Groundwater-Dependent Biodiversity and Associated Threats:

A statewide screening methodology and spatial assessment of Oregon

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JENNY BROWN
ABBY WYERS
LESLIE BACH
ALLISON ALDOUS

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1.0 Introduction:

Groundwater is a significant component of the freshwater supply on Earth and an important source of water for sustaining both ecological and human communities. Aquatic ecosystems such as springs, wetlands, rivers and lakes often rely on groundwater to meet their water needs. Groundwater is also important for maintaining the water temperature and chemistry conditions required by these ecosystems and the plants and animals they support. Humans rely on groundwater to provide clean drinking water, particularly in rural areas, and to meet industrial and agricultural water demands.

The supply and quality of groundwater and the connection of groundwater to ecosystems are increasingly at risk around the world (Millennium Ecosystem Assessment, 2005). In the Northwest United States, surface water supplies are fully allocated, and water management agencies and water users are increasingly turning to groundwater to meet future water needs. In addition, groundwater contamination by nutrients and chemicals has been documented in numerous locations, and many additional areas have been identified as susceptible to future contamination. These trends could have a significant effect on the health and viability of groundwater-dependent ecosystems as well as the suitability of groundwater for human uses.

Most groundwater conservation and management efforts have focused on protecting groundwater for drinking water and other human uses (e.g., Washington Department of Ecology Web site, 2008; OWRD and Institute of Water and Watersheds, 2008). In addition, while there are numerous efforts by conservation organizations and government agencies to protect and restore surface water quantity and quality for the benefit of aquatic ecosystems, there are few similar efforts focused on identifying and mitigating threats to groundwater quality and quantity. To address this disparity, The Nature Conservancy is working to identify conservation actions that will protect groundwater-dependent biodiversity in the Northwest United States.

The development of effective strategies to protect groundwater-dependent ecosystems and species depends on understanding where they occur, their groundwater requirements, and whether their groundwater supplies are impaired. Unfortunately, little of this information is readily available. Studies of groundwater availability and quality have been completed in the Pacific Northwest at scales ranging from specific river reaches to large drainage basins; however, most of these projects focused on the importance of groundwater to maintaining base flow (e.g., Lee and Risley, 2002; Sinclair and Pitz, 1999), the connectivity between surface and groundwater in specific settings (e.g., Gannett et al., 2007; Gannett et al., 2001), and the potential contamination of drinking water supplies by nutrients, pathogens and chemicals (e.g., Bartholomay et al., 2007). To date, no assessment has been made of the distribution of and risks to groundwater-dependent ecosystems in the Pacific Northwest.

To address these technical issues, the Conservancy has developed a new GIS-based screening tool to map the distribution and diversity of groundwater-dependent ecosystems and species as well as the type and location of potential threats to their groundwater supply. The results from this analysis will be used to prioritize areas for conservation of groundwater-dependent biodiversity and to guide the development of targeted conservation strategies to reduce threats to groundwater quantity and quality. The analysis will also help to identify areas where future conservation efforts may require additional scientific studies to better understand groundwater processes and the links between groundwater and aquatic ecosystems.

We began this work by developing and implementing these methods in Oregon; however, many states and countries have similar challenges, as groundwater contamination and depletion are common issues and data and information are generally lacking. Thus, the general approach and methods described in this report can provide a framework for similar assessments in other locations. In the future, we will apply the methods developed here to an assessment in Washington, thus broadening our understanding of the ecological importance of groundwater across the Pacific Northwest region of the US.

The results of the Oregon assessment are organized into four main components:

1. This report, which provides background on groundwater-dependent ecosystems and threats, a general description of the analysis methods, and a summary of results for Oregon;
2. Appendix A: An atlas containing maps of each data layer that we compiled and developed. Maps include groundwater-dependent ecosystems and species and threats to groundwater quality and quantity in Oregon;
3. Appendix B: A detailed, step-by-step description of the methods used in this analysis;
4. Appendix C: Tables of the data used in this analysis.

All parts of the assessment are available at http://conserveonline.org.

2.0 Background:

2.1 Groundwater-dependent ecosystems and species

We identify groundwater-dependent ecosystems and species (termed GDEs) using the definition of Murray et al. (2006): the ecological structure and function of these ecosystems depends on access to groundwater. Although we refer to these as groundwater-dependent ecosystems, this category also includes communities and species. We divided GDEs into two groups (Naiman et al., 2006): ecosystems that depend on groundwater regardless of their locations (obligately groundwater dependent), and those that may depend on groundwater, because of their particular hydrogeologic setting (facultatively groundwater dependent). As a result, some ecosystems are groundwater dependent by virtue of their type, but most are groundwater dependent by virtue of their location on the landscape.

Eamus and Froend (2006) identified six ecosystems that depend on groundwater: wetlands, rivers, lakes, springs, phreatophytes and subterranean ecosystems. Three of these — spring, phreatophytic and subterranean ecosystems — are obligately groundwater dependent, relying on groundwater regardless of where they occur. The water supply of springs and associated springbrooks comes solely from groundwater, and often this water has chemical or temperature characteristics that support uncommon communities of species (Sada et al., 2001; Williams and Williams, 1998). Phreatophytic plants have deep roots that can access water in the capillary fringe, immediately above the water table; if these plants use this deep water at some point during the year or the plant life cycle, they are considered to be groundwater dependent (Zencich and Froend, 2001). These species have been identified in arid climates, and recent work in more humid climates suggests this phenomenon may be more widespread than generally is acknowledged (Brooks et al., 2002). The ecological importance of subterranean ecosystems has only recently emerged in the scientific literature (Tomlinson and Boulton, 2008; Goldscheider et al., 2007; Hancock et al., 2005). There are a number of invertebrates and microbes, many of them endemic, that live in aquifers (Humphreys, 2006) and need to be accounted for in biodiversity conservation (Tomlinson et al., 2007).

The groundwater dependence of the other three types of ecosystems identified by Eamus and Froend (2006) — wetlands, rivers and lakes — is facultative, depending on their hydrogeologic setting. Wetlands can rely on groundwater to create specific hydroperiods, which govern wetland structure and function (Wheeler et al., 2004; Mitsch and Gosselink, 1986). For example, fens and slope wetlands receive most of their water supply from groundwater (Bedford and Godwin, 2003). In some ecosystems, such as calcareous fens, this influx creates unusual water chemistry (e.g., Almendinger and Leete, 1998). Rivers often rely on groundwater to maintain late-season base flow, moderate temperature regimes, create certain water chemistry conditions, or produce thermal refugia for fish and other species during temperature extremes (Power et al., 1999). Lakes can receive significant inputs of groundwater during certain times of the year under specific hydrologic, geologic and topographic conditions (Grimm et al., 2003; Riera et al., 2000; Winter, 1978; Winter, 1995). Even if the contribution of groundwater to a lake is small relative to that of surface water, locations of groundwater discharge can create ecologically distinct conditions that support different fish (King County DNR, 2000) or plant communities (Rosenberry et al., 2000; Sebeysten and Schneider, 2004; Lodge et al., 1989).

2.2 Threats to groundwater quality and quantity

GDEs can rely on groundwater to maintain (i) adequate quantity, timing and duration of water delivery; (ii) good water quality or specific water chemistry conditions or (iii) specific temperature regimes (Brown et al., 2007). As a result, the integrity of these ecosystems is threatened by activities that alter the quantity or quality of groundwater discharging at or near the surface. Land use activities that can change the amount or seasonal pattern of groundwater flow or alter groundwater chemistry or temperature all present a threat to GDEs.

Groundwater withdrawal for drinking water, irrigation or industrial uses can decrease the amount of groundwater available to GDEs. In addition to individual large wells, high densities of lower volume wells (such as those for individual homes) can alter groundwater flow paths, changing the rate or timing at which this water discharges to GDEs (USFS, 2007). In many parts of the world where much of the surface water supply is already allocated for use, water management agencies and water users are increasingly turning to groundwater to meet growing demands for water (Gannett et al., 2007; Oregon Water Resources Department (OWRD), 2007c; Yardley, 2007). Some countries are developing water policies that recognize the potential effects of increased groundwater withdrawal on GDEs and include the ecological requirements of groundwater in water management decisions (e.g., Australia – Environment Australia, 1994; South Africa – DWAF, 1997; European Union – WISE, 2008).

The extent of groundwater contamination in the U.S. has recently been studied by the U.S. Geological Survey (USGS) as part of the National Water-Quality Assessment (NAWQA) Program. Their evaluation of groundwater across the country has found contamination by pesticides, nutrients and other toxic contaminants in many study areas (Gilliom et al., 2006; Zogorski et al., 2006; Hamilton et al., 2004). Similar findings exist for other countries (Scheidleder, et al., 1999). These contaminants can have a profound effect on the suitability of groundwater for drinking water, so addressing this issue has been on the forefront of efforts to protect groundwater quality. Despite the fact that toxicity thresholds for some of these contaminants can be lower for aquatic biota than for humans (Boxall et al., 2006), much less attention has been given to protecting groundwater quality for ecosystems and species.

Finally, the high temperatures of hot springs are maintained by flow paths that bring groundwater into contact with deeper, warmer areas of the subsurface for prolonged periods of time. Development of geothermal resources, for either electricity generation or generation of heat, can reduce the volume of water discharging to hot springs, potentially altering the temperature of hot springs. These changes can shift the composition of the microbial flora and fauna that depend on specific temperature ranges for their habitat (Breitbart et al., 2004; Sompong et al., 2005).

While it is likely that climate change will alter groundwater availability, our work does not analyze this threat, as such an effort would be a separate modeling effort in and of itself.

3.0 Overview of Methods:[1]

In this assessment we identified, analyzed and mapped (i) groundwater-dependent ecosystems and species (GDEs) and (ii) threats to GDEs due to changes in groundwater quantity and quality. The analysis was conducted by using a Geographic Information System (GIS; ArcGIS v. 9.2). To manage the information and summarize the results at an appropriate scale, we divided the state into fourteen regional analysis units, which are based on the administrative basins of the Oregon Water Resources Department. Each of these regions (Atlas Map 1) has similar biota and groundwater processes due to the relative homogeneity of hydrogeologic, ecological and climatic conditions. We further subdivided each region into watersheds, using the sixth level Hydrologic Units of the USGS (referred to as HUC6; BLM OR and USFS, 2006; Atlas Map 2) as the watershed boundaries (mean size = 8055 ha or 19905 acres). Each HUC6 was evaluated for the presence of GDEs and activities that threaten groundwater quantity and quality. Thus, the analysis and summary of findings were completed at the HUC6 scale, rather than for the exact locations of the GDEs and land use activities.

The analysis relies on existing, fairly coarse datasets. Because there is limited information about both groundwater-dependent biota and the condition of groundwater across the region, we used a suite of surrogate indicators to develop new analytical methods. In general, these indicators highlight the potential threat to groundwater rather than actual effects on groundwater quantity and quality. Given the coarse nature of the datasets and the lack of strong analytical relationships, this assessment functions as both an inventory of information (see Appendix A, the Atlas) and a screening tool to identify high-priority areas for the conservation of groundwater-dependent ecosystems.

3.1 Groundwater-dependent ecosystems and species

We focused on four of the six types of ecosystems that have the potential to be groundwater dependent (Eamus and Froend, 2006): springs, wetlands, rivers and lakes. Phreatophytes and subterranean ecosystems were not included in the assessment because there is limited information on them in the Pacific Northwest. While springs are groundwater dependent regardless of location, the groundwater dependence of wetlands, rivers and lakes is usually a function of their hydrogeologic setting. So, for these three ecosystems, we first located them in Oregon and then assessed the likelihood that each is groundwater dependent in its given location. We also identified species and ecological communities of conservation concern that rely on habitat conditions maintained by groundwater.

[1] Detailed, step-by-step methods are provided in Appendices B and C. This section contains an overview of the methods used.

3.1.1 Mapping groundwater-dependent ecosystems and species

Table 1 lists the criteria used to delineate HUC6s in Oregon that support GDEs. An overview of the GIS methods used to determine whether each of these criteria was met is provided here; see Appendix B for detailed methods.

Table 1: Criteria used to identify HUC6s in Oregon in which GDEs occur

GDE	Criteria
Springs	Contains >1 spring/2236 ha (5525 acres)
Wetlands	Contains a fen OR Area of groundwater-dependent wetlands >1% of HUC6 area
Rivers	Contains groundwater-dependent river
Lakes	Contains a lake
Species and communities	Contains an obligately groundwater-dependent species or community

Springs

We mapped springs (Atlas Map 3) using water points data from the Pacific Northwest Hydrography Framework Clearinghouse (2005), the Geographic Names Information System data of USGS (1996) and the University of Idaho EPSCoR data for Alvord Desert springs (Idaho EPSCoR, 2006). Hot springs (Atlas Map 4) were identified with data from the Oregon Department of Geology and Mineral Industries (Niewendorp et al., 2007); however, these data were not available until later in the study so are only included in the analysis of altered thermal regimes, not in the mapping of groundwater-dependent biodiversity. Each HUC6 was identified as containing springs if it had more than one spring per 2236 ha (one per 5525 acres) (Table 1). These datasets likely do not include all the existing springs in Oregon, so the analysis may underestimate the distribution and number of HUC6s containing significant springs.

Wetlands

To date, neither a comprehensive map of wetlands nor a map of groundwater-dependent wetlands exists for Oregon. For our analysis, we first developed a map of wetland locations using the best available data and then analyzed each for potential groundwater dependence (Atlas Map 5).

We located wetlands in Oregon using seven data sources: palustrine wetlands in the National Wetland Inventory dataset of the U.S. Fish and Wildlife Service (USFWS, 2007); hydric soils in the SSURGO county soil surveys of U.S. Department of Agriculture, Natural Resources Conservation Service (2006a); wet areas in the Pacific Northwest Hydrography Framework Clearinghouse (2005); wetland communities identified in TNC ecoregional assessments (Vander Schaaf et al., 2004; Floberg et al., 2004); wetland ecosystems identified from LANDSAT imagery (TNC eds., 2007); wetland communities tracked by NatureServe and the Oregon Natural Heritage Information Center (TNC and NatureServe, 2007); and fens known to exist in protected natural areas. Fens are typically defined as groundwater-fed wetlands.

As a first step in identifying groundwater-dependent wetlands, we developed a map of fens in Oregon by selecting fens from some of the wetland ecosystem and community types provided in the above datasets and including these with known fens. All fens were included as groundwater-dependent wetlands with no further analysis. Each of the other wetlands was evaluated and identified as a GDE if it (i) contained soils of the order Histosols or subgroup histic according to the SSURGO county soil surveys, or (ii) was within 100 m of a mapped spring. HUC6s containing a fen or with more than 1% of their area covered by groundwater-dependent wetlands were identified as containing groundwater-dependent wetlands. The above datasets do not fully identify all of the wetlands in Oregon (data gaps shown on Atlas Map 6), so the analysis may underestimate the distribution and number of HUC6s containing groundwater-dependent wetlands.

Rivers

In certain hydrogeologic settings, groundwater can maintain the hydrologic regime of rivers and streams and their associated riparian ecosystems. In particular, the base flow component of the hydrograph is maintained by groundwater inflow. Our analysis of rivers differs from our assessment of other ecosystems because we evaluated whether a HUC6 has perennial rivers that depend on groundwater, rather than indentifying individual rivers or river reaches that are groundwater dependent and then summarizing the results at the HUC6 scale.

We used two sets of data to identify these HUC6s: the permeability of surficial geologic deposits and flow data from gaging stations. For the former, we assigned relative permeability ratings (i.e., high or low) to surficial geologic deposits mapped by Miller et al. (2002) (1:500,000; Atlas Map 7). For the latter, we identified watersheds in which stream gages indicated the mean monthly low flow was more than 15% of the mean monthly flow. This was determined by examining USGS gaging data (2007) on unregulated streams unaffected by glacial snowmelt from all active and discontinued gages with two or more complete years of data (Atlas Map 8).

We identified HUC6s likely to support groundwater-dependent rivers (Atlas Map 9) as those that contain perennial rivers and meet one of the following criteria:

1. are composed of ≥70% permeable geologic deposits
2. are composed of 50–69% permeable geologic deposits, if those deposits either intersect most of the perennial rivers or form large valleys through which the perennial rivers flow
3. contain the mainstem of, or a tributary to, a river with a USGS gaging station at which the flow data analysis indicated significant groundwater contributions (mean monthly low flow >15% mean monthly flow)

Lakes

Lakes were mapped as all water bodies larger than 20 acres (to distinguish them from wetlands; Cowardin et al., 1978) in the Pacific Northwest Hydrography Framework Clearinghouse water bodies dataset (2005). The consensus of experts was that, except for perched lakes, it is unlikely that many lakes in the Pacific Northwest are isolated from groundwater. Many other studies indicate that, even when groundwater inputs are a relatively small portion of water inflow, this discharge has profound ecological effects such as changing water quality conditions to support different plant communities and concentrations of fish (Lodge et al., 1989; Sebeysten and Schneider, 2004; Rosenberry et al., 2000; King County DNR, 2000). As a result, we assumed that all natural, perennial lakes depend on groundwater (Atlas Map 10) and included all HUC6s with groundwater-dependent lakes in our analysis (Table 1).

<u>Species and communities</u>
The groundwater dependence of nearly 1650 species and 64 plant communities of conservation concern was evaluated from the literature and online databases (e.g., NatureServe Explorer (2006) and Flora of North America (2006). All of the communities and 1230 of these species were mappable from GIS data (TNC and NatureServe, 2007). Obligately groundwater-dependent species were defined as those that relied on habitat maintained by groundwater for some aspect of their life cycle (Atlas Map 11). HUC6s with at least one obligately groundwater-dependent species were included in the assessment (Table 1).

We also identified facultatively groundwater-dependent species: these species rely on a river, lake or wetland that may be maintained by groundwater, depending on its location (Atlas Map 12). However, as the groundwater-dependent ecosystems that support these species were already included in this assessment, we did not include facultatively groundwater-dependent species in our maps or analyses.

3.1.2 GDE synthesis

After mapping the HUC6s that contain GDEs, we summarized the distribution of GDEs by identifying “GDE clusters” (shown in Atlas Map 13). These are HUC6s that contain at least a) two groundwater-dependent ecosystems or b) one groundwater-dependent ecosystem and one obligately groundwater-dependent species.

GDE cluster: A HUC6 in which two or more GDEs were identified according to the criteria established in Table 1.

3.2 Threats to groundwater-dependent ecosystems and species

The integrity of GDEs can be threatened by alteration of either the availability (quantity) or quality of groundwater. We first located these threats by mapping watersheds in Oregon in which conditions or activities occur that could reduce groundwater supply or degrade groundwater quality. Then, to locate GDEs that are at risk, we identified the subset of the watersheds containing these threats that are also GDE clusters.

3.2.1 Threats to groundwater quantity

The ecological integrity of GDEs can be threatened by a change in the amount or timing of groundwater discharging to an ecosystem. We evaluated this in two ways.

First, we located known declines in water table elevation. Second, we evaluated the risk of altered groundwater availability to GDEs under current and projected future conditions. Further, we established criteria for identifying HUC6s in which there is a risk to groundwater quantity (Table 2).

Table 2: Criteria for identifying HUC6s with a threat of altered groundwater quantity

Threat	Criteria
Known water table decline	Presence of a Groundwater Restricted Area
Current groundwater extraction	≥1 large well/ 2130 ha (5263 acres)
	≥1 small well/ 43.5 ha (108 acres)
Future groundwater extraction	Presence of rural residential zoning in counties expected to grow by more than 15%
	≥1 pending groundwater permit application

3.2.1.1 Known water table declines

We used Groundwater Restricted Areas to locate known water table declines in which GDEs may be at risk of reduced groundwater supply. These are areas, delineated by the Oregon Water Resources Department (OWRD, 2007a), where permitting of groundwater rights is currently either selectively or completely restricted. HUC6s that intersect these areas were considered at risk for alteration of groundwater availability to ecosystems and species (Table 2; Atlas Map 14).

