Analysis of Future Land Use Conflict with Volcanic Hazard Zones Mount Rainier, Washington

By

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To my sister, parents, and grandparents

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List of Abbreviations

AHP	Analytical Hierarchy Process
CMUA	Complex-Multi Utility Assignments
GIS	Geographic information system
LUCIS	Land Use Conflict Identification Strategy
MUA	Multiple Utility Assignments
SUA	Single Utility Assignments
UGB	Urban Growth Boundary
USGS	United States Geological Survey

Abstract

The population of the State of Washington is growing rapidly, especially in areas surrounding Seattle and Tacoma. The population in 2010 was reported as 6.7 million and is projected to be 9.9 million by 2060, an anticipated growth rate of approximately 50%. This population growth leads to increased development in the suburbs of major cities and towns, causing urban sprawl. Washington State is also home to seven active volcanoes, all within 100 miles of major cities. As urban sprawl occurs, development extends into areas adjacent to volcanoes. Due to these trends it is important to understand the location and size of future development of the region for decision-making and hazard mitigation. This study focused on the region surrounding Mount Rainier, as it is the volcano closest to Seattle and Tacoma. A land use change analysis must be performed to assess how urban development could be impacted by volcanic hazards. This study uses the Land Use Conflict Identification Strategy (LUCIS) model created by Carr and Zwick (2007) to visualize potential land use in conflict with volcanic hazards. Potential future allocation of conservation, agriculture, and urban land use was determined using economic, transportation, physical geography, agricultural, and biological data. Results show that urban land is most suitable in areas near existing urban areas in the western portion of the study area. Agriculture lands are most suitable through the central portion of the study area and conservation land is suitable in the majority of the study area. Future land allocated to urban land exceeds the number of acres required to sustain the future population, by pushing into the agriculture land while conserving more lands suitable for conservation. Urban cells affected by a volcanic eruption of Mount Rainier have the potential to double with new development. This study creates a visualization of where developers can plan for the future while limiting the impact of volcanic hazards on humans and their property.

Chapter 1 Introduction

Washington State's population is projected to add 3.2 million new residents by 2060, an increase of 50% of the 2010 population. As population increases, land use for the state must change. This research visualized how land use surrounding Mount Rainier might change by the year 2060. As development continues, it encroaches on seven active volcanos in Washington and their hazards. Determining locations of high-risk volcanoes and their potential risks is key to recognizing whether or not there is danger present in developed areas. Potential conflicts for development can be seen by combining a future land use map and volcanic hazards.

This study focused specifically on the urban area surrounding Mount Rainier, Washington. This study used the Land Use Conflict Identification Strategy (LUCIS), created by Carr and Zwick (2007), to determine potential future urban land in conflict with Mount Rainier volcanic hazards and to quantify potential future agriculture and conservation land use. LUCIS uses Model Builder in ArcGIS to identify suitable lands for urban, agriculture, and conservation land use for the future. Once these were identified, the model continued to allocate future land use based on the projected population and acreage required per person (Carr and Zwick 2007).

1.1 Motivation

In 2013, there were 30 eruptions around the globe, three of which were in the United States. There are 57 active volcanoes in the contiguous United States, seven of those are located in the state of Washington (Smithsonian Institute 2015). Five of those seven volcanoes are considered to have a high threat potential. The "high" threat potential rating was determined by the eruption history and the proximity to population centers, using a national volcanic early warning system (USGS 2015). These volcanoes are Glacier Peak, Mount Adams, Mount Baker, Mount Rainier, and Mount St. Helens. Mount St. Helens was the most recent volcano to erupt, in 1980. It is within 100 miles of Seattle, Washington's biggest city, and therefore may have a significant effect on urbanized land.

According to the United States Census Bureau, the population in Washington is expected to rise from approximately 6,700,000 to 9,900,000 by 2060, just shy of a 50% population increase (Proximity 2014). Additionally, the population density is expected to rise from 101.2 people/miles^2 in 2010 to 148.9 people/miles^2 in 2060 (U.S. Census Bureau 2013). Urban development must continue in order to keep up with demands associated with population growth. Grass, agriculture, and forested areas are being destroyed in order to build more urban areas. As a result development is extending into canyons, which are in the path of volcanic hazards (Hepinstall-Cymerman, Coe, and Hutyra 2013). This issue will become even greater as population continues to grow, leading to the possibility of more property damage and death.

As population growth continues, so does urban development of major cities and suburban areas. This type of development is considered urban sprawl; notably, sprawl can often grow at a faster rate than the population growth. One key issue with urban sprawl is the loss of agriculture, wetlands, and forests (Robinson, Newell, and Marzluff 2005; Azuma, Thompson, and Weyermann 2013; Hepinstall-Cymerman, Coe, and Hutyra 2013). This issue pertains to this study because of the possible proximity of this development to the volcanoes. Each volcano is dominantly surrounded by both public and private forests (Washington State Department of Ecology 2011). Risk increases as urban sprawl causes development along the perimeters of these forests.

Robinson, Newell, and Marzluff (2005) conducted research on the urban sprawl seen due east of Seattle, Washington. They digitized land use based on five classifications using black-and-white aerial photography from 1974 and 1998. The five classifications are: urban, suburban, rural, exurban, and wildlands. Urban land was defined as having high building density whereas suburban lands had moderate building density with the presence of lawns and vegetation. Both rural and exurban lands had relatively low building density however rural lands were surrounded by agricultural land whereas exurban lands are surrounded by forest. Wildlands were primarily forests with an occasional building. A map was created for the two time periods using the definitions of land type and compared. Over those 24 years, wildlands and rural lands decreased by 19% and 65% respectively, indicating a strong sense of growth and development. The sprawl was determined for the study area by comparing aerial imagery over a series of years.

Azuma, Thompson, and Weyermann (2013) studied the issue of development in the proximity of public forest land in Oregon and Washington. Roughly 44,000 points were selected from a photo-interpreted grid to represent land outside of the federally owned forests. The points and 80-acre buffers were compared using images from 1976, 1994, and 2006. A point was left out of the study if it fell within an urban area. Structures within 1 km of public forests doubled from the 1970s to mid-2000s. This study again demonstrates the success of comparing change through satellite imagery.

Hepinstall-Cymerman, Coe, and Hutyra (2013) focused their attention on urban growth along the Central Puget Sound, Washington, which is relatively close to the study area of this project. Images from 1986, 1991, 1995, 1999, 2002, and 2007, both with foliage on and off, were used to construct 14-class land cover maps. These maps were compared on a pixel-by-pixel scale in order to determine the land cover change. The number of pixels was calculated to determine the area of the urban class in each time period and then compared. Comparisons were completed with respect to the urban growth boundaries (UGB), a boundary put in place to regulate development. Urban land use within the UGB increased by 65.9% and outside increased by 289%. The most important factor for this study is that 10.5% of the area outside of the UGB was in the Cascade Range. People are still developing in this region despite it being extremely rugged and forested lands. The potential risks associated with an eruption increase with this encroachment into the Cascade Range.

1.2 Study Area

Washington State has steadily grown since 1990 by roughly 1 million people every 10 years. The population was approximately 4.9 million in 1990, 5.9 million in 2000, and 6.7 million in 2010 (U.S. Census Bureau 2013). From 1990 to 2008, net migration was the leading cause for population growth, constantly rising and falling but staying above natural increase. From 2008 to 2011 net migration into the state of Washington decreased dramatically, however in 2011 began to increase again, surpassing natural increase in 2013. The western portion of Washington is experiencing a greater percentage of change than the eastern portion, 1.5% to 0.8% respectively. This study focused on four counties located in western Washington (King, Lewis, Pierce, and Thurston) all which experienced growth from 2010 to 2015. King County grew the most in the state followed by Thurston, Pierce, and Lewis (1.76%, 1.29%, 1.07%, and 0.47% respectively) (State of Washington 2015).

Washington State is composed of a wide variety of geologic settings grouped together in eight different physiographic provinces (Figure 1): 1) Okanogan Highlands, 2) Columbia Basin,

3) Cascade Range, 4) Puget Lowland, 5) Olympic Mountains, 6) Willapa Hills, 7) Blue Mountains, and 8) Portland Basin. Volcanic rocks and deposits are consistently found throughout the state. Volcanic rocks are found in the Okanogan Highlands, the Cascade Range, the Puget Lowland, the Willapa Hills, and the Portland Basin (Moses 2013). Although the majority of Washington has volcanic rocks, active volcanism occurs in the Cascade Range.

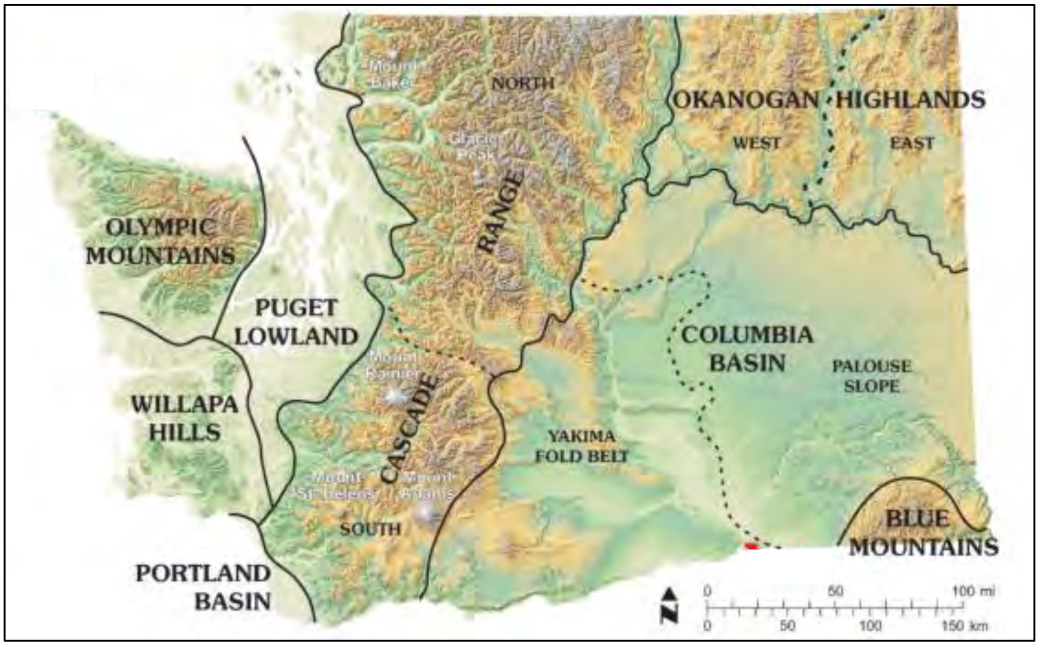


Figure 1: Physiographic provinces of Washington State. Subprovinces are separated by dashed lines.

Subduction of the Juan De Fuca plate under the North American plate created the Cascade Range, located from northern California into British Columbia. The Cascade Range first became apparent about 36 million years ago, however major volcanic centers became apparent within the last 1.6 million years. This volcanic chain has been erupting for the last 5 million years with over 3,000 eruptions (USGS 2014). As the Juan De Fuca plate subducts below the North America plate, temperature and pressure increase causing the mantle to melt. Overtime this magma rises to the surface and eventually leads to an eruption. Stratovolcanoes are created in subduction zones causing extremely violent eruptions.

Mount Rainier is located in the southern Cascade Range (Figure 2) 54 miles south-southeast of Seattle and 38 miles southeast of Tacoma. Seattle is the largest city in Washington State with a population of almost 670,000 and Tacoma is third with a population of 205,000 (U.S. Census Bureau 2015). Mount Rainier is the highest mountain in the Cascades, soaring over the valleys at an elevation of 14,410 (Driedger and Scott 2008).

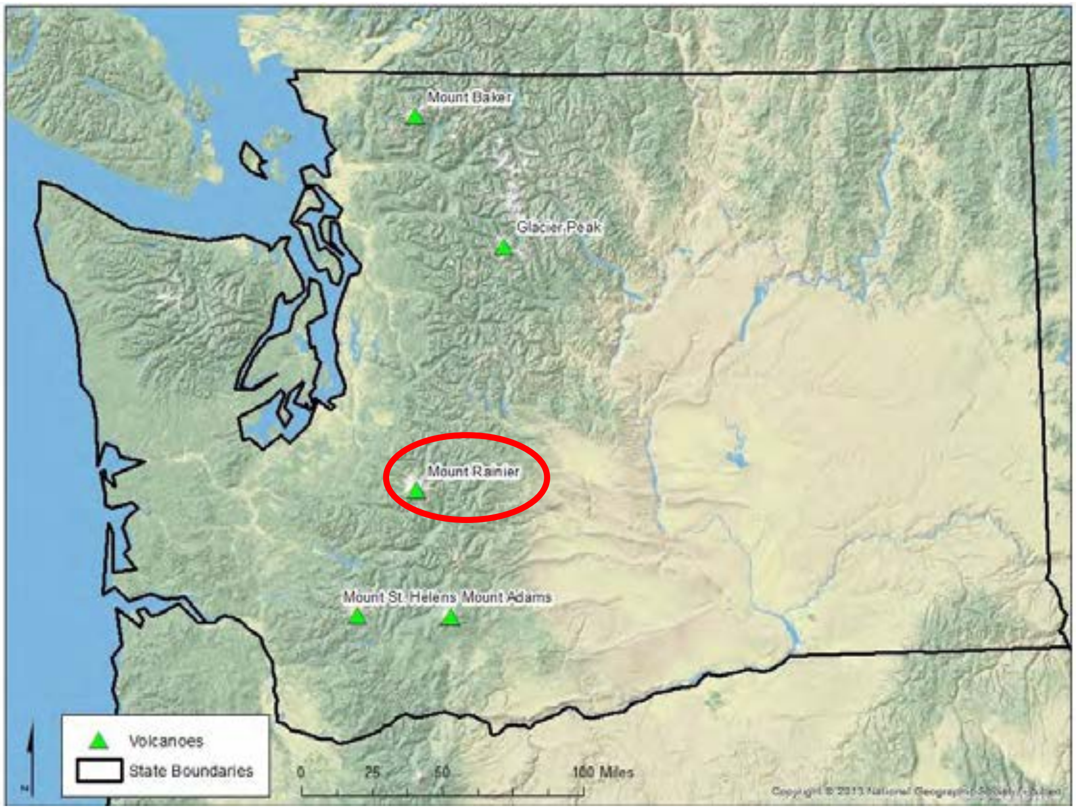


Figure 2: Location of high risk volcanoes in Washington State. Mount Rainier seen in the southern half of the state, circled in red.

The hazards associated with Mount Rainier include, but are not limited to, tephra fallout out, debris flows, pyroclastic flows, and lahars. A hazard map produced by the U.S. Geological Survey (USGS), seen in Figure 3, demonstrates that lahars have the potential to flow all the way into Tacoma with subsequent flooding into Seattle. The hazards in extreme proximity to Mount Rainier include the pyroclastic, lava, and debris flows. The pyroclastic and lava flows are seen in green and the debris flows are in red. The lahar flows are seen in yellow, flowing outwards from Mount Rainier. The purple area represents flooding caused by lahars and post-lahar sedimentation.

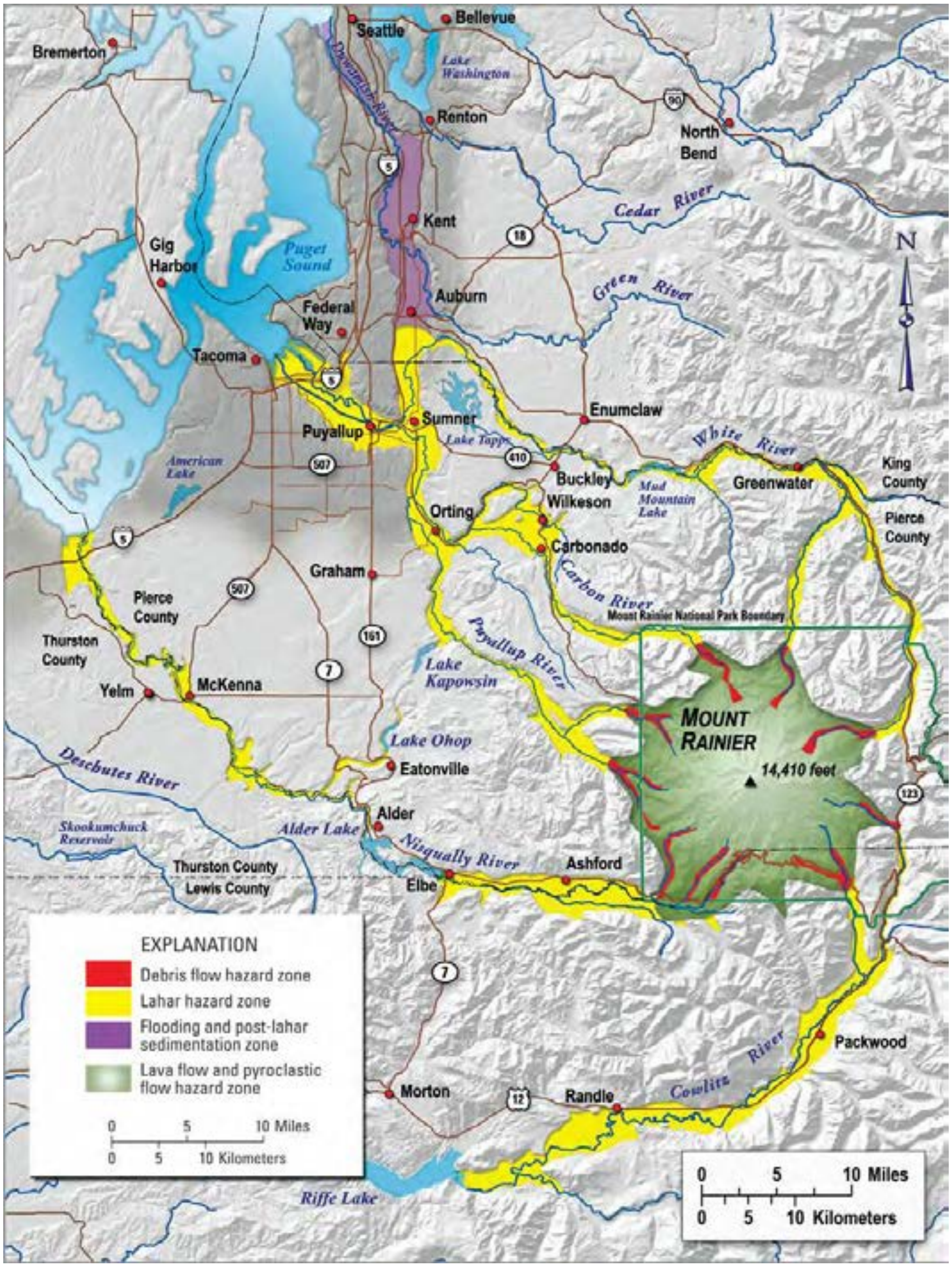


Figure 3: Hazard map for Mount Rainier (Driedger and Scott 2008)

Lahars are the most dangerous hazard for people and existing development associated with Mount Rainier because they have the potential to flow through many populated and developed regions. Portions of the developed valleys surrounding Mount Rainier have been built on previous lahars, which reached speeds of 50 miles per hour and were as thick as 100 feet (Driedger and Scott 2008). It is key to understand what impacts these volcanic hazards pose on the location of potential future development because of the predicated population growth and development.

1.3 Research Questions

The primary objective of this research was to determine potential conflicts between urban development and the hazards associated with Mount Rainier. In order to determine this, a series of steps were required, each having their own questions. The four research questions were: 1) Where are the volcanic hazards around Mount Rainier? 2) What lands in this area are most suitable for urban development? 3) How is the urban growth around Mount Rainier likely to change by the year 2060? and 4) Where are the potential conflicts present between volcanic hazards and potential urban development around Mount Rainier?

Questions two and three were answered using an adaptation of the LUCIS model. The results from questions three and four can help with future development. This study will allow individuals to make better-informed decisions on where they choose to live and what type of insurance they may need.

1.4 Implementation of LUCIS Model

LUCIS is a goal oriented ArcGIS model using a variety of datasets to determine the lands most suitable for conservation, agriculture, and urban land use. Datasets include economic data, current land use data, transportation, schools, hospitals, lakes and streams, flood zones, biological data, and agricultural assessments. These datasets were implemented into models through a series of goals and objectives, creating suitability maps. After suitability maps were created they were used to make preference maps, a conflict map, and the potential future basemap. The LUCIS model follows a six-step procedure, beginning with the creation of goals and objectives and ending with the conflict map. This research went a step further by comparing the future basemap with the presence of volcanic hazards. The goals, objectives, and subobjectives are discussed further in Chapter 3, with the discussion of the methods.

1.5 Thesis Organization

This thesis is organized into chapters, each focuses on specific aspects of the research. Chapter 2 focuses on relevant research that was used as the base of this study. The research pertains to urban growth models and studies completed using the LUCIS model. Chapter 3 explains the methodology used to complete this study, which includes the goals and objectives used, data requirements, and how this adaptation of the LUCIS model was built and used. Chapter 4 explains the results from this study. The suitability maps for each land type, (conservation, agriculture, and urban), preference maps, conflict maps, and the basemap are included in the results. Chapter 5, the final chapter, is composed of the conclusions, limitations, and possible future work on this subject.

Chapter 2 Related Work

GIS benefits many fields of study, including land use change, by incorporating spatial analysis. As long as GIS continues to develop, the models used to determine future land use and map urban sprawl will as well. This chapter introduces urban growth and some of the environmental issues it is creating. This chapter also summarizes a few of the many models available to map urban growth and potential land use change. Finally, this chapter reviews studies that use the LUCIS model to develop the methodology used in this project.

2.1 Urban Growth

As the world-wide population continues to grow, surpassing 9.5 billion by 2050 (United Nations 2013), subsequently as do urban centers in order to accommodate the new population. Development is occurring around the edges of cities and into more rural areas due to the density within existing cites. This type of development is called urban sprawl. The Sierra Club describes urban sprawl as low-density development outside of the current employment and service boundary, causing a separation of where individuals work and live (Johnson 2001). More individuals rely on automobiles for transport from their homes to work as the separation increases. Automobile usage increase is just one of the many environmental impacts caused by urban growth. Additional environmental impacts are loss of agricultural land, native vegetation, and open space, and ecosystem fragmentation (Johnson 2001).

There are two types of development that have an impact on agricultural growth, along the urban fringe and outside of the urban fringe (Heimlich and Anderson 2001). The development along the urban fringe impacts agriculture by building on those open lands close to major cities. Although this might not have a huge impact at first, there is an edge effect that occurs and the urban fringe will eventually become part of new urban center. This will cause the new urban fringe to impede even further into agricultural lands. Growth outside of the urban fringe is considered to be randomly scattered homes. Although this does not have a major impact on the overall region, development removes land from agricultural production and alters the open space. Between the years of 1994 and 1997 this type of development made up almost 2 million acres of land loss in the United States (Heimlich and Anderson 2001).

Another issue associated with urban growth is developing in regions that are susceptible to natural hazards. Although many major cities are currently built in areas of natural hazards, mitigation plans have been put in place. However, as the population continues to grow, urban vulnerability increases dramatically, especially in Seattle and Tacoma where development may start to encroach on volcanic hazards zones. Urban vulnerability is increasing dramatically in cities and will continue to if no development restrictions are put in place (Brauch 2003). By modeling potential conflicts between future urban development and volcanic hazards, actions can be taken to minimize urban vulnerability.

2.2 Urban Growth Models

Many models have been created to visualize the change in urban growth over time. As seen in the Motivation section of Chapter 1, a key issue with urban growth is the loss of agriculture and conservation lands, particularly forest lands. In order to estimate how land use is going to change over time, a GIS model may be useful. Many developed models use GIS to identify how land use is changing over time. Models incorporate current land use, current trends, and potential growth trends to determine future land use. The following sections summarize land use change models available to determine potential future land use change. Research was conducted on different land use models to discover which model would best answer the research questions for this project. The model should use current data, take into consideration the future population, and the effect urban development has on agricultural and forested land.

2.2.1. SLEUTH Model

The SLEUTH model is a simulation modeling used to show urban growth. The name is derived from the input layers used (Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade) (Jantz, Goetz, and Shelley 2003; Chaudhuri and Clarke 2013). SLEUTH is a cellular automata model that captures four types of growth: spontaneous growth, diffusive growth, edge growth, and influenced growth (Verburg, et al. 2004). Spontaneous growth shows a random urbanization based on pixels. Diffusion, or new spreading center growth, creates new urbanizing centers from two neighboring cells that come into contact with a new urbanized cell. New centers can then go through edge growth which is controlled by the spread coefficient. Growth starts along the edge of the centers and continues out in a radial fashion. The last type of growth is influenced growth which shows the growth caused by transportation (Jantz, Goetz, and Shelley 2003).

There are two phases to this model, calibration and prediction. Calibration requires at least 4 years of historical urban data, two historical transportation networks, a slope, and an exclusion layer (i.e. water). The Monte Carlo method was used to derive growth parameters that represent the change during the historical time periods. Prediction requires an urban extent, transportation network, excluded layer, slope, and hillshade. Combining this data creates probability images showing urban extent and types/areas of land cover change (Jantz, Goetz, and Shelley 2003).

2.2.2. SERGoM

The Spatially Explicit Regional Growth Model (SERGoM) uses accessibility to urban and protected lands to relate historical growth patterns and forecasts landscape patterns. Theobald (2005) used the SERGoM to show the landscape patterns of exurban growth in the USA. This is done on a decade scale and can be applied to multiple decades. The most important dataset for the SERGoM is the population per housing unit ratio and housing density. There are three steps to performing a forecast in SERGoM. These are: 1) The number of new housing units must meet the demands of the projected population level, 2) An average growth rate must be calculated from two past times, and 3) The new housing density must be added to the old to show the increase overtime. This model shows where sprawl is likely to occur in the future. Unfortunately, this model does not show change in land use, which is a key aspect of this project.

2.2.3. Land Transformation Model (LTM)

The Land Transformation Model (LTM) was created by Pijanowski, Gage, and Long (2000) to determine land use change for a region. This model is partnered with an artificial neural network (ANN) in order to forecast land use change. The ANN finds patterns in complex images and uses those patterns as a projection of future patterns. Pijanowski, et al. (2002) use LTM and ANN in a study to determine land use change in Grand Traverse Bay, Michigan. Base layers, such as roads, rivers, and land use are inputs into the LTM. These are coded to become rasters as either a value of 1= present or 0=absent. Next, four spatial transition rules are applied. 1) neighborhoods or densities; 2) patch size; 3) site specific characteristics; and 4) distance from predicator cell. These all relate to the Euclidean distance between each cell and the predicator cell. Cells are 0 if a transition cannot be found and 1 otherwise. The third step is to create a map of the likelihood change values based on the ANN. The last step is to implement the temporal aspect in one of two ways. The first is assuming the same number of transitioned cells and using historical land use data to create a forecast. The other method of implementation is to use the population growth over a time interval for the region. Per capita requirements for land are determined by combining population and historical land use and can then be applied to the future.

2.2.4. Change and Time Series Analysis in IDRISI

Clark University developed a GIS and image processing software system called IDRISI that completes analysis, image processing, surface analysis, change and time series analysis, modeling, and decision support for development. The change and time series analysis uses many images of a region, over a course of time, to determine how regions have changed. This software allows the execution of many different types of analysis. IMAGEDIFF compares two images with the same variable from different dates. CROSSTAB compares two qualitative images, in this case land cover, from two different years. A new image is created showing if there is change or no change in land cover (Eastman 2001)

While this model primarily focuses on historical land use change it can also produce future change models. Future land cover types are determined by the Markov and STCHOICE models. The Markov model creates a transition matrix, a transition areas matrix, and a set of conditional probability images. The transition matrix is the probability that each land cover will change to any of the other land covers. The transition areas matrix counts the number of pixels that are expected to change from one to another type of land cover. The conditional probability images create the probability of each land cover type changing to any of the others for specific times. This is done at the pixel scale (Eastman 2001).

The STCHOICE model uses a random number generator to determine which pixels are to change from one land type to another. It takes the probability of each land cover changing to the other as in the Markov model and sums the pixels that change. The number of changes must exceed the random number generated to create the final map (Eastman 2001).

A case study on the urbanization of East and West St Paul, Manitoba, Canada used this software. Aerial images from 1960 and 1989 of urban and agriculture land use areas were scanned and digitized. Using these maps, the Markov model created predictions of land use change (Hathout 2002).

2.2.5. LUCIS

The Land Use Conflict Identification Strategy (LUCIS) model focuses on future land use patterns (Carr and Zwick 2005). These patterns are broken into three categories; agriculture, conservation, and urban. A series of six steps are applied to each of the three categories to determine the future potential land use. The six steps are (Carr and Zwick 2005):

1. Define goals and objective.
2. Identify data sources which are relevant to each goal/objective.
3. Analyze data to determine the suitability for each goal.
4. Combine the suitability for each goal to determine the preference.
5. Normalize the preference for each goal into high, medium, or low.
6. Compare ranges of land use preference to determine the conflict.

