. Watershed Vulnerability Evaluation for Potential Herbicide Contamination of Groundwater

DISCUSSION AND CONCLUSIONS

Though all the factors discussed above influence rating scores, it appears that depth to groundwater and pesticide leachability account for most of the "High" ratings. Though his model is designed for a planning level, and is not appropriate for on-site design, the data depicted in Figure 1 are accurate enough to use on a district level if mapped at that scale. They provide useful "red flag" indicators for applications specialists when in areas designated "High" risk.

For the case using a highly-leachable herbicide, almost all of the Gallatin Forest falls in the "low to moderate" risk class. Only five percent falls in the "High" class (Table 5.) This indicates that as far as groundwater contamination is concerned, considered and careful use of herbicides on most lands on the Forest is likely a reasonable activity. There are "hot spots" in each Ranger district that should be candidates for special mitigation (Figure 1.) The Gardiner District has the most area in this class (Table 6), primarily due to the high elevation area near Cooke City.

In any of these areas, use of an alternate pesticide with a low leaching index should reduce risk to reasonable levels. High-risk areas average a score of 75. Selecting an alternative herbicide with a low leachability (from Table 1) giving a rating factor value of 5 rather than 20. This lowers the average score to 60, well within the "Low to Moderate" risk class (Table 2.)

Figure 2 shows there are some watersheds that should be reviewed for risks of groundwater contamination, based upon not only their potential for contamination through existing weed infestations, but also for potential contamination in the future if weeds are found in or migrate to those areas. These watersheds are listed in Table 8. The watersheds having existing weed infestations in "High" risk areas should have special mitigation designed into all current treatment plans, because though they may be in a watershed having generally a "Low to Moderate" risk, weeds occur in small "hotspots" needing on-site design and mitigation.

Though on a Forest basis only a small portion of weeds fall into the "High" risk areas (Table 7), there are some areas of specific concern. Watersheds having both a significant area in "High" risk and a significant area of weeds in those "High" risk areas should have a planning level designation for special treatment. Watersheds of "Low to Moderate" risk can be evaluated at a less intense level. In terms of long term planning, watersheds having few weeds, but some potential for contamination should include prevention and monitoring at a higher level than other watersheds to prevent spread of weeds into those areas. For example, the Cooke City area (Figure 2) have few weeds at present. However because of shallow groundwater, and abundant surface water, the area should be specified for special interventive mitigation (e. g. using pesticides of low leachability and higher cost of application) as well as increased preventative measures such as travel restrictions or washing guidelines for vehicles.

Generalizing from the above discussion, it appears that the Gallatin Forest has a low to moderate potential for groundwater contamination from foliar-applied herbicides. The areas of higher risk probably can be mitigated with herbicide selection and specification of Best Management Practices to minimize that contamination potential.

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