3.2.1.2 Current threats

We used well density as an indicator of the current threat from groundwater extraction. Using the OWRD well log database (reports of all new well construction since the 1950s; OWRD, 2007b), we classified each well as either large (for irrigation, community or industrial use) or small (for domestic or livestock use). At-risk watersheds were defined as HUC6s with more than one large well per 2130 ha (5623 acres) or more than one small well per 43.5 ha (108 acres) (Table 2; Atlas Map 15 and 16, respectively). In addition, to gain an understanding of the patterns and trends in domestic well use over time, we mapped the construction of new domestic wells by decade since the 1950s (Atlas Map 17).

3.2.1.3 Future threats

Watersheds with future threats from increased groundwater extraction by large wells were identified as those with any pending groundwater rights applications, obtained from OWRD (2008) as of January 15, 2008 (Table 2; Atlas Map 18). To identify the areas most at risk from future development of small domestic wells, we identified watersheds with expected high population growth where domestic water was least likely to be supplied by municipal water systems and, therefore, most likely to be supplied by individual or community domestic wells (Table 2; Atlas Map 19). These are watersheds in counties with expected population growth rates greater than 15% over the next 15 years (Oregon Office of Economic Analysis, 2004) that also have rural residential zoning outside of the urban growth boundary (Oregon Department of Land Conservation and Development, 2007).

3.2.2 Threats to groundwater quality

GDEs also can be threatened by groundwater contamination and by alterations to groundwater chemistry or temperature. In this analysis, we assessed the threats of groundwater contamination by nutrients (both nitrate and phosphorus), pesticides and other toxic contaminants in HUC6s across Oregon. We did this by locating HUC6s with known groundwater contamination or with conditions (i.e., specific land use activities or physical characteristics) that increase the likelihood that GDEs may be threatened by contaminated groundwater.

3.2.2.1 Known groundwater contamination

We located known groundwater contamination using two sets of data. Contamination by nutrients was identified by Groundwater Management Areas, and contamination by nutrients, pesticides or other toxic contaminants was identified from groundwater chemical analysis data compiled in two databases: the Oregon Department of Environmental Quality Laboratory Analytical Storage and Retrieval (LASAR) (ODEQ, 2007c) and the USGS National Water Information System (NWIS) (USGS, 2007).

Beginning with nutrients, we considered HUC6s that occur in Groundwater Management Areas (Atlas Map 20) to be at risk for degraded groundwater quality (Table 3). The Oregon Department of Environmental Quality (ODEQ, 2003) has designated Groundwater Management Areas as areas within the state where groundwater is known to exceed the drinking water standard for nitrate (10 mg/l). In addition, a restricted set of groundwater samples in the two databases (LASAR and NWIS) was used to identify watersheds with nutrient-contaminated groundwater (Atlas Map 21). We used samples analyzed for a small suite of parameters (see Appendices B and C) collected after January 1, 1996, that exceeded either drinking water standards (10 mg/L nitrate-N and 1 mg/L nitrite-N; U.S. Environmental Protection Agency (US EPA), 2003) or the recommended total phosphorus concentrations for lakes and streams in the Western Forested Ecoregion (0.01 mg/L; US EPA, 2002). All HUC6s meeting these criteria (Table 3) were identified as having nutrient-contaminated groundwater.

For pesticides and other toxic contaminants, we identified all watersheds in which either the LASAR or NWIS database indicated that groundwater samples contained a detectable amount of a pesticide, pesticide by-product or other non-natural chemical (see Appendices B and C; BRIDGE, 2007). Any HUC6 meeting this criteria was also identified as having contaminated groundwater (Atlas Maps 22 and 23).

Table 3: Criteria for identifying HUC6s with threats of altered groundwater quality due to known groundwater contamination

Threat	Criteria
Known groundwater contamination	Presence of a Groundwater Management Area
	Presence of groundwater sample with N concentrations in excess of 10 mg/L nitrate-N and 1 mg/L nitrite-N
	Presence of groundwater sample with P concentrations in excess of 0.01 mg/L total phosphorus
	Presence of groundwater sample with detectable concentrations of pesticides or pesticide degradates
	Presence of groundwater sample with detectable concentrations of other toxic chemicals

3.2.2.2 Threat of groundwater contamination — Nutrients

Threats of nitrate contamination of groundwater were associated with agricultural and rural residential land uses and underground injection control sites. Groundwater contamination by nitrates in agricultural areas is found where there are certain kinds of livestock operations and where fertilizers are applied either on irrigated fields underlain by permeable geologic deposits or in zones of high recharge. Increased risk of groundwater contamination by nitrate in rural residential areas is associated with high densities of septic systems. We used five indicators to locate these threatened areas; each of these indicators is mapped individually in Atlas Maps 24–28.

1. Areas at high or moderate risk of shallow groundwater contamination by nitrates, as predicted by a nationwide logistics regression model (Nolan et al., 2002a and 2002b).
2. High nitrogen fertilizer use in areas susceptible to groundwater contamination. We defined high N fertilizer use as application rates greater than 1,401 kg/km^2 (4 tons/ mile^2) (Battaglin and Goolsby, 1994) and susceptible areas as either agricultural land use (USGS, 2003) or irrigated areas (place of use data; OWRD, 2005) on permeable geologic deposits.
3. High densities of septic systems, defined as more than 2.5 systems/ha (>1 system per acre; ODEQ and Oregon Health Division, 2000). As a surrogate for density of septic systems, we used the number of households outside the urban growth boundaries (Oregon Department of Transportation et al., 1995), determined from population density (U.S. Census Bureau, 2000) and average household size (U.S. Census Bureau, 2004).
4. Presence of at least one concentrated animal feeding operation (CAFO; Oregon Department of Agriculture, 2007).
5. Presence of Class V Underground Injection Control sites associated with septic system waste (ODEQ, 2007d).

Threats of phosphorus contamination of groundwater are associated with agricultural and urban land use. We identified the agricultural component of this threat in HUC6s with agricultural land use (USGS, 2003) in counties with high amounts of phosphorus fertilizer use (Battaglin and Goolsby 1994). We defined high P fertilizer use as application rates greater than 420 kg/km^2 (1.2 $tons/mile^2$; Atlas Map 29). Urban land use (developed – high and medium intensity; USGS, 2003; Atlas Map 30) within a watershed was also used as an indicator of the threat of phosphorus contamination, and the results highlight the same areas identified in the analysis of potential groundwater contamination by urban pesticide use (in Section 3.2.2.3).

Tables 4 and 5 summarize the criteria for identifying HUC6s containing threats of groundwater contamination by nitrates and phosphorus.

Table 4: Criteria for identifying HUC6s with threats of altered groundwater quality due to potential contamination by nitrates

Threat	**Criteria**
Agricultural use of N fertilizer	Risk level ≥ 3 in USGS nationwide model of risk of nitrate contamination in shallow groundwater
	Presence of agricultural land use or irrigated land on permeable geologic deposits in counties with >1,401 kg/km^2 (4 $tons/mile^2$) of N fertilizer use
Septic systems	Presence of a census block with ≥ 6.15 people/ha (2.46 people/acre)
Concentrated animal feeding operations	≥1 Concentrated animal feeding operation
Underground Injection Control wells	Presence of Class V UICs posing nutrient contamination risk

Table 5: Criteria for identifying HUC6s with threats of altered groundwater quality due to potential contamination by phosphorus

Threat	**Criteria**
Agricultural use of P fertilizer	Presence of agricultural land use in counties with >420 kg/km^2 (1.2 $tons/mile^2$) of P fertilizer use
Urban use of fertilizers	Presence of urban land use

3.2.2.3 Threat of groundwater contamination — Pesticides

We identified areas with threats of groundwater contamination by pesticides from both urban and agricultural land uses. Pesticide use in urban areas is high and often more intense than in agricultural areas (Gilliom et al., 2006). However, since the Oregon Department of Agriculture only recently began to record pesticide application in urban areas, actual use data are not yet available. Instead we used the presence of urban land use (developed – high and medium intensity; USGS, 2003; Atlas Map 30) within a watershed as an indicator for the threat of groundwater contamination by pesticides (Table 6).

In agricultural areas, the threat posed by a pesticide to GDEs can be described as a function of three factors: (1) the chemical characteristics of the pesticide, (2) the toxicity of the pesticide to aquatic life and (3) the physical characteristics of the location where the pesticide is used. We evaluated these factors for the 43 pesticides for which locations of use are mapped in Oregon (Nakagaki and Wolock, 2005).

Pesticides are more likely to be mobile, and therefore pose a greater risk to groundwater, if they have low volatility, high solubility and a long half-life (Hamilton et al., 2004; Gilliom et al., 2006). Of the 43 pesticides we evaluated, 10 were mobile, posing a risk to groundwater: atrazine, bentazon, carbofuran, ethoprop, methomyl, metolachlor, metribuzin, nicosulfuron, simazine and terbacil (Vogue et al., 1994; Kegley et al., 2008; USDA NRCS, 2006b). All of these have been found to be toxic to aquatic life (Kegley et al., 2008; Pesticide Management Education Program, various dates).

The likelihood of mobile pesticides reaching groundwater depends on the soil characteristics in the location of use. Soil that is likely to retain or absorb a pesticide is said to have a low soil leaching potential (SLP), whereas soil that does not retain pesticide particles easily has a high SLP. We used the NRCS Windows Pesticide Screening Tool (USDA NRCS, 2005) to predict the places where SLP values indicated a high risk of pesticide leaching and therefore groundwater contamination. All areas where any of the 10 mobile pesticides were used on soils with intermediate or high SLP were mapped as high-risk areas for groundwater contamination (Goss and Wauchope, 1990).

Each HUC6 was evaluated for the number of these mobile pesticides used in high-risk areas (Atlas Map 31). We identified HUC6s most at risk for groundwater contamination by pesticides (Table 6) as those in which two or more mobile agricultural pesticides were used in high-risk areas or those with urban land use.

Table 6: Criteria for identifying HUC6s with threats of altered groundwater quality due to potential contamination by pesticides

Threat	Criteria
Agricultural pesticide use	Presence of ≥2 high-risk pesticides in places where they are likely to contaminate groundwater
Urban pesticide use	Presence of urban land use

3.2.2.4 Threat of groundwater contamination — Other toxic contaminants

The threat of groundwater contamination from industrial and manufacturing chemicals is greater near the industries that use the toxic chemicals and near storage tanks and spills. We considered watersheds with specific industrial land use activities located within 0.8 km (0.5 miles) of a GDE (Hart Crowser et al., 2007) to be at risk for groundwater contamination by industrial or petro- chemicals. Indicators of these land uses were based on state managed datasets and the USGS GNIS dataset (Table 7).

Table 7: Land uses associated with the threat of groundwater contamination by other toxic contaminants when located within 0.8 km (0.5 miles) of a GDE

Land Use	Type of Contamination	Data Source	Atlas Map
Leaking underground storage tanks	Petrochemicals	ODEQ Facility Profiler (ODEQ, 2007a); Program ID= 'LUST'; includes unregulated tanks with incomplete clean up	32
Underground Injection Control sites for non-septic waste	Petrochemicals, industrial chemicals, pesticides	ODEQ (Barbara Priest, personal communication); Class V wells not clearly used for gray, waste or drinking water (details of use in Appendix C, Table C-22)	33
Hazardous waste spills	Petrochemicals, industrial chemicals, pesticides	ODEQ Facility Profiler (ODEQ, 2007a); Program ID= 'ECSI'; includes all except those requiring no further clean up	34
Gas stations	Petrochemicals, industrial chemicals	ODEQ Downloadable Tank Facilities Lists (ODEQ, 2007e); Program ID= 'UST' includes those with certification number to receive fuel (M. Scheel, personal communication)	35
Dry cleaners	PERC (trichloroethylene)	ODEQ, 2007b; includes all except those using PERC alternative (Ed Patnode, personal communication)	35
Mines	Heavy metals	Permitted Mines database (ODGAMI, 2007); (V. Belzer, personal communication)	35
Airports and military bases	Industrial chemicals, explosives, petrochemicals	USGS GNIS (1996)	35

The criteria used to assess HUC6s threatened by groundwater contamination by other toxic contaminants are listed in Table 8.

Table 8: Criteria for identifying HUC6s with threat of altered groundwater quality due to contamination by other toxic contaminants

Threat	Criteria
Leaking underground storage tanks	Presence of leaking underground storage tanks that have not undergone cleanup and are located within 0.8 km (0.5 miles) of a GDE
Underground Injection Control wells	Presence of Class V UICs associated with industrial contaminants and located within 0.8 km (0.5 miles) of a GDE
Hazardous waste spills	Presence of environmental cleanup sites needing current or future action and located within 0.8 km (0.5 miles) of a GDE
Spills and leaching from specific land uses	Presence of activities that increase likelihood of spills and are located within 0.8 km (0.5 miles) of a GDE: • gas stations • dry cleaners • active mines • military bases • airports

3.2.2.5 Threat of altered thermal regime — Hot springs

Geothermal development has the potential to affect hot springs by reducing the volume of water discharging to the ecosystem; this can not only alter the hydrologic regime but potentially alter the thermal regime of these ecosystems. Geothermal development is a broad term, encompassing everything from the use of shallow 40°–70°F water to generate heat for heat pumps and heat exchangers to the use of much hotter and usually deeper water (>200°F) for electricity generation (US GAO, 2006). In Oregon, the Oregon Department of Geology and Mineral Industries has mapped areas likely to support a variety of geothermal development (Niewendorp et al., 2007), and we used these data to locate potential threats of altered thermal regime to hot springs. For those HUC6s with hot springs, the thermal regime is threatened if the HUC6 contains either: (1) known geothermal resources (i.e., sources of thermal water that can be used in geothermal applications), or (2) potential geothermal resources (areas that, because of their geologic similarity to areas with known geothermal resources, are expected to contain thermal water).

We identified HUC6s with hot springs (Niewendorp et al., 2007) most at risk for alteration of the thermal regime (Table 9; Atlas Maps 36 and 37).

Table 9: Criteria for identifying HUC6s with hot springs and the threat of altered thermal regime due to the presence of geothermal resources

Threat	Criteria
Geothermal development	Presence of known geothermal resource areas
	Presence of potential geothermal resources

3.2.3 Threat synthesis

After mapping HUC6s facing threats of altered groundwater quantity or quality or altered thermal regime, we overlaid this information with the HUC6s containing GDE clusters. Our summary of at-risk GDEs focuses on the number and percentage of GDE clusters in which the threat criteria were met, as described in the tables of Section 3.2. To assess geographic patterns and identify where in Oregon particular threats are most prevalent, we summarize the findings in each of the 14 analysis regions.

4.0 Results:

4.1 Overview of assessment of groundwater-dependent ecosystems and species

The first part of the analysis consisted of identifying and mapping the types and locations of GDEs in Oregon. The results are first summarized for the entire state, and limitations of the data and findings are provided. This is followed by a more detailed description of the types and abundances of GDEs in each analysis region of the state. Finally, GDE clusters are identified and mapped, which will serve as the basis for the threats assessment portion of the results.

4.1.1 Occurrence of GDEs across the state

Springs

High densities of mapped springs (>1 spring/2236 ha; Table 1) occur in 1472 (47%) of the HUC6s in Oregon. These HUC6s are distributed throughout eastern Oregon, in the Rogue region and in the higher elevation portions of the Deschutes region (Figure 1A).

Previous work has shown that the High Cascades area (younger volcanic deposits immediately west of the Cascades crest) is populated with numerous springs (Jefferson et al., 2006); however, as many of these are not mapped in any of the data layers used in this assessment, HUC6s containing these springs may be missing from Figure 1A.

Wetlands

Groundwater-dependent wetlands are identified in 477 (15%) of the HUC6s in Oregon. These HUC6s are concentrated along the coast; in the lower elevation portions of both the Klamath and Oregon Basin and Range regions; and in the Grande Ronde Valley of Northeast Oregon (Figure 1B).

In general, wetland mapping in Oregon is incomplete, particularly with regard to fens. Therefore, our assessment does not include many of the HUC6s in which local experts know fens occur. Overall, this assessment provides an incomplete picture of the distribution of wetlands, both groundwater dependent and otherwise, in Oregon.

Rivers

The analysis showed that the hydrologic regime of perennial rivers is supported by groundwater in 1252 (40%) of the HUC6s in Oregon. In western Oregon, these HUC6s are concentrated in the Willamette Valley and in the High Cascades, near the crest of the mountains on both the east and west side. Few HUC6s with groundwater-dependent rivers are located on the coast (Figure 1C). HUC6s with groundwater-dependent rivers occur throughout eastern Oregon (Figure 1C).

In our assessment we used two approaches to identify watersheds with groundwater-dependent rivers. The first approach, an examination of the relative permeability of geologic deposits from a 1:500,000 geology map of Oregon, was coarse but covered the whole state. The second approach, an examination of flow data, was much more accurate but could only be conducted in the few locations that had gaged streams. To verify the coarse-scale analysis, we compared the results from the two methods and found that 81% of the rivers identified by gage data as groundwater dependent were correctly predicted by the geologic permeability analysis. Since the gage sites were well distributed across the state, we believe that our predictions based solely on geologic characteristics are reasonable.

Some mainstem rivers, such as the Deschutes and Willamette, were not identified as groundwater dependent since the underlying geology of their HUC6s does not meet the permeability requirements of our analysis. Additionally, many of these larger rivers are regulated and so were excluded from our stream gage analysis. However, because the tributaries to these rivers often receive significant groundwater input, these large rivers are also groundwater dependent, even though they are not identified as such in our results.

Lakes

Groundwater-dependent lakes are identified in 230 (7%) of the HUC6s in Oregon. Most of these lakes occur in the coast regions, the Willamette Valley, the High Cascades, and the Klamath and the Oregon Basin and Range regions (Figure 1D). Many of the lakes along the coast are interdunal lakes, which are known to receive groundwater discharge (Nielsen and Cummings, 2005). Lakes in the more arid parts of the state, such as Lake Abert and Summer Lake, rely on groundwater for both water supply and water chemistry characteristics (Phillips and Van Den Burgh, 1971).

Our assessment of groundwater-dependent lakes was limited in two ways. First, digital data of lake locations in Oregon are incomplete, so our assessment does not include all lakes in Oregon. Second, it is difficult to identify groundwater-dependent lakes across a large region. The consensus of experts was that most lakes in Oregon, unless perched, are connected to groundwater, both recharging groundwater and receiving groundwater discharge. In response to these comments, we included all permanent, non-regulated lakes as groundwater dependent.

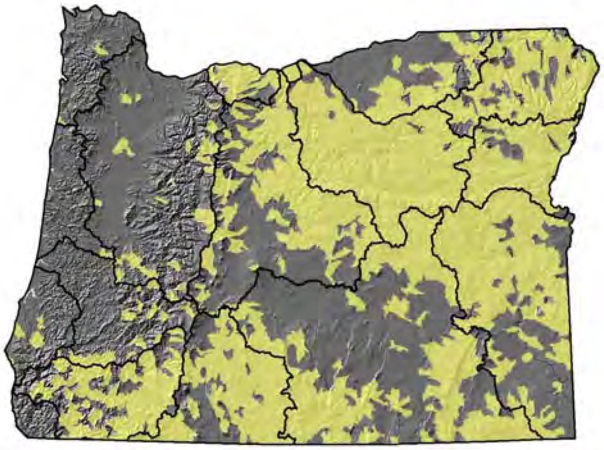
Species

Of the nearly 1650 species of conservation concern evaluated for groundwater dependence, 9% are obligately groundwater dependent (141 species) and 31% are facultatively groundwater dependent (511 species). The taxonomic groups in which groundwater dependence is most important are aquatic mollusks and other invertebrates (Table 10). Of the invertebrates, 76% of the dragonfly/ stonefly/ mayfly group and 42% of caddisflies are obligately groundwater dependent. Additionally, 9% of non-vascular plants, including 25 of the liverworts, are obligately groundwater dependent.

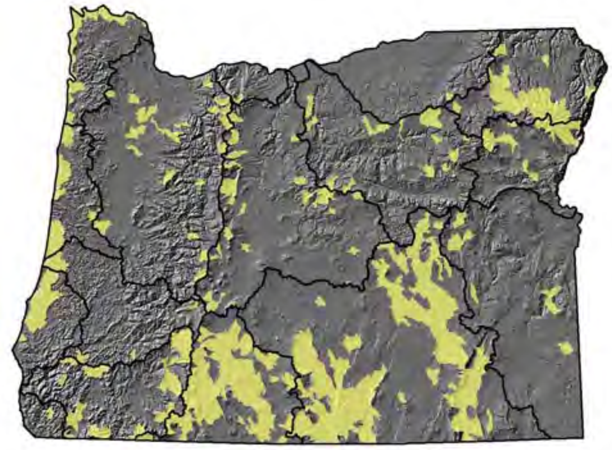
Table 10: Species of conservation concern in Oregon and groundwater dependence by taxonomic group. Includes all species assessed, not just those with mappable locations.