The goals and objectives, data sources, and suitability are specific for each region and land type. Each objective and goal pair was performed in ArcGIS Model Builder. Once suitable lands for agriculture, conservation, and urban use were determined, they were combined to see where conflicts arise. A conflict occurs if a land supports more than one of the three types of land use. This model would demonstrate areas that are more suitable for urbanization, that are now forest (conservation) or agriculture. Because there are so many forested areas surrounding Mount Rainier, it would be useful for developers to know if these regions are most suitable for urban growth. If this is the case, then extra measures will need to be made to ensure the safety of the residents if an eruption occurs.

This study used the LUCIS model instead of one of the previously discussed models as it includes multiple land types and current data to determine the potential future land use. The LUCIS model uses parameters determined by extensive research and current data as compared to projecting historical patterns into the future. The extensive data used in LUCIS creates the projection of urban, agriculture, and conservation land use change instead of simply urban land use. Finally, the LUCIS model considers how the projected population can impact land use change.

2.3 LUCIS Model Studies

Since LUCIS was developed in 2005, it has been used in many land use change studies due to its ease and versatility. This section reviews the literature used to create the methods section of this project. Carr and Zwick (2005), the creators of LUCIS, used their model to determine the potential future land use conflicts in North Central Florida, a fast growing area. Tims (2009) used LUCIS to model a potential land use development plan for Rwanda, which relies heavily on agriculture for income. Cotroneo (2015) used LUCIS to determine future land use conflicts in Mecklenburg County, North Carolina. This diverse range of locations demonstrates that the LUCIS model can be used for a wide variety of purposes all while using a very similar methodology.

The LUCIS model was first introduced to study land use change in North Central Florida (Carr and Zwick 2005). The initial study area was composed of nine counties: Alachua, Columbia, Bradford, Union, Clay, Putnam, Marion, Gilchrist, and Levy. A recommended step for LUCIS is to create a buffer around the study area to ensure the consideration of enough growth factors. Carr and Zwick (2005) ensured this by placing a 50 mile buffer around the nine counties. The entire analysis was completed in ArcGIS Model Builder and required a cell size of 100 meters to keep the results consistent. Three separate groups of people were created to focus on the different land types. These focus groups conducted extensive research to determine the parameters used in each analysis.

Each of the six steps discussed in Section 2.2.5 were presented in the Carr and Zwick study. The overall goals for urban growth were to maximize opportunities for residential development, retail and office/professional commercial development, and medium and heavy industrial development. Goals for agricultural growth were to maximize opportunities for cropland/row crops, timberland/silviculture, livestock/pastureland, orchards and groves, and nurseries/greenhouse production. Goals for conservation growth were to protect and conserve biodiversity, surface waters and groundwater for human and ecosystem use, areas where fire helps shape the landscape, wetlands and floodplain that pertain to a service such as filtration of contaminates, and lands that provide ecological connectivity.

This study also introduced the ranking scale used for suitability, 1=low suitability and 9= high suitability. This scale allowed for consistency and an ease of combination for each result raster. The classifications for areas of conflict were introduced once the suitability maps were created. Table 1 is a variation on the original table in Carr and Zwick (2005) where 1=low, 2=medium, and 3=high were used instead of high (H), medium (M), and low (L).

Table 1: Combinations of preference rankings that result in major, moderate, or no conflict. The left column contains the codes for areas in conflict and the right column contains the codes for areas no in conflict. Each code has three ranks: - the first number is agriculture, second is conservation, and third is urban preference. A 3 is high preference, 2 moderate, and 1 low (Carr and Zwick 2007).

Areas of Conflict		**Areas of No Conflict**	
Code	**Description**	**Code**	**Description**
111	All in conflict, all low preference	**112**	Urban preference dominates
122	Moderate conservation preference conflicts with moderate urban preference	**113**	Urban preference dominates
133	High conservation preference conflicts with high urban preference	**121**	Conservation preference dominates
233	High conservation preference conflicts with high urban preference	**123**	Urban preference dominates
221	Moderate agriculture preference conflicts with moderate conservation preference	**131**	Conservation preference dominates
212	Moderate agriculture preference conflicts with moderate urban preference	**132**	Conservation preference dominates
222	All in conflict, all moderate preference	**211**	Agriculture preference dominates
313	High agriculture preference conflicts with high urban preference	**213**	Urban preference dominates
323	High agriculture preference conflicts with high urban preference	**223**	Urban preference dominates

Areas of Conflict		**Areas of No Conflict**	
Code	**Description**	**Code**	**Description**
331	High agriculture preference conflicts with high conservation preference	**231**	Conservation preference dominates
332	High agriculture preference conflicts with high conservation preference	**232**	Conservation preference dominates
333	All in conflict, all high preference	**311**	Agriculture preference dominates
		312	Agriculture preference dominates
		321	Agriculture preference dominates
		322	Agriculture preference dominates

Conflicts were determined using the codes in Table 1 after compiling all suitability maps and land use preferences. This study concluded that the majority of conflicts were between urban and agriculture. The final results were consistent with current trends, which indicate agricultural lands are being subsumed by urban land use. Carr and Zwick use this study to develop their book *Smart Land use Analysis: The LUCIS Model* (Carr and Zwick 2007) where they explain the model in extreme detail and supply sample data and the models themselves.

Tims (2009) completed an analysis using LUCIS to determine how the country of Rwanda could develop. Agriculture is the number one concern in Rwanda as it supplies the income for almost 80% of the population. Although Rwanda is a relatively small country it has the highest population density in Africa with over nine million people, and is growing at a rate of 3.5% a year (Tims 2009). The biggest difference between the Florida study (Carr and Zwick 2005) and the Rwanda study (Tims 2009) was the availability of data. After the goals and objectives were set, Tims (2009) determined that less than 50% of the data needed was available. Because of the limitation, the cell size for all rasters had to be 50m. Another major difference was the lack of a buffer in order to limit the influence of neighboring countries.

Tims (2009) followed the system seen in Table 1 to create preference and conflict maps. To correctly identify the preference for urban, agriculture, and conservation, the rasters were reclassified with an order of magnitude difference for each. Urban was reclassified as 1, 2, and 3 for low, medium, and high preference respectively. Conservation was reclassified as 10, 20, and 30 for low, medium, and high preference respectively. Finally, agriculture was reclassified as 100, 200, and 300, for low, medium, and high preference respectively. The majority of the country was highly suitable for agriculture and high to medium for urban. The preference map was combined with aerial photographs to determine patterns with what was already present. Due to the missing data, the results could not be solely used for planning purposes, however this study gave Rwanda an idea of where they should build and how to protect agricultural lands.

Cotroneo (2015) used the LUCIS model to determine future land use conflict in Mecklenburg County, North Carolina, an area that has grown by 32% from 2000 to 2015. Very similar goals were used for Mecklenburg County as in Florida (Carr and Zwick 2005). The agricultural goal was to identify lands suitable for croplands/row crops, livestock and timber. The conservation land goal was to identify lands suitable for protecting native biodiversity, water quality, important ecological processes, and resource-based recreation. The urban development goal was to identify lands suitable for residential, office/commercial, retail, and industrial land use. Cotroneo (2015) introduced a data design structure that splits data into categories: geophysical, biological/ecological, demographic, economic, political, cultural, and infrastructure.

This approach was adapted from Carr and Zwick (2007) and allows any future users to have an organized set of data.

All steps taken to develop suitability maps were very well documented and were used to set up the methodology for this project. Additionally, the Analytical Hierarchy Process (AHP) used to create the preference maps, is described. The AHP generated a weight for each parameter based on the user's comparison of importance. The final aspect of this study was the inclusion of a future land use scenario map. This map took into consideration the population of a time in the future. By using future population estimates and the required amount of land to support this population, the location of future urban land use were determined. LUCIS allocated the urban land preference land first and then took land from areas of urban/agriculture conflict and then urban/conservation conflict. Overall agriculture land was most affected, which is consistent with the other two studies.

The results of all three studies demonstrate that in short spans of time, urban development is encroaching on agricultural land. Although the majority of land surrounding Mount Rainier is considered conservation, the bordering land is agriculture. Development surrounding Mount Rainier can be determined using the LUCIS model and creating a future land use map as was done in Cotroneo (2015). From there the issue of development within volcanic hazards can be addressed.

Chapter 3 Methodology

This chapter describes the research questions, study area, data requirements, and methodology used to implement the LUCIS model. Methodology contains the statement of intent and goals for all three land use types.

3.1 Research Questions

Land use conflicts were determined for the region surrounding Mount Rainier using the LUCIS model. Volcanic hazards associated with Mount Rainier were displayed using a hazard map provided by USGS. By combining hazards and land use conflicts the following research questions can be addressed. 1) Where are the volcanic hazards around Mount Rainier? 2) What lands in this area are most suitable for urban development? 3) How is the urban growth around Mount Rainier likely to change by the year 2060? 4) Where are potential conflicts between volcanic hazards and potential urban development around Mount Rainier?

The LUCIS model was used to answer questions 2-4. Suitable lands for urban, agriculture, and conservation were determined first. Each land use has its own statement of intent and goals, seen in Table 2.

Table 2: Goals for each land use type for the LUCIS model

	Agriculture
Statement of Intent	Identify lands most suitable for agricultural use
Goal 1	Identify lands suitable for croplands
Goal 2	Identify lands suitable for livestock
Goal 3	Identify lands suitable for timber
	Conservation
Statement of Intent	Identify lands most suitable for conservation and permanent protection
Goal 1	Identify lands suitable for protecting native biodiversity
Goal 2	Identify lands suitable for protecting water quality
Goal 3	Identify lands suitable for protecting important ecological processes
Goal 4	Identify lands suitable for resource-based recreation
	Urban
Statement of Intent	Identify lands most suitable for urban development
Goal 1	Identify lands suitable for residential land use
Goal 2	Identify lands suitable for office/commercial land use
Goal 3	Identify lands suitable for retail land use
Goal 4	Identify lands suitable for industrial land use

3.2 Data Requirements

Three groups of data were required to complete this analysis: basemaps, volcanic hazards, and LUCIS model data. One basemap, two datasets for the volcanic hazards, and five groups of data for the LUCIS model were needed.

The basemap and volcanic hazards were used to create the base of the analysis. The basemap is a topological map obtained through ArcGIS Online (National Geographic Society 2011) and was used as a reference and background for the results. This analysis focused only on Mount Rainier because its hazards impact Tacoma and Seattle. Therefore volcanic hazards dataset includes the location of Mount Rainier and its associated hazards. The Smithsonian Institute, Global Volcanism Program (2015) and the hazard map from USGS Volcanic Hazards Program (2015) ascertained the volcano's location. The only obstacle in using this location is ensuring it is in the correct projection, however it is only used as a basis for the location and not analyzed.

The USGS compiled hazards seen in **Error! Reference source not found.** and created a hazards shapefile seen in Figure 5. Near-volcano hazards, such as lava and pyroclastic flows, tephra, lahars, and rock fall and rose color and lahars are shown in red to yellow, flowing from the volcano in all directions. These lahars flow towards and surround Tacoma, seen in the northern portion of the image.

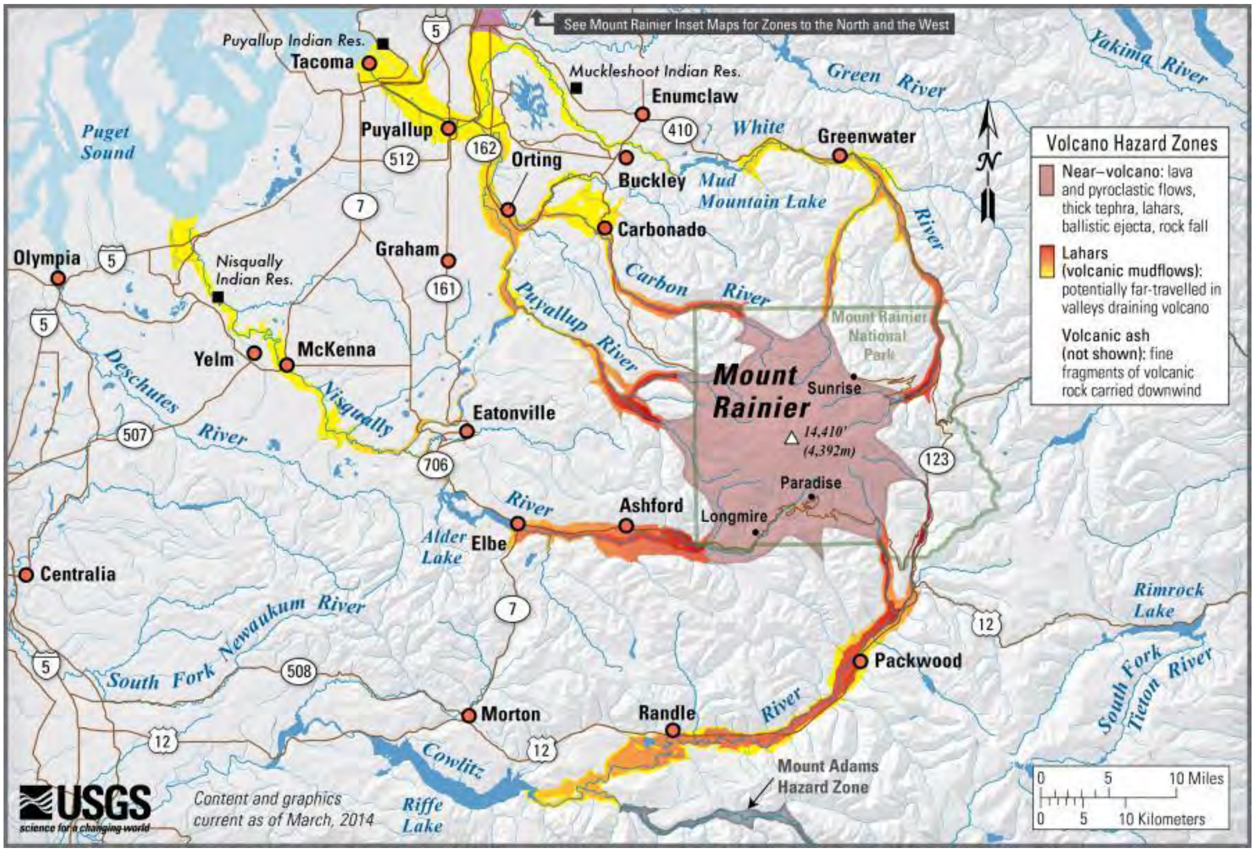


Figure 4: Hazard map for Mount Rainier (USGS 2015)

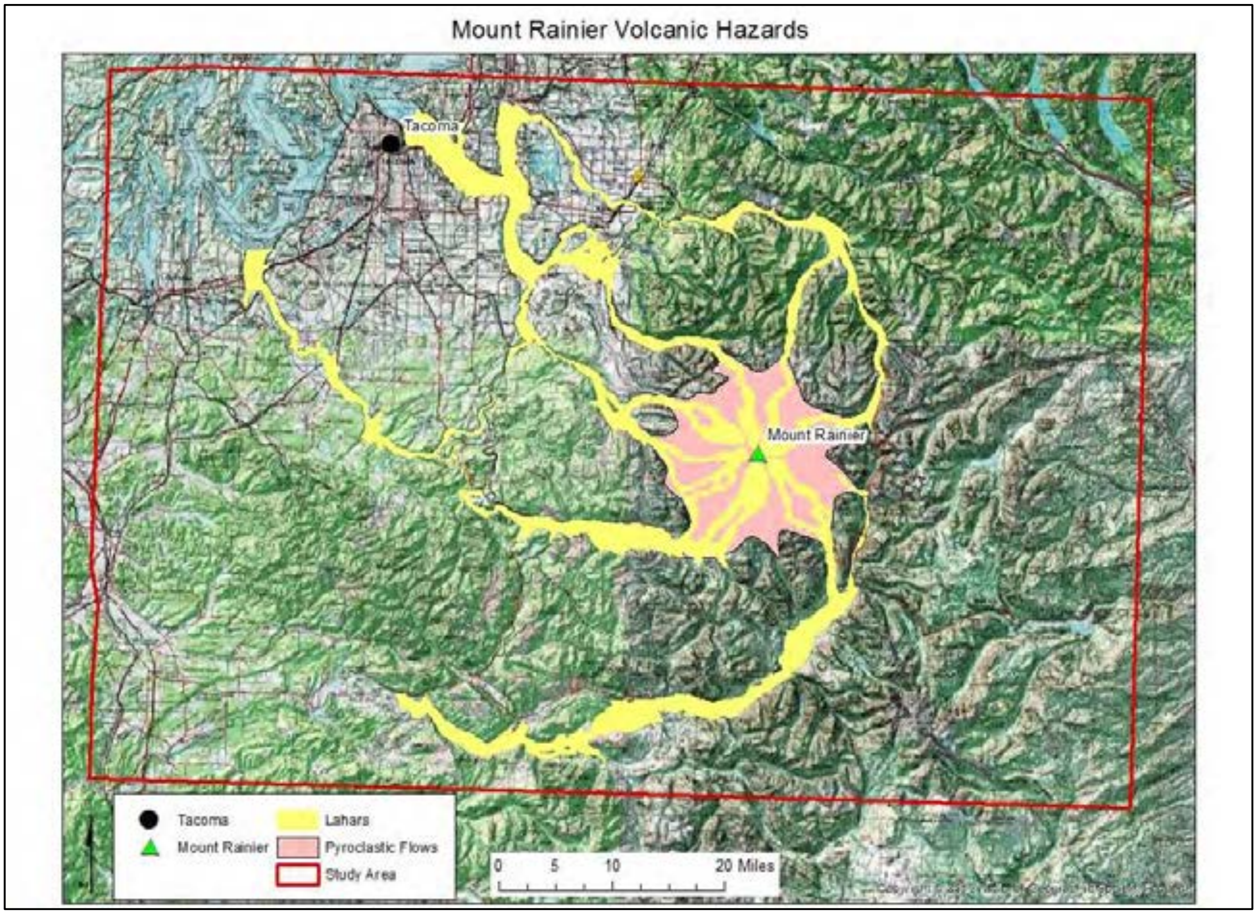


Figure 5: Digital representation of volcanic hazards associated with Mount Rainier

The LUCIS model groups data into five broad categories; geophysical, biological/ecological, cultural, infrastructure, and political. These terms can be misleading for this study because geophysics is an area of study that focuses on seismic activity and monitoring volcanic activity. Therefore “geophysical data” will be called “physical geography data” for this analysis. Physical geography data is composed of soil, river, lakes and ponds, streams, and agricultural assessment datasets. Biological/ecological includes wetlands and biological wildlife habitat datasets. Cultural includes land cover, historical sites, and trails. Infrastructure has airports, roads, railroads, hospitals, and schools. Political has the county boundaries and city boundaries. See Table 3 for the dataset, source, and the category to which they belong.

Table 3: Datasets used in LUCIS model along with the source and data type category.

Data Type	Dataset	Source
Physical Geography	Rivers	Washington State Geospatial Portal (WSGP)
Physical Geography	Lakes and ponds	WSGP
Physical Geography	Streams	WSGP
Physical Geography	Springs	WSGP
Physical Geography	Agricultural assessment (Crops)	U.S. Department of Agriculture
Physical Geography	Aquifer	Ground Water Atlas of the United States
Biological/Ecological	Wetlands	WGSP
Biological/Ecological	Habitat Conservation Land	WSGP
Biological/Ecological	Biological wildlife habitat	Washington State Department of Fish and Wildlife
Cultural	Land cover	WGSP
Cultural	Historic properties	Washington State Department of Archaeology and Historic Preservation
Cultural	Trails	Bureau of Land Management
Cultural	Parks	WGSP
Infrastructure	Airports	U.S. Geological Survey (USGS)
Infrastructure	Roads	WGSP
Infrastructure	Railroads	WGSP
Infrastructure	Hospitals	WGSP
Infrastructure	Schools	Department of Education
Infrastructure	Hazardous Sites	WGSP
Infrastructure	Power Plants	U.S. Energy Information Administration
Infrastructure	Sewage sites	USGS
Infrastructure	Water Treatment Facilities	Ground Water Atlas of the United States
Political	County boundaries	WGSP
Political	City zoning	WGSP

The data used in this study was based on datasets used in Carr and Zwick (2005). While many datasets in both this study and Carr and Zwick (2005) are similar, some datasets were derived from a series of data and others were left out entirely from this study. Table 4 compares the original Carr and Zwick (2005) data and the datasets used in this study. The column on the right shows changes, if any, that were made to make datasets resemble those in the original model.

Table 4: Comparison of data used in this study agianst the data used in Carr and Zwick (2005).

Carr and Zwick (2005) Data	**Data Used in this Study**	**Changes Made to Data to Resemble Carr and Zwick (2005)**
Rivers	Rivers	None
Hydrology	Lakes and ponds, Rivers, Streams	Combined the three datasets
Springs	Springs	None
Soil rasterized on crop yield	Crops	Yield was obtained from Washington State Department of Agriculture
Regional Land Value		Excluded
City Limits	City Limits	None
Aquifer	Aquifer	None
Timber Soils	Soil	Used soil type attribute
Priority Wetland Habitats	Wetlands	None
Strategic Habitat Conservation Areas	Habitat Conservation Lands	None
Managed Areas	Habitat Conservation Lands	None- represented same information
Habitat	Biological wildlife habitat	Biodiversity rankings were attributed based on the National Heritage Program; Fire-maintained value was applied from Carr and Zwick (2005)
Nonburnable Areas	Nonburnable Areas	Processed from Land Use dataset
Parks	Parks	Processed from Land Use dataset

Carr and Zwick (2005) Data	Data Used in this Study	Changes Made to Data to Resemble Carr and Zwick (2005)
Trails	Trails	None
Historical Sites	Historical Sites	None
Utility Corridor	Utilities	Utilities processed from Land Use dataset
Roads	Roads	None
Railroads	Railroads	None
Airports	Airports	None
Radon Potential	Hazardous Sites	Radon sites included
Hazardous Sites	Hazardous Sites	Includes arsenic, asbestos, and mercury sites
Sewage Treatment Plants	Sewage Sites	None
Power Plants	Power Plants	None
Schools	Schools	Combined private and public schools in the region
Health Care Facilities	Hospitals	None
Major Roads	Highways	Highways were exported from roads dataset
Recreation Opportunities	Recreation Activities	Processed from Land Use dataset
Residential Land Use	Land Use	Residential land use exported from Land Use dataset
Office/Commercial Land	Land Cover	Office/Commercial Land processed from Land Use dataset
Retail Land	Land Cover	Retail Land processed from Land Use dataset
Industrial Land	Land Cover	Industrial Land processed from Land Use dataset

3.3 Analysis

3.3.1. Study Area Creation

This analysis has two study areas, one for initial analysis using the LUCIS model and the final study area, which is restricted to the volcanic hazards of Mount Rainier. The larger study area acts as the buffer from Carr and Zwick (2005). The study area is composed of four counties into which volcanic hazards from Mount Rainer flow (Figure 6); Pierce, Lewis, Thurston, and King Counties. This is to ensure that projected land use change is accurately represented due to the impact of all surrounding areas.

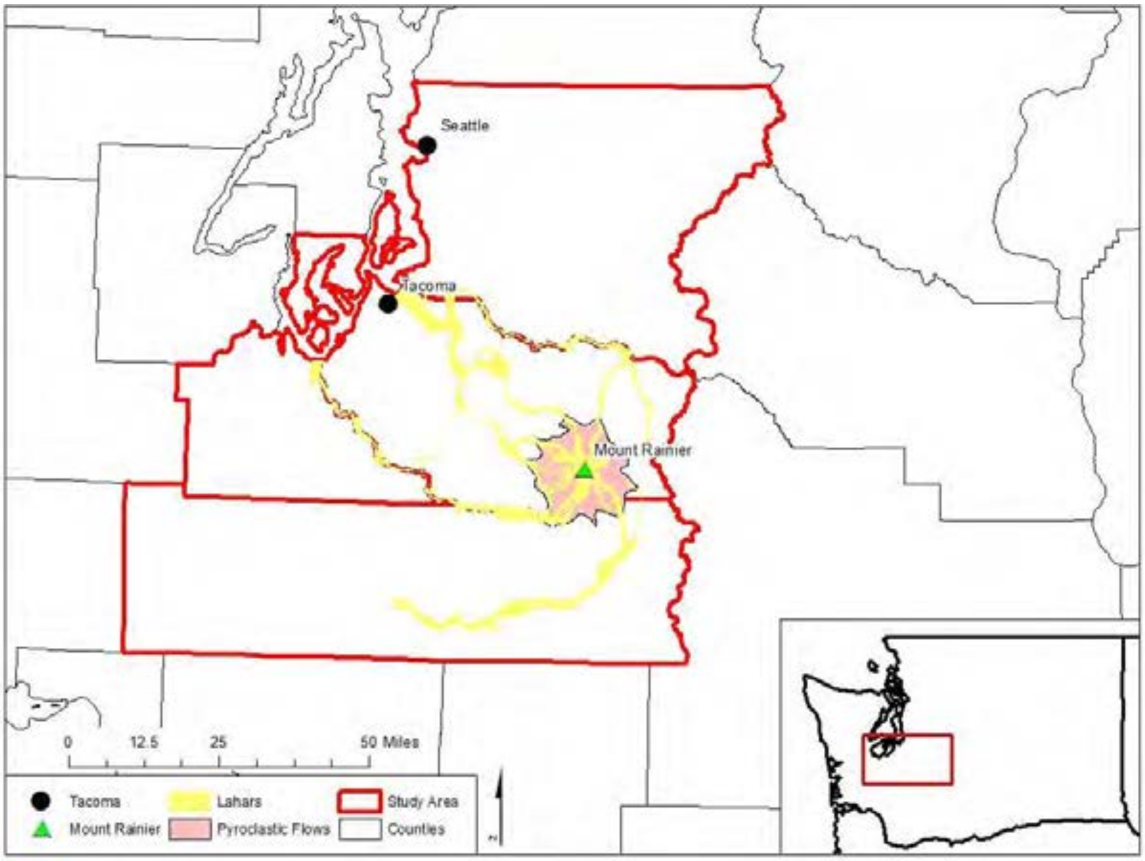


Figure 6: Study Area composed of counties affected by Mount Rainier hazards

3.3.2. LUCIS Model

Each dataset was used to achieve the goals and objectives stated in Table 2Table 3. Each main goal has a series of objectives and subobjectives that were processed first in order to determine the overall goal of land use. Each step was completed in ArcCatalog using Model

Builder and the Spatial Analyst extension (Figure 7). The entire analysis was run using a cell size of 208.71 feet, equivalent to 1-acre, which introduced roughly 4.5 million cells into the analysis. This cell size was used because the final raster must be in 1-acre units to depict the number of acres required to support the future population.

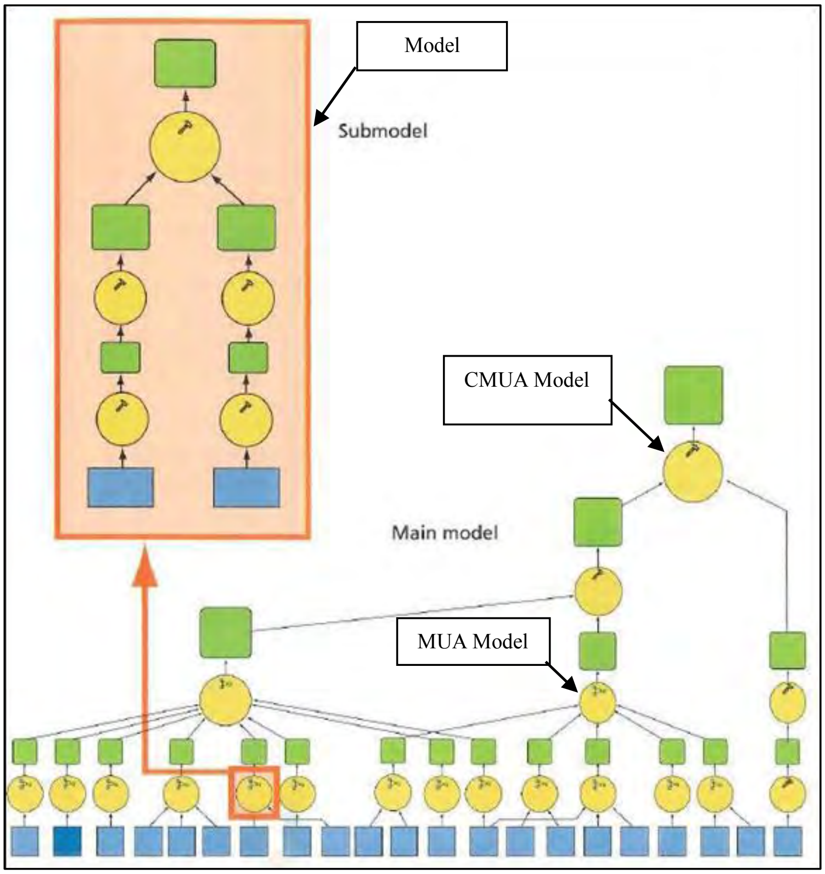


Figure 7: Model Builder for LUCIS Model. Main model is used for goals, preference, conflict, and future allocation. The submodel is used for subobjectives and objectives. SUA, MUA, and CMUA are indicated (Carr and Zwick 2007).