Taxonomic Group	Groundwater-Dependent Species		No Information Available (#)	Species Total (#)
	Obligate (%)	Facultative (%)		
Vascular plants	0.1	18	88	756
Non-vascular plants	9	39	8	261
Fish	6	92	1	79
Amphibians and reptiles	0	43	0	107
Aquatic mollusks	68	32	0	110
Birds	1	40	0	144
Mammals	0	20	0	61
Other invertebrates	27	40	1	130

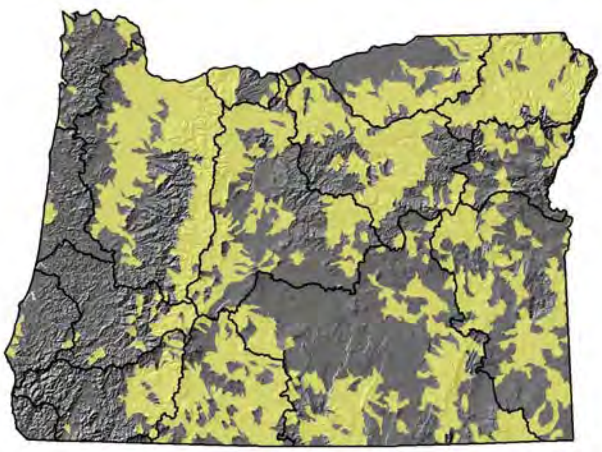
We were able to map the locations of 95 of the obligately groundwater-dependent species and 289 of the facultatively groundwater-dependent species using Oregon Natural Heritage data. Obligately groundwater-dependent species are identified in 312 (10%) of the HUC6s in Oregon. Even though the distribution of records is uneven across the state (Figure 1E), at least one obligately groundwater-dependent species occurs in each region.



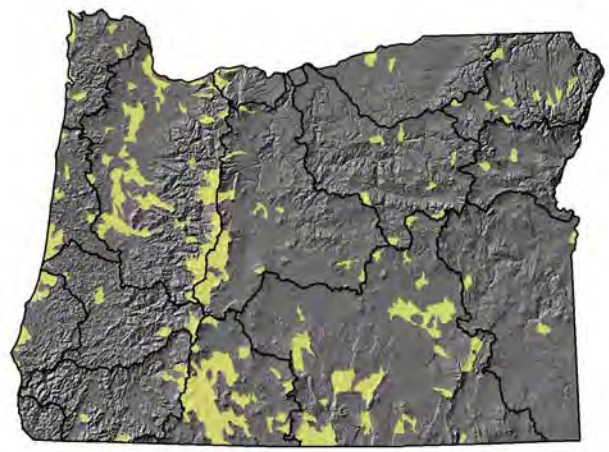
A. Springs



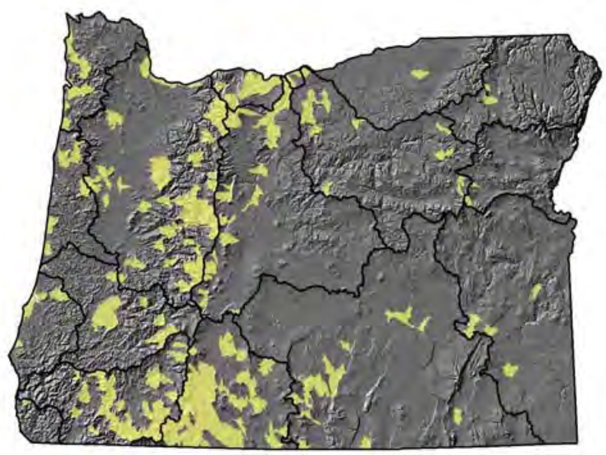
B. Groundwater-Dependent Wetlands



C. Groundwater-Dependent Rivers



D. Groundwater-Dependent Lakes



E. Obligately Groundwater-Dependent Species

Figure 1: HUC6s that meet the criteria (Table 1) for containing groundwater-dependent ecosystems and species (yellow).

4.1.2 Abundance of GDEs in each region

Below we summarize the abundance and distribution of groundwater-dependent ecosystems and species by analysis region, referring to Figures 1 through 3 and Tables 11 and 12. For each region we describe the number of different GDEs and the number of HUC6s in which springs and groundwater-dependent wetlands and lakes and obligately groundwater-dependent species occur. Our summary for groundwater-dependent rivers describes the number of HUC6s *with perennial rivers* in which the analysis shows these rivers are groundwater dependent. Additionally, the obligately groundwater-dependent species of each region are listed in a series of tables.

Table 11: Number and percentage of HUC6s in each region that contain specific GDEs and GDE clusters.

[1] Wetland mapping data are poor in some regions (*; see Atlas Map 6).

[2] GDE clusters are HUC6s containing two or more GDEs.

Region	Total # HUC6s in Region	Springs		GW-Dep. Wetlands[1]		GW-Dep. Rivers		GW-Dep. Lakes		Obligately GW-Dep. Species		GDE Clusters[2]	
		#	%	#	%	#	%	#	%	#	%	#	%
Columbia Drainages	185	82	*44*	2	*1*	90	*69*	5	*3*	20	*11*	70	*38*
Deschutes	339	175	*52*	31*	*9**	147	*43*	28	*8*	33	*10*	111	*33*
John Day	257	246	*96*	19*	*7**	136	*53*	7	*3*	17	*7*	148	*58*
Klamath	156	109	*70*	68	*44*	90	*58*	34	*22*	53	*34*	117	*75*
Malheur/ Owyhee	302	192	*64*	10*	*3**	125	*41*	3	*1*	5	*2*	98	*32*
Middle Coast	90	3	*3*	23	*26*	5	*6*	9	*10*	11	*12*	11	*12*
North Coast	104	3	*3*	24	*23*	15	*14*	7	*7*	14	*13*	14	*13*
Northeast OR	205	152	*74*	40	*20*	159	*78*	10	*5*	2	*1*	137	*67*
OR Basin & Range	497	228	*46*	155	*31*	160	*32*	44	*9*	17	*3*	209	*42*
Powder/Burnt	129	113	*88*	20	*16*	38	*29*	2	*2*	2	*2*	44	*34*
Rogue	172	106	*62*	35	*20*	40	*23*	5	*3*	41	*24*	70	*41*
South Coast	99	7	*7*	15	*15*	6	*6*	10	*10*	7	*7*	11	*11*
Umpqua	166	23	*14*	8	*5*	29	*17*	7	*4*	16	*10*	18	*11*
Willamette	410	33	*8*	27	*7*	212	*52*	59	*14*	74	*18*	101	*25*
STATEWIDE	**3111**	**1472**	***47***	**477**	***15***	**1252**	***40***	**230**	***7***	**312**	***10***	**1159**	***37***

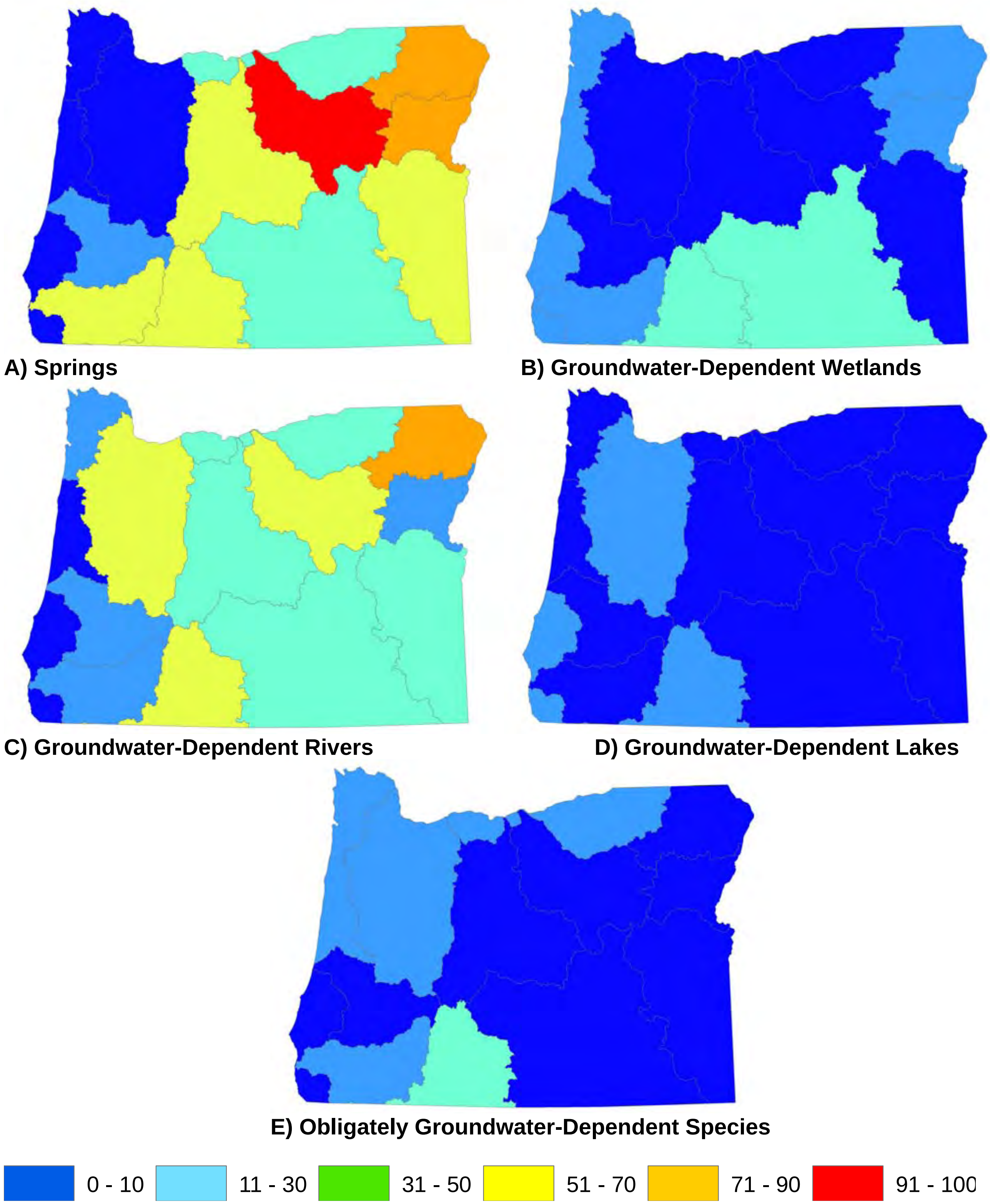


Figure 2: Percentage of HUC6s in each analysis region that contain (A) springs, (B) groundwater-dependent wetlands, (C) groundwater-dependent rivers, (D) groundwater-dependent lakes and (E) obligately groundwater-dependent species.

Table 12: Average number of springs per HUC6 in analysis region

Region	Average Number Springs per HUC6
Columbia Drainages	6.5
Deschutes	10.3
John Day	23.0
Klamath	12.5
Malheur/Owyhee	14.1
Middle Coast	0.4
North Coast	0.2
Northeast OR	8.8
OR Basin and Range	13.9
Powder/Burnt	18.4
Rogue	17.0
South Coast	0.9
Umpqua	2.1
Willamette	1.0

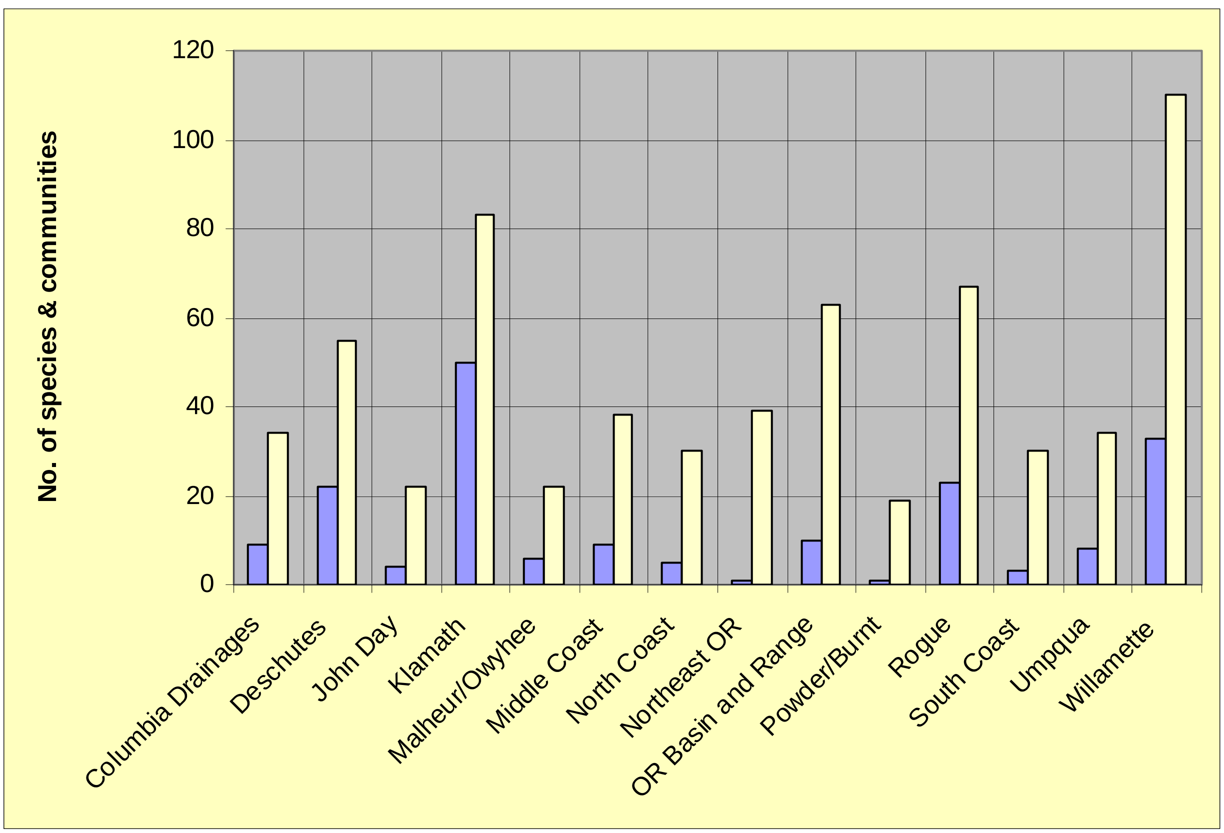


Figure 3: Number of obligately (blue) and facultatively (white) groundwater-dependent species and communities of conservation concern identified in each analysis region. Note that the facultatively groundwater-dependent species are not included in our analysis.

a. Coast (North, Middle and South)

Mapped springs are relatively uncommon in the Coast regions (Table 11 and Figure 2A), averaging less than one spring per HUC6 (Table 12). A total of 62 (21%) of the Coast regions HUC6s contain mapped groundwater-dependent wetlands. Most of these wetlands are located at the junction of the coastal mountains and the narrow coastal plain, and local studies indicate these are largely interdunal wetlands that receive significant inputs of groundwater (Cole and ODEQ, 2004; Brown and Newcomb, 1963; Nielsen and Cummings, 2005). In contrast, both groundwater-dependent rivers and lakes are much less prevalent, occurring in fewer than 30 (9%) HUC6s along the coast (Table 11 and Figure 2, C and D).

A total of 10 obligately groundwater-dependent species of conservation concern occur in 32 (11%) of the HUC6s throughout the Coast regions. These species include six species of non-vascular plants and one species each of vascular plant, caddisfly, mollusk and dragonfly (Table 13). An additional 64 species of conservation concern are facultatively groundwater dependent but within the Coast regions rely on habitats that are maintained by groundwater (Figure 3).

Table 13: Obligately groundwater-dependent species of conservation concern in the Oregon coast regions

Scientific Name	Common Name	Taxonomic Group
Calypogeia sphagnicola	A Liverwort	non-vascular plants
Cephaloziella spinigera		non-vascular plants
Filipendula occidentalis	Queen-of-the-forest	vascular plants
Limbella fryei	A Moss	non-vascular plants
Lophozia laxa	A Liverwort	non-vascular plants
Pohlia sphagnicola	A Moss	non-vascular plants
Polytrichum strictum	A Haircap Moss	non-vascular plants
Pomatiopsis californica	Pacific Walker	mollusks
Rhyacophila haddocki	Haddock's Rhyacophilan Caddisfly	caddisflies
Tanypteryx hageni	Black Petaltail	dragonflies/stoneflies/mayflies

b. Columbia Drainages

Springs are an important GDE in the Columbia Drainages region. On average there are 6.5 mapped springs per HUC6 in this region, and these springs are distributed across nearly half of the HUC6s (Table 12 and Figure 2A). Most springs are located on the slopes of Mt. Hood and the mountains south of Hermiston. In contrast, there are few groundwater-dependent wetlands in this region, and only two HUC6s were identified as containing groundwater-dependent wetlands. The analysis showed that 90 (69%) of HUC6s have groundwater-dependent rivers in the Columbia Drainages region. Few HUC6s contain groundwater-dependent lakes in this region (Table 11 and Figure 2D).

A total of seven species and two communities of conservation concern are obligately groundwater dependent in the Columbia Drainages region (Table 14). This includes three species each of caddisfly and mollusk and one species of vascular plant. These species are concentrated in the vicinity of Mt. Hood (Figure 1E). An additional 34 species of conservation concern are facultatively groundwater dependent but within the Columbia Drainages region rely on habitats that are maintained by groundwater.

Table 14: Obligately groundwater-dependent species of conservation concern in the Columbia Drainages

Scientific Name	Common Name	Taxonomic Group
Allomyia scotti	Scott's Caddisfly	caddisfly
Amnicola sp. 4	Columbia Duskysnail	mollusk
Eobrachycentrus gelidae	Mt. Hood Primitive Brachycentrid Caddisfly	caddisfly
Farula jewetti	Mt. Hood Farulan Caddisfly	caddisfly
Fluminicola fuscus	Ashy Pebblesnail	mollusk
Mimulus jungermannioides	Hepatic Monkeyflower	vascular plant
Pristinicola hemphilli	Pristine Pyrg	mollusk

c. Deschutes

On average, more than 10 springs are mapped in every HUC6 of the Deschutes region (Table 12). Springs occur in more than half of the HUC6s in this region (Table 11 and Figure 2A) and are distributed across both the flanks of the Cascades and the mountains in the northeast portion of the region (Figure 1A). Despite the low permeability of the underlying geology in the Ochocos, this area has a noticeably high concentration of springs (Figure 1A). A total of 31 (9%) of the HUC6s are likely to contain groundwater-dependent wetlands. Due to the absence of wetland data for the eastern Ochoco Mountains and the Upper Crooked River (Atlas Map 6), it is likely that the distribution of groundwater-dependent wetlands is underrepresented in our findings. Groundwater-dependent rivers are common in the Deschutes region. Our analysis identified groundwater-dependent rivers in 147, or nearly half, of HUC6s (Table 11 and Figure 2C). These HUC6s with groundwater-dependent rivers are generally located on the eastern slope of the Cascades and along the Deschutes and Crooked river valleys (Figure 1C). We identified groundwater-dependent lakes in 28 (8%) of the HUC6s in the Deschutes region.

A total of 22 species and communities of conservation concern are obligately groundwater dependent in the Deschutes region (Table 15). This includes six species of mollusk, five species of non-vascular plant, four species of caddisfly and one species each of vascular plant and dragonfly/ mayfly/ stonefly. An additional 55 species and communities are facultatively groundwater dependent but within the Deschutes region rely on habitats that are maintained by groundwater.