Sub-models were created for all of the subobjectives and objectives (Figure 7). Figure 7 shows the overall model structure for the LUCIS model. Each subcomponent is explained in the following section along with tools used in submodels. The blue squares represent the input data, yellow circles represent the submodel seen in the red rectangle. Finally the green squares represent the outputs of models. The main tools used were: Conversion, Reclassify, Math, Euclidean Distance, and Zonal Statistic tools. A raster was created for each subobjective where each cell received a value of 1-9 for the suitability of that parameter, 9 being most suitable and 1 being least suitable. The objectives were combined using the main model to determine the overall suitability of layers, preference maps, conflict maps, and future allocation maps.

Prior to being placed in the model, the projection of each layer was checked and if it was not in NAD_1983_HARN_StatePlane_Washington_South_FIPS_4602_Feet, it was transformed. Once all layers were in the correct projection, they were clipped to encompass only the study area counties, which decreased processing time for the remaining analysis. All layers, except the political data, were converted to rasters for use in the models. This was done using the Feature to Raster tool, however to ensure data is not loss, the proper cell size must be used. If the cell size is too small the dataset is too large but if the cell size is too large, not all of the data will be captured. A cell size of 208.71 feet was used, encompassing an area smaller than the original polygons, resulting in each cell containing its true value and not an average. This did not have an impact on the results as the values used in the analysis were equivalent to the original vector data.

The LUCIS model is divided into four stages: 1) Suitability maps, 2) Preference maps, 3) Conflict maps, and 4) Potential future land use basemap. The following sections describe the methods used for each stage.

3.3.2.1. Suitability Analysis

The suitability analysis used data and tools in Model Builder to solve the statement of intent for each land use type. This process was completed through a series of Single Utility

Assignments (SUAs), Multiple Utility Assignments (MUAs), and Complex-Multi Utility Assignments (CMUAs) (Figure 7). SUAs were used to answer subobjectives by taking one piece of data and performing either a simple reclassification or a more complex series of analyses. MUAs used multiple pieces of data, or multiple SUAs, to answer the objectives. Finally, the CMUAs combined MUAs to answer the goals for each land use type.

Figure 8 demonstrates a simple SUA used in the urban land use goal 1 analysis and introduces the code used throughout the analysis for all grids "UG1O11SO111". "U" was used for Urban analysis, "C" for Conservation, and "A" for Agriculture. "G" indicates the goal, "O" the objective, and "SO" the subobjective. Wetland habitats and open waters were classified as 1=the presence of floodplain, or 9=everything else. The analysis of this data was used to answer goal 1 (Identify lands suitable for residential land use), objective 1.1 (Determine lands physically suitable for residential land use), subobjective 1.1.1 (Identify lands free of flood potential).

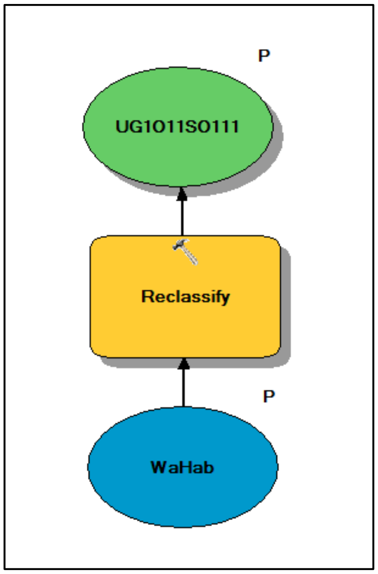


Figure 8: SUA for Urban Goal 1 (Identify lands suitable for residential use), Objective 1.1 (Determine lands physically suitable for residential land use), Subobjective 1.1.2 (Identify lands free of flood potential).

Figure 9 demonstrates a complex SUA used in this analysis. A complex SUA takes a single dataset and applies a series of analyses to it. This SUA used the schools layer and the Euclidean Distance tool to determine the distance of public schools, the results which were run through the Zonal Statistics tool to determine the mean distance from schools. The results were used in the reclassification to create the UG1O12SO122 SUA. A cell that was 0 to the mean from a school, received a reclassified value of 9. As the standard-deviation increased by ¼ the reclassified value decreased from 8-2. All over values were assigned a value of 1.

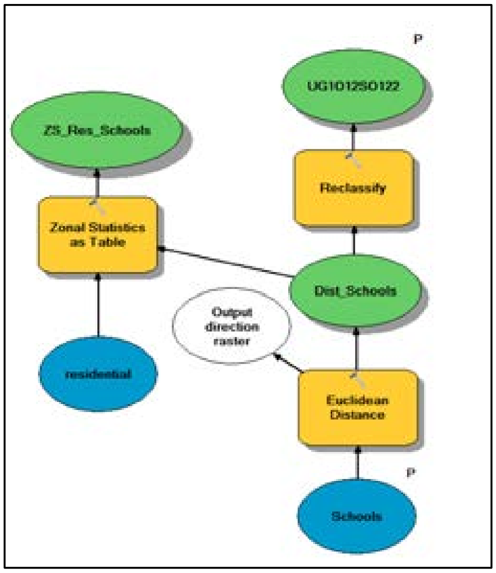


Figure 9: SUA for Urban Goal 1(Identify lands suitable for residential use), Objective 1.2 (Determine lands economically suitable for residential land use), and Subobjective 1.2.2 (Identify lands proximal to schools)

Figure 10 demonstrates an MUA used in this analysis. This MUA uses the SUAs UG1O11SO111 (flood construction suitability), UG1O11SO112 (residential quiet), UG1O11SO113 (residential hazard), and UG1O11SO114 (residential air quality) created in the subobjective stage to answer Objective 1.1 (Determine lands physically suitable for residential land use). These SUAs were added together using the Raster Calculator tool after weighting each accordingly: Flood at 40%, Quiet at 30%, Hazard at 20%, and Air Quality at 10% (adapted from (Carr and Zwick 2007)). Flooding was considered the highest weight as it has a direct correlation to construction costs and insurance. Each weight received 10% less in order to ensure the impact from each parameter decreased evenly.

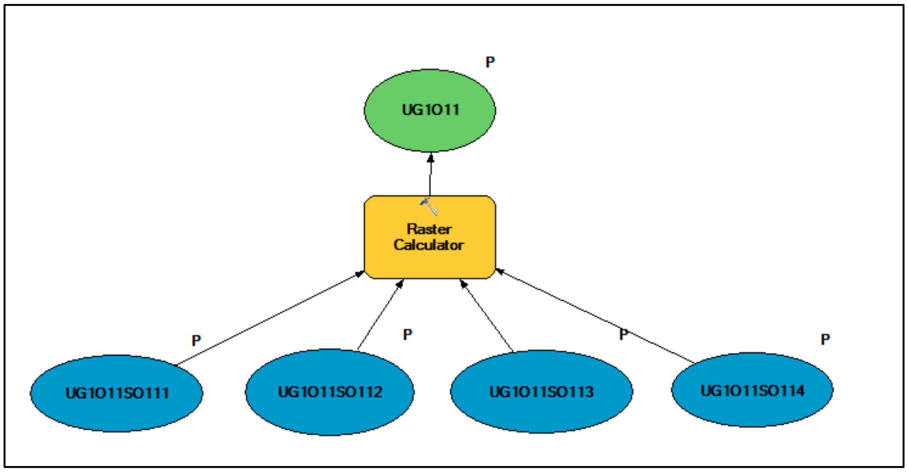


Figure 10: MUA for Urban Goal 1(Identify lands suitable for residential use), Objective 1.1 (Determine lands phyically suitable for residential land use).

The final type of model used was the CMUA, seen in Figure 11 for Goal 1 (Identify lands suitable for residential land use) two combine two MUAs, UG1O11 (Determine lands physically suitable for residential land use) and UG1O12 (Determine lands economically suitable for residential land use). The Raster Calculator used equal weights for both MUAs to create the "UG1_MUAs_combined" and combined that with the pre-existing residential land using a conditional statement. The conditional statement used was CON(Reclassed_Residential == 9, 9, UG1_MUAs_combined) stating if the reclassified residential layer = 9 the new cell was assigned a value of 9, otherwise the new call was assigned value of the "UG1_MUAs_combined". This produces the CMUA UG1.

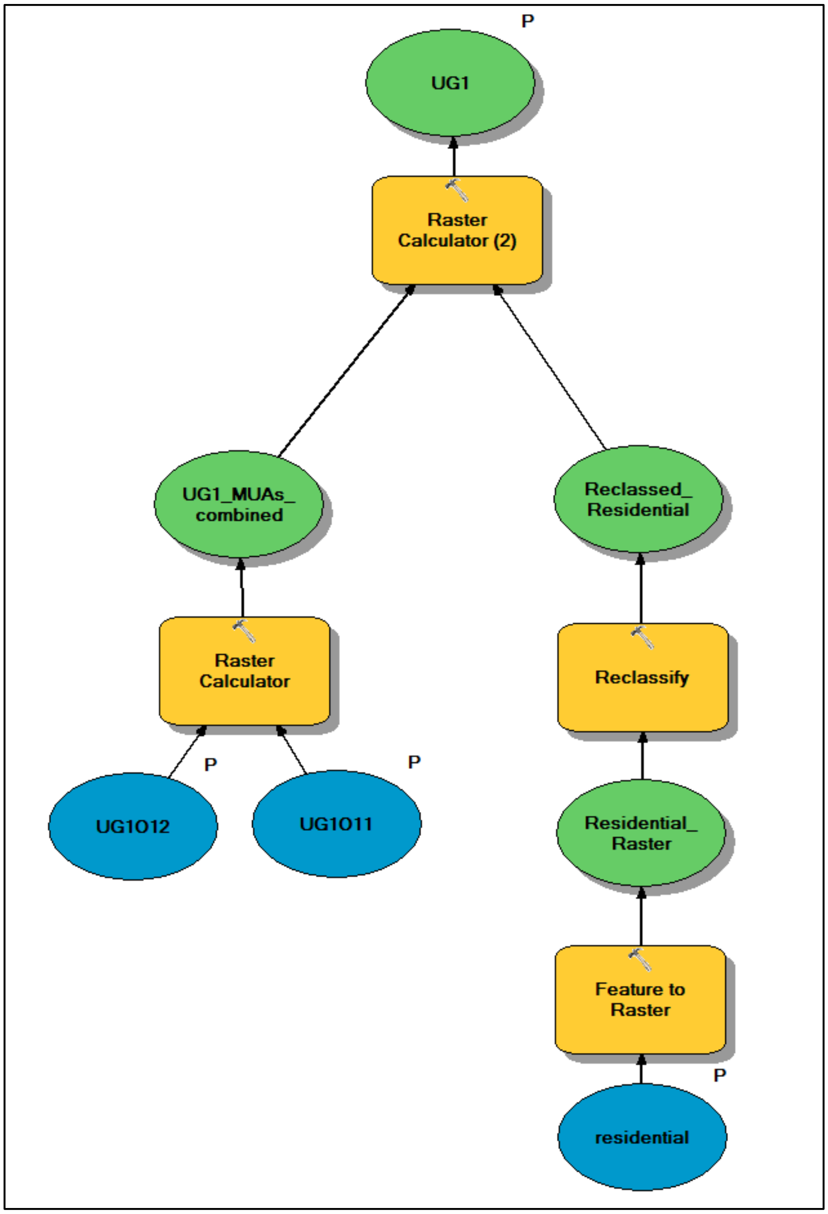


Figure 11: CMUA for Goal 1(Identify lands suitable for residential land use)

These procedures were completed for all subobjectives, objectives, and goals for agriculture, conservation, and urban land use creating the suitability maps. The parameters for each of the subobjectives, objectives, and goals are seen in Appendix A: Suitability Models. In total three agriculture suitability maps, four conservation suitability maps, and four urban suitability maps.

3.3.2.2. Preference Analysis

Suitability maps were weighted, using an analytical hierarchy process (AHP), to produce preference maps. The use of Expert Choice software is highly recommended (Carr and Zwick 2007), however due to unavailability of this resource, the goals were equally weighted with the exception for UG1 (Residential land use). Residential land use was weighted more heavily due to the increase in population and the Raster Calculator was used to combine the weighted goals. Figure 12 shows the model used to combine all four urban suitability grids to create the final urban preference map.

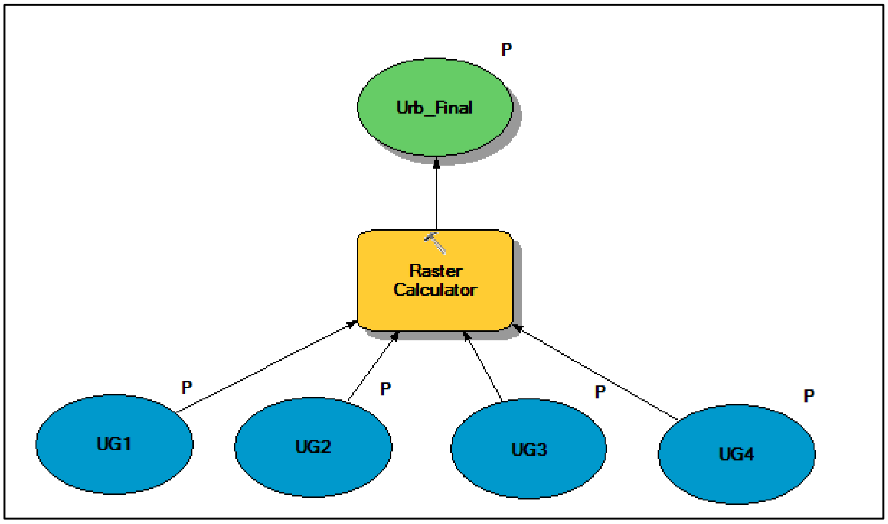


Figure 12: Urban land use preference model

3.3.2.3. Conflict Analysis

Conflict maps were executed through two steps: 1) create a development mask and 2) identify where conflicts existed between each land use. The development mask indicated which cells could be developed by extracting cells that would not change from the analysis. Cells excluded from the analysis include hydrology and existing urban and conservation lands. Each layer was reclassified and assigned a value of 1 if the condition were true and ‘NoData’ if the condition were not true. This created three grids, Urbdevmask, Hydrdevmask, and Condevmask, which were combined using multiplication (Urbdevmask * Hydrdevmask * Condevmask) to create the development mask layer (Figure 13). If a cell contains a value of 1, it will remain a value of 1 when multiplied by a cell containing 'NoData'.

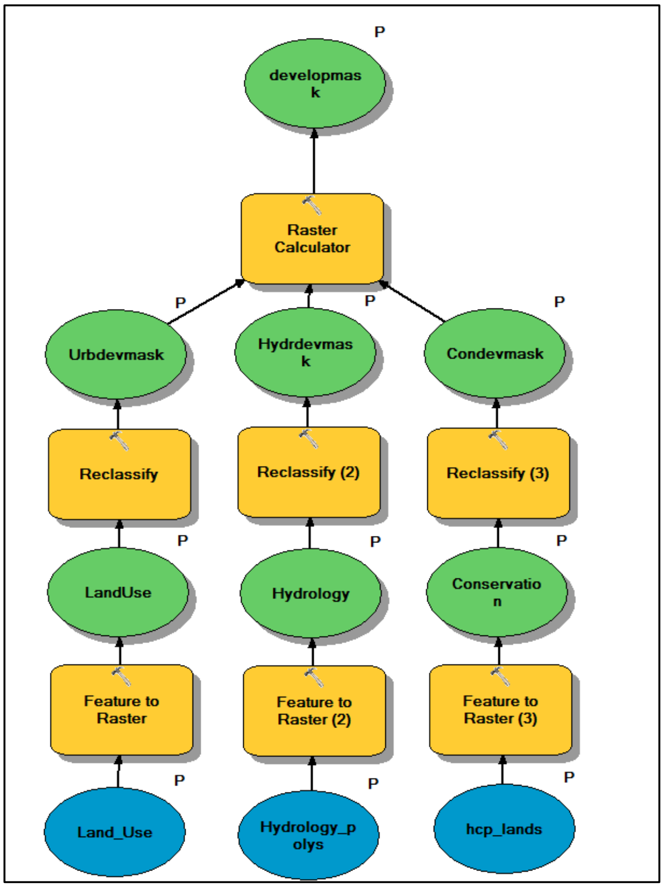


Figure 13: Model used to create development mask.

The regional conflict grid was completed in a series of steps using the development mask as a processing mask and land use preferences as the inputs. The first step was to normalize, reclassify, and collapse the three preference maps (Figure 14). Three land use types were normalized to the highest possible value, 9, in a grid using the divide tool. Those outputs were reclassified to high, medium, and low suitability values creating three collapsed preference rasters. High, medium, and low values were used to determine which land type was preferred. Unique values were assigned to determine which land use type was preferred once all three were combined. Urban growth values were collapsed into 1, 2, and 3 conservation into 10, 20, and 30 and agriculture into 100, 200, and 300. The three rasters were then added together, indicating the land most preferred. Table 1 shows 27 possible preference rankings and where conflicts exist.

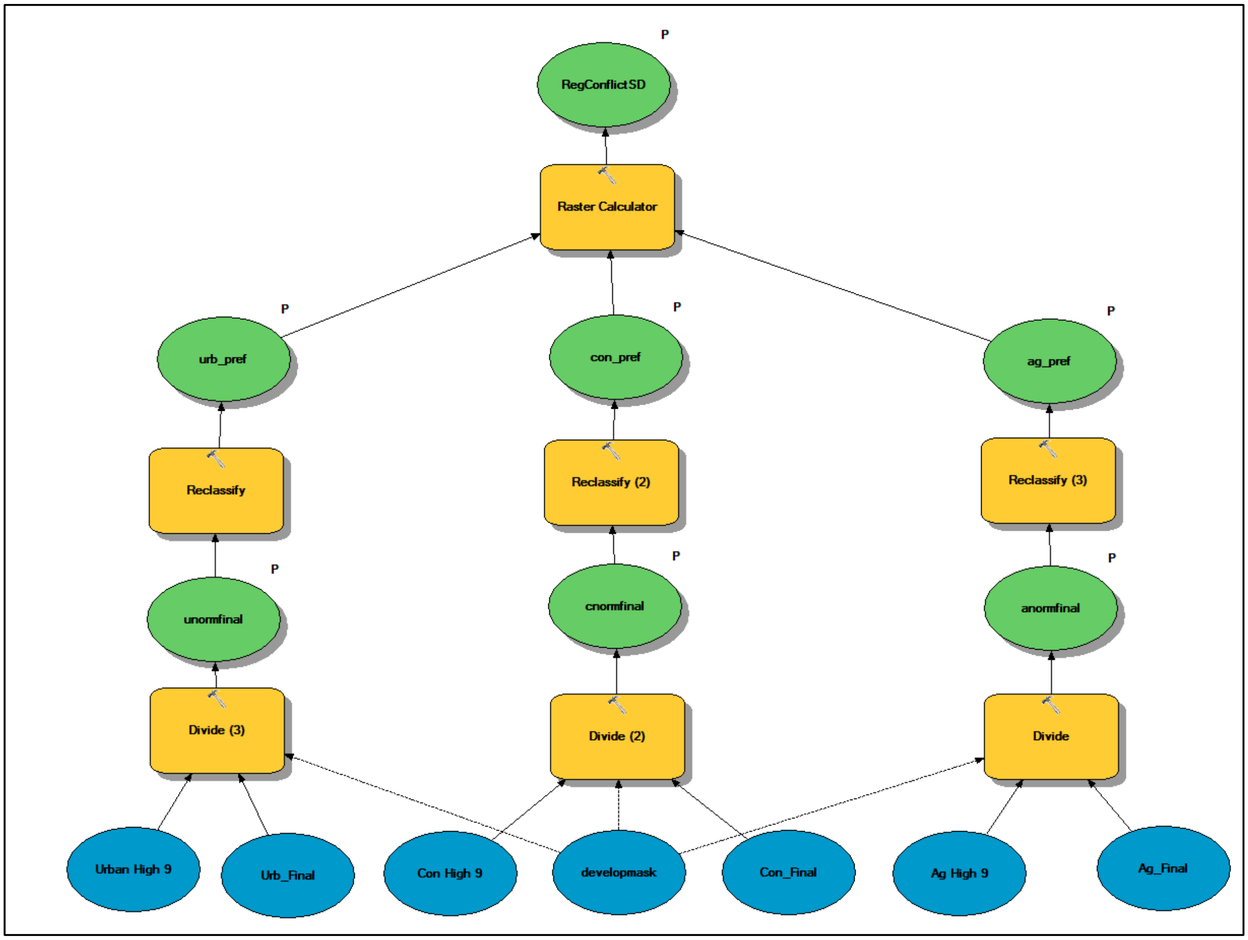


Figure 14: Model used to determine the land use preferences of each land use type and conflicts.

The conflict map was composed of seven values based on 27 preference and conflict rankings (Carr and Zwick 2007):

1. Areas of agriculture and urban conflict
2. Areas of agriculture and conservation conflict
3. Areas of conservation and urban conflict
4. Areas of conflict among all three major land use classifications
5. Areas of agriculture preference (No conflict)
6. Areas of conservation preference (No Conflict)
7. Areas of urban preference (No Conflict)

Resulting conflicts were used to determine how to allocate land use in the potential future land use basemap.

3.3.2.4. Potential future land use basemap

Finally the future land use basemap was created through projected population, required acres of land needed to support human settlement, and conflict values. Equation 1 is the fundamental regional land use equation (Carr and Zwick 2007) that indicates how many new acres are needed.

$$\text{acres of land needed to support human settlement} = \frac{\text{Projected Population}}{\text{Gross urban density}} \quad (1)$$

Esri Demographics, a data product composed of global population and lifestyle datasets, was used to obtain for each county the population for 2010 and 2015, the projected population for 2020, growth rates for 2010 to 2015 and 2015 to 2020, and urban density from 2015 and 2020. Growth rate was calculated prior to calculating the projected population using Equation 2 assuming that the rate from 2010 to 2020 continues. Equation 4 (projected population for 2060) was calculated by manipulating Equation 3 (annual compound growth rate).

$$\text{Rate}_{60} = \left(\frac{\text{Rate}_{10\text{ to }15} + \text{Rate}_{15\text{ to }20}}{2}\right) \quad (2)$$

$$\text{Rate}_{60} = \left[\left(\frac{P_{60}}{P_{10}}\right)^{1/50} - 1\right] * 100 \quad (3)$$

$$P_{60}=\left[\left(\frac{Rate_{60}}{100}+1\right)^{50}\right]*P_{10} \qquad (4)$$

where P = population

The gross urban density was calculated by dividing the 2010 population by the total acreage of urban land. Equation 1 was executed, and the number of acres needed to support human settlement was determined, once the population was calculated. The cells were allocated to their specific land use types using the total number of acres needed. This was completed in a series of six steps (Figures 15-20):

1. Allocate cells to future urban land use where there is no conflict and urban preference dominates.

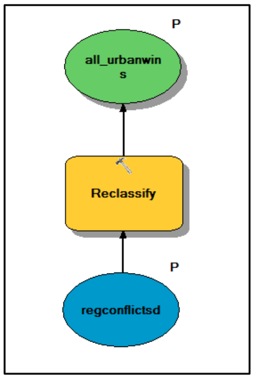


Figure 15: Model used to allocate cells were urban land use wins

2. Allocate cells to future urban land use from urban preference that are in moderate conflict with agriculture and conservation, only where urban has the higher preference.

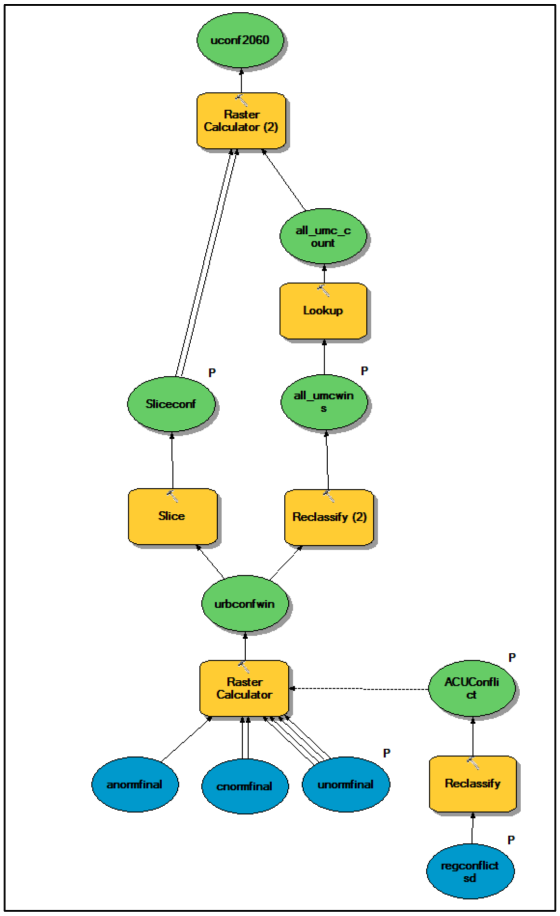


Figure 16: Model used to allocate cells where urban wins in conflict.

3. Create a mask for remaining land, accounting for all land used in steps 1 and 2.

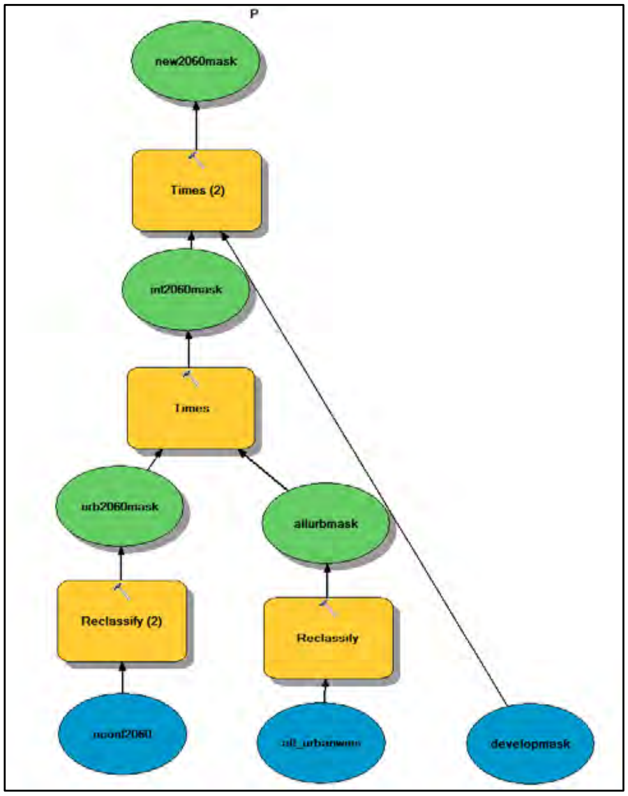


Figure 17: Model used to create 2060 remaining lands mask

4. Allocate remaining cells to future agriculture where there is no conflict.

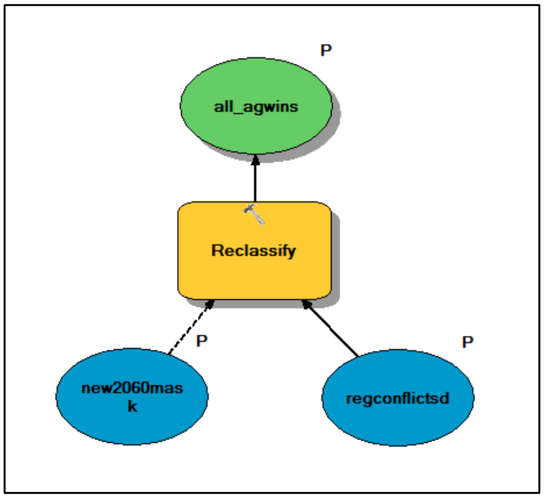


Figure 18: Model used to allocate cells where agriculture wins

5. Allocate remaining cells to future conservation where there is no conflict.

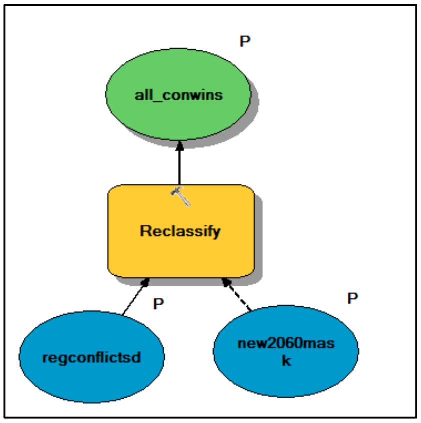


Figure 19: Model used to allocate cells where conservation wins.

6. Allocate all remaining cells to either agriculture or conservation based that are in moderate conflict, only where the agriculture and conservation has the higher preference value, respectively.