Table 15: Obligately groundwater-dependent species of conservation concern in the Deschutes region

Scientific Name	Common Name	Taxonomic Group
Allomyia scotti	Scott's Caddisfly	caddisfly
Amnicola sp. 4	Columbia Duskysnail	mollusk
Deroceras hesperium	Evening Fieldslug	mollusk
Eobrachycentrus gelidae	Mt Hood Primitive Brachycentrid Caddisfly	caddisfly
Farula jewetti	Mt. Hood Farulan Caddisfly	caddisfly
Fluminicola fuscus	Ashy Pebblesnail	mollusk
Helodium blandowii		non-vascular plant
Helodium blandowii var. blandowii		non-vascular plant
Jamesoniella autumnalis var. heterostipa		non-vascular plant
Juga bulbosa	Bulb Juga	mollusk
Mimulus jungermannioides	Hepatic Monkeyflower	vascular plant
Pristiloma arcticum crateris	Crater Lake Tightcoil	mollusk
Pristinicola hemphilli	Pristine Pyrg	mollusk
Rhyacophila unipunctata	One-spot Rhyacophilan Caddisfly	caddisfly
Tanypteryx hageni	Black Petaltail	dragonfly/stonefly/mayfly
Tomentypnum nitens		non-vascular plant
Tritomaria exsectiformis		non-vascular plant

d. John Day

Springs occur throughout the John Day region (Atlas Map 3). Almost every HUC6 in this region (246 or 96%) contains a spring. Not only are springs well distributed throughout the region, but the concentrations are the highest in Oregon, with an average of 23 springs per HUC6. Our analysis found groundwater-dependent wetlands to be fairly uncommon, but it is important to note that both primary data layers used to map wetlands (National Wetlands Inventory and county soil surveys) are unavailable for about a third of the region (Atlas Map 6). Groundwater-dependent rivers were found to be more common, occurring in 136 HUC6s or more than half of the HUC6s with perennial rivers (Table 11). This finding is supported by local stream flow analysis within the basin, which indicates significant base flow due to groundwater inputs (Richards et al., 1986). The HUC6s with geologic conditions that support groundwater-dependent rivers are located in a north/south band through the middle of the region and at the lower end of the basin (Figure 1C). Few HUC6s containing groundwater-dependent lakes were identified in the John Day region (Table 11 and Figure 2D).

A total of four species of conservation concern are obligately groundwater dependent in the John Day region (Table 16). An additional 22 species and communities of conservation concern are facultatively groundwater dependent but within this region rely on habitats that are maintained by groundwater.

Table 16: Obligately groundwater-dependent species of conservation concern in the John Day region

Scientific Name	Common Name	Taxonomic Group
Crumia latifolia		non-vascular plant
Helodium blandowii		non-vascular plant
Mimulus jungermannioides	Hepatic Monkeyflower	vascular plant
Pristinicola hemphilli	Pristine Pyrg	mollusk

e. Klamath

Springs are widely distributed within the Klamath region, meeting our density criteria in 109 (70%) of the HUC6s. In addition, the concentration of springs across the region is high, with an average of 12.5 springs per HUC6. Springs are known to play an important role in providing habitat for groundwater-dependent species and in the maintenance of base flow in this region (Conaway, 1999; Gannett et al., 2007; Frest and Johannes, 1999). We identified the Klamath Basin as the region with the second largest number of HUC6s with groundwater-dependent wetlands, following the Oregon Basin and Range. A total of 68 (44%) of the HUC6s have groundwater-dependent wetlands. This finding is supported by local studies describing a fen at Sycan Marsh (Christy and Cornelius, 1980) and 86% of the inflow to Klamath Marsh coming from groundwater (Melady, 2002). Our analysis showed that groundwater-dependent rivers in the Klamath region are common because they occur in 90 HUC6s, or almost 70% of HUC6s with perennial rivers. Groundwater-dependent rivers are well distributed throughout the region (Figure 1C), a finding that has been corroborated by a basin-wide synthesis of hydrogeologic conditions (Gannett et al., 2007). Groundwater-dependent lakes were identified in 34 (22%) of the HUC6s in this region; this is the region with highest proportion of HUC6s containing groundwater-dependent lakes in Oregon (Table 11).

A total of 50 species and communities of conservation concern are obligately groundwater dependent in the Klamath region (Table 17). This includes 36 species of mollusk, five species of non-vascular plant and two species of caddisfly. The importance of mollusk species in this list is largely due to the intensive survey conducted in the region (Frest and Johannes, 1999). Obligately groundwater-dependent species are well distributed throughout the region, occurring in more than 30% of the HUC6s (Table 11 and Figure 2E). An additional 83 species and communities of conservation concern are facultatively groundwater dependent but within the Klamath region rely on habitats that are maintained by groundwater.

Table 17: Obligately groundwater-dependent species of conservation concern in the Klamath region

Scientific Name	Common Name	Taxonomic Group
Amnicola sp. 8	Nodose Duskysnail	mollusk
Calliergon trifarium	A Moss	non-vascular plant
Deroceras hesperium	Evening Fieldslug	mollusk
Farula davisi	Green Springs Mountain Farulan Caddisfly	caddisfly
Fluminicola sp. 11	Nerite Pebblesnail	mollusk
Fluminicola sp. 12	Odessa Pebblesnail	mollusk
Fluminicola sp. 13	Ouxy Spring Pebblesnail	mollusk
Fluminicola sp. 14	Tall Pebblesnail	mollusk
Fluminicola sp. 15	Tiger Lily Pebblesnail	mollusk
Fluminicola sp. 16	Toothed Pebblesnail	mollusk
Fluminicola sp. 18	Wood River Pebblesnail	mollusk
Fluminicola sp. 19	Keene Creek Pebblesnail	mollusk
Fluminicola sp. 2	Casebeer Pebblesnail	mollusk
Fluminicola sp. 20	Crooked Creek Pebblesnail	mollusk
Fluminicola sp. 22	Topaz Pebblesnail	mollusk
Fluminicola sp. 24	Contrary Pebblesnail	mollusk
Fluminicola sp. 26	Fredenburg Pebblesnail	mollusk
Fluminicola sp. 3	Diminuitive Pebblesnail	mollusk
Fluminicola sp. 36	Clarke Pebblesnail	mollusk
Fluminicola sp. 38	Little Butte Pebblesnail	mollusk
Fluminicola sp. 39	Chinquapin Pebblesnail	mollusk
Fluminicola sp. 4	Fall Creek Pebblesnail	mollusk
Fluminicola sp. 5	Klamath Pebblesnail	mollusk
Fluminicola sp. 6	Klamath Rim Pebblesnail	mollusk
Fluminicola sp. 7	Lake of the Woods Pebblesnail	mollusk
Fluminicola sp. 8	Lost River Pebblesnail	mollusk
Helisoma newberryi newberryi	Great Basin Rams-horn	mollusk
Helodium blandowii		non-vascular plant
Helodium blandowii var. blandowii		non-vascular plant
Homoplectra schuhi	Schuh's Homoplectran Caddisfly	caddisfly
Juga acutifilosa	Topaz Juga	mollusk
Lanx klamathensis	Scale Lanx	mollusk
Pisidium sp. 1	Modoc Peaclam	mollusk
Pisidium ultramontanum	Montane Peaclam	mollusk
Pyrgulopsis archimedis	Archimedes Pyrg	mollusk
Pyrgulopsis sp. 7	Lost River Springsnail	mollusk
Pyrgulopsis sp. 9	Klamath Lake Springsnail	mollusk
Splachnum ampullaceum		non-vascular plant
Tomentypnum nitens		non-vascular plant
Vorticifex effusa dalli	Dall Rams-horn	mollusk
Vorticifex effusa diagonalis	Lined Rams-horn	mollusk
Vorticifex klamathensis klamathensis	Klamath Rams-horn	mollusk
Vorticifex klamathensis sinitsini	Sinitsin Rams-horn	mollusk

f. Malheur/Owyhee

High densities of springs are mapped in more than 60% of the HUC6s in the Malheur/Owyhee region (Table 11 and Figure 2A). Most of the springs are concentrated in the Malheur watershed, but considerable concentrations also occur in the Middle Owyhee River drainage and the headwaters of West Little Owyhee River (Figure 1A and Atlas Map 3). There is an average of 14 mapped springs per HUC6 in this region. The presence of groundwater-dependent wetlands is impossible to assess in this region due to the almost complete absence of both the National Wetland Inventory and county soil survey data layers for mapping wetlands (Atlas Map 6). This area has high evaporation rates and relatively low precipitation, so it is reasonable to expect that permanent wetlands in this region will be supported by groundwater, but we were unable to test this assumption with our analysis. Groundwater-dependent rivers are common in the Malheur/Owyhee region, where they were identified in 125 HUC6s, or more than 60% of those HUC6s with perennial rivers. The geology of this region is predominately permeable deposits (Atlas Map 7); therefore, groundwater-dependent rivers are widely distributed throughout the region (Figure 1C). Groundwater-dependent lakes were identified in only three (1%) of the HUC6s in the Malheur/Owyhee region.

Six species of conservation concern are obligately groundwater dependent in this region (Table 18). This includes three species of mollusk and two species of invertebrates, including one cave isopod. An additional 22 species and communities of conservation concern are facultatively groundwater dependent but within the Malheur/ Owyhee region rely on habitats that are maintained by groundwater.

Table 18: Obligately groundwater-dependent species of conservation concern in the Malheur/Owyhee region

Scientific Name	Common Name	Taxonomic Group
Amerigoniscus malheurensis	Malheur Isopod	invertebrate
Kenkia rhynchida	A Flatworm	invertebrate
Pisidium ultramontanum	Montane Peaclam	mollusk
Pyrgulopsis intermedia	Crooked Creek Springsnail	mollusk
Pyrgulopsis robusta	Jackson Lake Springsnail	mollusk
Stygobromus hubbsi	Malheur Cave Amphipod	invertebrate

g. Northeast Oregon

Groundwater is important to ecosystems in Northeast Oregon. Each HUC6 has an average of nearly nine springs (Table 12), and almost 75% of the HUC6s in this region meet our spring criteria, making it one of the top three regions for springs in Oregon, after the John Day and the Powder/Burnt regions (Table 11 and Figure 2A). A total of 40 (20%) HUC6s were identified with groundwater-dependent wetlands. Most of these HUC6s are on the south slope of the Wallowas and in the Grande Ronde Valley (Figure 1B). Our analysis showed that Northeast Oregon has the highest proportion of HUC6s with groundwater-dependent rivers and that these HUC6s are well distributed throughout the region (Table 11 and Figure 2C). The importance of springs and groundwater inflow to tributaries of the Wallowa and Grande Ronde rivers has been identified in conservation plans for salmonid populations (Wallowa County and the Nez Perce Tribe, 1999; Watershed Sciences, LLC, 2000). Few HUC6s with groundwater-dependent lakes were identified in Northeast Oregon (Table 11 and Figure 2D).

Only one species of conservation concern — a mollusk — is known to be obligately groundwater dependent in Northeast Oregon (Table 19). An additional 39 species or communities of conservation concern are facultatively groundwater dependent but within the Northeast Oregon region rely on habitats that are maintained by groundwater.

Table 19: Obligately groundwater-dependent species of conservation concern in Northeast Oregon

Scientific Name	Common Name	Taxonomic Group
Pristinicola hemphilli	Pristine Pyrg	mollusk

h. Oregon Basin and Range

Springs occur in 228 (46%) of the HUC6s in the Oregon Basin and Range. These are concentrated in the Steens, the headwaters of the Silvies and Silver rivers, and in the Lake Abert, Goose Lake and Warner Valley drainages (Figure 1A and Atlas Map 3). There is an average of 14 mapped springs per HUC in this region. Of the wetlands and rivers found in the Oregon Basin and Range region, those that depend on groundwater are common because this is an area with high evaporation and low precipitation. Groundwater-dependent wetlands occur in 155 (31%) of the HUC6s, more than in any other region (Table 11), and they are well distributed throughout the region (Atlas Map 5). However, it is important to note that only one of the two primary data layers (county soil surveys) was available for mapping wetlands across most of this region (Atlas Map 6). Our analysis showed that groundwater is important to rivers in 160 (32%) of the HUC6s; however, 63% of the HUC6s with perennial rivers were identified as groundwater dependent, indicating that when a river is perennial in this region, it is likely to be supported by groundwater. Most of these are located in areas draining the Steens, the lower valleys draining to Malheur and Harney lakes, the Warner Valley, the Chewaucan watershed and the Fort Rock region (Atlas Map 9). It is worth noting in this region that most of the lakes, with the exception of Malheur Lake (Leonard, 1970), were identified as groundwater dependent. This finding is supported by a local study that found groundwater to be vital to some lakes for maintaining water chemistry even if the volumetric input of groundwater is low (Phillips and Van Den Burgh, 1971).

A total of nine species of conservation concern are obligately groundwater dependent in the Oregon Basin and Range (Table 20). This includes five species each of fish and mollusk. An additional 63 species and communities of conservation concern are facultatively groundwater dependent but within the Oregon Basin and Range region rely on habitats that are maintained by groundwater.

Table 20: Obligately groundwater-dependent species of conservation concern in the Oregon Basin and Range region

Scientific Name	Common Name	Taxonomic Group
Fluminicola modoci	Modoc Pebblesnail	mollusk
Fluminicola turbiniformis	Turban Pebblesnail	mollusk
Gila bicolor oregonensis	X-l Spring Tui Chub	fish
Gila bicolor ssp. 1	Hutton Tui Chub	fish
Gila boraxobius	Borax Lake Chub	fish
Planorbella oregonensis	Lamb Rams-horn	mollusk
Pyrgulopsis hendersoni	Harney Lake Springsnail	mollusk
Pyrgulopsis robusta	Jackson Lake Springsnail	mollusk
Rhinichthys osculus ssp. 3	Foskett Speckled Dace	fish

i. Powder/Burnt

Springs occur throughout the Powder/Burnt region (Atlas Map 3). Nearly 90% of all the HUC6s met our spring criteria (Table 11 and Figure 2A). Not only are springs well distributed through the region but the concentrations are very high, averaging more than 18 springs per HUC6. Our analysis identified 20 (16%) of the HUC6s in the Powder/Burnt region that contain groundwater-dependent wetlands; most of these are concentrated in the Powder drainage (Figure 1B). It is important to note that only one of the two most detailed sources of data used for mapping wetlands (county soil surveys) was available to map wetlands in almost two-thirds of the region (Atlas Map 6). Groundwater-dependent rivers are uncommon in the Powder/Burnt region. Our analysis showed that 38 (29%) of the HUC6s contained groundwater-dependent rivers. As with the wetlands, most of the HUC6s with the geologic conditions to support groundwater-dependent rivers are found in the Powder River watershed, which is composed of large permeable geologic deposits such as the relatively young Wanapum basalt and valleys of alluvium. In contrast, much of the Burnt River watershed is composed of very old sedimentary rocks with lower permeability, which reduces the occurence of groundwater-dependent rivers (Atlas Maps 7 and 9). Only two (2%) of the HUC6s in this region contained groundwater-dependent lakes.

Only one species of conservation concern — a mollusk — is known to be obligately groundwater dependent in the Powder/ Burnt region (Table 21). An additional 19 species and communities of conservation concern are facultatively groundwater dependent but within the Powder/Burnt region rely on habitats that are maintained by groundwater.

Table 21: Obligately groundwater-dependent species of conservation concern in the Powder/ Burnt region

Scientific Name	Common Name	Taxonomic Group
Pristinicola hemphilli	Pristine Pyrg	mollusk

j. Rogue

On average there are 17 mapped springs per HUC6 in the Rogue region. This is not only a very high concentration of springs for any region in Oregon but extremely unusual for areas west of the Cascade crest (Figure 1A). Furthermore, the springs are well distributed across the region; 60% of the HUC6s contain at least one spring. At least one very large group of springs (Big Butte Springs) has provided the municipal water for Medford since 1927 (Young, 1961). In the Rogue Basin, 35 (20%) HUC6s were identified as containing groundwater-dependent wetlands. Most groundwater-dependent wetlands in this region are located in the Cascades and in the Klamath Mountains in the southern part of the region (Figure 1B). Our analysis identified HUC6s with groundwater-dependent rivers and lakes primarily in the Cascade headwater portion of the watershed (Figure 1, C and D). In a geologic analysis of this region, Young (1961) noted the highly permeable nature of geologic deposits above 5000’, which supports this finding. He also noted large alluvial areas that are important for groundwater discharge to streams in the Agate Desert area, Applegate Valley and perhaps also in the Central Illinois Valley.

A total of 19 species and four communities of conservation concern are obligately groundwater dependent in the Rogue region. These include four species of non-vascular plant, 12 species of mollusk, one species of caddisfly and one species of bird (Table 22). Mollusks dominate this list in part due to an intensive survey that was completed by Frest and Johannes (2000). Obligately groundwater-dependent species are well distributed in the middle and upper parts of the region, occurring in 41 (24%) of the HUC6s, the second largest number in a region after the Klamath region (Figure 2E). A large number of other species and communities of conservation concern are facultatively groundwater dependent but within the Rogue region rely on habitats that are maintained by groundwater (Figure 3).

Table 22: Obligately groundwater-dependent species of conservation concern in the Rogue region

Scientific Name	Common Name	Taxonomic Group
Crumia latifolia		non-vascular plant
Fluminicola sp. 19	Keene Creek Pebblesnail	mollusks
Fluminicola sp. 26	Fredenburg Pebblesnail	mollusks
Fluminicola sp. 33	Stewart Pebblesnail	mollusks
Fluminicola sp. 34	Evergreen Pebblesnail	mollusks
Fluminicola sp. 35	Camp Creek Pebblesnail	mollusks
Fluminicola sp. 36	Clarke Pebblesnail	mollusks
Fluminicola sp. 37	Beaverdam Pebblesnail	mollusks
Fluminicola sp. 38	Little Butte Pebblesnail	mollusks
Fluminicola sp. 39	Chinquapin Pebblesnail	mollusks
Fluminicola sp. 40	Pilot Rock Pebblesnail	mollusks
Helodium blandowii		non-vascular plant
Helodium blandowii var. blandowii		non-vascular plant
Meesia uliginosa		non-vascular plant
Patagioenas fasciata	Band-tailed Pigeon	birds
Pristiloma arcticum crateris	Crater Lake Tightcoil	mollusks
Pristinicola hemphilli	Pristine Pyrg	mollusks
Rhyacophila fenderi	Fender's Rhyacophilan Caddisfly	caddisflies
Tomentypnum nitens		non-vascular plant

k. Umpqua

Groundwater-dependent ecosystems and species are relatively uncommon in the Umpqua region. Few springs are mapped (Tables 11 and 12), and HUC6s with either groundwater-dependent wetlands or rivers are not very abundant in the basin (Table 11 and Figure 2, B and C, respectively). Most groundwater-dependent wetlands are located in the lower part of this basin while most groundwater-dependent rivers are found in the headwaters of the Upper Umpqua, as it lies in the High Cascades area (Figure 1, B and C, respectively). Only seven (4%) of the HUC6s in the Umpqua region contain groundwater-dependent lakes.

A total of nine obligately groundwater-dependent species of conservation concern occur in this basin (Table 23), many of which depend on springs for their habitat. This includes four species of caddisfly, two species of non-vascular plant and one species each of bird, mollusk and cave amphipod. An additional 34 species of conservation concern are facultatively groundwater dependent but within the Umpqua rely on habitats that are maintained by groundwater.

Table 23: Obligately groundwater-dependent species of conservation concern in the Umpqua region

Scientific Name	Common Name	Taxonomic Group
Crumia latifolia		non-vascular plant
Eobrachycentrus gelidae	Mt. Hood Primitive Brachycentrid Caddisfly	caddisfly
Farula reapiri	Tombstone Prairie Farulan Caddisfly	caddisfly
Patagioenas fasciata	Band-tailed Pigeon	bird
Pristiloma arcticum crateris	Crater Lake Tightcoil	mollusk
Rhizomnium nudum		non-vascular plant
Stygobromus oregonensis	Oregon Cave Amphipod	invertebrate

I. Willamette

Mapped springs are not abundant throughout the Willamette region (Table 11 and Table 12), although this is an area where there are more springs than are currently mapped in digital databases, particularly in the High Cascades (Jefferson et al., 2006). Even though a number of mapped fens exist in the Willamette region, our analysis showed few groundwater-dependent wetlands (Table 11 and Figure 2B), with most occurring in the valley floor and in the foothills of the Cascades (Figure 1B). In contrast, our analysis showed that more than 212 (50%) HUC6s in the Willamette region contain groundwater-dependent rivers, which is the highest number of any region in Oregon (Table 11). The distribution of the groundwater-dependent rivers is uneven. Most are located in the valley itself and in the headwaters of the Cascades, and only a few are in the coast mountains (Figure 1C; Conlon et al., 2005; Lee and Risley, 2002).