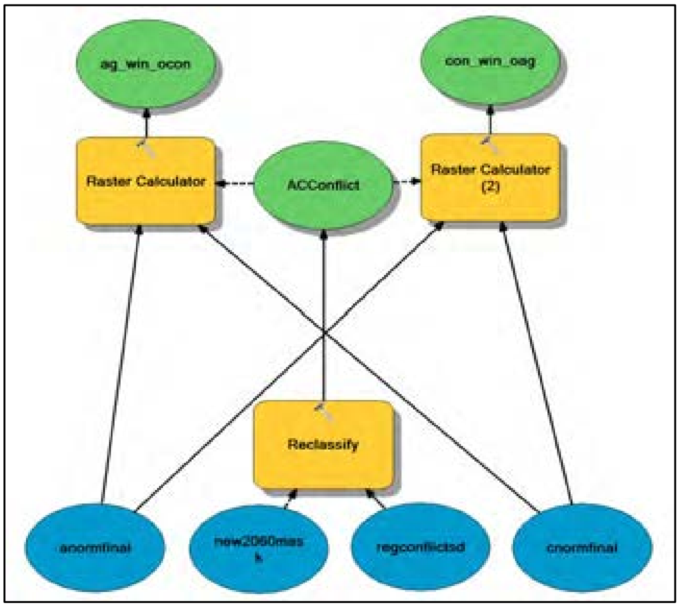


Figure 20: Model used to allocate cells where agriculture wins over conservation and cells where conservation wins over agriculture

3.3.3. Hazard Analysis

The final step in this analysis was to determine conflicts between future land use and volcanic hazards. The two urban datasets, all urban wins and urban wins in conflict, were initially combined to obtain the complete future urban land use dataset. The cells from the future land use basemap that resided within hazards from Mount Rainier were extracted using the Extract by Mask tool (Figure 21) which indicated new urban cells in conflict with volcanic hazards.

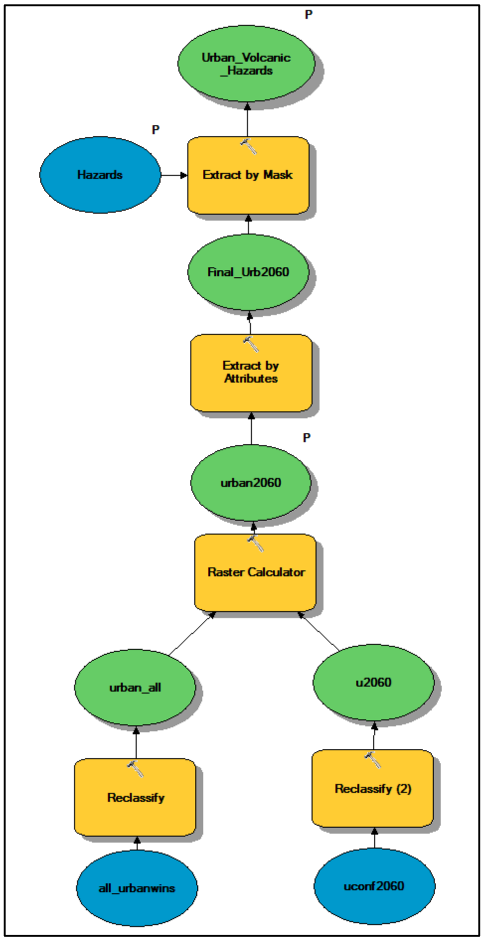


Figure 21: Model used to determine future urban cells in conflict with hazards associated with Mount Rainier.

Chapter 4 Results

This chapter shows the results of running the LUCIS model on King, Lewis, Pierce, and Thurston County, Washington. The results are divided into four distinct categories; land use suitability, conflict between land use preference, potential future land use, and conflict between future urban land use and volcanic hazards associated with Mount Rainier.

4.1 Land Use Suitability

The models used in this study created three land use suitability maps, one for agriculture, conservation, and urban land use. The maps in the following three sections display the results for the individual goals defined for each land use and the overall suitability. The color ramp used for each map shows the range of suitability scores from low to high (red to green). This is consistent throughout each of the three land use types.

4.1.1. Agriculture Land Use Suitability

The agriculture land use suitability map is a result of the three goals stated in Table 2. Individual objectives and subobjectives are found in Appendix A. Results for goals 1-3 are seen in Figures 22-24.

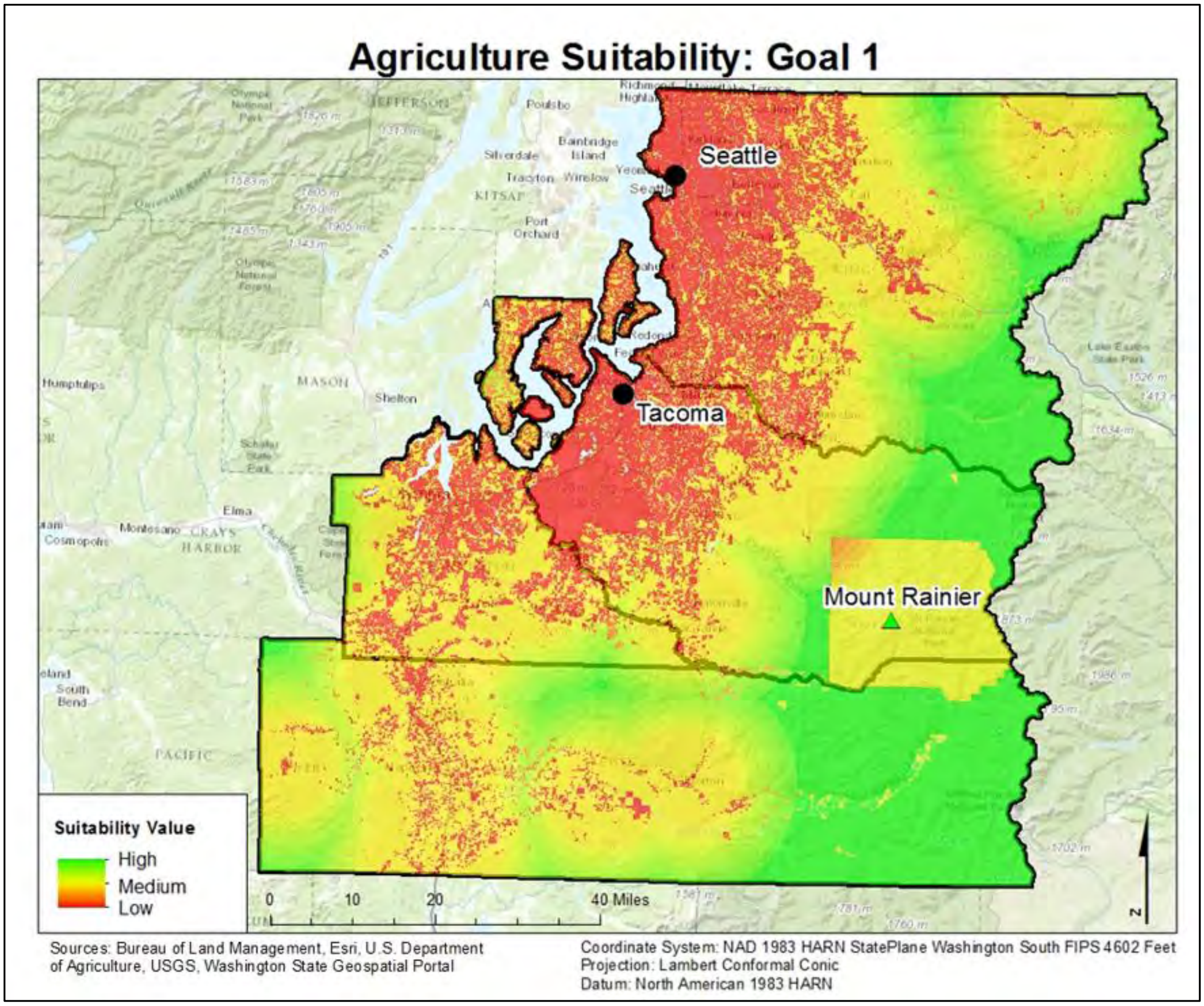
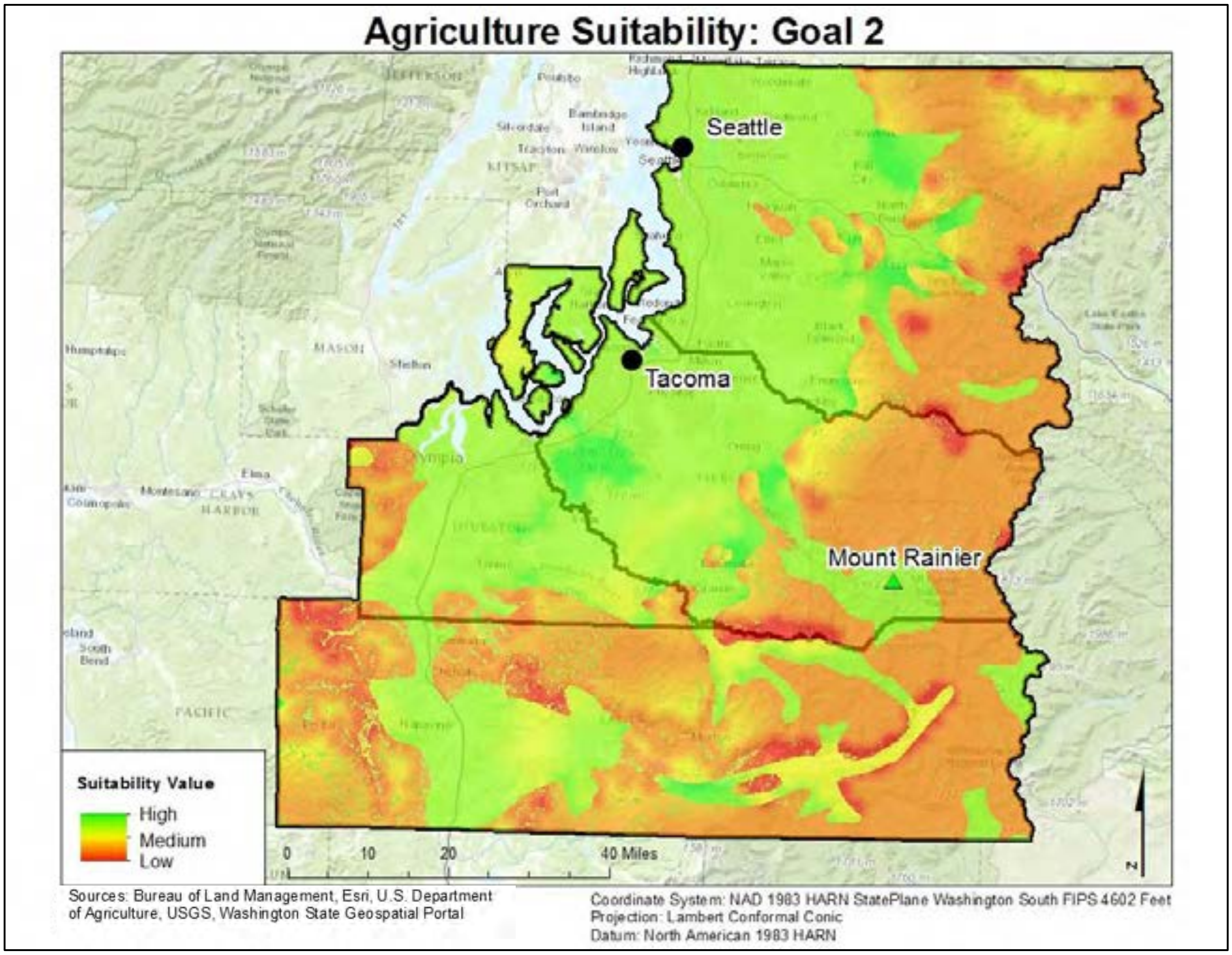


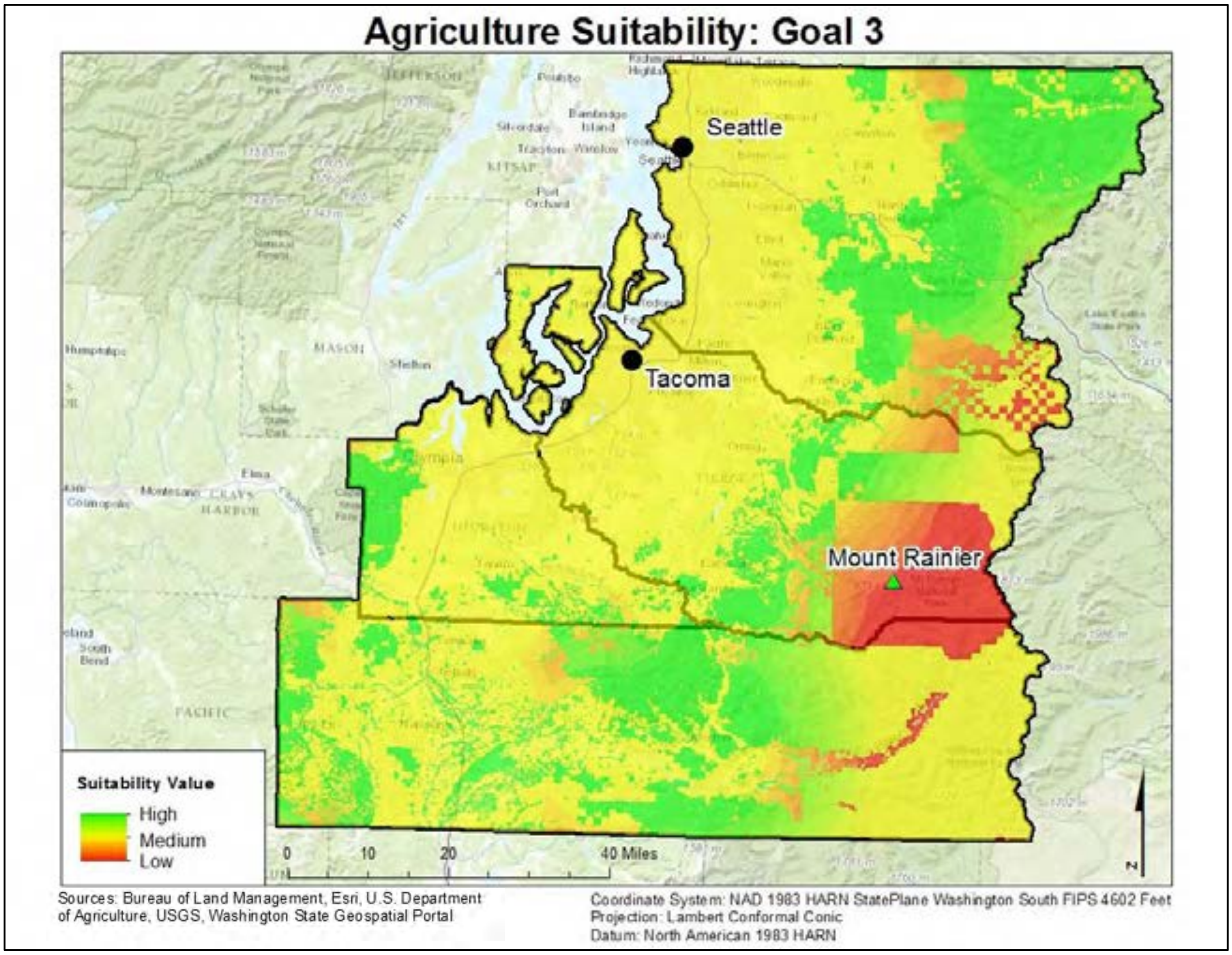
Figure 22: Results for agriculture suitability goal 1; Identify lands suitable for croplands



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 23: Results for agriculture suitability goal 2; Identify lands suitable for livestock

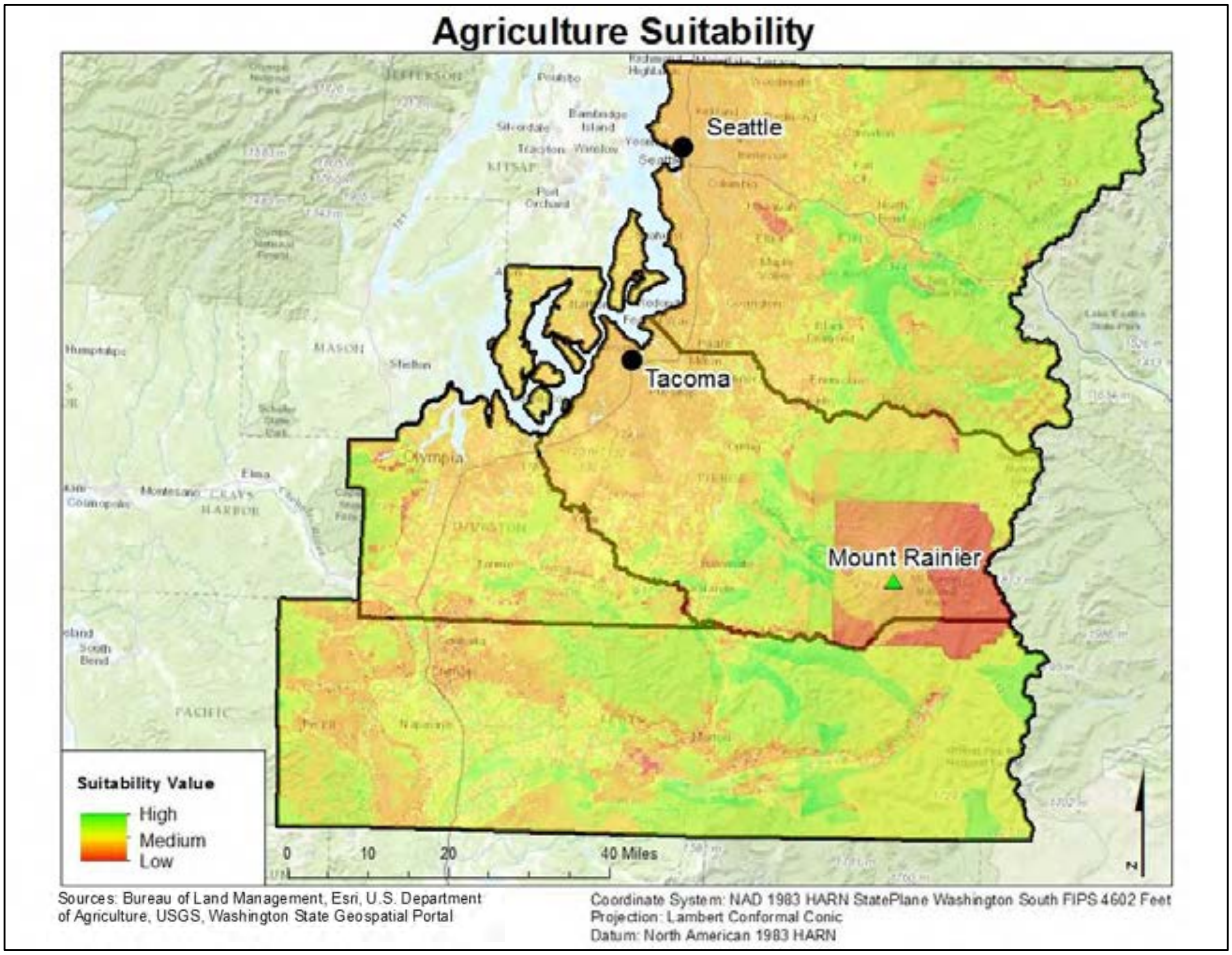


Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 24: Results for agriculture suitability goal 3; Identify lands suitable for timber

Croplands were least suitable in urbanized areas and most suitable along the study area's eastern side. Lands most suitable for livestock were along the western side of the study area and lands most suitable for timber ran from the northeast corner to the south central. Overall suitability for agriculture land use was determined by combining these three goals. (Figure 25).



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 25: Results for agriculture land use suitability

Agricultural suitability for the study area was highest through the region's center. The least suitable area for agricultural land surrounds Mount Rainier. The majority of the study area was medium to medium high suitability for agriculture land, with the exception of urbanized areas which was medium low.

4.1.2. Conservation Land Use Suitability

The conservation land use suitability map is a result of four goals as stated in Table 2. Individual objectives and subobjectives are found in Appendix A. Results for goals 1-4 are seen in Figures 26-29.

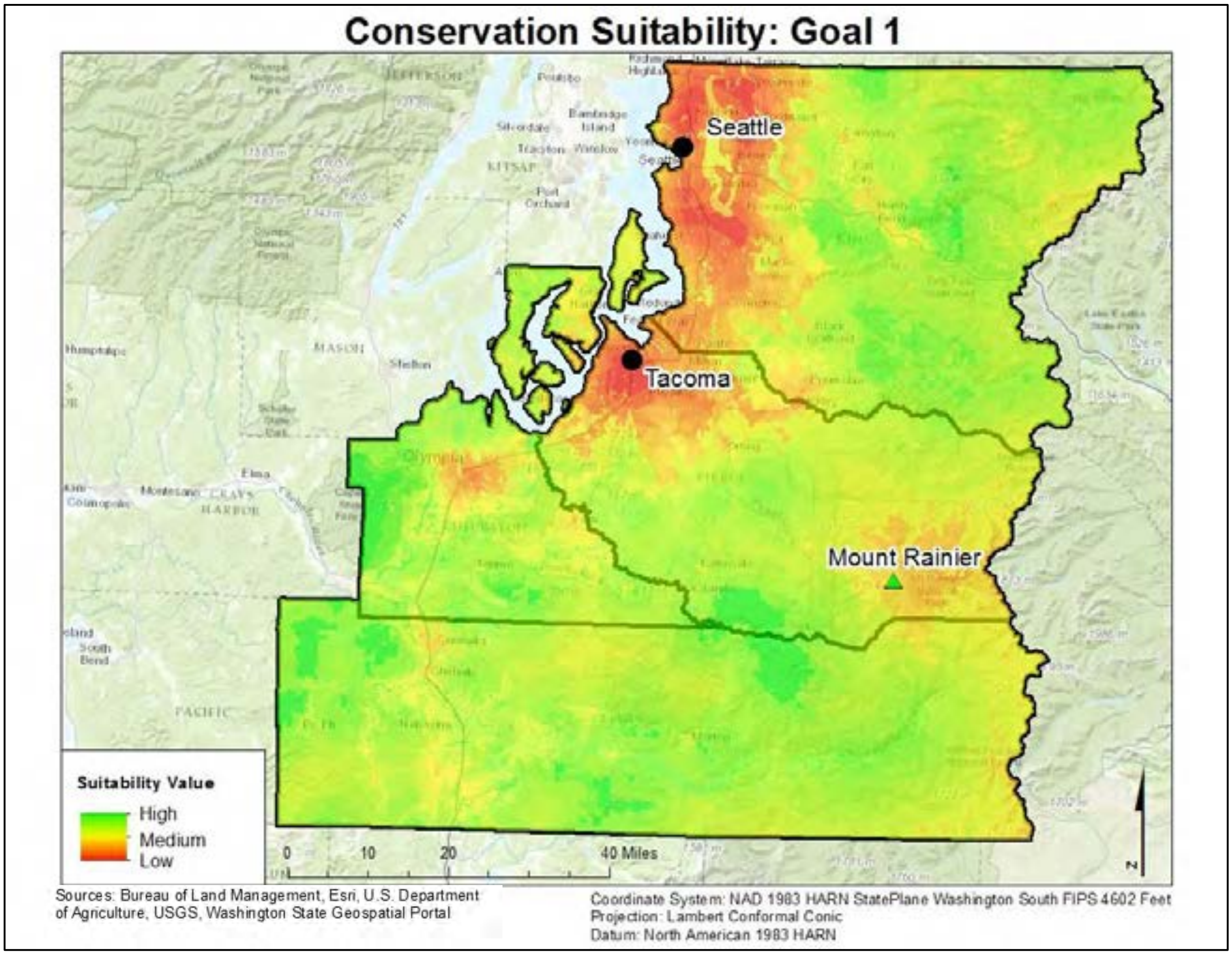
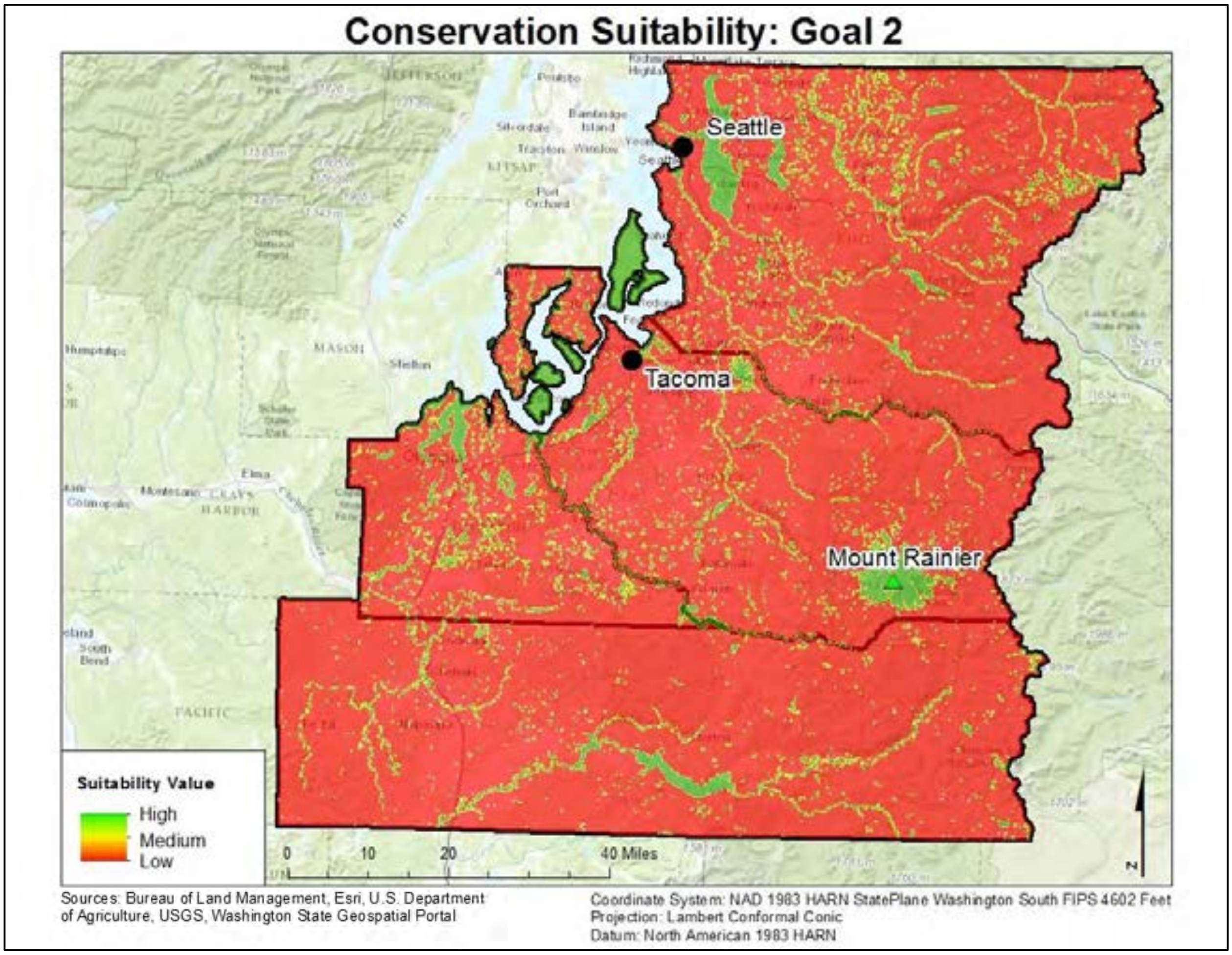


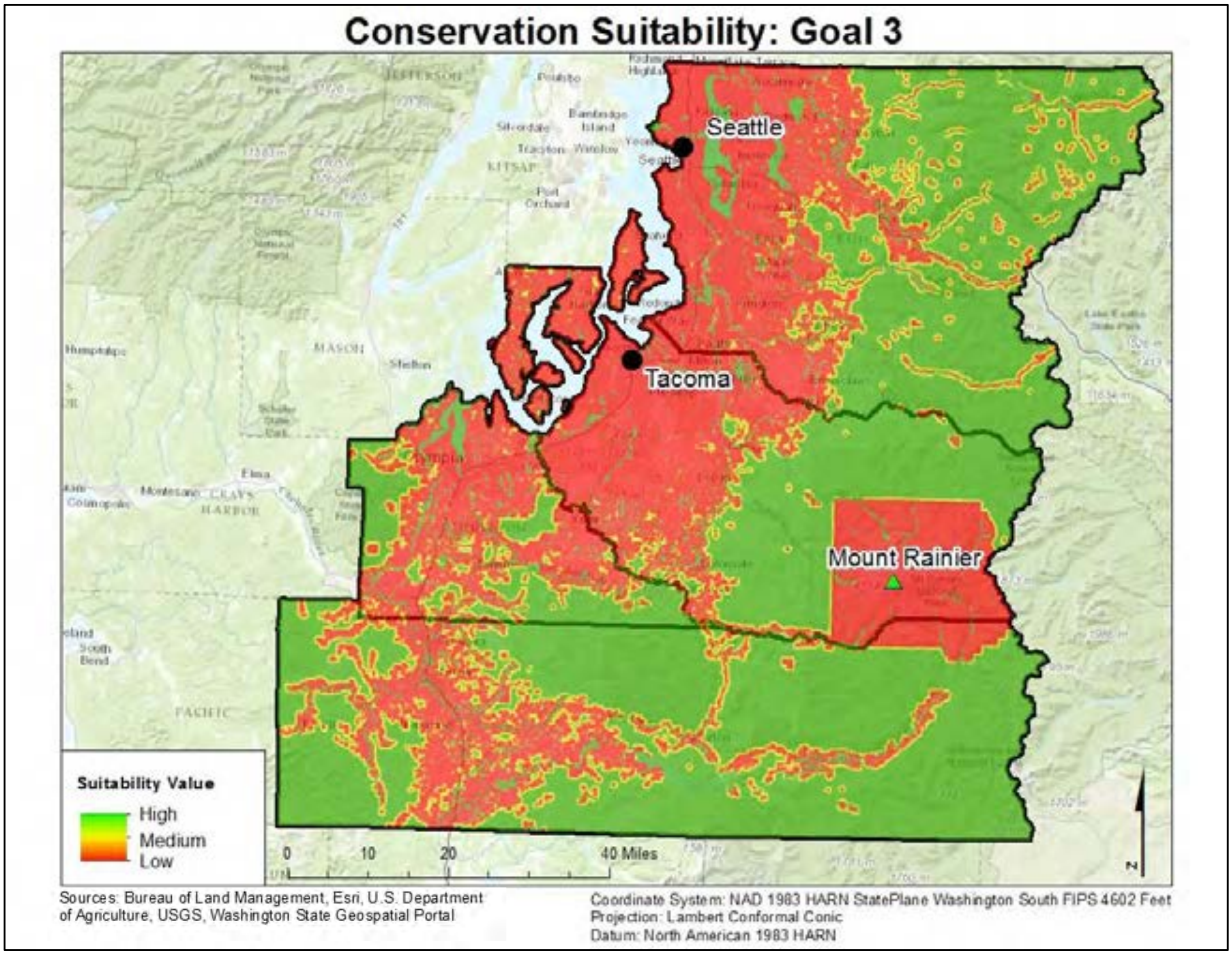
Figure 26: Results for conservation suitability goal 1; Identify lands suitable for protecting native biodiversity