The Willamette region is renowned for Waldo Lake, an ultraoligotrophic lake that maintains its exceptional water quality in part due to groundwater inputs (Sytsma et al., 2004). Overall, groundwater-dependent lakes were identified in 59 (14%) of the HUC6s in this region, the second highest percentage per region in the state.

A total of 21 species and 11 communities of conservation concern are obligately dependent on groundwater in the Willamette (Figure 3). This includes nine species of non-vascular plant, seven species of caddisfly, three species of mollusk and one species each of bird and dragonfly/stonefly/mayfly (Table 24). These species occur in 74 (18%) of the HUC6s in the region. More than 100 additional species and communities of conservation concern are facultatively groundwater dependent but within the Willamette rely on habitats that are maintained by groundwater (Figure 3).

Table 24: Obligately groundwater-dependent species of conservation concern in the Willamette region

Scientific Name	Common Name	Taxonomic Group
Allomyia scotti	Scott's Caddisfly	Caddisfly
Amnicola sp. 4	Columbia Duskysnail	Mollusk
Calypogeia sphagnicola	A Liverwort	non-vascular plant
Chiloscyphus gemmiparus		non-vascular plant
Eobrachycentrus gelidae	Mt. Hood Primitive Brachycentrid Caddisfly	Caddisfly
Farula jewetti	Mt. Hood Farulan Caddisfly	Caddisfly
Farula reapiri	Tombstone Prairie Farulan Caddisfly	Caddisfly
Fluminicola fuscus	Ashy Pebblesnail	Mollusk
Haplomitrium hookeri		non-vascular plant
Jamesoniella autumnalis var. heterostipa		non-vascular plant
Lophozia laxa	A Liverwort	non-vascular plant
Micromitrium synoicum		non-vascular plant
Neothremma andersoni	Columbia Gorge Neothremman Caddisfly	Caddisfly
Patagioenas fasciata	Band-tailed Pigeon	Bird
Physcomitrella patens		non-vascular plant
Pristinicola hemphilli	Pristine Pyrg	Mollusk
Rhizomnium nudum		non-vascular plant
Rhyacophila fenderi	Fender's Rhyacophilan Caddisfly	Caddisfly
Rhyacophila unipunctata	One-spot Rhyacophilan Caddisfly	Caddisfly
Tanypteryx hageni	Black Petaltail	dragonfly/stonefly/mayfly
Tomentypnum nitens		non-vascular plant

4.1.3 GDE clusters

The number of GDEs in a HUC6 can serve as one way to prioritize areas for conservation work. Using the criteria established in Table 1, we have identified the number of GDEs in each HUC6 and highlighted **GDE clusters** (Figure 4).

Four areas in Oregon stand out for their high number of GDEs per HUC6:

- *The crest of the Cascades*: In the Willamette, Rogue, Umpqua, Columbia Drainages, Klamath and Deschutes regions, the crest of the Cascades (or High Cascades) forms a nearly continuous ribbon of GDE clusters.
- *The Klamath Basin*: Most HUC6s in the Klamath region qualify as GDE clusters, containing more than two GDEs, and many of them contain four or five GDEs.
- *The Oregon Basin and Range*: Wherever aquatic ecosystems exist in the Basin and Range, GDE clusters occur. As a result, the only part of this region with no GDE clusters is the central area, which is generally too dry, with too high of an evaporation rate, to support perennial water at the surface. Many of the GDE clusters support three or four GDEs per HUC6.
- *Northeast Oregon*: The Grande Ronde and Wallowa river drainages both contain a high concentration of HUC6s with three or four GDEs each.

Additionally, the lower John Day area and the Neskowin River and New River on the coast contain GDE clusters that include at least one HUC6 with three or four GDEs.

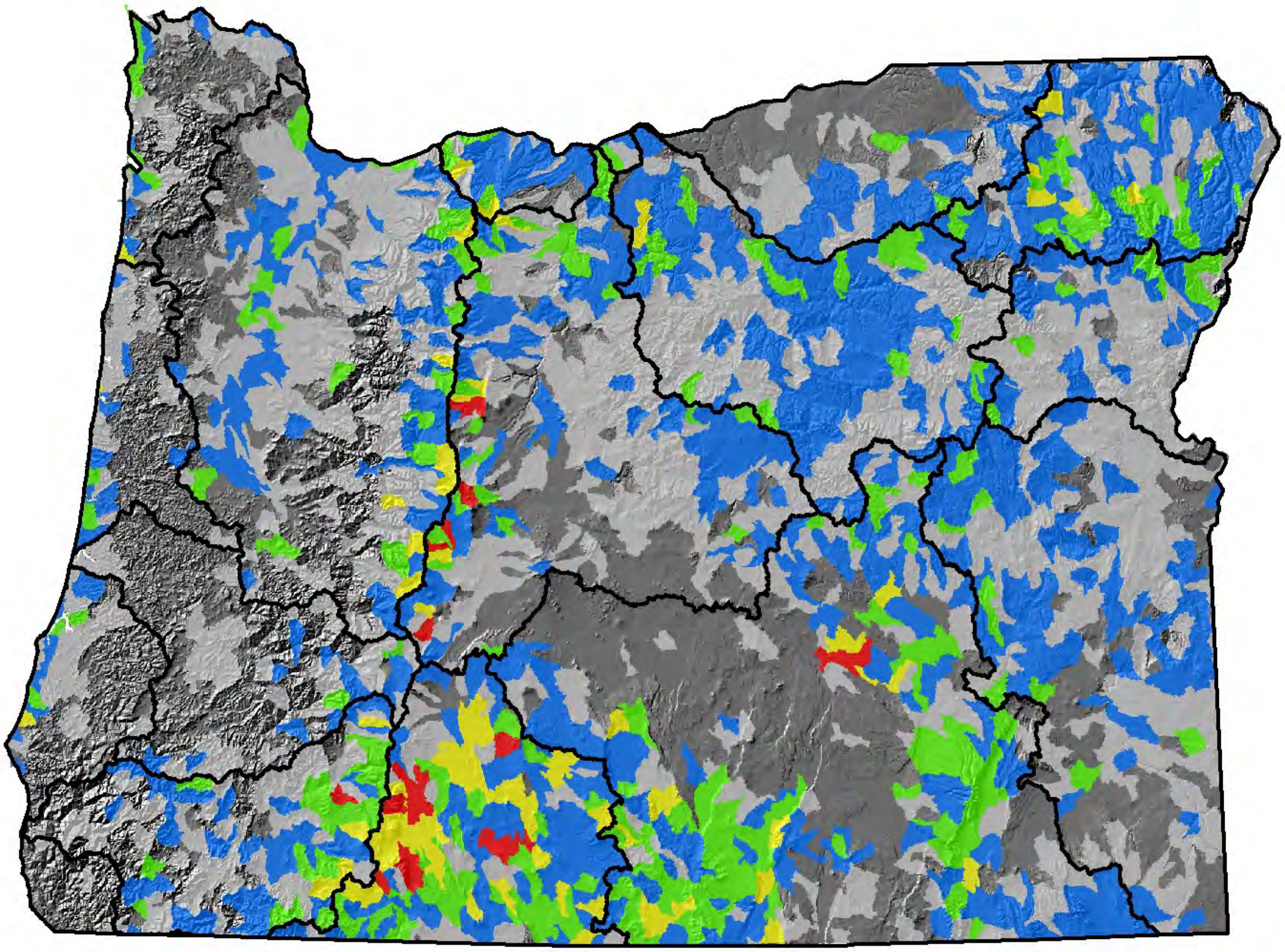


Figure 4: GDE clusters (blue through red). Number of GDEs present in each HUC6 (per criteria in Table 1): 5 (red), 4 (yellow), 3 (green), 2 (blue), 1 (light gray) and 0 (dark gray).

4.2 Overview of threat analysis

In the second part of this analysis, we evaluated the threats to groundwater in the HUC6s with groundwater-dependent biodiversity. We conducted the threat assessment across the entire state and mapped the findings in their entirety in the Atlas (Appendix A). In this section we overlay the mapped threats to groundwater quantity and quality with the map of GDEs and report only the results that are relevant to GDE clusters (HUC6s that contain two or more GDEs, as defined in Table 1). By focusing just on GDE clusters, we are able to prioritize the areas where groundwater management and protection is likely to be most important to the conservation of groundwater-dependent ecosystems and species.

4.3 Threats to groundwater quantity

Conditions and land use activities that indicate a threat of altered groundwater availability to GDEs were assessed for each GDE cluster. Known declines in water table elevations, along with indicators of current and potential future groundwater extraction, were included in this analysis.

4.3.1 Known water table declines

Areas with documented water table decline from groundwater extraction have been designated Groundwater Restricted Areas by Oregon Water Resources Department in the following locations: the Willamette Valley; the Umatilla River and Mosier Creek portions of the Columbia Drainages; the Fort Rock portion of the Oregon Basin and Range; and Cow Valley in the Malheur/Owyhee region. Except for the Cow Valley site, each of these intersects at least one GDE cluster (Figure 5).

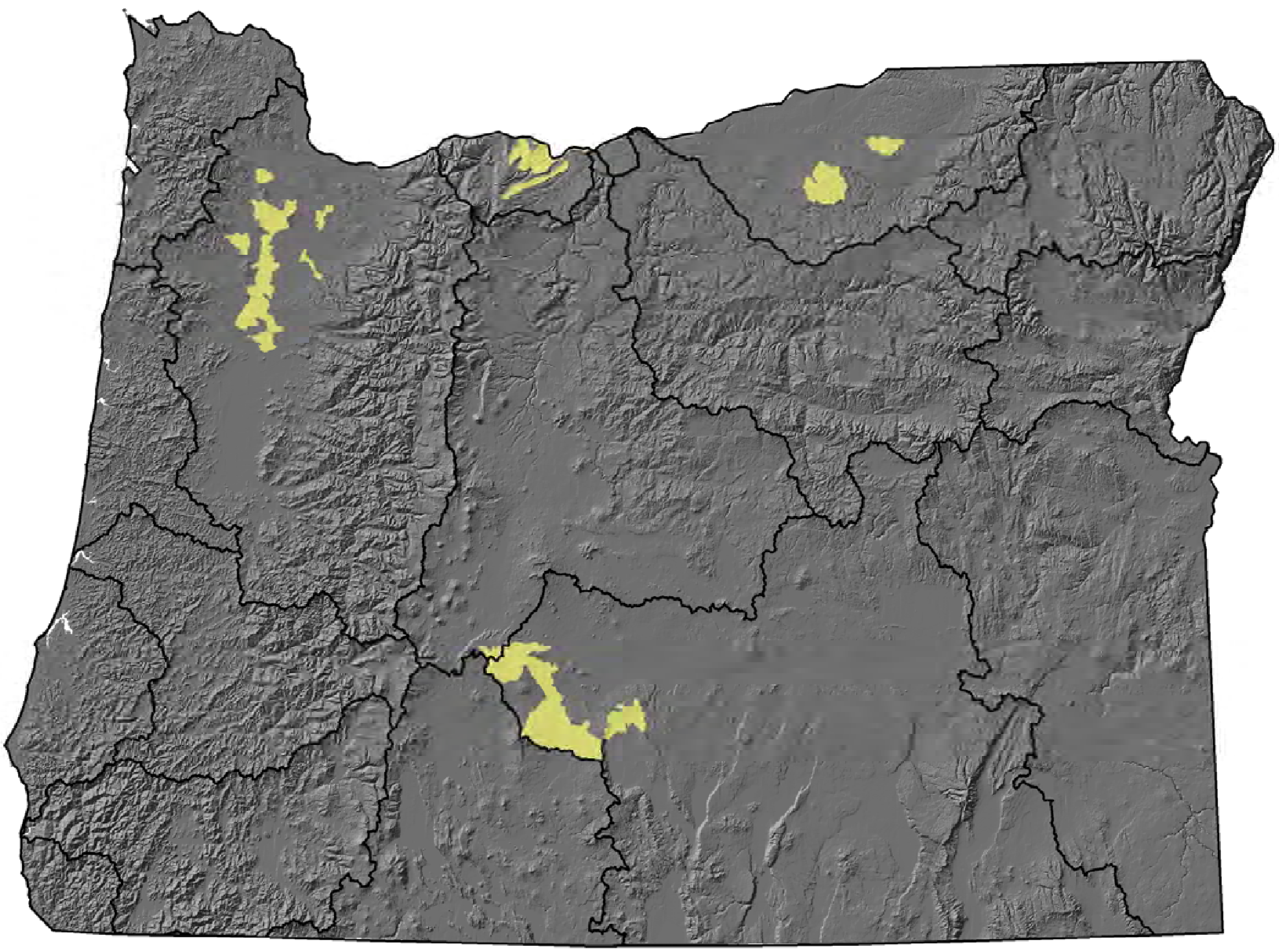


Figure 5: GDE clusters with known declines in the water table elevation, as indicated by the presence of a Groundwater Restricted Area designation (yellow)

4.3.2 Threat of altered groundwater quantity: Current

GDEs in additional parts of the state are threatened by high densities of groundwater wells (see Table 2 for methods) that have the potential to reduce both water table levels and the volume of groundwater discharging to aquatic ecosystems. For this analysis, we divided groundwater wells into large wells (those used for irrigation, industrial, or municipal water) and small wells (those used to water livestock or supply domestic water to individual homes or small communities). HUC6s are identified as threatened if the density of large wells exceeds one well per 2130 ha (one per 5263 acres) or if the density of small wells exceeds one well per 43.5 ha (one per 108 acres).

There are approximately 21,400 large wells in Oregon, providing for agricultural, industrial and municipal water uses. GDE clusters are identified as threatened from high densities of large wells in every region of the state (Table 25). Of the 36 GDE clusters in the South, Middle and North Coast regions, 22 (60%) are at risk from large wells, as are 28 (40%) of the GDE clusters in the Columbia Drainages and 43 (43%) in the Willamette region. Other concentrations of threatened GDE clusters are found in the Rogue region; near Goose Lake and Malheur Lake in the Oregon Basin and Range; and in the Grande Ronde Valley in Northeast Oregon (Figure 6A).

Table 25: Number and percentage of GDE clusters with threats to groundwater quantity

Region	Total # GDE Clusters	Current Large Wells		Current Small Wells		Future Large Wells		Future Small Wells	
		#	%	#	%	#	%	#	%
Columbia Drainages	70	28	*40*	2	*3*	11	*16*	10	*14*
Deschutes	111	14	*13*	5	*5*	15	*14*	9	*8*
John Day	148	6	*4*	0	*0*	3	*2*	0	*0*
Klamath	117	27	*23*	5	*4*	16	*14*	0	*0*
Malheur/Owyhee	98	5	*5*	1	*1*	1	*1*	0	*0*
Middle Coast	11	4	*36*	3	*27*	1	*9*	4	*36*
North Coast	14	9	*64*	1	*7*	4	*29*	2	*14*
Northeast OR	137	13	*10*	5	*4*	9	*7*	1	*1*
OR Basin and Range	209	34	*16*	0	*0*	9	*4*	0	*0*
Powder/Burnt	44	6	*14*	0	*0*	5	*11*	0	*0*
Rogue	70	14	*20*	18	*26*	1	*1*	22	*31*
South Coast	11	9	*82*	6	*55*	2	*18*	0	*0*
Umpqua	18	1	*6*	0	*0*	0	*0*	0	*0*
Willamette	101	43	*43*	37	*37*	28	*28*	29	*29*
TOTAL	**1159**	**213**	***18***	**83**	***7***	**105**	***9***	**77**	***7***

More than 215,000 small wells are recorded in Oregon well logs. High densities of these wells coincide with a large number of GDE clusters in the Willamette and Rogue regions (Table 25), threatening GDEs in these areas. In the South and Middle Coast regions, nine GDE clusters face threats from high densities of small wells, but due to the concentrated nature of GDEs, the threatened HUC6s include 41% of GDE clusters in these regions. Additional concentrations of GDE clusters at risk from small wells occur in the western portion of the Klamath and Deschutes regions and in the Grande Ronde Valley of Northeast Oregon (Figure 6B).

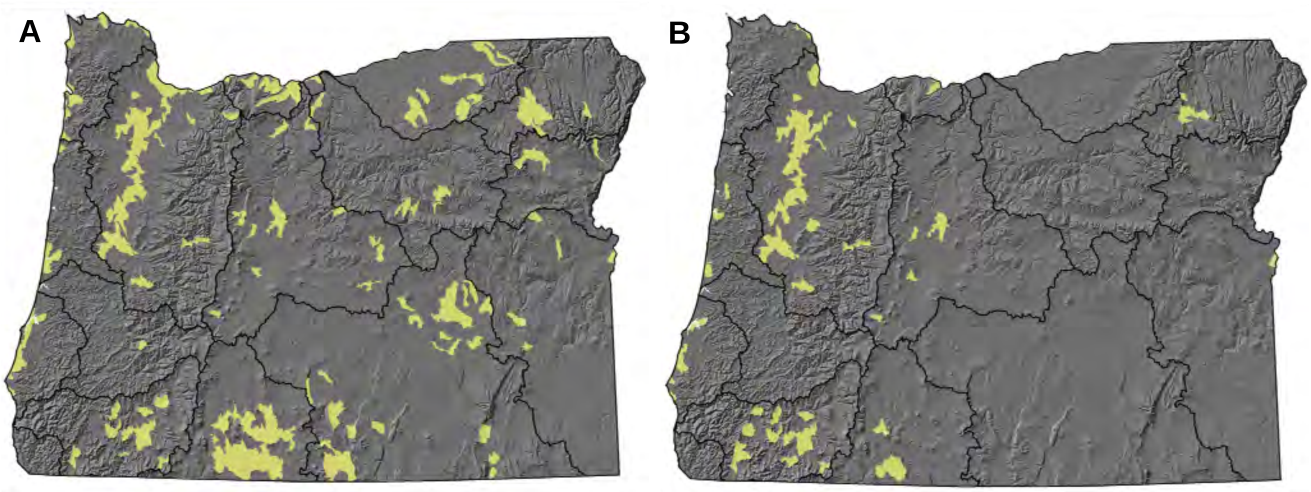


Figure 6: GDE clusters threatened by high densities of existing (A) large and (B) small wells

4.3.3 Threat of altered groundwater quantity: Future

We used the number of pending applications for groundwater rights as an indicator of the future threat to an area from installation of new large wells. These applications are filed with Oregon Water Resources Department prior to the use of large wells to meet new irrigation, municipal or industrial water needs. More than 500 applications for groundwater rights are pending in Oregon; 181 of these occur in GDE clusters and at least one application is pending in each region of Oregon except the Umpqua. The Willamette has the highest number of pending applications in GDE clusters, followed by the Deschutes and Klamath (Figure 7). These applications are distributed widely throughout these three regions, indicating a large number of GDE clusters in these regions are at risk from future large wells (Table 25 and Figure 8A). Other GDE clusters at risk from future large wells are in the western Oregon Basin and Range, Northeast Oregon and Columbia Drainages near the Dalles (Figure 8A).

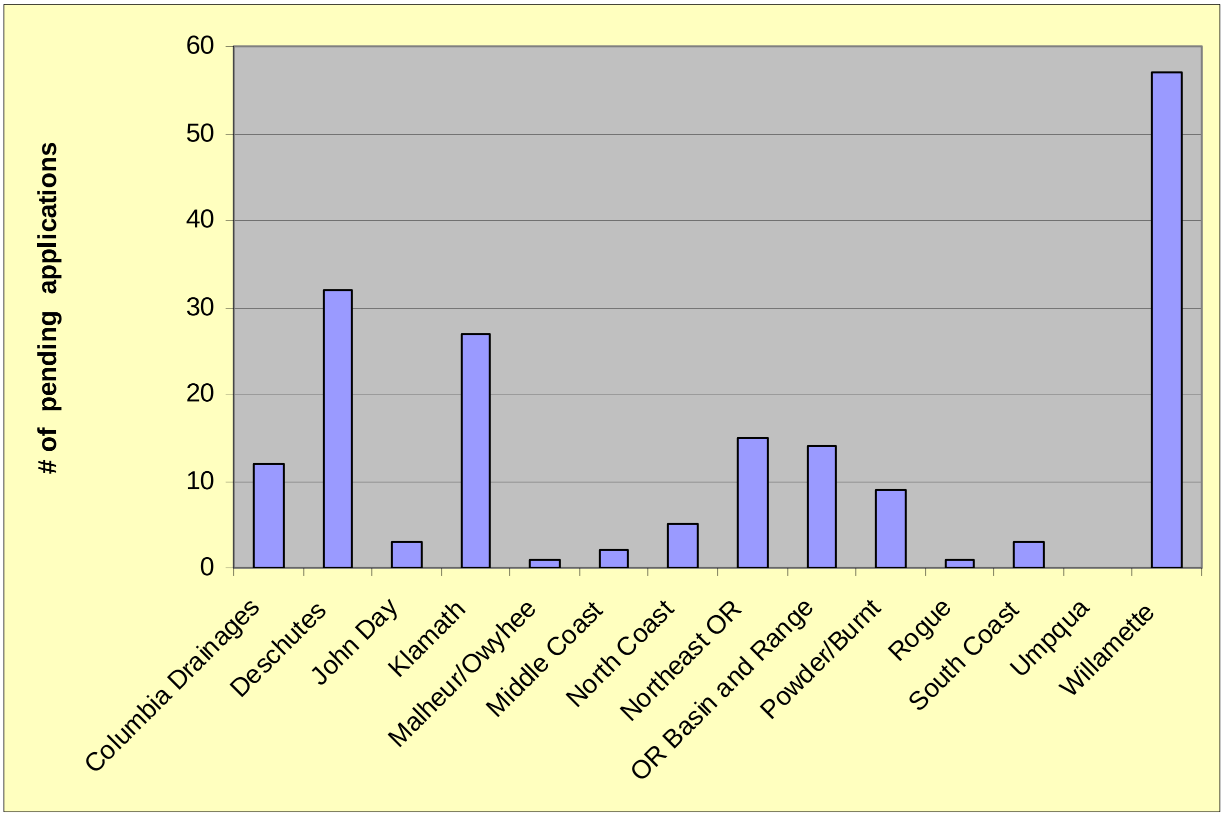


Figure 7: Total number of pending groundwater rights applications in GDE clusters for each analysis region

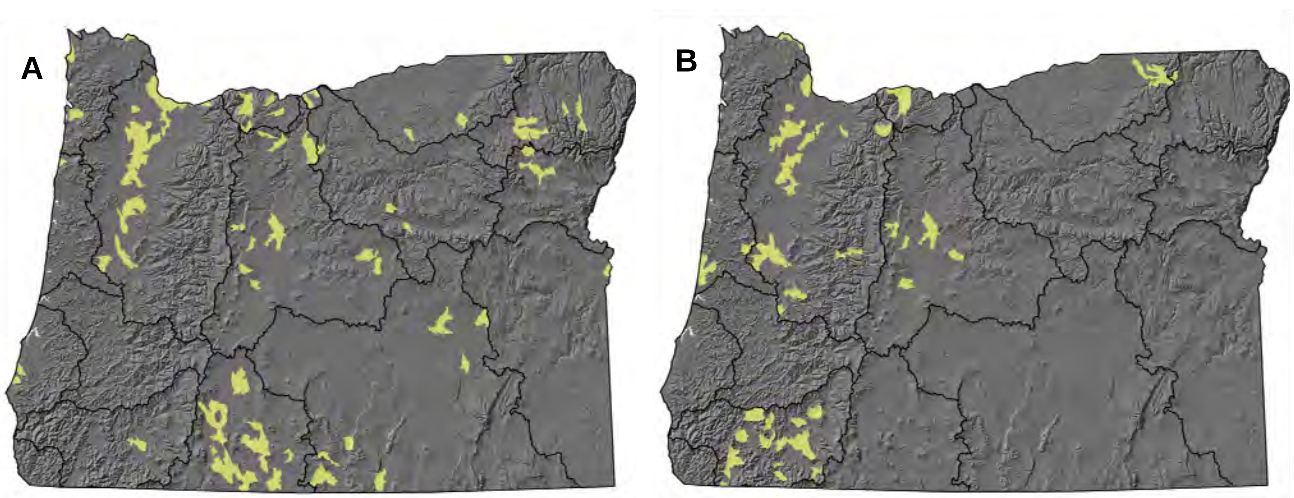


Figure 8: GDE clusters threatened by future installations of (A) large and (B) small wells

Domestic wells are currently exempt from regulation in Oregon and their installation does not require a groundwater right, so we developed a surrogate measure of future small-well development using population growth and zoning data (see section 3.2.1.3). Many of the analysis regions identified as currently threatened by small wells (Figure

6B) were also identified as at risk from future domestic well installations (Figure 8B). The regions with the largest number of GDE clusters facing this threat are the Willamette and Rogue regions (Table 25). Additional GDE clusters considered threatened are located near Pendleton in the Columbia Drainages region and in the Deschutes region (Figure 8B).

4.4. Threats to groundwater quality

Using a similar approach to our evaluation of threats to groundwater quantity, we conducted an assessment of threats to groundwater quality across the entire state and mapped these findings in their entirety in the Atlas (Appendix A). In this section, we overlay the mapped groundwater quality threats with the map of GDEs and report only on results that are relevant to GDE clusters. Threats to groundwater quality were evaluated by locating areas where groundwater is either known to be contaminated or at risk of contamination by (i) nutrients, (ii) pesticides or (iii) other toxic contaminants (Table 26). We also evaluated the threat of geothermal development to HUC6s containing mapped hot springs.

Table 26: Number and percentage of GDE clusters with known groundwater contamination and indicators of the threat of groundwater contamination by nutrients, pesticides or other toxic contaminants

Region	Total # GDE Clusters	Known Groundwater Contamination		Nutrient Contamination		Pesticide Contamination		Other Toxic Contamination	
		#	%	#	%	#	%	#	%
Columbia Drainages	70	8	*11*	62	*89*	39	*56*	34	*49*
Deschutes	111	2	*2*	26	*23*	68	*61*	36	*32*
John Day	148	0	*0*	41	*28*	32	*22*	36	*24*
Klamath	117	2	*2*	30	*26*	76	*65*	37	*32*
Malheur/ Owyhee	98	0	*0*	6	*6*	39	*40*	20	*20*
Middle Coast	11	1	*9*	9	*82*	3	*27*	7	*64*
North Coast	14	5	*36*	13	*93*	2	*14*	14	*100*
Northeast OR	137	0	*0*	27	*20*	56	*41*	34	*25*
OR Basin and Range	209	2	*1*	17	*8*	154	*74*	48	*23*
Powder/Burnt	44	0	*0*	16	*36*	28	*64*	23	*52*
Rogue	70	0	*0*	28	*40*	37	*53*	32	*46*
South Coast	11	0	*0*	10	*91*	8	*73*	7	*64*
Umpqua	18	0	*0*	2	*11*	4	*22*	4	*22*
Willamette	101	28	*28*	54	*53*	65	*64*	53	*52*
TOTAL	**1159**	**48**	***4***	**341**	***29***	**611**	***53***	**385**	***33***

4.4.1 Known groundwater contamination

We identified existing groundwater contamination by nutrients by mapping Draft Groundwater Management Areas identified by the Oregon Department of Environmental Quality and by locating groundwater samples in which either nitrate concentrations exceeded drinking water standards or phosphorus concentrations exceeded the Environmental Protection Agency's ecoregional standards (see Section 3.2.2.1) over the past 10 years. To identify known groundwater contamination by pesticides or other contaminants, we located groundwater samples with detectable concentrations of pesticides, pesticide by-products and other toxic chemicals.

Across Oregon, 48 (4%) GDE clusters have known groundwater contamination, most occurring in the Willamette region (28 GDE clusters, 28% of GDE clusters in this region). In the North Coast region, only five GDE clusters have known groundwater contamination, but because the total number of GDE clusters is small, this equates to more than 36% of the GDE clusters with known groundwater contamination. A total of eight GDE clusters (11%) in the Columbia Drainages region have known groundwater contamination, primarily by pesticides and nutrients (Figure 9). Additional known contamination of groundwater coincides with GDE clusters in a few scattered HUC6s in eastern Oregon and the Middle Coast (Table 26 and Figure 9).

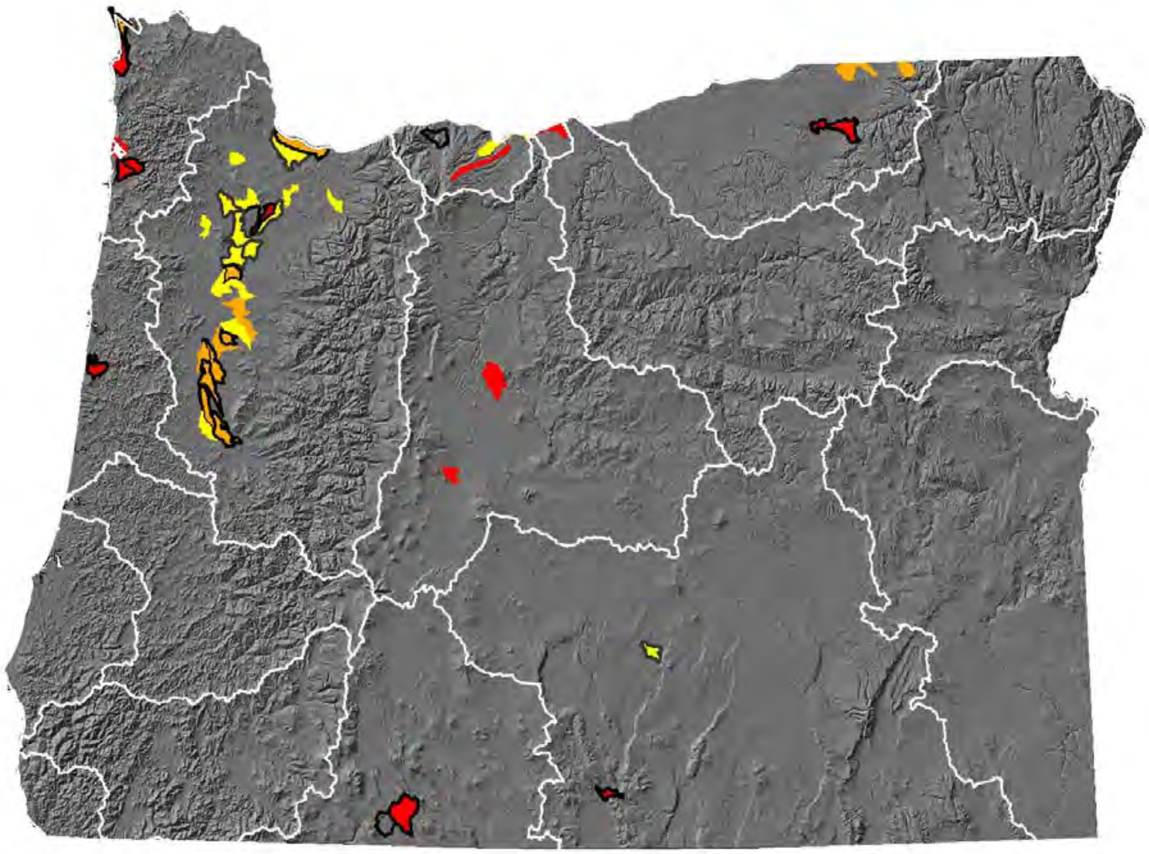


Figure 9: GDE clusters with known groundwater contamination. Contamination by nutrients only (red), pesticides only (yellow), other toxic contaminants (black outline) and both nutrients and pesticides (orange).

4.4.2 Threat of groundwater contamination — Nutrients

We used four indicators to assess threats of groundwater contamination by nitrates: high agricultural use of nitrogen fertilizer (two analyses were conducted for this indicator), high densities of septic systems, concentrated animal feeding operations (CAFOs) and Underground Injection Control wells (UICs) for wastewater disposal (see Section 3.2.2.2 and Table 4). We used two indicators to assess threats of phosphorus contamination of groundwater: high agricultural use of phosphorus fertilizers and urban land use (see Section 3.2.2.2 and Table 5).

In the analysis of nitrate contamination of groundwater, at least one threat indicator coincided with 323 (28%) of the GDE clusters in Oregon. The threat of nitrate contamination affects more than 50 GDE clusters in the Willamette and Columbia Drainages regions and more than 25 GDE clusters in the Deschutes, John Day, Klamath, Rogue and Northeast Oregon regions (Table 27). In the Coast regions only 32 GDE clusters face this threat; however, this accounts for 89% of the GDE clusters in these regions, therefore nitrate contamination may pose a significant risk in the areas where GDEs are concentrated. In many of the regions in Oregon, four or more indicators of this threat are present (Figure 10).

Table 27: Number and percentage of GDE clusters with indicators of the threat of groundwater contamination by nitrates. [1]Refers to GDE clusters in which any one of the five indicators was present. CAFO = concentrated animal feeding operation; UIC = Underground Injection Control wells for wastewater disposal.

Region	**Total # GDE Clusters**	**Any Nitrate Threat**[1]		**Prediction of USGS Model**		**Agricultural Fertilizer Use**		**Septic System Density**		**CAFOs**		**UICs**	
		#	**%**	**#**	%	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**
Columbia Drainages	70	63	*90*	32	*46*	41	*59*	12	*17*	3	*4*	10	*14*
Deschutes	111	26	*23*	15	*14*	0	*0*	10	*9*	2	*2*	11	*10*
John Day	148	41	*28*	14	*9*	23	*16*	3	*2*	2	*1*	3	*2*
Klamath	117	30	*26*	23	*20*	0	*0*	12	*10*	5	*4*	9	*8*
Malheur/ Owyhee	98	6	*6*	3	*3*	0	*0*	2	*2*	0	*0*	3	*3*
Middle Coast	11	9	*82*	2	*18*	0	*0*	7	*64*	1	*9*	8	*73*
North Coast	14	13	*93*	8	*57*	0	*0*	9	*64*	7	*50*	9	*64*
Northeast OR	137	26	*19*	16	*12*	3	*2*	8	*6*	4	*3*	6	*4*
OR Basin & Range	209	17	*8*	8	*4*	0	*0*	4	*2*	5	*2*	5	*2*
Powder/Burnt	44	16	*36*	14	*32*	0	*0*	1	*2*	2	*5*	2	*5*
Rogue	70	28	*40*	20	*29*	0	*0*	19	*27*	4	*6*	8	*11*
South Coast	11	10	*91*	7	*64*	0	*0*	7	*64*	0	*0*	3	*27*
Umpqua	18	2	*11*	0	*0*	0	*0*	2	*11*	0	*0*	0	*0*
Willamette	101	54	*53*	45	*45*	32	*32*	39	*39*	20	*20*	35	*35*
TOTAL	**1159**	341	*29*	207	*18*	99	*9*	135	*12*	55	*5*	112	*10*

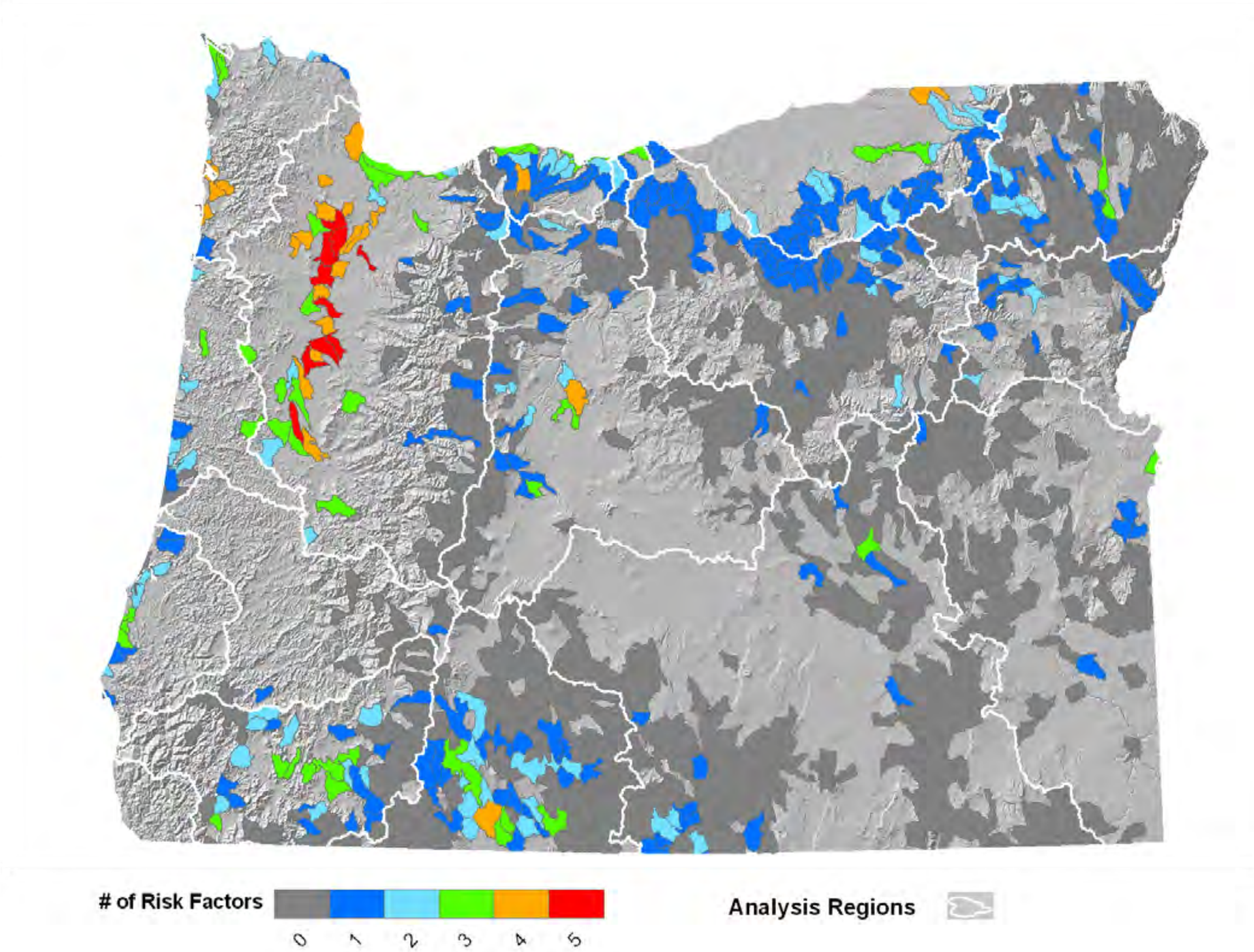


Figure 10: GDE clusters with a threat of groundwater contamination by nitrate. # of Risk Factors refers to indicators defined in Table 4.

As shown in Table 27, agricultural fertilizer use, high septic system density and the presence of UICs for wastewater disposal all are indicators of the threat of groundwater contamination by nitrates in more than 100 GDE clusters across the state. Agricultural fertilizer use is identified as a threat in a large number of GDE clusters (more than 20) in the Columbia Drainages, John Day and Willamette regions. The Willamette region has the highest number of GDE clusters that coincide with threat indicators for high septic system density, CAFOs and UICs, but more than half the GDE clusters in the Coast regions coincide with indicators for septic systems and UICs. CAFOs are also a particular concern in the North Coast and septic system density is also of concern in the Rogue Basin. The USGS predicts a high risk of nitrate contamination of shallow groundwater in more than 30 GDE clusters in the Columbia Drainages and the Willamette regions. Again, although this risk is predicted for only 17 GDE clusters in the Coast regions, this means that more than half the GDE clusters in this area are at risk.

In the analysis of the threat of phosphorus contamination of groundwater, agricultural fertilizer use indicated a threat in 95 (8%) of the GDE clusters in Oregon. The areas with the greatest number of threatened GDE clusters are in the Columbia Drainages, the Willamette and the northern part of the John Day regions (Table 28 and Figure 11). Urban areas, indicative of the threat of phosphorus contamination of groundwater, coincide with GDE clusters throughout the state, occurring in every region.