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

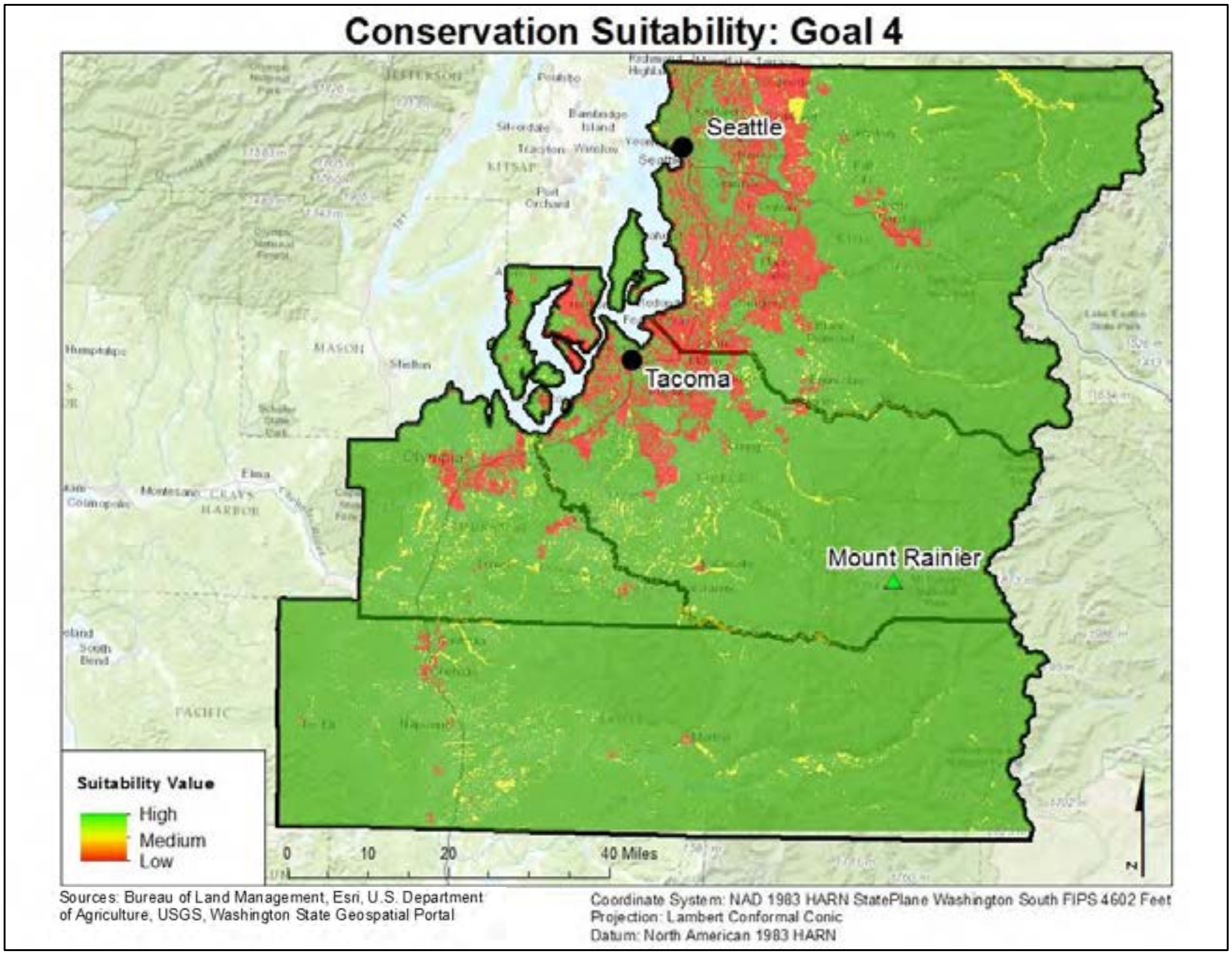
Figure 27: Results for conservation suitability goal 2; Identify lands suitable for protecting water quality



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 28: Results for conservation suitability goal 3; Identify lands suitable for protecting important ecological processes

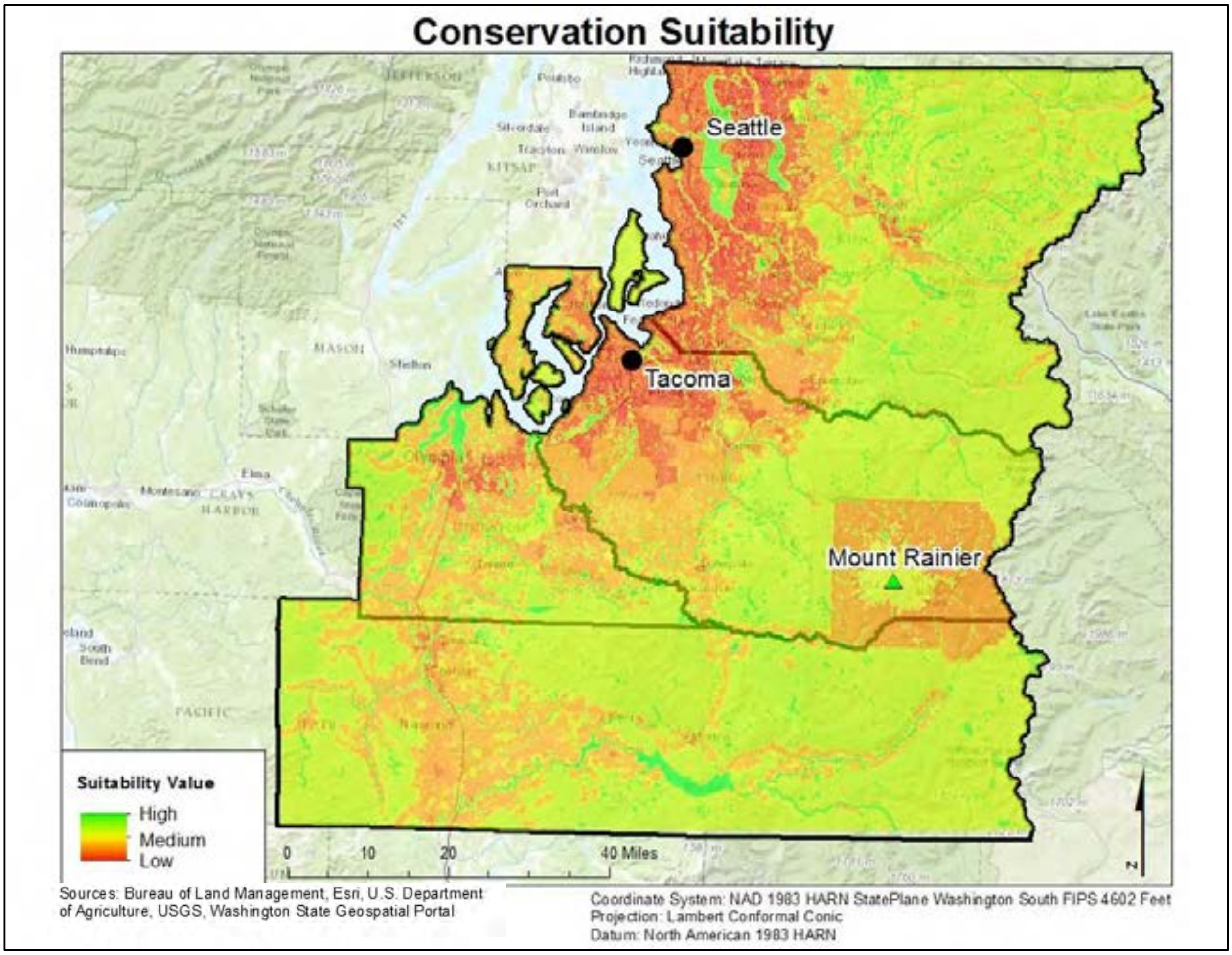


Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 29: Results for conservation suitability goal 4; Identify lands suitable for resource-based recreation.

The majority of the study area, with exception of urbanized areas and Mount Rainier, was most suitable for protecting native biodiversity. Lands suitable for protecting water quality followed the presence of rivers and open water throughout the study area and those suitable for protecting important ecological processes surrounded urbanized areas and the Mount Rainier National Park, covering the majority of the eastern and southern regions of the study area. The majority of the study area was highly suitable for resource-based recreation, with exception to some urbanized regions. Combining these four goals derived the overall conservation land use suitability (Figure 30).


Conservation Suitability

Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

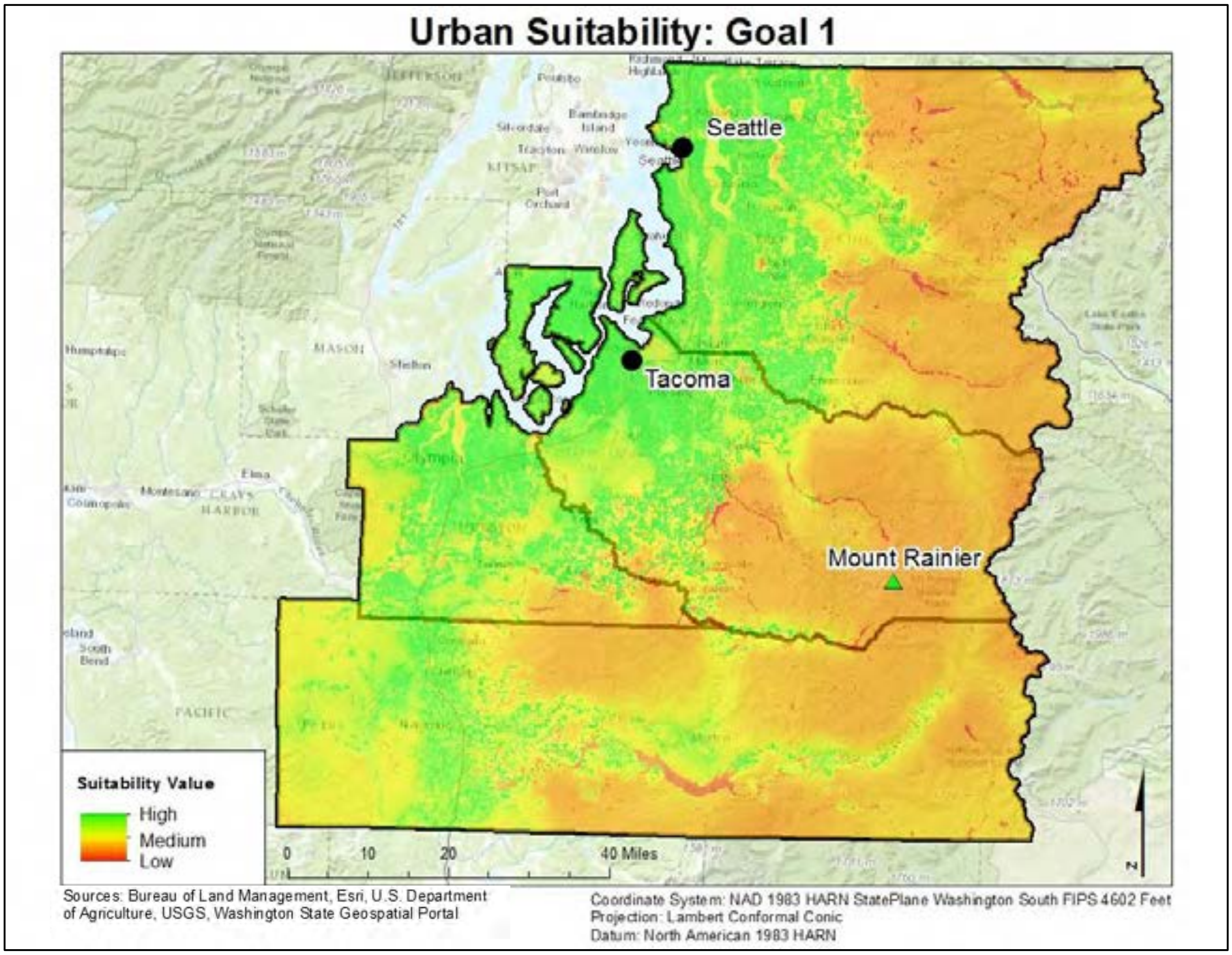
Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 30: Results for conservation land use suitability

The conservation suitability for the study area was highest directly east of Seattle and south and west of Tacoma. The majority of the study area contains land that had a value of medium suitability for conservation land use.

4.1.3. Urban Land Use Suitability

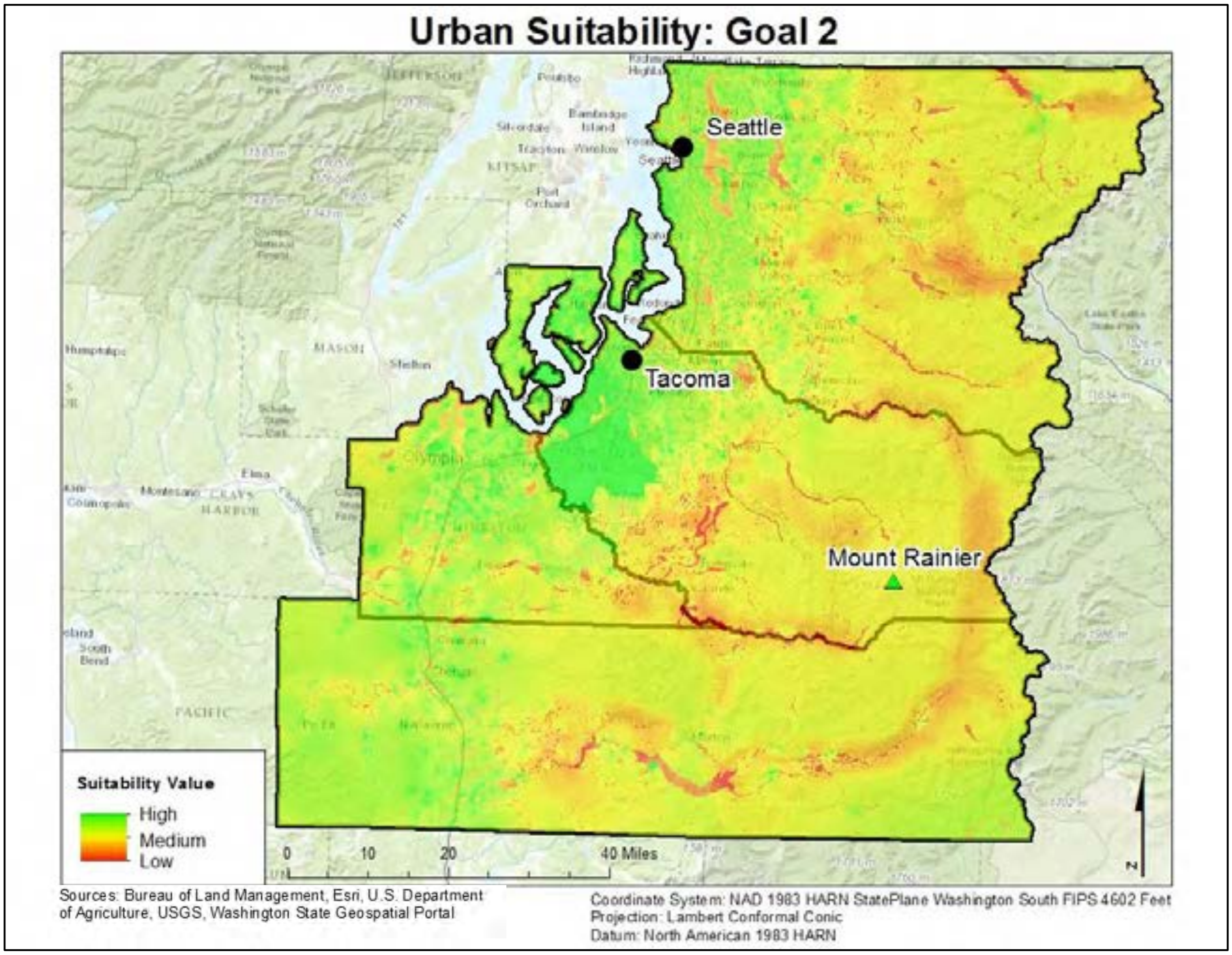
The urban land use suitability map is a result of the four goals stated in Table 2. Individual objectives and subobjectives are found in Appendix A and results for goals 1-4 are seen in Figures 31-34.



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

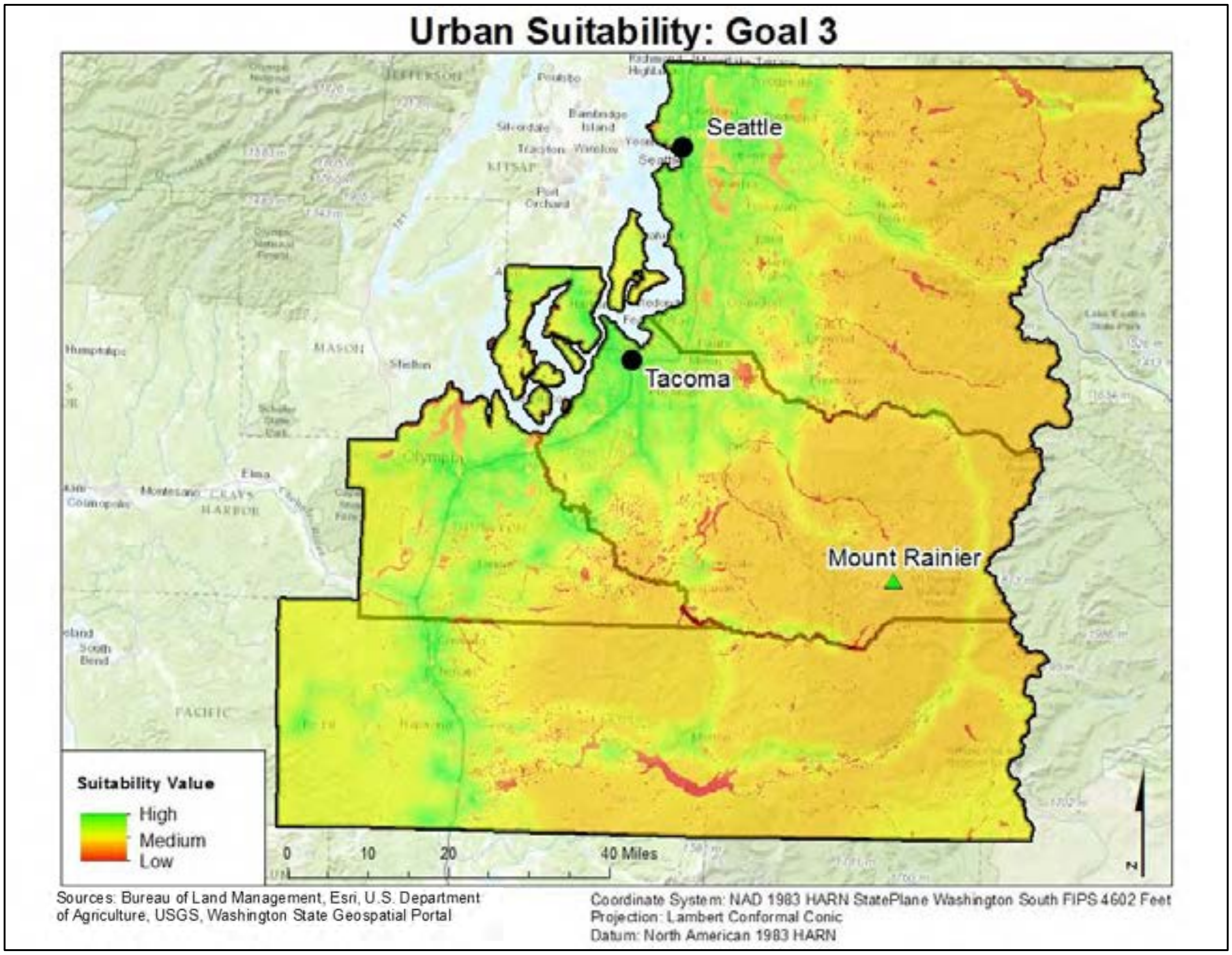
Figure 31: Results for urban suitability goal 1; Identify lands suitable for residential land use


Urban Suitability: Goal 2

Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

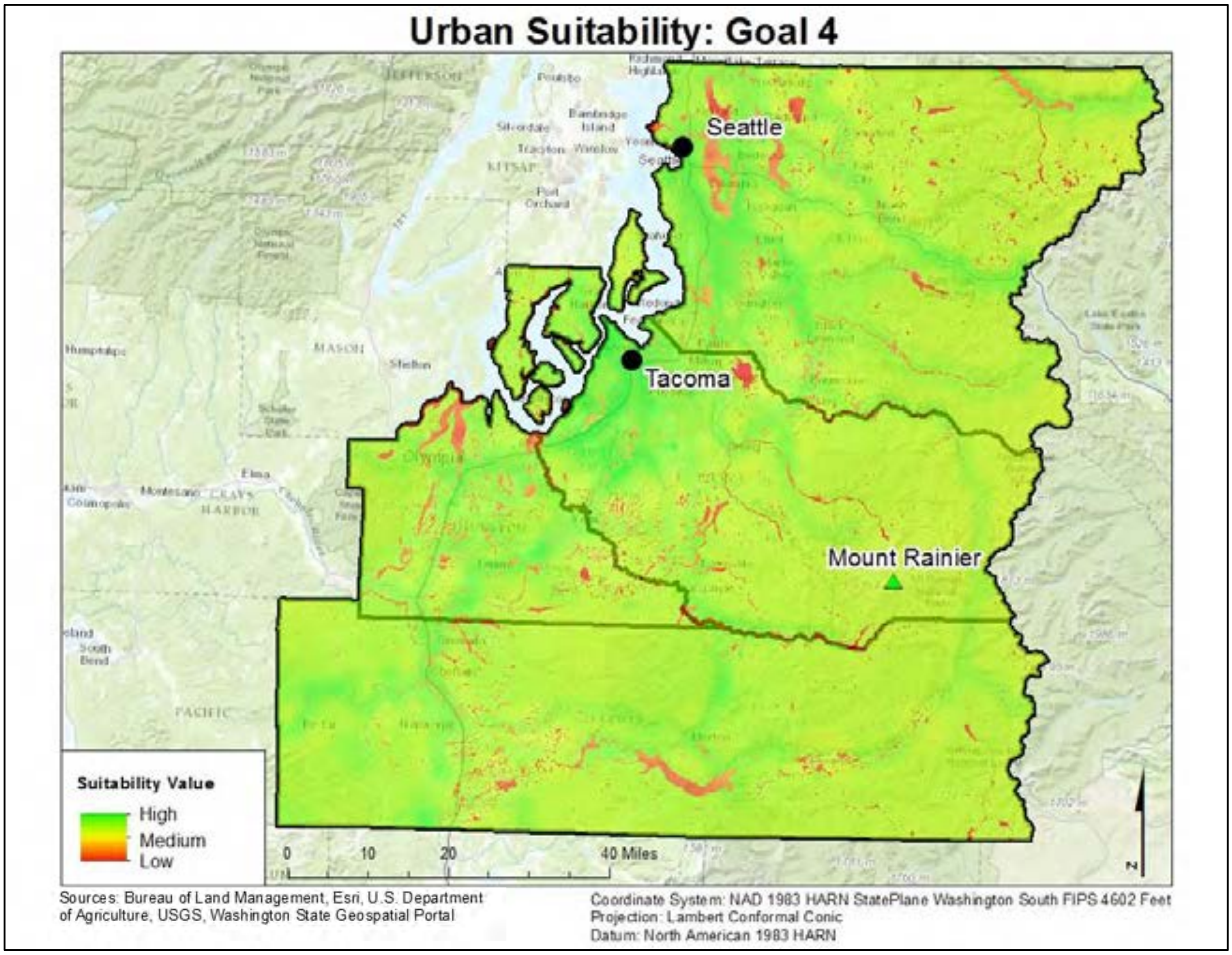
Figure 32: Results for urban suitability goal 2; Identify lands suitable for office/commercial land use


Urban Suitability: Goal 3

Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 33: Results for urban suitability goal 3; Identify lands suitable for retail land use



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 34: Results for urban suitability goal 4; Identify lands suitable for industrial land use

The land most suitable for residential use was near existing urbanized areas, the western region, and medium-low for eastern portion of the study area. The lands suitable for office/commercial land use was once again the western portion of the study area, but in comparison to residential, the eastern portion of the study area was medium suitability. Retail land was most suitability in areas surrounding existing urbanized areas and was similar to office/commercial land in that the eastern portion is medium suitability. Industrial land use was medium-high to high suitability for the majority of the study region with a few exceptions of low suitability. Combining these four goals determined the overall urban land use suitability (Figure 35).

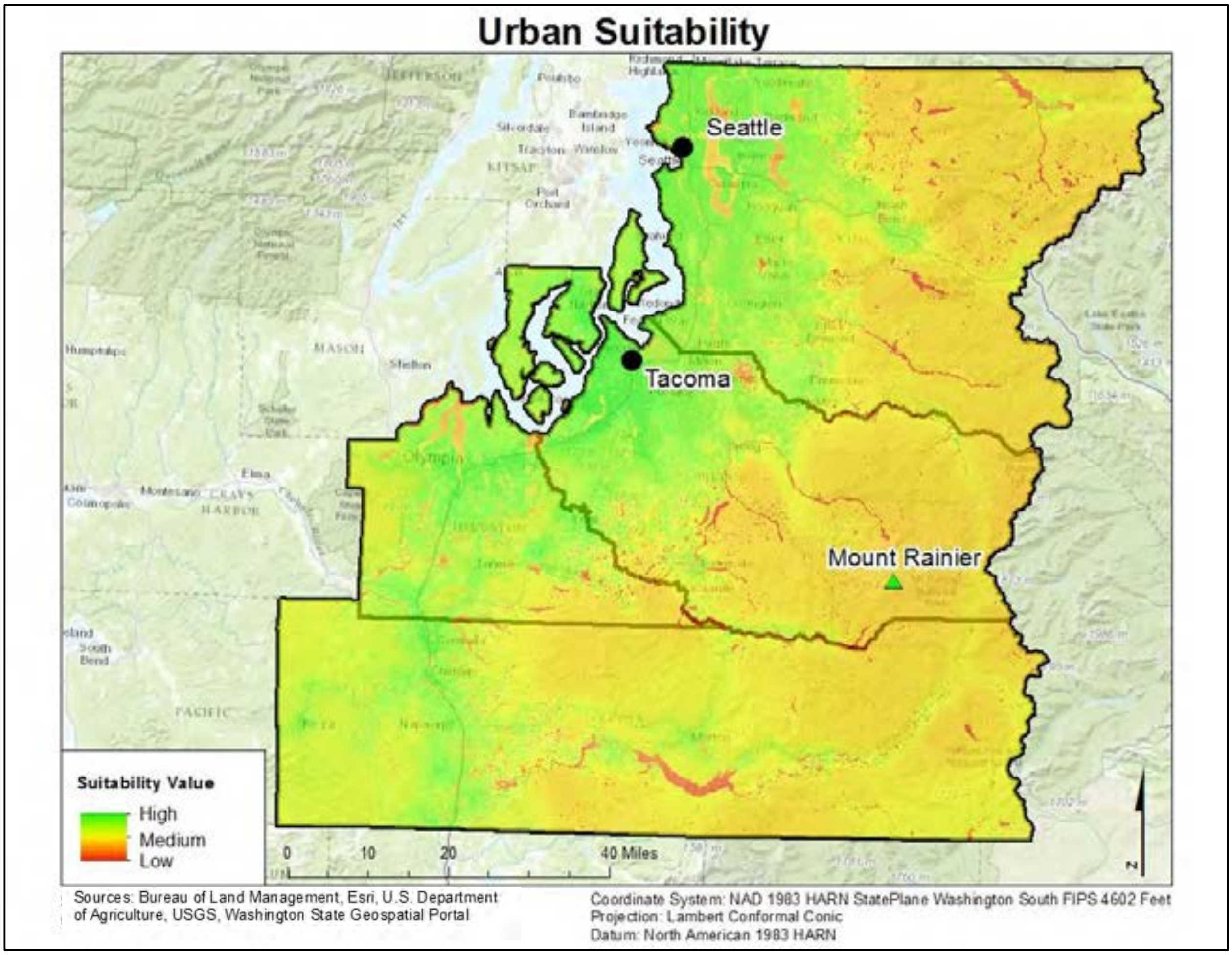


Figure 35: Results for urban land use suitability

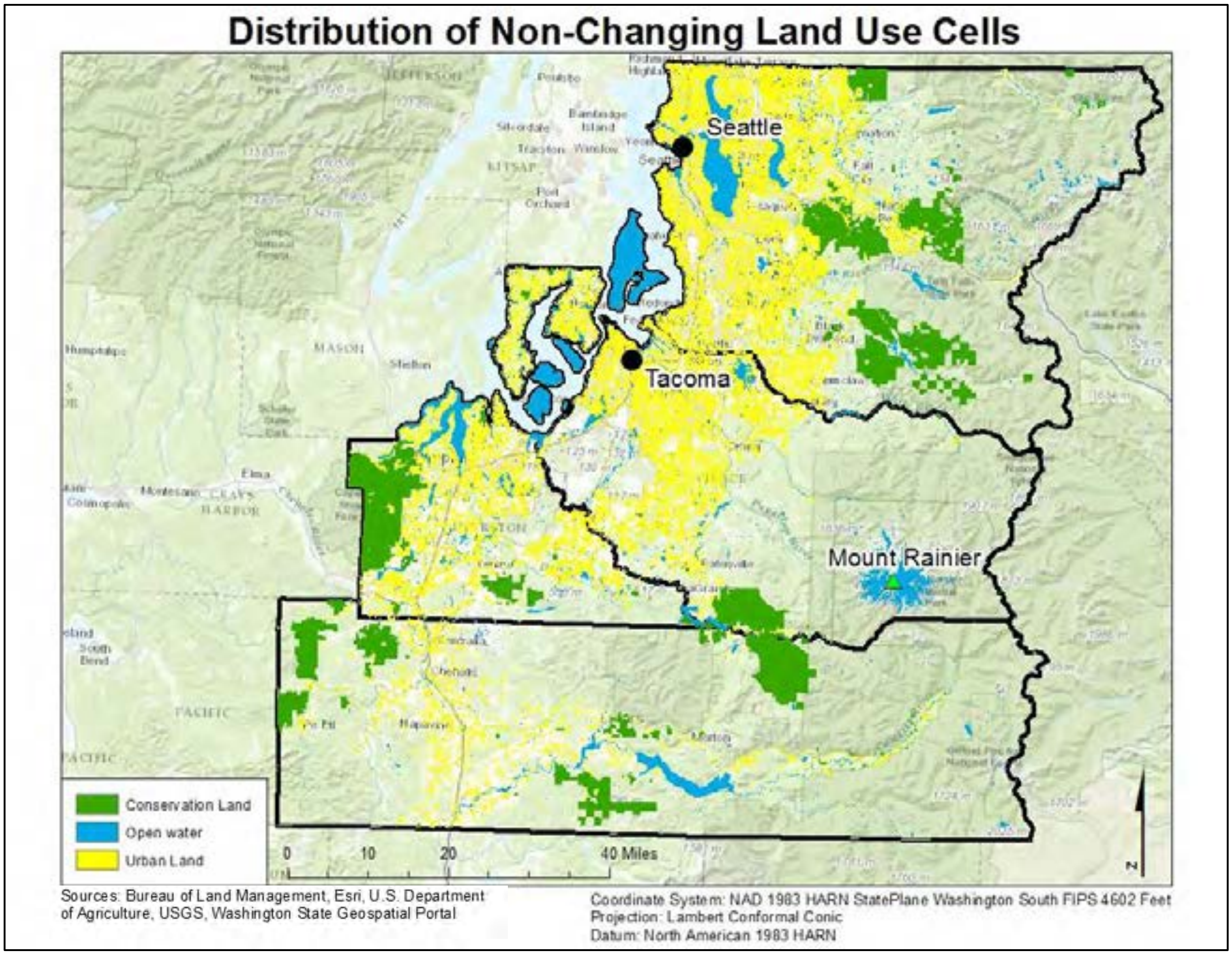
Urban land use suitability was highest in the western portion of the study area, lands near existing urbanized regions. Very few areas are low suitability, although the entire eastern portion of the study area was medium-low suitability.

4.2 Land Use Preference Conflict

The land use preference conflict stage of the LUCIS model results is broken into three sequential sections. The first is removal of all cells that will not change, second is normalized suitability results for each land use type, and the last is combined preferences to determine the areas of conflict.

4.2.1. Removal of Non-Changing Land Use

Cells that will not change are existing urban lands, open water, and existing conservation lands. This stage created a development mask for the rest of the analysis. The cells shown in Figure 36 were excluded from the future basemap analysis. Existing urban areas will remain urban, existing conservation lands will remain conserved, and open water will remain as water features.


Distribution of Non-Changing Land Use Cells

Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

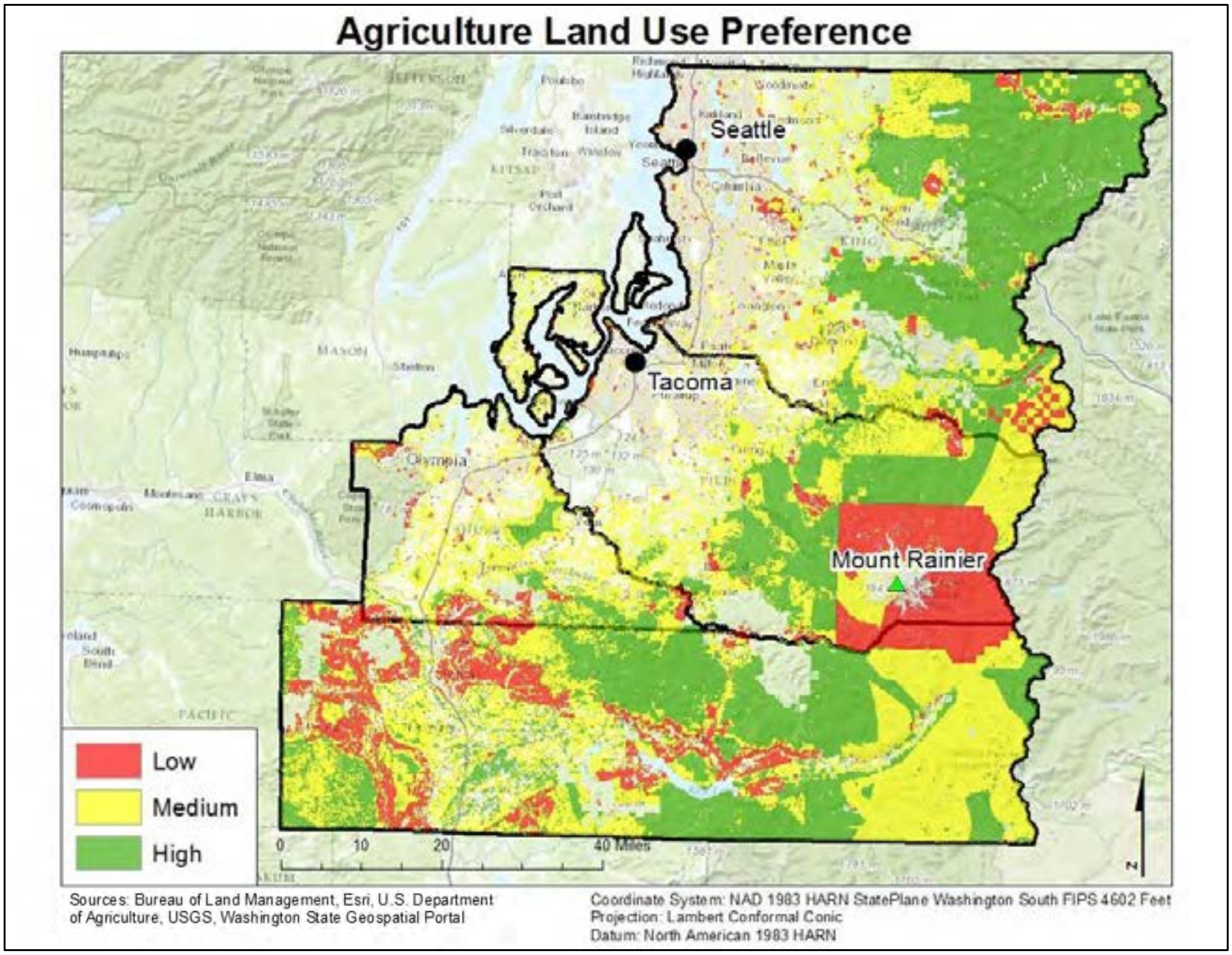
Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 36: Non-changing land use cells

4.2.2. Normalization and Collapsing of Land Use Suitability

Although the resulting normalized and collapsed maps do not differ significantly from the overall suitability maps, these maps give a more effective view of where land should be developed. Figures 37-39 depict results from normalizing and collapsing the three land use preferences, depicting high, medium, and low suitability. The resulting figures are limited to lands available for development, clipped by the development mask. The color ramp again depicts the range of low to high (red to green) for each cell. Once the development mask was applied, there were 3,114,079 acres available for future development.

The agricultural preference map (Figure 37) confirms that land most suitable for agriculture was dominant in the northeast corner and flows through the center of the study area. This preference map depicts that land surrounding existing urban land has a very low suitability for agriculture. Additionally, land inside of Mount Rainier National Park was not suitable for agriculture.



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 37: Normalized and collapsed agricultural suitability limited to developable lands

The conservation preference map (Figure 38) depicts the wide but limited sprawl of high suitability lands. Similarly to agriculture, the lands surround existing urban lands and those in

Mount Rainier National Park have a low suitability for conservation development. National Parks are considered conservation land, however in this model, Mount Rainier National Park is only considered a park and is therefore not existing conservation land. The National Park is included in the resource-based recreation suitability goal, however is not suitable enough to have an impact in the final conservation preference map. Figure 30 shows the National Park is considered to be medium-low suitability and when normalized and reclassified it became a low preference area.

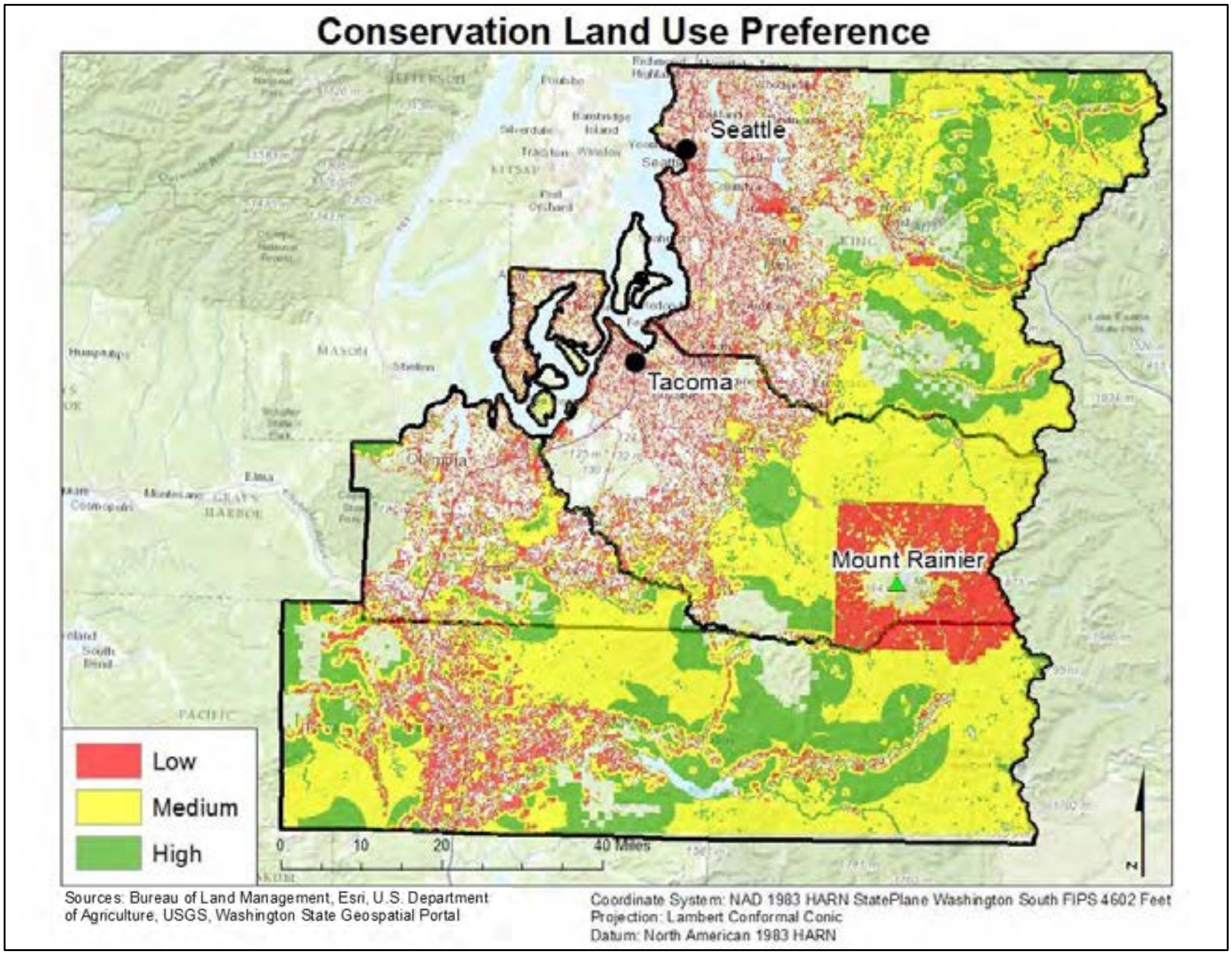
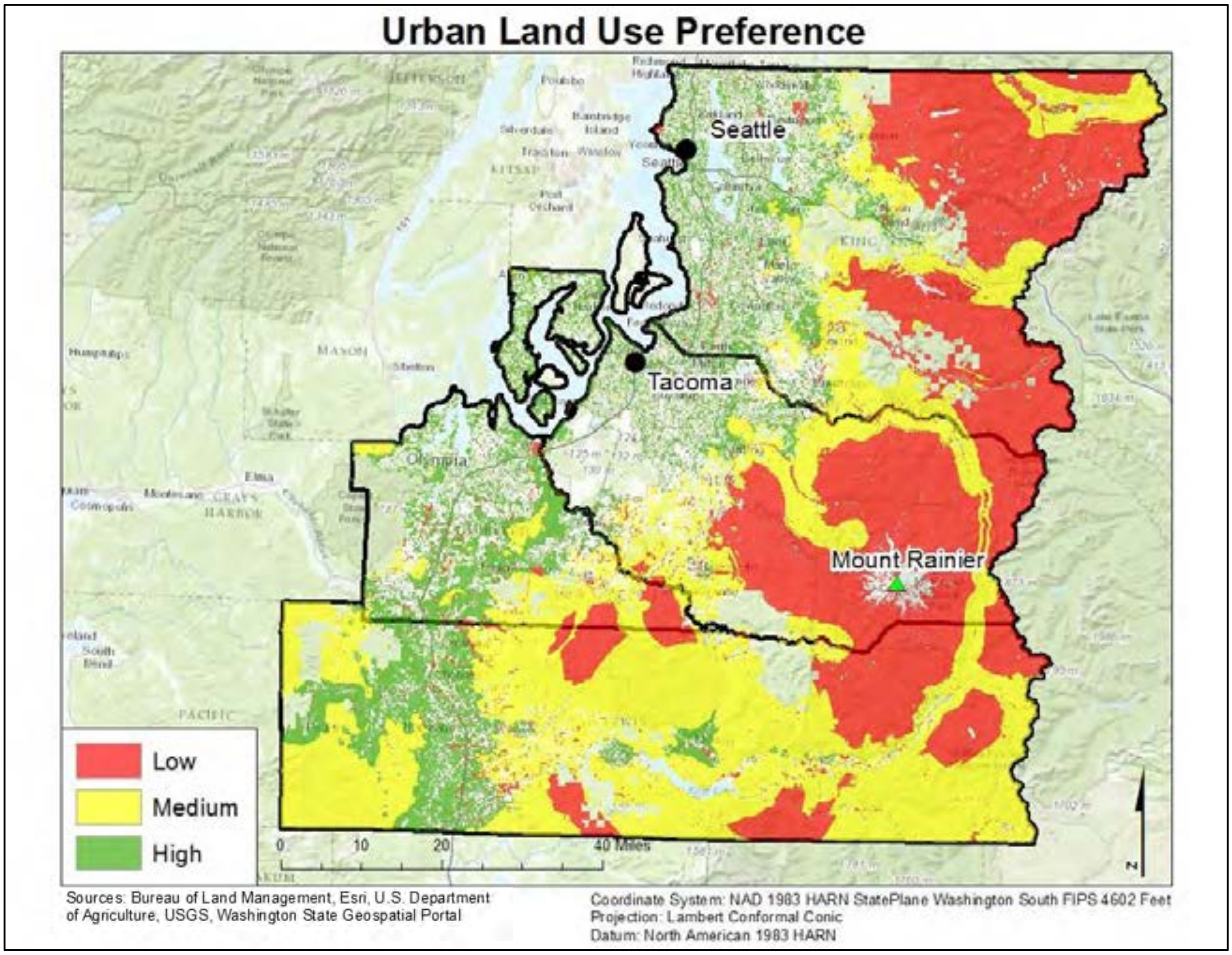


Figure 38: Normalized and collapsed conservation suitability limited to developable lands

The urban preference map (Figure 39) depicts areas surrounding existing urban areas as the highest suitability land for future urban development. The majority of land in the western portion of the study area was high suitability whereas the majority of the eastern land was low suitability.



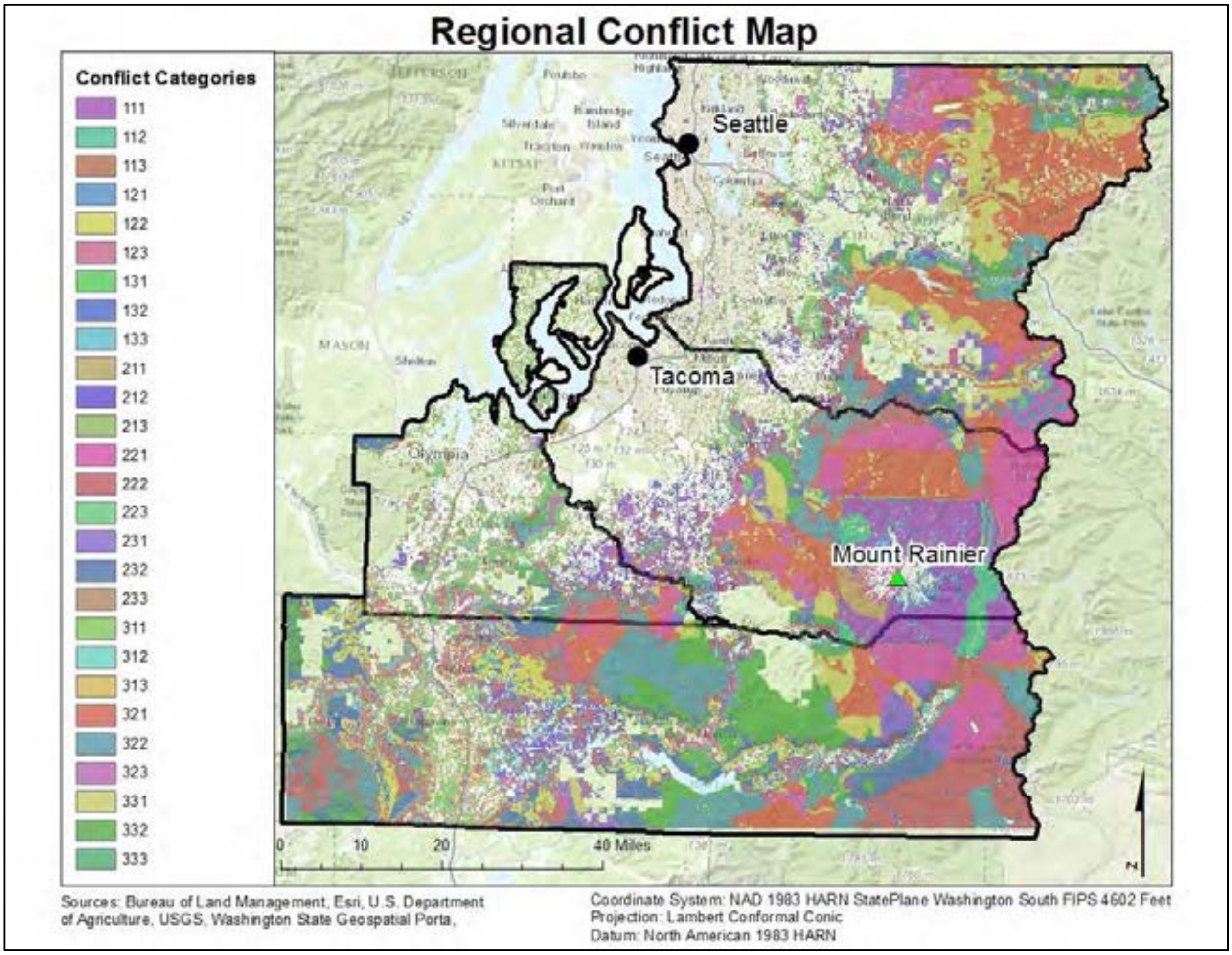
Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 39: Normalized and collapsed urban suitability limited to developable lands

4.2.3. Combination of Land Use Preferences and Identification of Land Use Conflicts

The conflict map was created using preference maps and depict the 27 unique conflicts categories (Table 1) to identify the distribution of land use conflict and preferences. Figure 40: Regional conflict map depicting the 27 unique conflict categories illustrates the distribution of individual conflict categories on an acre cell size basis.



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Porta,

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 40: Regional conflict map depicting the 27 unique conflict categories

As the individual conflicts cannot be identified in Figure 40, results are graphed in Figure 41, showing the number of acreages in each conflict category. Figure 41 shows that 1,644,206 acres or 52.8% of cells are not in conflict and will be assigned to their preferred land use type (Figure 42). Urban suitability dominates this category with 481,287 acres or 29.3% of the 1,644,206 acres and agriculture suitability dominance represents 430,549 acres or 13.8% of all acres in the study area. Additionally 343,268 acres or 11% of the cells are in major conflict with all land use categories in moderate preference. With the exception of the major conflict, agriculture and conservation, share the most conflicts between land uses, making up 708,035 acres or 22.7%.

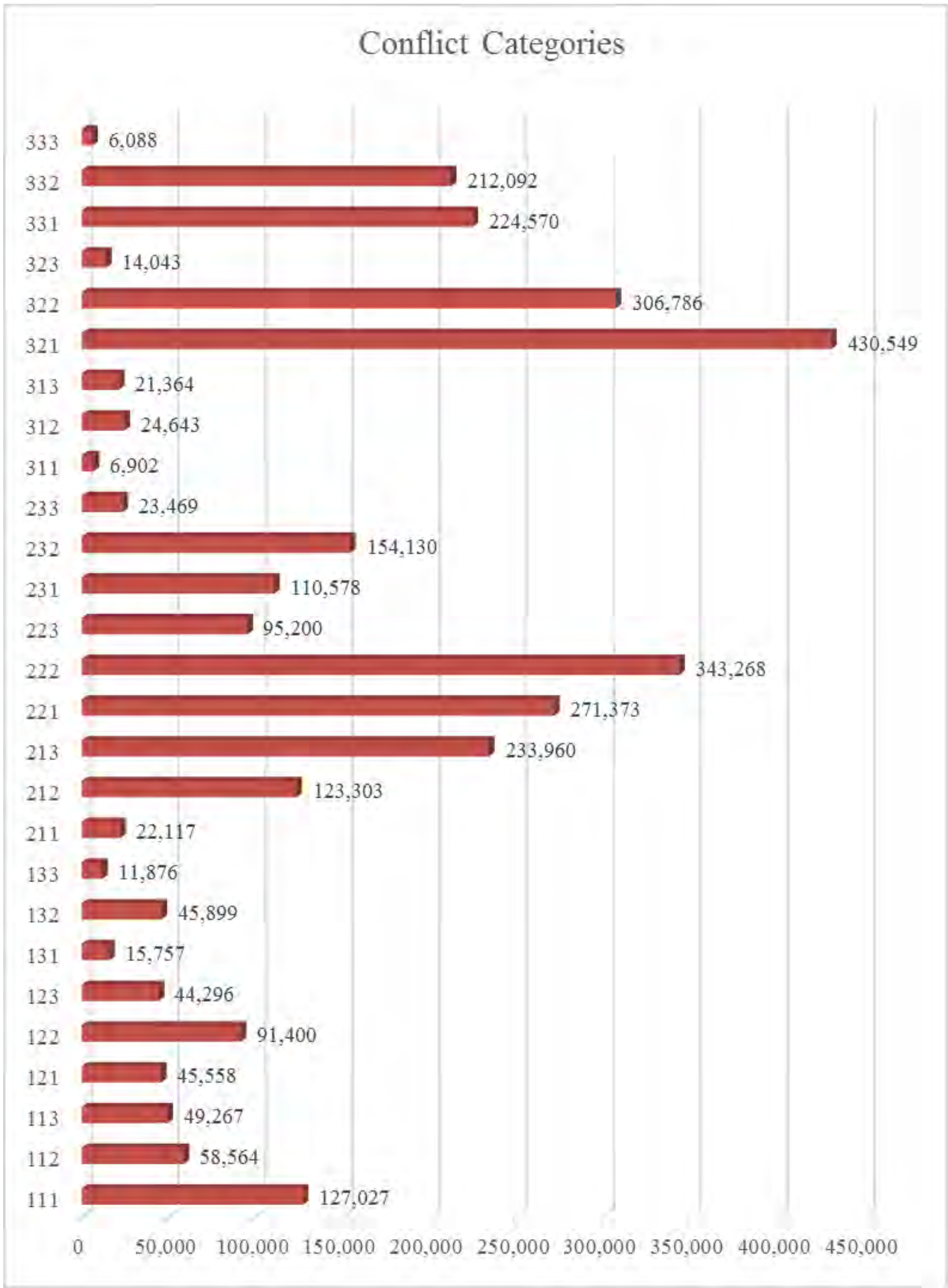
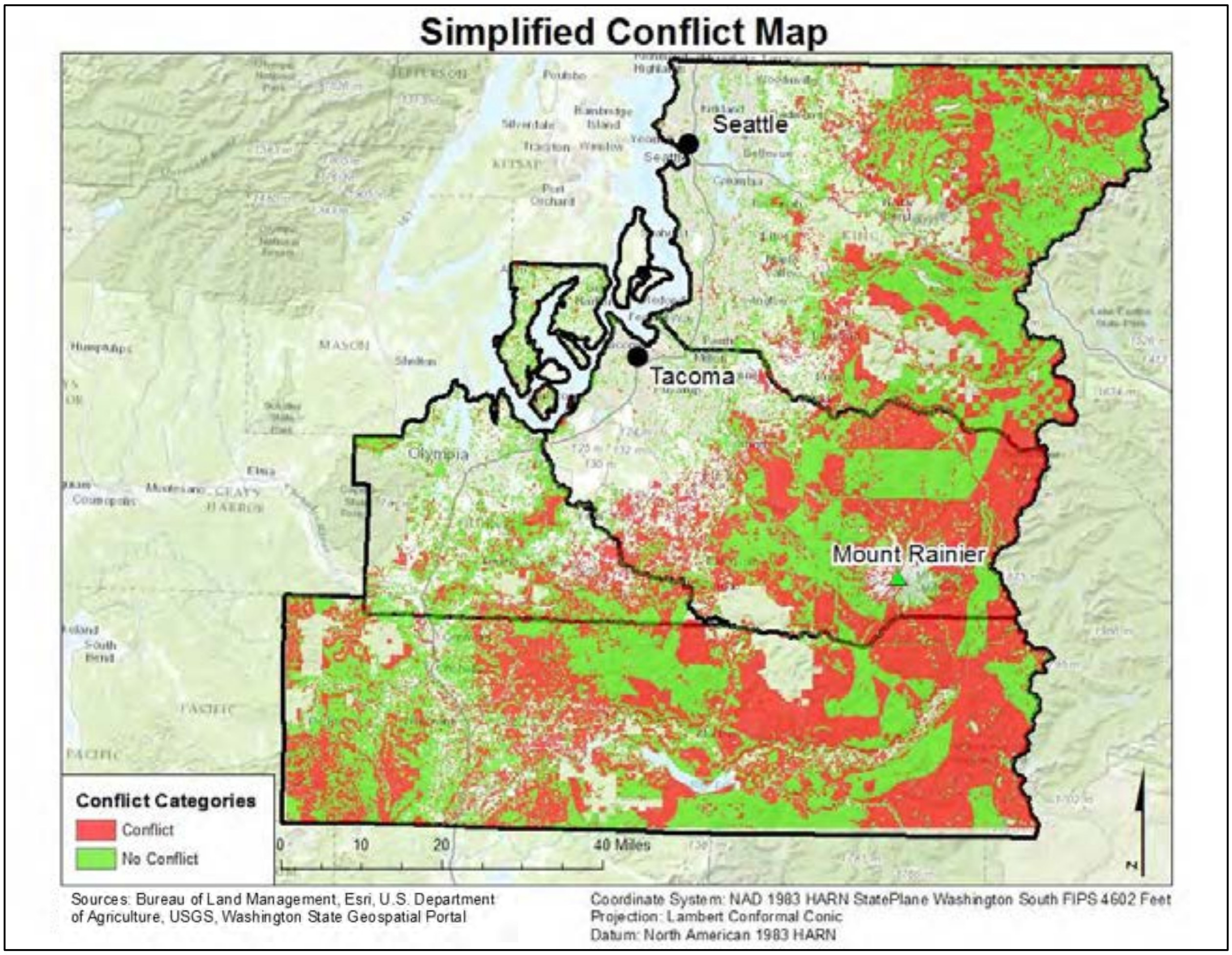


Figure 41: Acres in conflict based on conflict categories

A simplified map of cells that were and were not in conflict is seen in Figure 42. Areas in conflict are seen in red and made up 47.2% of the developable land. Green shows areas that were not in conflict and assigned their preferred land use type. These two categories are further examined in Figures 43 and 44.