Table 28: Number and percentage of GDE clusters with indicators of the threat of groundwater contamination by phosphorus due to agricultural fertilizer use

Region	Total # GDE Clusters	Agricultural Fertilizer Use	
		#	**%**
Columbia Drainages	70	40	*57*
Deschutes	111	0	*0*
John Day	148	20	*14*
Klamath	117	0	*0*
Malheur/ Owyhee	98	0	*0*
Middle Coast	11	0	*0*
North Coast	14	0	*0*
Northeast OR	137	3	*2*
OR Basin & Range	209	0	*0*
Powder/Burnt	44	0	*0*
Rogue	70	0	*0*
South Coast	11	0	*0*
Umpqua	18	0	*0*
Willamette	101	32	*32*
TOTAL	**1159**	**95**	***8***

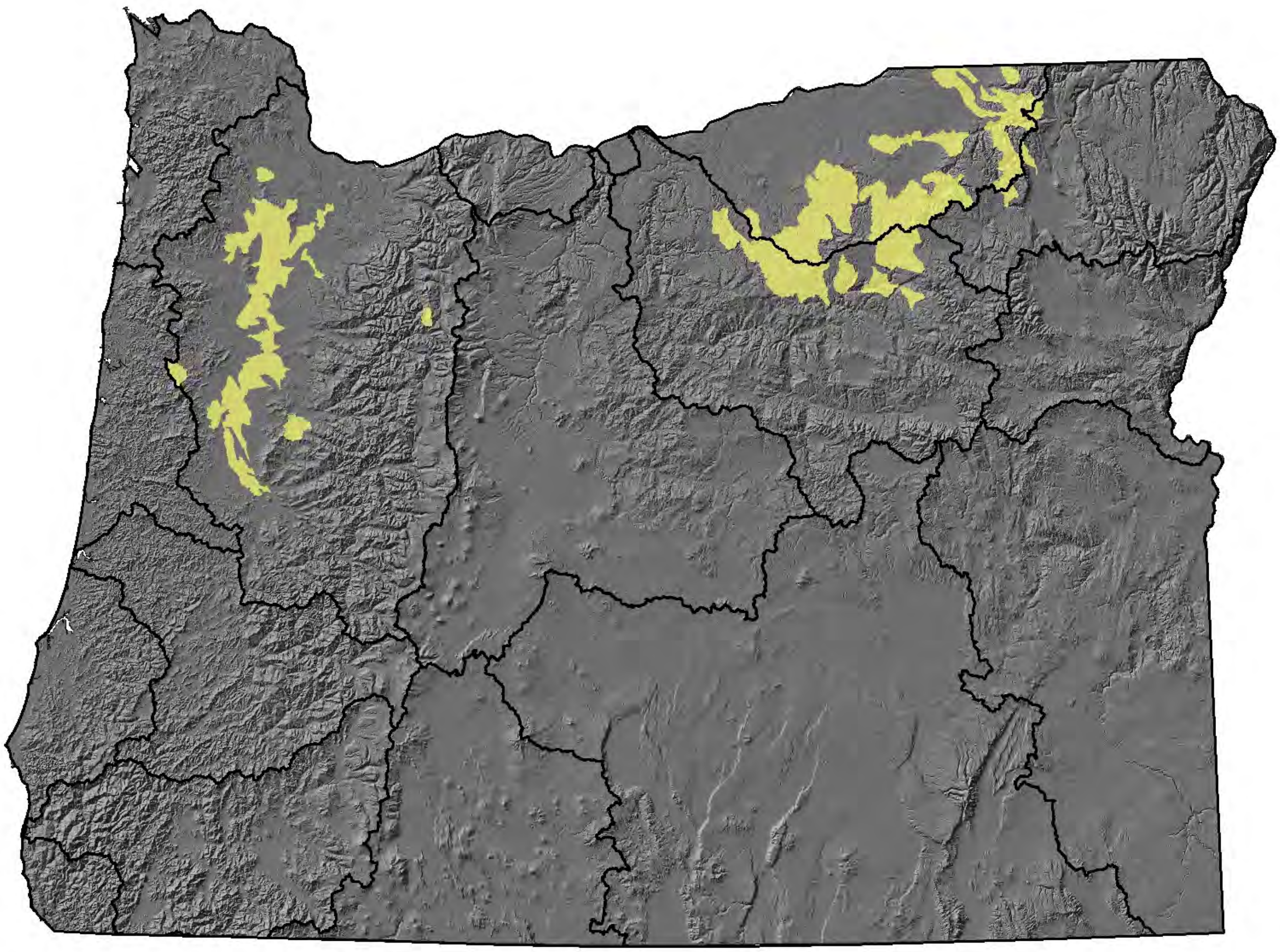


Figure 11: GDE clusters at risk of groundwater contamination by phosphorus due to agricultural use of phosphorus fertilizers (yellow)

4.4.3 Threat of groundwater contamination — Pesticides

To evaluate the threat of groundwater contamination by agricultural pesticide use, we examined 43 agricultural pesticides that are used in Oregon. Ten of these pesticides are toxic to aquatic biota and are mobile in water. We then evaluated the soil characteristics in the areas where these 10 pesticides are used to identify places where they are unlikely to be adsorbed by soil particles and therefore have a high potential of reaching groundwater. We identified a threat where two or more of these pesticides were likely to reach groundwater (see Table 6).

Across Oregon, two or more mobile pesticides were used in 611 (53%) of the GDE clusters, posing a threat of groundwater contamination by agricultural pesticides. More than a third of GDE clusters are at risk in every analysis region except for the John Day, the North and Mid Coast and the Umpqua (Table 29). The highest number of at-risk GDE clusters is in the Oregon Basin and Range region, while the fewest number were in the Coast regions and the Umpqua (Table 29). Aggregations of GDE clusters in which a high number of pesticides are used are located in the Willamette, Columbia Drainages, Powder/Burnt, Rogue, and Klamath regions (Figure 12).

Of the pesticides included in our analysis, all except carbofuran, ethoprop and methomyl are herbicides. These three chemicals are used primarily as insecticides, but both carbofuran and ethoprop are also used as nematicides. Statewide, the most prevalent pesticides in GDE clusters are metribuzin and carbofuran, each used in 500 or more GDE clusters (Table 29 and Figure 13). Two other pesticides are used in more than 300 (30%) of GDE clusters across the state: atrazine and methomyl (Figure 13). The Oregon Basin and Range region has the highest number of GDE clusters in which mobile pesticides are used. In this region carbofuran and metribuzin are used in more than 150 GDE clusters (Table 29).

In addition to assessing the agricultural use of pesticides, we located urban areas in which the unregulated and often intensive use of pesticides may pose a threat to groundwater quality. As with the phosphorus analysis (Section 4.4.2), urban areas indicative of the threat of pesticide contamination of groundwater coincide with GDE clusters in every region of the state.

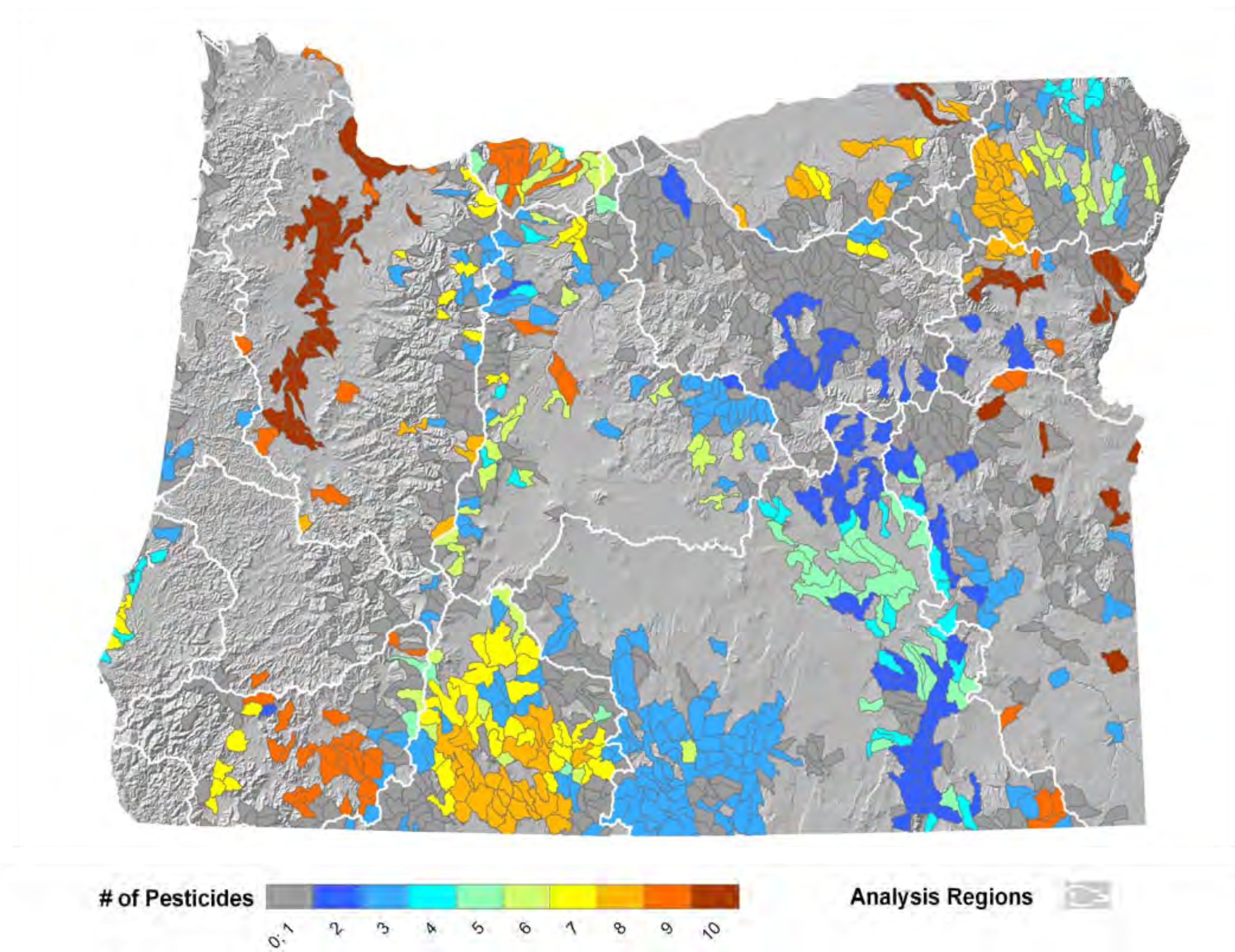


Figure 12: GDE clusters with the threat of groundwater contamination by agricultural pesticides: Number of agricultural pesticides used indicated by color code**.**

Table 29: Number and percentage of GDE clusters with (i) threat of groundwater contamination by pesticides and (ii) use of a specific pesticide. * = GDE clusters where two or more pesticides were likely to reach groundwater. Individual pesticide data indicate use of the pesticide in portions of GDE clusters where pesticide is likely to reach groundwater.

Region	Total # GDE Clusters	Agricultural Pesticide Threat Identified*		Metolachlor		Terbacil		Bentazon		Metribuzin		Atrazine		Carbofuran		Simazine		Ethoprop		Methomyl		Nicosulf-uron	
		#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Col. Dr.	70	39	*56*	35	*50*	15	*21*	35	*50*	36	*51*	39	*56*	33	*47*	15	*21*	11	*16*	36	*51*	31	*44*
Deschutes	111	68	*61*	14	*13*	21	*19*	27	*24*	68	*61*	62	*56*	61	*55*	7	*6*	3	*3*	33	*30*	4	*4*
JDay	148	32	*22*	2	*1*	0	*0*	2	*1*	32	*22*	6	*4*	32	*22*	0	*0*	0	*0*	2	*1*	2	*1*
Klamath	117	76	*65*	59	*50*	53	*45*	0	*0*	76	*65*	70	*60*	76	*65*	59	*50*	23	*20*	59	*50*	0	*0*
Mal/Owyhee	98	39	*40*	10	*10*	12	*12*	10	*10*	39	*40*	22	*22*	39	*40*	16	*16*	7	*7*	16	*16*	10	*10*
Mid Coast	11	3	*27*	0	*0*	0	*0*	0	*0*	3	*27*	3	*27*	3	*27*	0	*0*	0	*0*	0	*0*	0	*0*
North Coast	14	2	*14*	2	*14*	2	*14*	2	*14*	2	*14*	2	*14*	2	*14*	2	*14*	0	*0*	2	*14*	2	*14*
NE OR	137	56	*41*	23	*17*	45	*33*	23	*17*	56	*41*	45	*33*	46	*34*	48	*35*	0	*0*	48	*35*	0	*0*
OR B&R	209	154	*74*	3	*1*	28	*13*	3	*1*	154	*74*	74	*35*	154	*74*	41	*20*	0	*0*	41	*20*	3	*1*
Powder/ Burnt	44	28	*64*	19	*43*	19	*43*	19	*43*	28	*64*	20	*45*	28	*64*	19	*43*	12	*27*	19	*43*	15	*34*
Rogue	70	37	*53*	32	*46*	24	*34*	29	*41*	37	*53*	33	*47*	37	*53*	26	*37*	0	*0*	32	*46*	29	*41*
South Coast	11	8	*73*	7	*64*	4	*36*	7	*64*	0	*0*	7	*64*	1	*9*	4	*36*	0	*0*	4	*36*	6	*55*
Umpqua	18	4	*22*	1	*6*	1	*6*	1	*6*	4	*22*	4	*22*	4	*22*	1	*6*	0	*0*	1	*6*	1	*6*
Willamette	101	65	*64*	54	*53*	48	*48*	54	*53*	65	*64*	65	*64*	63	*62*	39	*39*	37	*37*	54	*53*	54	*53*
Statewide	**1159**	**611**	***53***	**261**	***23***	**272**	***23***	**212**	***18***	**600**	***52***	**452**	***39***	**579**	***50***	**277**	***24***	**93**	***8***	**347**	***30***	**157**	***14***

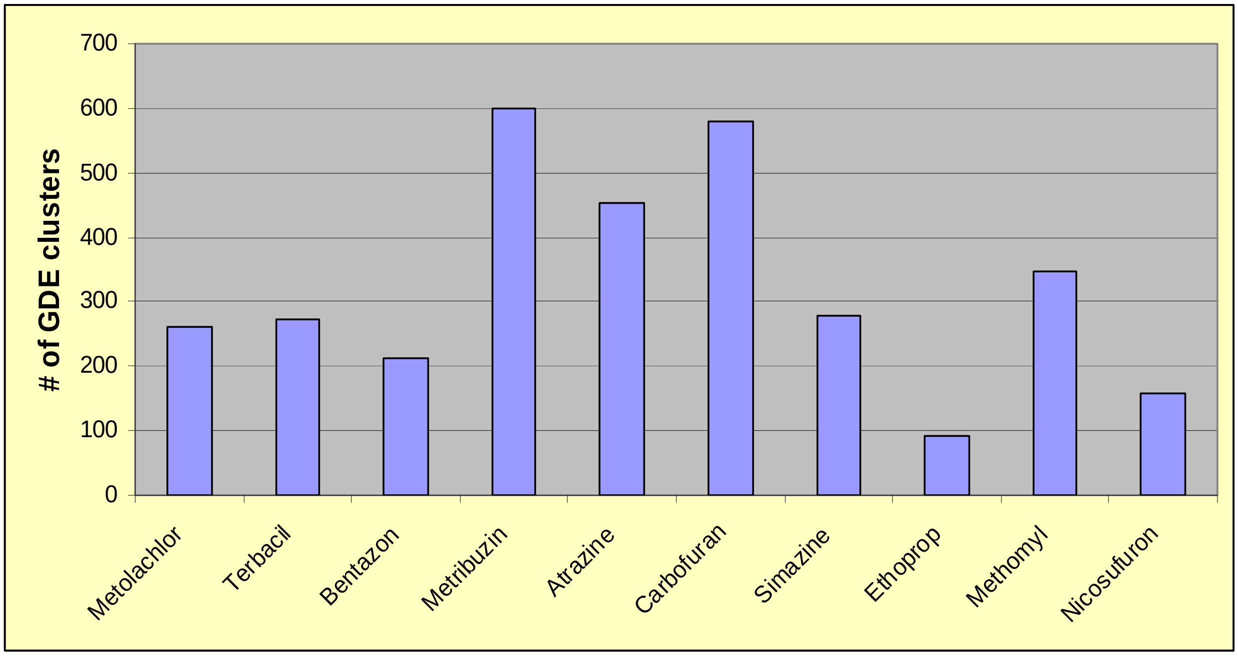


Figure 13: Number of GDE clusters in which each pesticide poses a threat

4.4.4 Threat of groundwater contamination — Other toxic contaminants

To identify areas threatened by groundwater contamination with toxic contaminants, we used the occurrence of four risk factors within 0.8 km (0.5 miles) of a GDE (See Table 8 and Section 3.2.2.4). The risk factors are leaking underground storage tanks (LUSTs), Underground Injection Control wells for non-septic waste disposal (UICs), active hazardous waste spills, and specific land uses where the risk of spills or contaminant leaching is high (e.g., PERC from dry cleaners, petroleum products from gas stations and heavy metals from mines; see Table 7).

Table 30: Number and percentage of GDE clusters with the threat of groundwater contamination by other toxic contaminants. Leaking underground storage tanks (LUSTs), Underground Injection Control wells (UICs), hazardous waste spills (HW Spills), and specific land uses (gas stations, dry cleaners, airports or active mines within 0.8 km of a GDE). See Table 8 for details.
[1]Any one of the four indicators is present.

Region	**Total # GDE Clusters**	**Overall Contamination Threat[1]**		**LUST**		**UIC**		**HW Spills**		**Specific Land Uses**	
		#	*%*	#	*%*	#	*%*	#	*%*	#	*%*
Columbia Drainages	70	34	*49*	8	*11*	11	*16*	15	*21*	29	*41*
Deschutes	111	36	*32*	2	*2*	9	*8*	13	*12*	24	*22*
John Day	148	36	*24*	2	*1*	0	*0*	5	*3*	35	*24*
Klamath	117	37	*32*	4	*3*	4	*3*	20	*17*	26	*22*
Malheur/Owyhee	98	20	*20*	1	*1*	1	*1*	4	*4*	17	*17*
Middle Coast	11	7	*64*	4	*36*	1	*9*	5	*45*	7	*64*
North Coast	14	14	*100*	6	*43*	2	*14*	11	*79*	12	*86*
Northeast OR	137	34	*25*	5	*4*	4	*3*	14	*10*	31	*23*
OR Basin and Range	209	48	*23*	3	*1*	1	*0*	15	*7*	42	*20*
Powder/Burnt	44	23	*52*	2	*5*	0	*0*	7	*16*	19	*43*
Rogue	70	32	*46*	5	*7*	1	*1*	8	*11*	30	*43*
South Coast	11	7	*64*	2	*18*	2	*18*	6	*55*	6	*55*
Umpqua	18	4	*22*	0	*0*	0	*0*	1	*6*	3	*17*
Willamette Valley	101	53	*52*	30	*30*	23	*23*	30	*30*	42	*42*
Statewide	**1159**	**385**	***33***	**74**	***6***	**59**	***5***	**154**	***13***	**323**	***28***

Across Oregon, 385 (33%) of the GDE clusters are at risk for groundwater contamination by toxic contaminants. More than half of GDE clusters are at risk in the Coast, Columbia Drainages, Powder/Burnt and Willamette regions (Table 30). The Willamette Valley has the highest number of GDE clusters in which LUSTs and UICs occur (Table 30). Multiple indicators of the threat of groundwater contamination by toxic chemicals exist in several parts of the state (Table 30 and Figure 14). Aggregations of GDE clusters containing three or four risk factors are found in the Willamette, Klamath, Northeast Oregon, Columbia Drainages and all Coast regions.