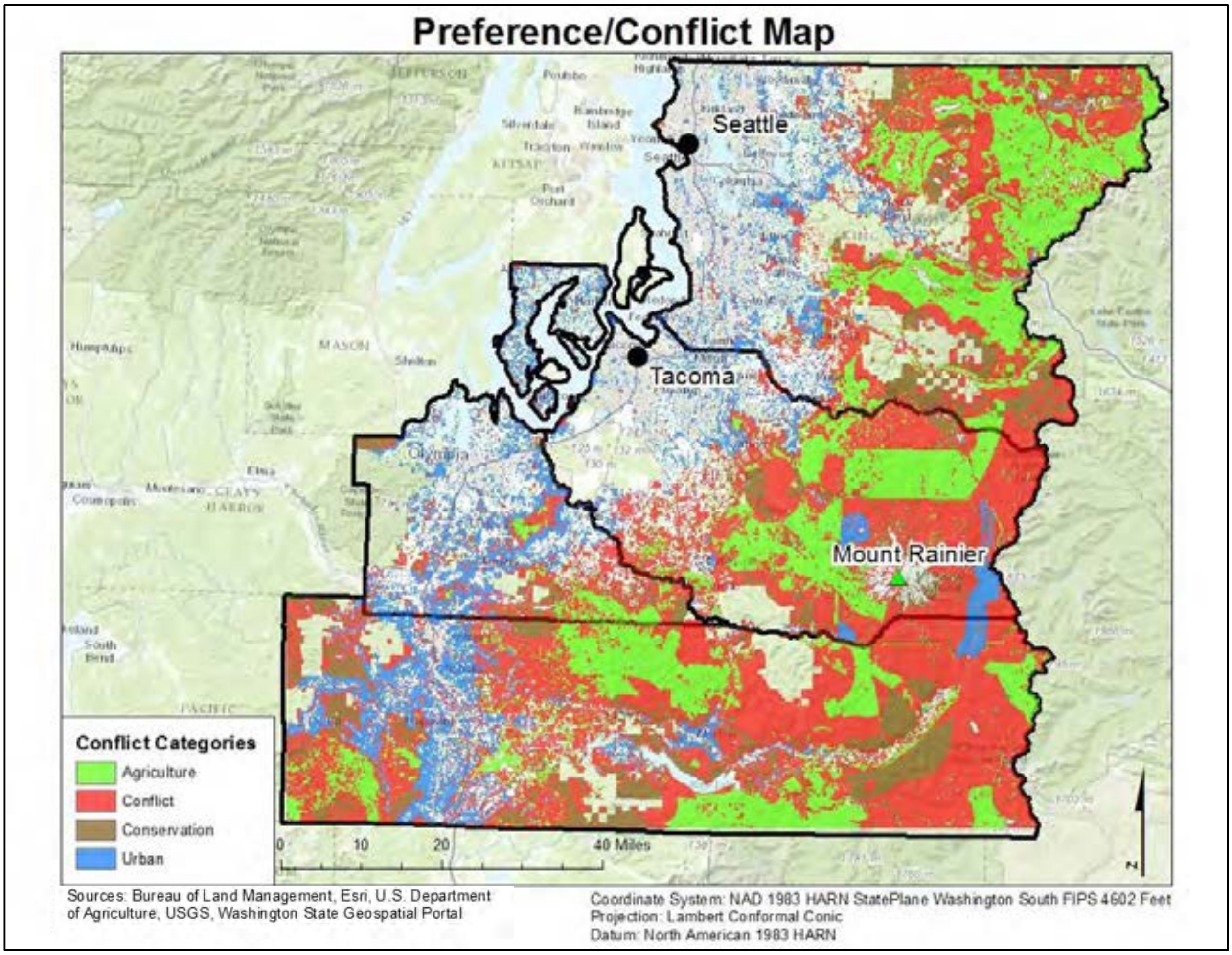


Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 42: Developable land with or without conflicts of land use preferences

A more detailed view of the preferences and land use conflicts are seen in Figures 43 and 44. The acreage and percentage of each land use preference and conflict are seen in Table 5. Figure 43 depicts developable lands according to which land use is dominant. Urban land was without conflict near the existing urbanized areas whereas conservation and agriculture lands were spread throughout the study region. It is evident that areas in conflict were spread relatively evenly through the eastern portion of the study region. Compared to other conflict categories, the agriculture land use suitability was most dominant.


Preference/Conflict Map

Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

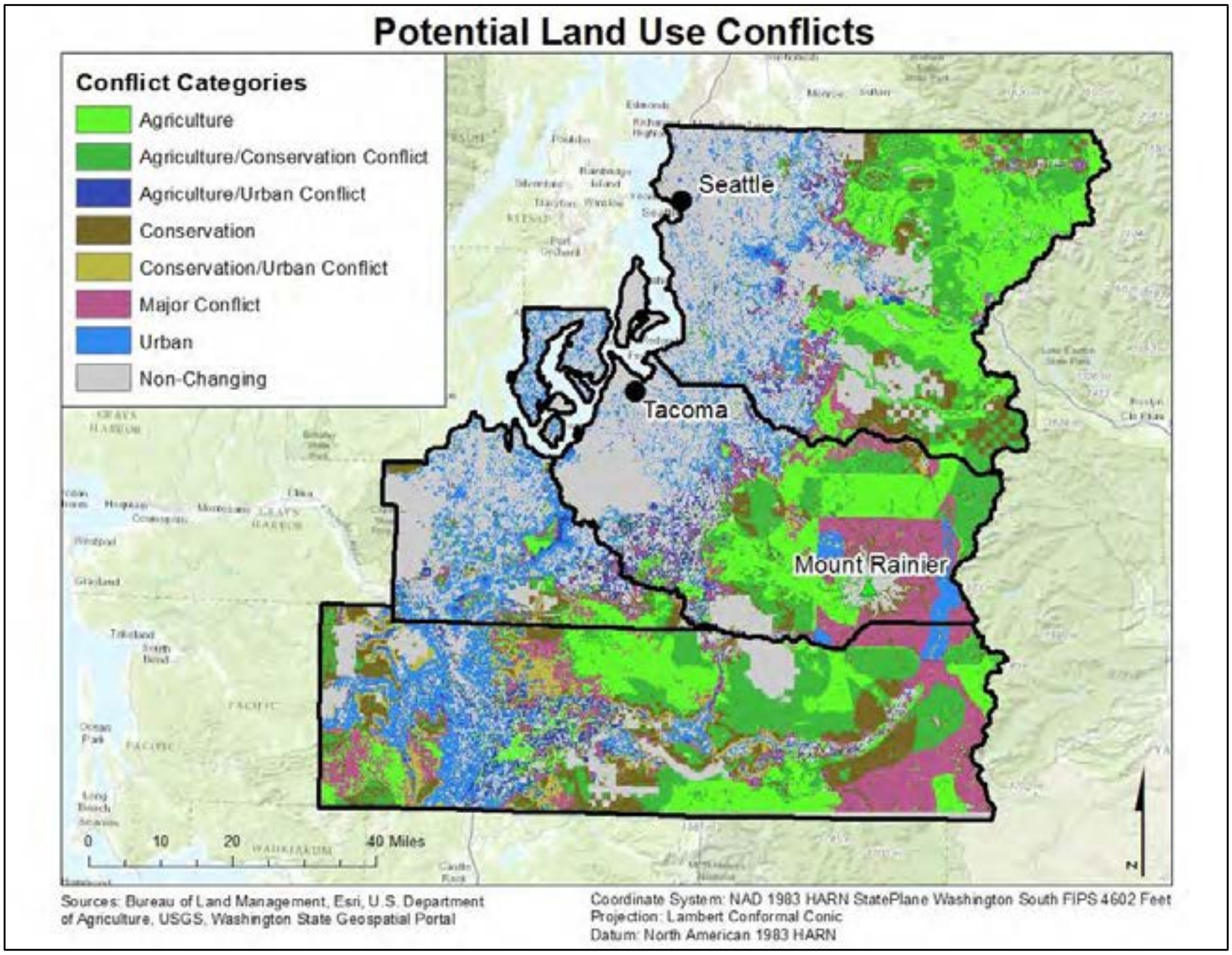
Figure 43: Developable lands with land use preference for cells with no conflict and cells with land use conflict

Each conflict category was defined by the acres of conflict/preference and the percentage of total developable land in Table 5. Not only did agriculture suitability occupy the most acreage, but the largest number of acres in conflict were associated with agriculture. The majority of suitable conservation lands were in conflict with agriculture land and the smallest percentage of acreage in conflict was Agriculture/Urban and Conservation/Urban. The majority of lands suitable for urban development fall into the urban preference type codes and therefore were not as likely to be in conflict with another land use type.

Table 5: Areas of potential future land-use conflict, described in acres and percentage of total developable land

Conflict or Preference Type	**Acres of Conflict or Preference**	**Percentage of Total Developable Land**
Agriculture/Urban Conflict (Conflict Codes: 212, 313, and 323)	158,710	5%
Agriculture/Conservation Conflict (Conflict Codes: 221, 331, and 332)	708,035	23%
Conservation/Urban Conflict (Conflict Codes: 122, 133, and 233)	126,745	4%
Major Conflict (Conflict Codes: 111, 222, and 333)	476,383	15%
Agriculture Preference (Conflict Codes: 311, 312, 321, 322, and 211)	790,997	25%
Conservation Preference (Conflict Codes: 121, 131, 132, 231, and 232)	371,922	12%
Urban Preference (Conflict Codes: 112, 113, 123, 213, and 223)	481,287	16%

Each of the seven conflict types are displayed in one map, Figure 44, adding an additional level of examination. Each conflict type was symbolized to indicate their location and acreage. As seen in Figure 41 and Table 5, the majority of the map was composed of land in major conflict and agriculture/conservation conflict, the latter of which make up the majority of the eastern side of the study region. This is expected as it is furthest from the existing urbanized areas.


Potential Land Use Conflicts

Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

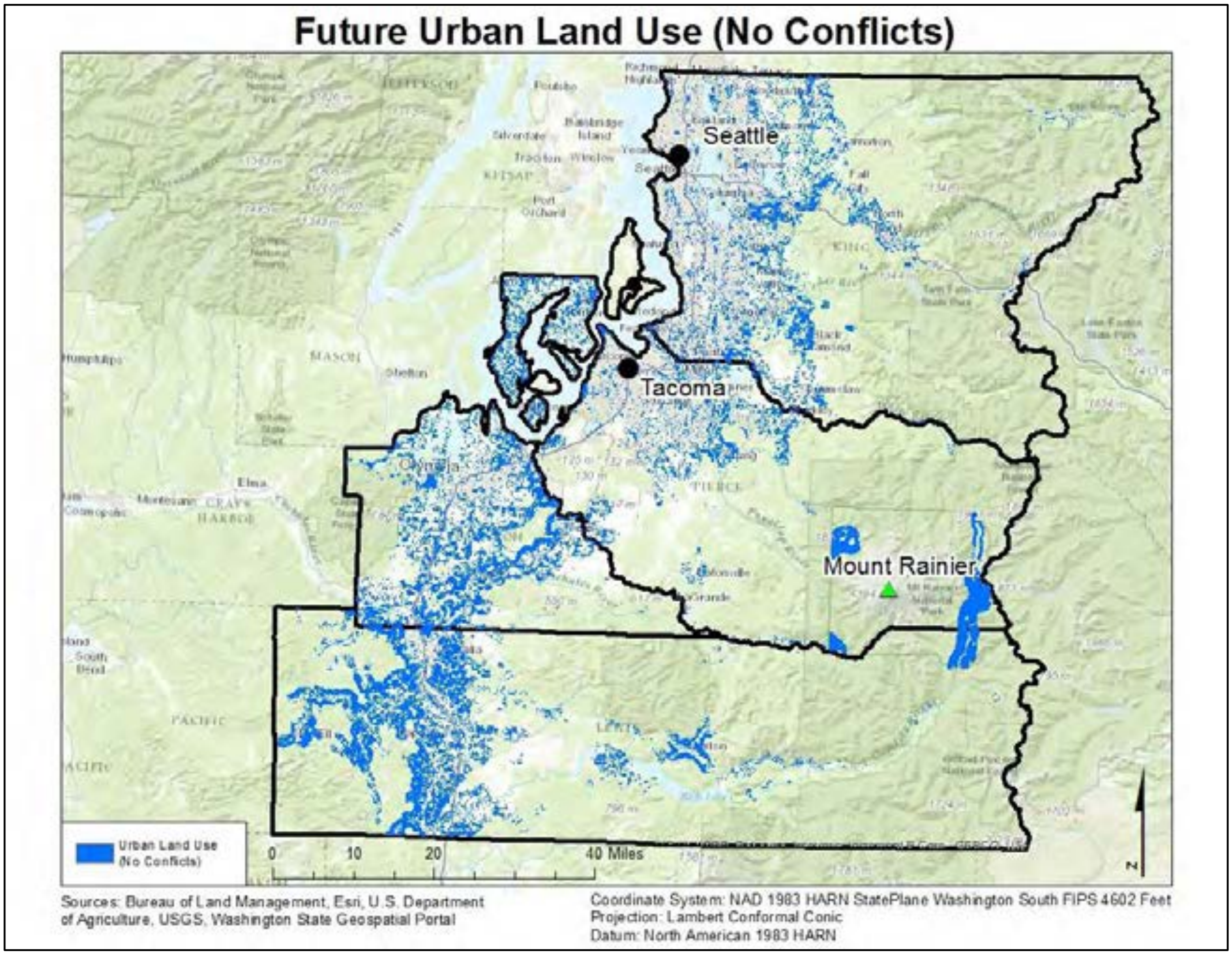
Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 44: Areas of land use conflict

4.3 Potential Future Land Use

Up to this point, all of the results have been identifying suitability and preference for land use types. Suitability results were built upon to create preference and conflict, and those built upon to create potential future land use. Developers can use these results for future land development. The results indicate which cells should be allocated to urban development to support population growth, and subsequently agriculture and conservation lands.

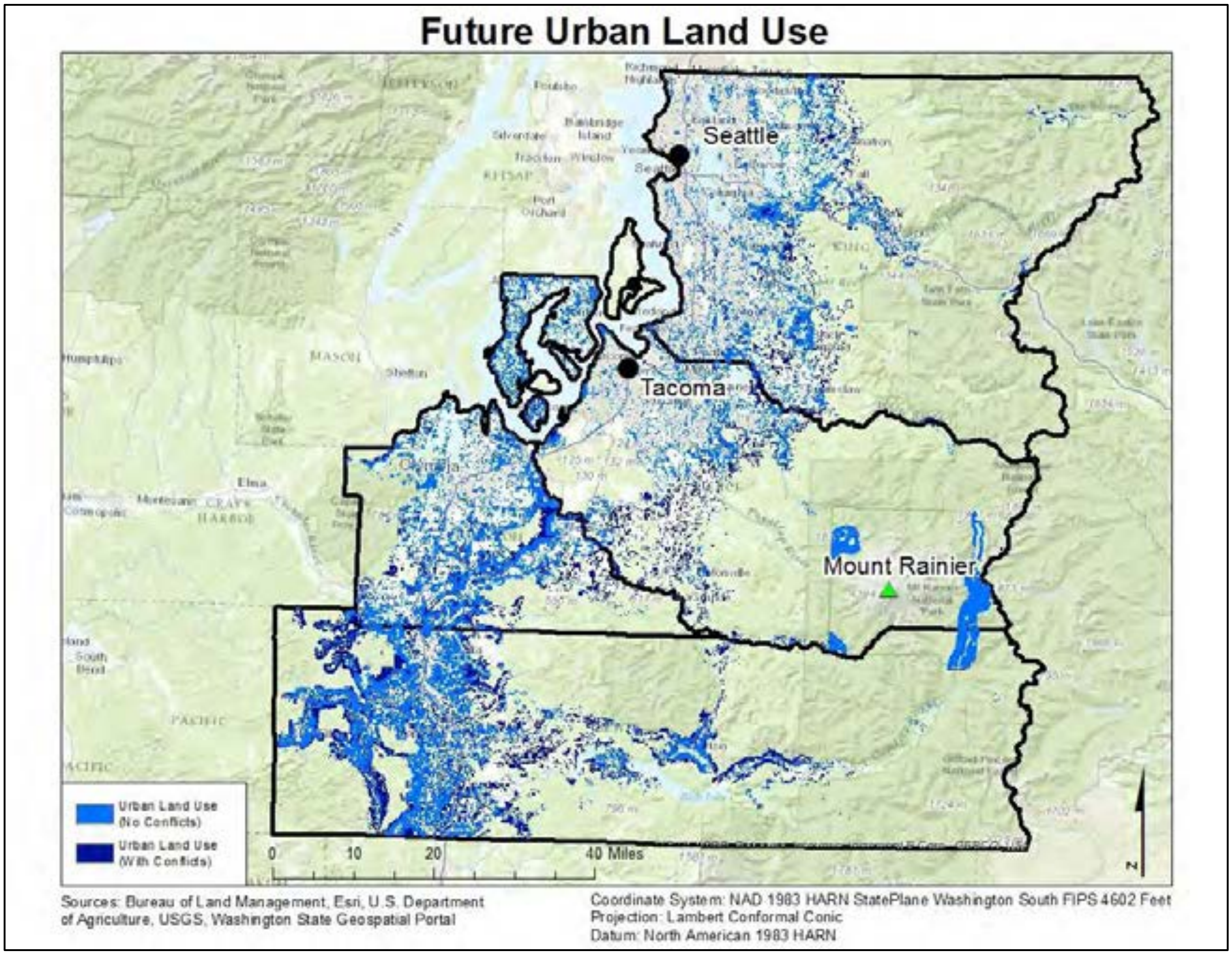
By the year 2060 the projected population of King, Lewis, Pierce, and Thurston counties is 5,372,395, which is 2,318,202 people more than the 2010 population. Using the projected gross population density of 3.75 people per acre, the study region needed 621,405 additional urban acres in order to support the estimated future population. That is approximately 20% of the 3,114,079 acres that are developable in the future. 481,287 acres (77%) were allocated to urban land, from those cells with urban preference (Figure 45). This left an additional 140,118 cells to be allocated from either conservation/urban conflict cells or agriculture/urban conflict cells. 209,299 additional cells were allocated from these two conflict categories representing an over-allocation of 69,181 acres. This over-allocation was due to the slice process. This slice tool creates 1,000 equal areas with a range of urban preferred cells over agriculture and conservation cells. During the slice process, all cells that prefer urban over agriculture and conservation are allocated to urban if an area is selected, therefore over-allocating the urban cells. The total number of urban acres assigned to the future land use was 690,586 (22%) (Figure 46).



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 45: 77% of potential urban land use in 2060. Acres were assigned from where urban was preferred and no in conflict with other land uses.


Future Urban Land Use

Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 46: Potential urban land use in 2060.

After urban cells were allocated, 2,423,493 acres (78%) remained to be allocated. For the remaining land, acres were allocated to agriculture where agriculture was not in conflict with any other land use and was preferred. 790,997 total acres were allocated to agriculture accounting for 33% of the remaining land (Figure 47).

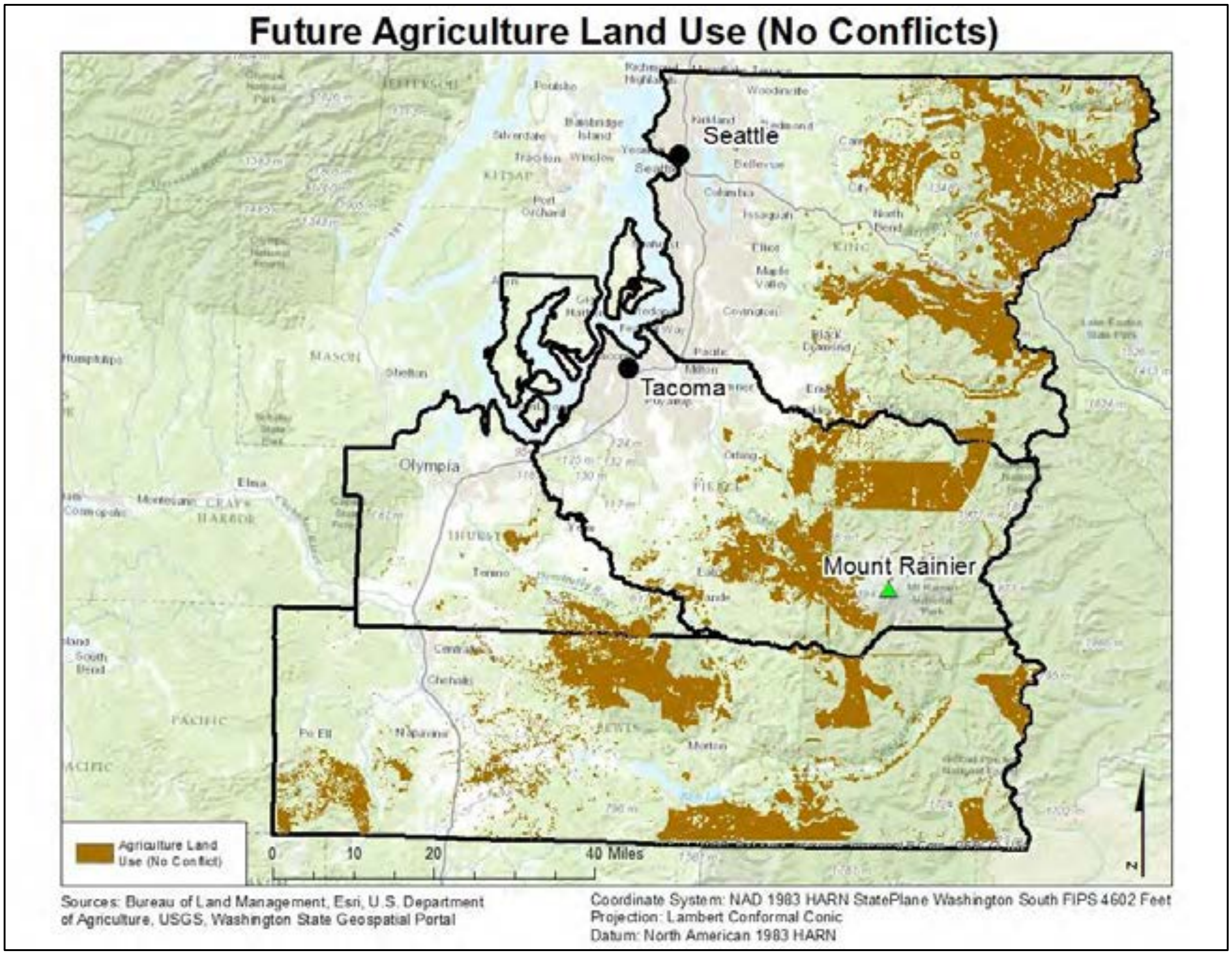


Figure 47: Potential agriculture land use in 2060. Acres were assigned from where agriculture was preferred and no in conflict with other land uses.

Additionally, acres were allocated to conservation where conservation was not in conflict with any other land use and was preferred. 371,922 total acres were allocated to conservation accounting for 15% of the remaining land (Figure 48). This left 1,260,574 acres (52%) of the remaining developable land to be allocated. Resulting acres were allocated from those acres that were in agriculture/conservation conflict. An additional 285,455 acres were assigned to agriculture, allocating a total of 1,076,452 acres for agriculture (Figure 49). An additional

1,054,545 acres were assigned to conservation, allocating a total of 1,426,467 acres for conservation (Figure 50).

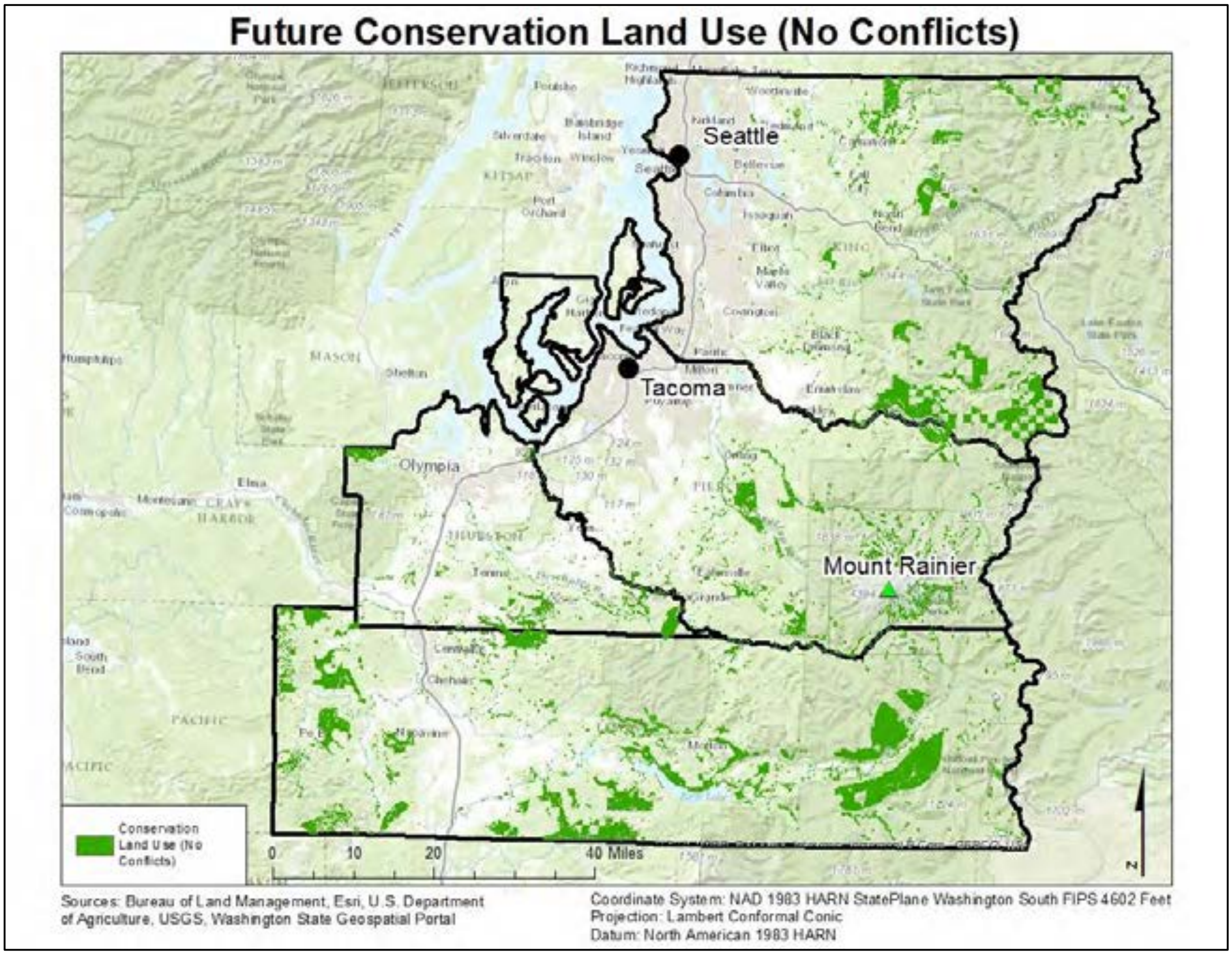
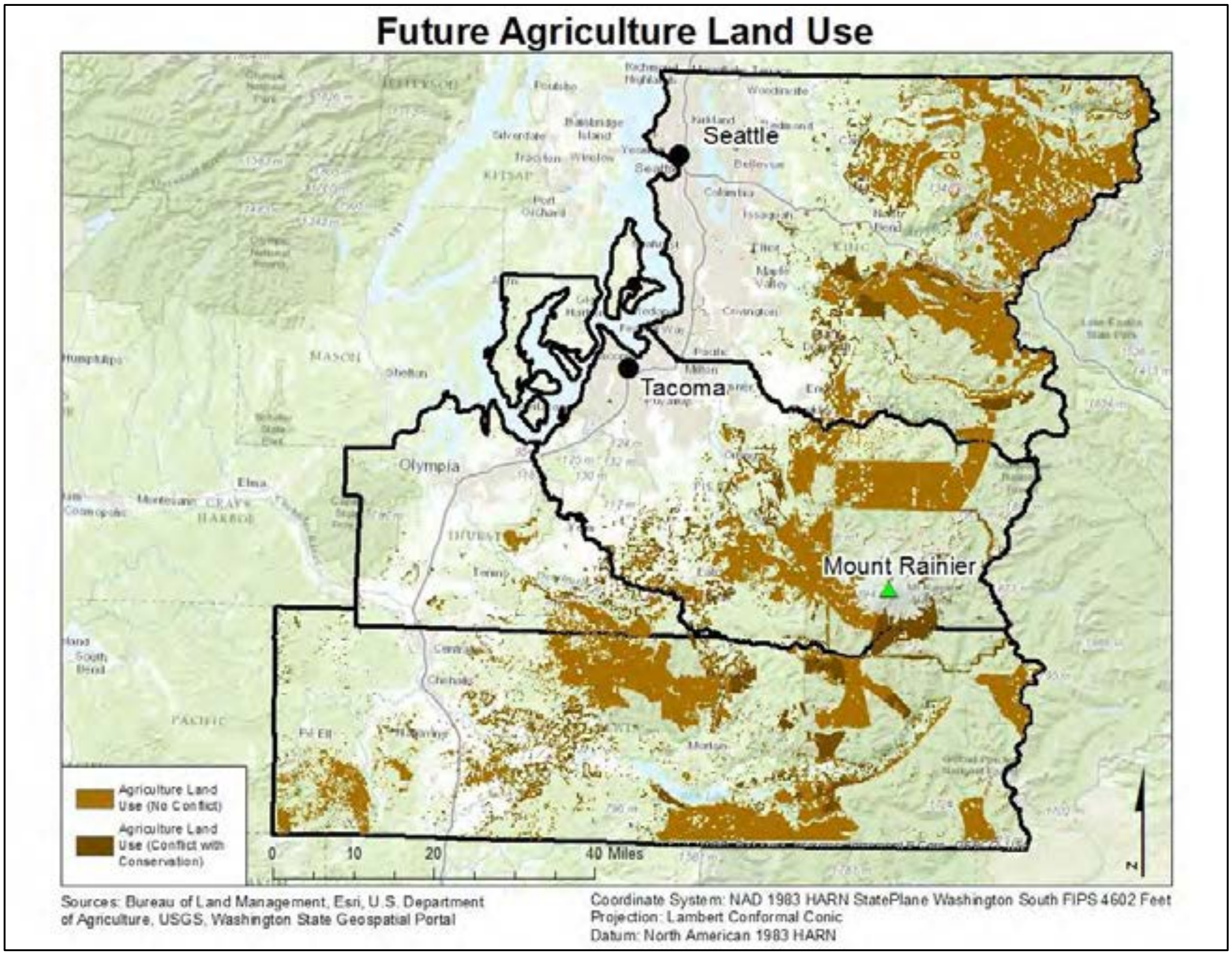