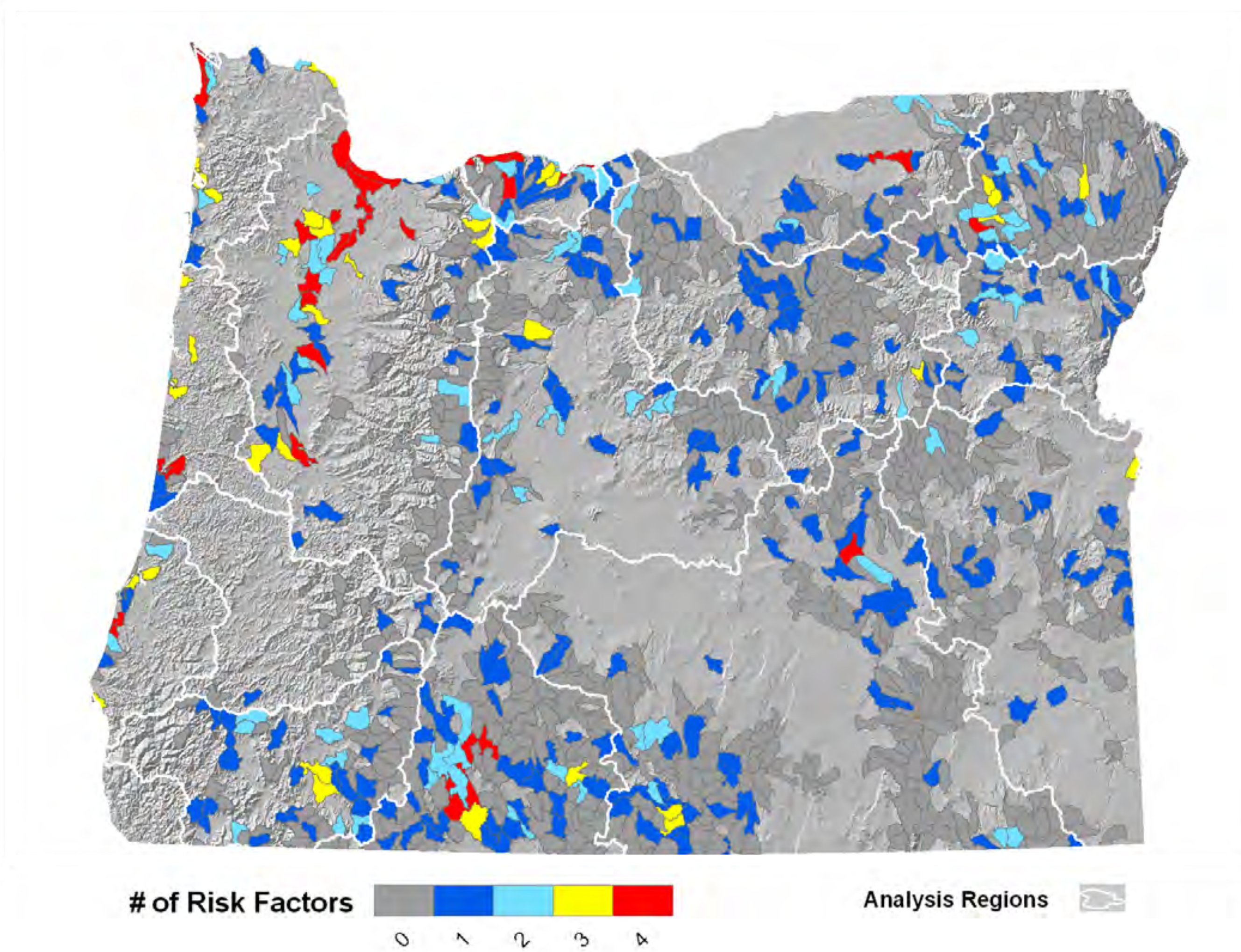


Figure 14: GDE clusters with the threat of groundwater contamination by toxic contaminants. # of Risk Factors refers to indicators defined in Table 8.

The most prevalent indicator of the threat of groundwater contamination by toxic chemicals is the presence of specific land uses in close proximity to GDEs; these land uses are abundant in all regions except the Coast, Umpqua and Malheur/Owyhee regions (Table 30). Of these specific land uses, the presence of mines is the most dominant: a quarter of all GDE clusters in the state (290) contain mines within 0.8 km of a GDE. In the Coast regions, 20 of the 36 GDE clusters (56%) contain mines, as do more than 25 GDE clusters in the Oregon Basin and Range, Columbia Drainages, Rogue, Willamette and John Day regions (Figure 15).

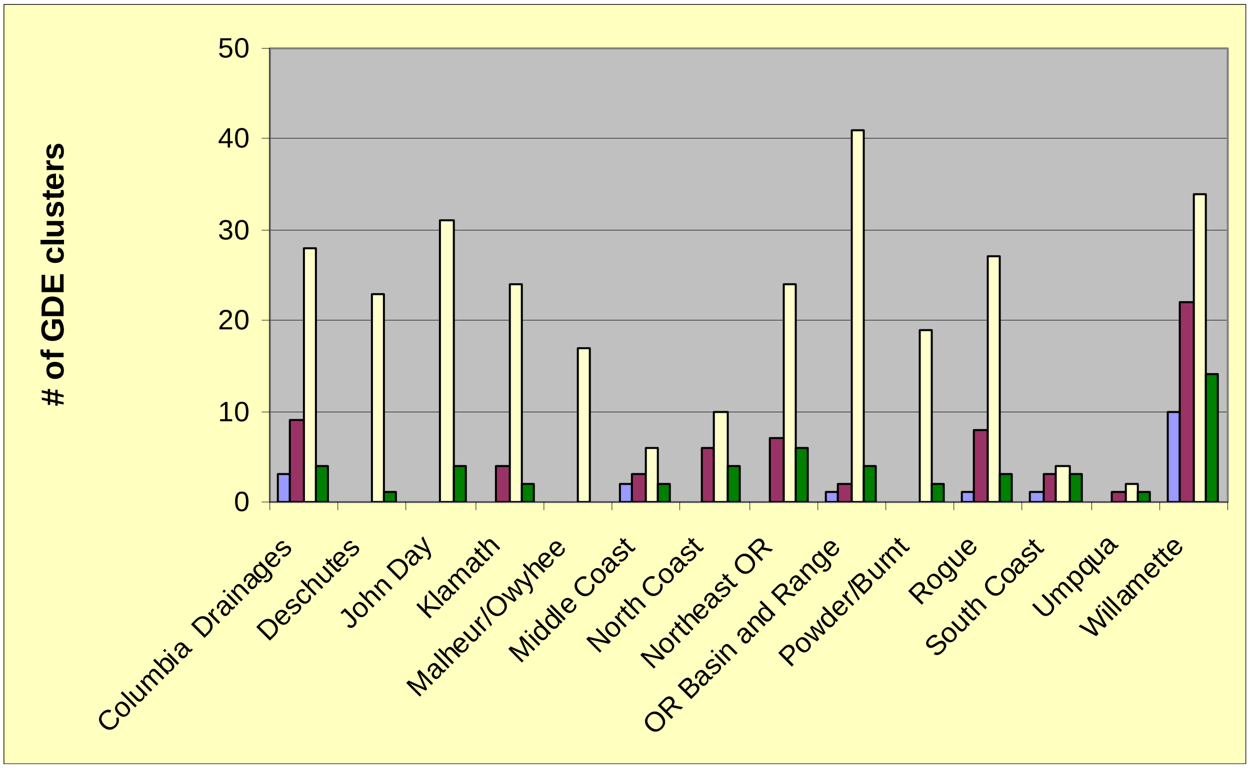


Figure 15: Number of GDE clusters in which dry cleaners (blue), gas stations (red), mines (white) or airports (green) are within 0.8 km of GDEs. No military bases occur in GDE clusters in Oregon.

4.4.5 Threat of altered thermal regime — Hot springs

We evaluated the threat of altered thermal regime to hot springs by assessing the overlap between either known or potential geothermal development areas and the HUC6s that contain hot springs.

Across Oregon, 95 (64%) of HUC6s with hot springs co-occur with known or potential geothermal resources and, therefore, face the threat of an altered thermal regime should extraction of thermal groundwater occur. Although all analysis regions except for the Coast and the Columbia Drainages regions have HUC6s with hot springs that are at risk, most are located in the Willamette, Oregon Basin and Range and Malheur/Owyhee regions (Table 31 and Figure 16).

Table 31: Number and percentage of HUC6s with hot springs identified as at risk for altered thermal regime. Geothermal Resources Present indicates the presence in a HUC6 with a hot spring of either known or potential geothermal resources (Niewendorp et al., 2007).

Region	**# HUC6s with Hot Springs**	**Geothermal Resources Present**	
		#	**%**
Columbia Drainages	1	0	*0*
Deschutes	11	4	*36*
John Day	9	2	*22*
Klamath	12	6	*50*
Malheur/Owyhee	32	20	*63*
Middle Coast	0	0	*0*
North Coast	0	0	*0*
Northeast OR	10	6	*60*
OR Basin and Range	44	37	*84*
Powder/Burnt	8	4	*50*
Rogue	7	2	*29*
South Coast	0	0	*0*
Umpqua	1	1	*100*
Willamette	14	13	*93*
Statewide	**149**	**95**	***64***

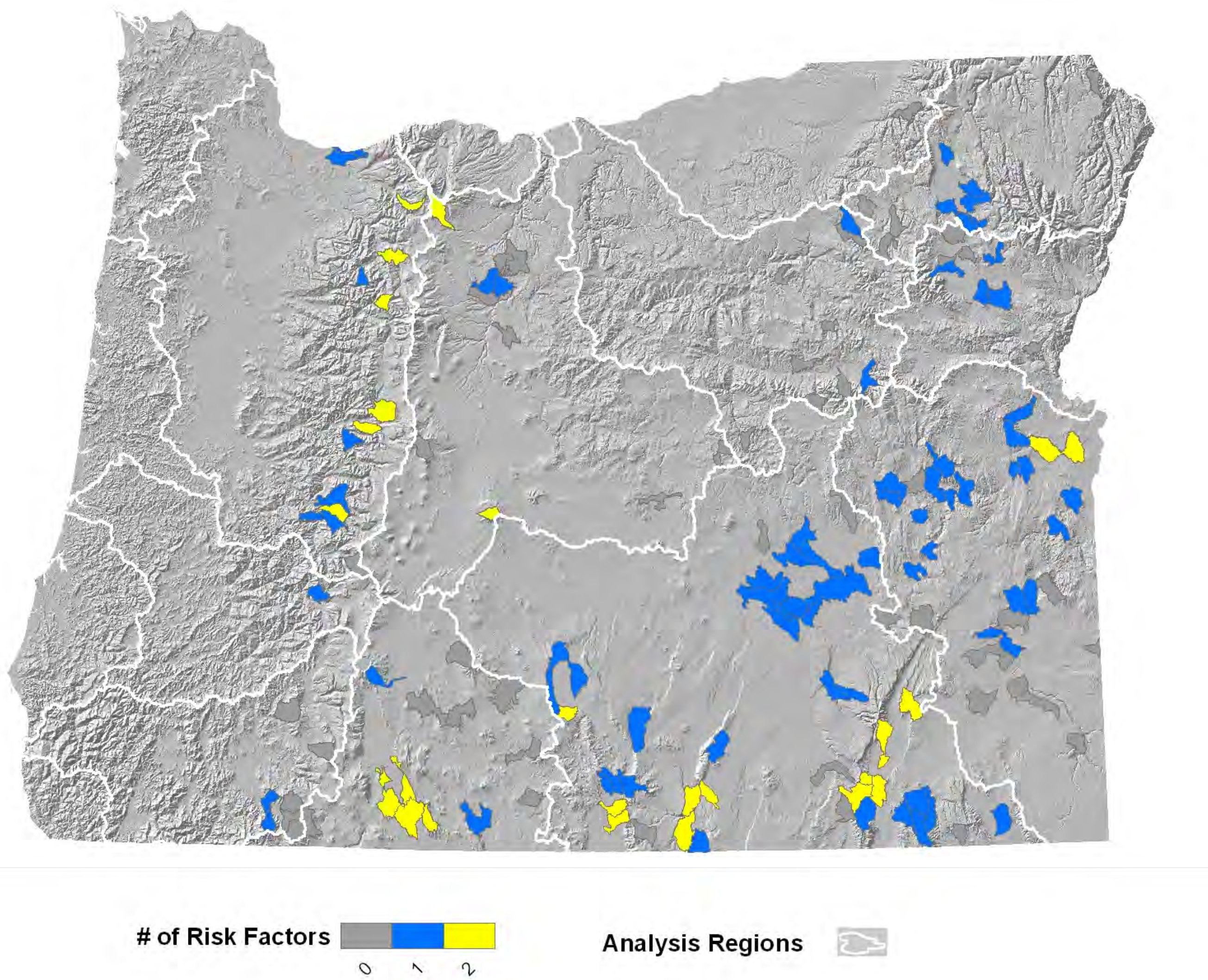


Figure 16: HUC6s with hot springs and the threat of altered thermal regime from potential geothermal development. Indicators defined in Table 9.

5.0 Discussion:

5.1 Summary

The goal of this assessment was to identify where in Oregon groundwater is important for the conservation of ecosystems and species and to understand the types and locations of threats to groundwater quantity and quality in these areas. The results will help in prioritizing areas for conservation of groundwater-dependent biodiversity and guide the development of targeted conservation strategies to reduce risks to groundwater quantity and quality.

Groundwater-dependent ecosystems and species (GDEs)

Ecosystems and species that depend on groundwater occur throughout the state, even in some areas where groundwater was not previously thought to be an important source of water to plants and animals. A total of 1159 (37%) of the watersheds (HUC6s) in Oregon contain two or more GDEs (Table 11 and Figure 4), referred to as *GDE clusters* in this report. Moreover, there are some parts of the state, including the crest of the Cascades and the Klamath, Oregon Basin and Range and Northeast Oregon regions, with high densities of GDE clusters. For these key areas, the way in which groundwater is managed will have significant implications for the health, survival and persistence of these biological communities over time.

Threats to groundwater availability

Several regions of the state are at risk for potential declines in water table levels and in the volume of groundwater discharging to aquatic ecosystems due to groundwater withdrawal. The Columbia Drainages, Klamath, Willamette and Oregon Basin and Range regions all have high densities of existing large (e.g., agricultural, industrial and municipal) wells, which we used as an indicator of potential reductions of water quantity. In addition, both the Willamette and Columbia Drainages have substantial declines in water table elevations in areas where GDEs occur. In general, these four regions, plus the Deschutes and Northeast Oregon regions, face threats from future development of large wells, as indicated by the number of pending groundwater rights applications. These areas would benefit from focused efforts to understand the ecological implications of existing and future groundwater withdrawal.

This assessment also highlights key parts of the state where efforts to manage small domestic wells to protect GDEs are warranted, and where further investigation of the relation between domestic well management and biodiversity would be beneficial. Groundwater use from domestic wells currently presents a threat to many GDE clusters in the Willamette and Rogue regions, and future population growth predictions suggest the risk will grow in these parts of the state. The Deschutes and Columbia Drainages are expected to see increased pressure from domestic wells in the future.

Threats to groundwater quality — Nutrients

The biogeochemical processes governing the movement and concentration of nutrients (nitrate and phosphorus) in groundwater and its discharge to aquatic ecosystems are fairly complex and depend on site-specific conditions, such as the length of groundwater flowpaths, substrate composition and water table levels. However, fertilizers and human and animal waste are the key sources of nitrate contamination of groundwater, and fertilizers are the primary source of phosphorus contamination. Through this assessment, we located the areas of the state with the greatest threat of nutrient contamination and identified the types of land use activities that create that threat.

Existing data indicate that nutrient contamination of groundwater is currently occurring in the Willamette region, in the Columbia Drainages region near Hood River and Pendleton, and in isolated areas of eastern Oregon and along the coast. The threat to GDEs of groundwater contamination by nitrate is significant in every region, except the Malheur/Owyhee, Oregon Basin and Range and Umpqua regions. A number of indicators were used to locate these threats. UICs (Underground Injection Control sites) for wastewater disposal are of concern in the Willamette region, where a third of GDE clusters are threatened, and in the Middle and North Coast where more than 60% of the 25 GDE clusters in these regions are threatened. CAFOs (concentrated animal feeding operations) are of concern in the Willamette and in the North Coast regions. High septic system density is more pervasive in rural areas and poses a risk to groundwater in the same areas where domestic wells are an issue — the Willamette, Rogue and Coast regions. UICs, CAFOs and some septic system concerns are being addressed through current policies and regulations, but few of these consider potential effects to GDEs. Agricultural fertilizer use poses a threat of groundwater contamination by both nitrates and phosphorus in the Willamette, John Day and Columbia Drainages regions. Urban use of fertilizers is also worth noting as a threat that exists in every region of the state. Our work suggests further evaluation of the relation between fertilizer use in urban and agricultural areas and GDEs is warranted in several parts of the state to better understand where efforts should be focused to reduce or alter fertilizer use.

Threats to groundwater quality — Pesticides

Groundwater contamination by pesticides is of growing concern among water managers and regulators charged with protecting drinking water supplies. Studies often note that pesticides detected in groundwater have concentrations that fall below the threshold for human consumption (e.g. Gilliom et al., 2006; Selker, 2004). However, toxic and even lethal effects to aquatic biota often occur at concentrations much lower than those required to produce human health effects (Gilliom et al., 2006). Our work highlights the pesticides of greatest concern to GDEs and the areas of the state where the risk of groundwater contamination is highest.

Known instances of groundwater contamination by pesticides in GDE clusters are concentrated in the Willamette Valley and the Columbia Drainages. We identified a threat of pesticide groundwater contamination where two or more mobile pesticides were used in GDE clusters, indicating an increased potential of the chemicals moving to groundwater. This threat was identified in more than half of the GDE clusters in Oregon. Only two regions stand out as having a fairly low risk to GDEs from pesticides in groundwater: the Umpqua and John Day regions. All other regions have either a large number of GDE clusters at risk (e.g., up to 147 in the Oregon Basin and Range) or a high percentage of GDE clusters at risk (e.g., 100% of the 14 GDE clusters in the North Coast region).

The results of this analysis help identify pesticides that may not be sufficiently regulated. Many of the chemicals we evaluated pose a risk to both aquatic ecosystems and human health. This suggests that including the potential effects of pesticides on GDEs in decisions regarding the type and location of pesticide use may be important. However, our selection of pesticides for analysis was limited by the availability of data showing the locations of use, therefore there may be additional pesticides that should be included in future assessments.

Threats to groundwater quality — Other toxic contaminants

We assessed the threat of groundwater contamination by toxic contaminants other than nutrients and pesticides, such as PERC (used in dry cleaning operations) and petroleum products. The threat was assessed by evaluating the proximity of GDEs to land uses often associated with chemical spills: leaking underground storage tanks, Underground Injection Control wells, hazardous waste spills, and specific industries including gas stations, dry cleaners, airports and active mines. The threat of groundwater contamination by toxic contaminants was significant for a large number or a high percentage of GDE clusters in all regions of the state except for the Umpqua and Malheur/Owyhee. Mines were the most prevalent industry posing a threat in many regions of the state, suggesting it may be useful to examine this issue more closely to understand where hard rock mines with potentially toxic ore extraction processes are located relative to GDEs. Dry cleaner locations are close to GDEs in a number of watersheds in the Willamette Valley. Alternatives to PERC, a particularly persistent groundwater contaminant, exist and are used by some dry cleaning operations.

Threat of altered thermal regime

Development of geothermal resources has the potential to alter the thermal regime of hot springs and to affect their groundwater-dependent species. This is currently an issue in some parts of the state, but with the push toward development of alternative sources of energy, the future threat could increase significantly. Predicting the effects of geothermal development on a specific hot spring requires a site-level study. Our results suggest that there are key areas in the state — primarily in eastern Oregon, but also in the Willamette region — where development of geothermal energy should be evaluated in relation to effects on GDEs.

5.2 Next steps

A key objective of this assessment was to increase awareness of the ecological importance of groundwater and to provide information so that groundwater management decisions can address both human and ecological groundwater requirements, many of which overlap. We will use the findings in this report to promote water management in Oregon that includes groundwater requirements of GDEs. We also plan to deepen our understanding of the ecological requirements of groundwater. To advance that latter goal, we are working with the U.S. Forest Service to develop protocols for quantifying the environmental groundwater requirements of fens and springs and answer the question, How much water does a fen or spring need to remain ecologically healthy? Additionally, we have started to evaluate the degree of overlap between protecting groundwater quality for drinking water and protecting it for GDEs. Our understanding of the importance of and threats to GDEs across the Pacific Northwest will be broadened as we extend the analysis summarized in this report to Washington state. Future areas of work will likely be site-specific efforts to understand more clearly the link between GDEs and groundwater extraction in areas of high groundwater pumping and to begin focusing on how the groundwater contamination threat posed by specific land use activities can be reduced in areas of the state where our conservation work is ongoing.

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