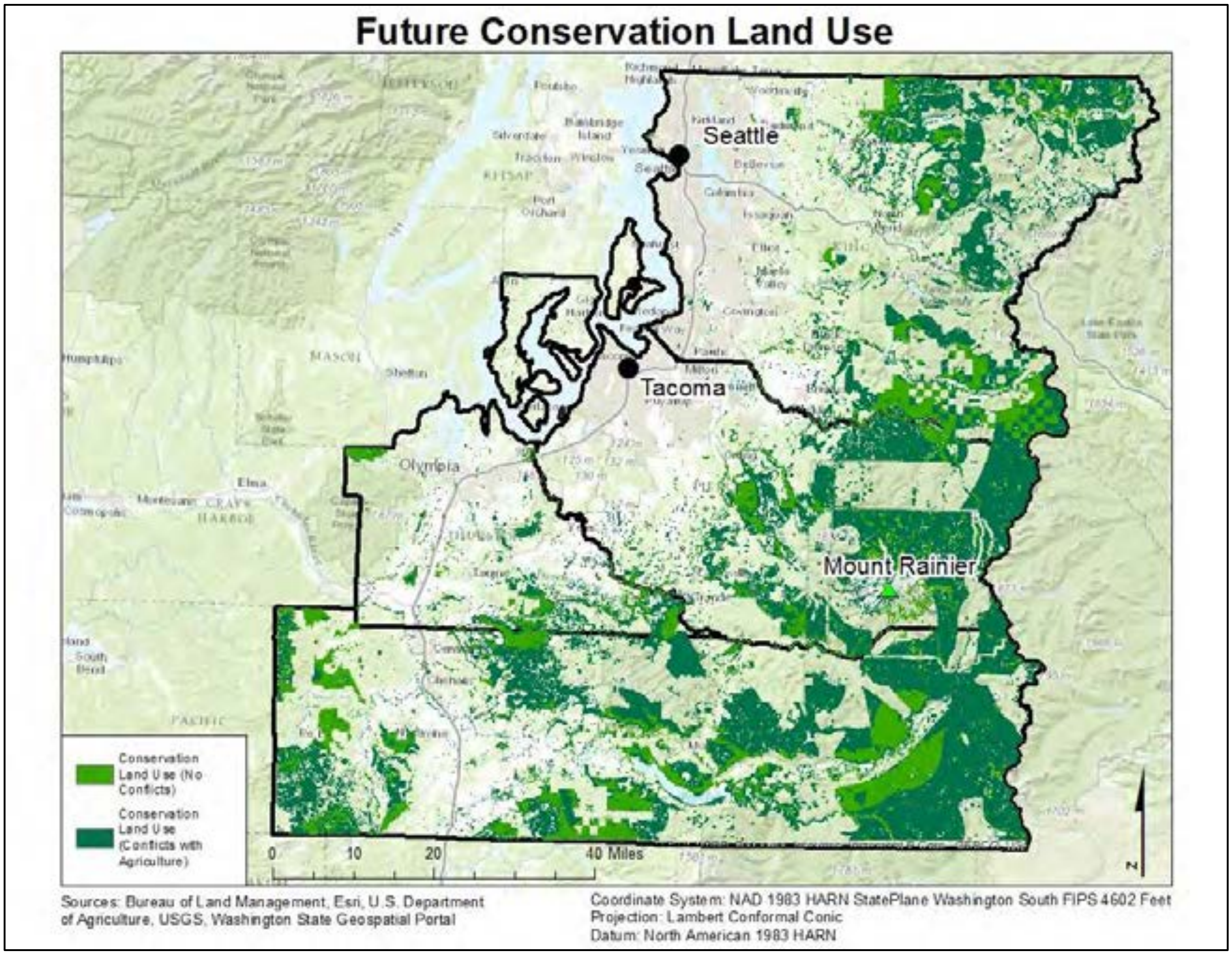
Figure 48: Potential conservation land use in 2060. Acres were assigned from where conservation was preferred and no in conflict with other land uses.



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 49: Potential agriculture land use in 2060.

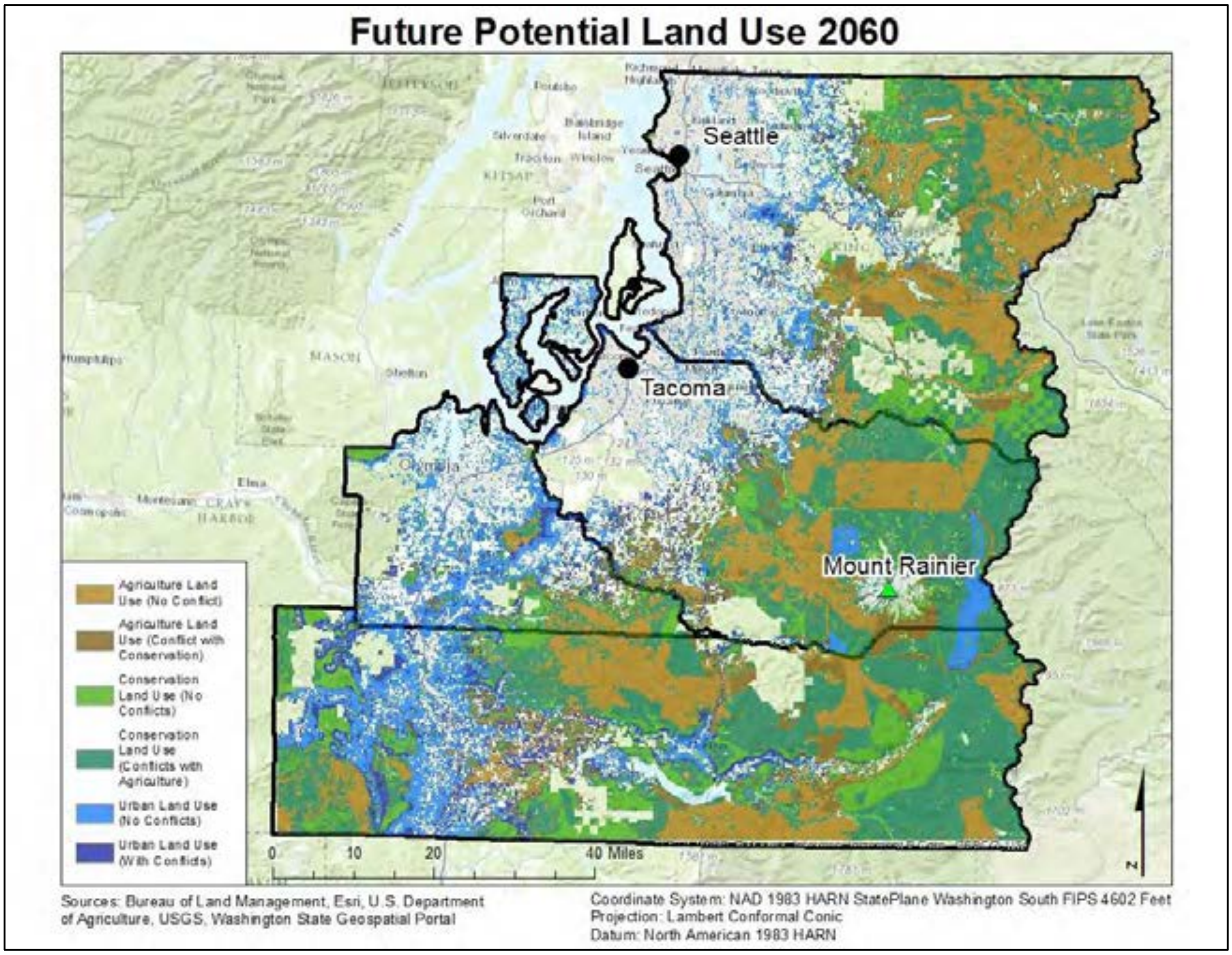


Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 50: Potential conservation land use in 2060.

Final potential future land use for the year 2060 indicated the continuation of urban development near existing urban centers and additional spread into more exurban regions. The agriculture and conservation lands were spread relatively evenly through the eastern and southern portions of the study region. Figure 51 shows potential future land use distribution for this study region in the year 2060. The number of acres and percentage of total developable land are found in Table 6.



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 51: Future potential land use for 2060.

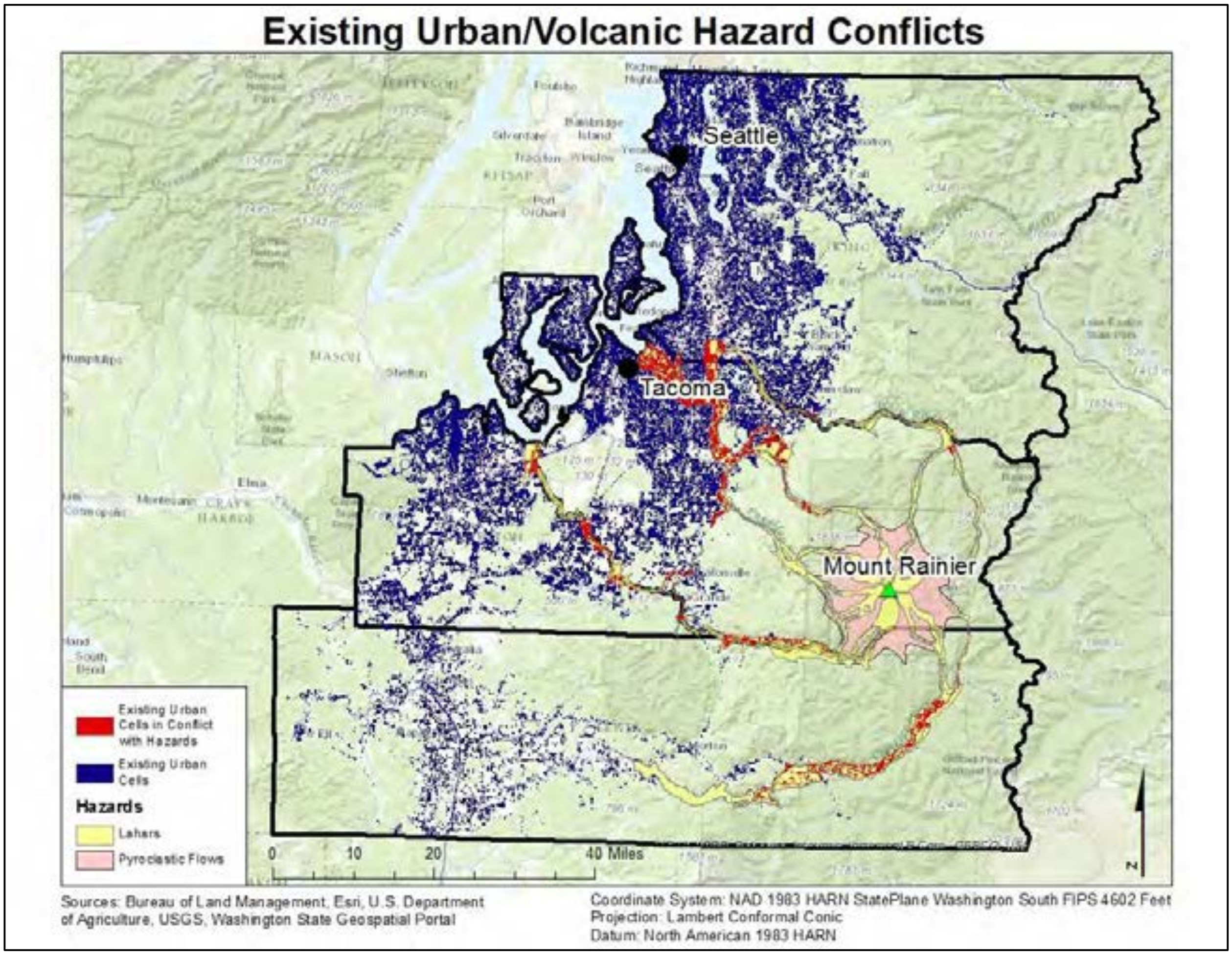
The color blue indicates future urban land use in Figure 51. The urban area surrounding Mount Rainier is only allocated to urban land use because it is deemed unsuitable for both agriculture and conservation land use in the LUCIS model. The two urban areas on the western side of Mount Rainier, fall within the boundaries of Mount Rainier National Park and cannot be developed. The area on the east, is extremely near Mount Rainier and the National Park and likely to not be developed.

Table 6: Future land use allocation for 2060 (* An over-allocation of 79,426 due to resampling)

Allocation Type	Acres	Percentage of Developable Land
Agriculture Allocation		
Future Agriculture Land (No Conflicts)	790,997	25%
Future Agriculture Land (With Conflicts)	285,455	9%
Total Agriculture	1,076,452	34%
Conservation Allocation		
Future Conservation Land (No Conflicts)	371,922	12%
Future Conservation Land (With Conflicts)	1,054,545	33%
Total Conservation	1,426,467	45%
Urban Allocation		
Future Urban Land (No Conflicts)	481,287	15%
Future Urban Land (With Conflicts)	209,299	7%
Total Urban	690,586	22%
Total Allocation		
Total	3,193,505*	100%

4.4 Conflict between Volcanic Hazards and Future Urban Land Use

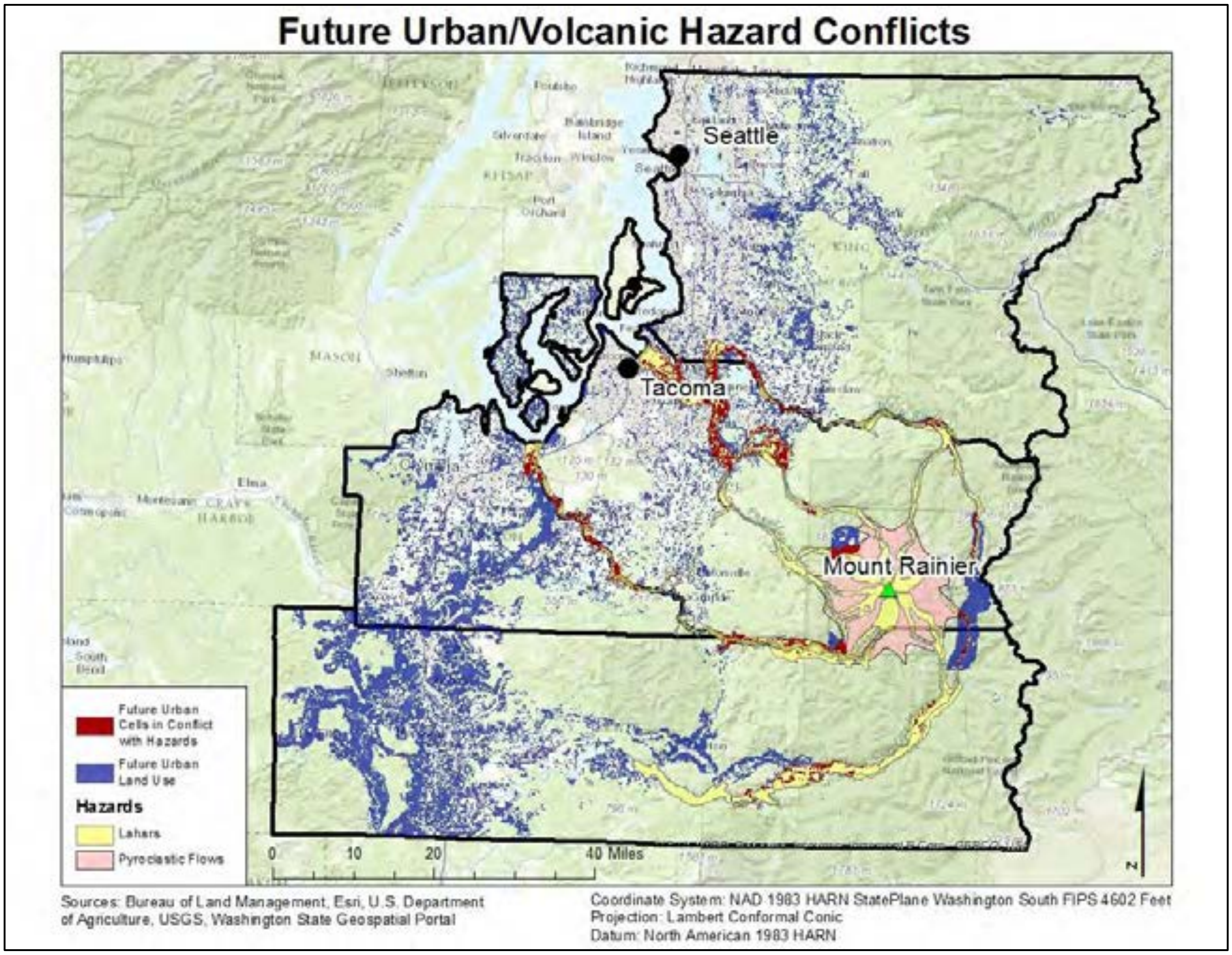
The final results used future potential land use to determine the number of urban developable lands in conflict with Mount Rainier’s volcanic hazards. Currently there were 34,394 acres in the path of Mount Rainier’s hazards (Figure 52: Existing urban cells and those that are currently in the path of Mount Rainier's hazards. More acres will be affected by the volcanic hazards due to the predicated urbanization that will occur by the year 2060. An additional 31,584 acres will be in harm’s way when Mount Rainier erupts, almost doubling the impact (Figure 53: Future urban cells and those in the path of Mount Rainier's hazards These additional acres were added to regions both near and far from the volcano. When comparing the two figures, urban cells were present in the pyroclastic flows associated with Mount Rainier in 2060 but not in 2010. Figure 54 depicts the location of all existing and future cells that are in conflict with Mount Rainier’s volcanic hazards.



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 52: Existing urban cells and those that are currently in the path of Mount Rainier's hazards.



Sources: Bureau of Land Management, Esri, U.S. Department of Agriculture, USGS, Washington State Geospatial Portal

Coordinate System: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet
Projection: Lambert Conformal Conic
Datum: North American 1983 HARN

Figure 53: Future urban cells and those in the path of Mount Rainier's hazards

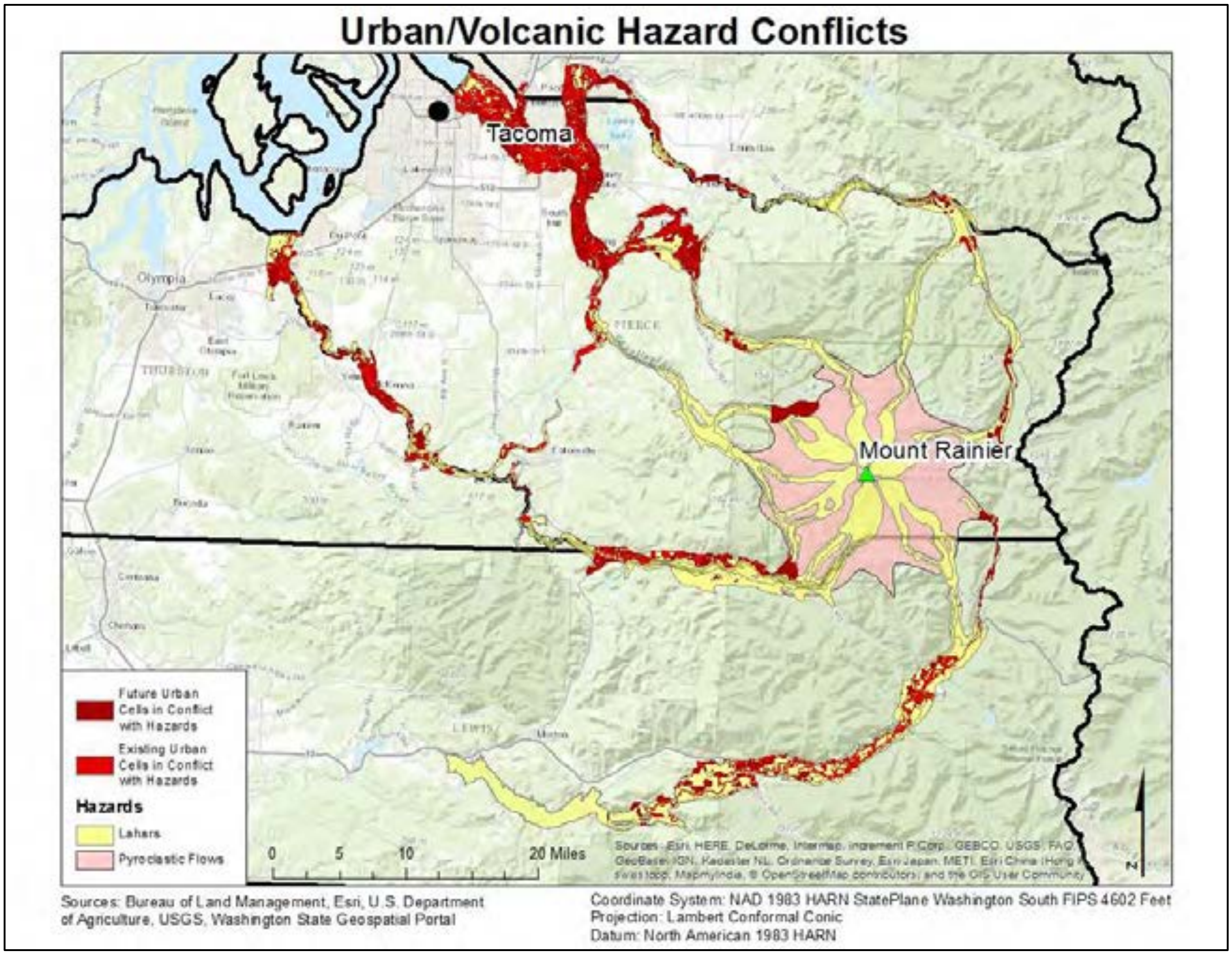


Figure 54: Urban cells (both existing and future) in the path of Mount Rainier's hazards).

4.5 Sensitivity Analysis

A sensitivity analysis was conducted to ensure the results are reliable. This step is crucial to combining land use goals when using community member weights. Two tests were run for this study. The first was keep all rankings the same, on a 1-9 scale, and change how goals were weighted when combined. The second was to keep weights the same and change the ranking scale.

The goals were equally weighted in the analysis, with the exception to Goal 1 of Urban land use, and for the sensitivity analysis they were weighted as follows.

- Agriculture: Goal 1 (30 %), Goal 2 (20 %), Goal 3 (50 %)
- Conservation: Goal 1 (20 %), Goal 2 (30 %), Goal 3 (20 %), Goal 4 (30 %)
- Urban: Goal 1 (40 %), Goal 2 (30 %), Goal 3 (15 %), Goal 4 (15 %)

By reweighting the goals, the conflicts between land types changed. Table 7 compares the number of acres in each land type with evenly weighted goals and the new weights. The number of cells in major conflict increased dramatically, causing the number of conservation preference cells to decrease. However the number of urban preference and agriculture preference increased.

Table 7: Comparison of cells in conflict using analysis weights for goals and the suitability analysis weights.

Conflict or Preference Type	**Acres of Conflict or Preference (Analysis)**	**Acres of Conflict or Preference (Weight Suitability Analysis)**
Agriculture/Urban Conflict (Conflict Codes: 212, 313, and 323)	158,710	158,104
Agriculture/Conservation Conflict (Conflict Codes: 221, 331, and 332)	708,035	469,063
Conservation/Urban Conflict (Conflict Codes: 122, 133, and 233)	126,745	73,309
Major Conflict (Conflict Codes: 111, 222, and 333)	476,383	717,377
Agriculture Preference (Conflict Codes: 311, 312, 321, 322, and 211)	790,997	1,047,965
Conservation Preference (Conflict Codes: 121, 131, 132, 231, and 232)	371,922	188,950
Urban Preference (Conflict Codes: 112, 113, 123, 213, and 223)	481,287	490,772

With the new conflicts, the 2060 basemap was recreated allocating 675,440 cells to urban development as compared to 690,586. This decreases the over-allocation to 54,035, decreasing the options of where developers can build. These weights only decreased the number of acres in conflict with volcanic hazards from 31,584 to 31,472.

In the analysis, every parameter was given a value on a 1-9 scale. This ranking system was implemented from Carr and Zwick (2005). To ensure the results were accurate, a test was run using a 1-12 scale, introducing more classes. Table 8 compares the number of acres for each land type for the original analysis and using the 1-12 ranking scale.

Table 8: Comparison of cells in conflict using parameter rankings for subobjectives and the suitability analysis parameter rankings.

Conflict or Preference Type	**Acres of Conflict or Preference (Analysis)**	**Acres of Conflict or Preference (Ranking Suitability Analysis)**
Agriculture/Urban Conflict (Conflict Codes: 212, 313, and 323)	158,710	211,423
Agriculture/Conservation Conflict (Conflict Codes: 221, 331, and 332)	708,035	213,330
Conservation/Urban Conflict (Conflict Codes: 122, 133, and 233)	126,745	163,030
Major Conflict (Conflict Codes: 111, 222, and 333)	476,383	634,363
Agriculture Preference (Conflict Codes: 311, 312, 321, 322, and 211)	790,997	891,972
Conservation Preference (Conflict Codes: 121, 131, 132, 231, and 232)	371,922	220,304
Urban Preference (Conflict Codes: 112, 113, 123, 213, and 223)	481,287	853,109

With the 1-12 scale for rankings there are 853,109 urban preference acres, which is 231,704 acres over the required amount to support the 2060 projected population. However 188,649 of those acres reside within Mount Rainier National Park and cannot be developed on. This allows for 664,460 acres for urban development, an over-allocation of 43,055 acres. This again limits the number of acres that can be developed. Including the acres within Mount Rainier National Park there are 75,786 acres in conflict with volcanic hazards, however 53,291 of those are within the National Park boundary, resulting in 22,495 acres in conflict with volcanic hazards outside of the boundary.

Overall when changing weights and rankings there is a change in the number of acres allocated, to urban development. Despite different numbers of acres being allocated the overall conclusion remains the same. Urban development is still likely to occur in areas conflicting with volcanic hazards.

Chapter 5 Discussion and Conclusions

The main objective of this study was to determine how urban land use could change from 2010 to 2060 and how those urban cells might be impacted by an eruption of Mount Rainier. This chapter discusses the results from the study and how the results can be used in future development. The results from this study are discussed first, followed by the strengths and weaknesses of the methodology and study, and finally future work that could be done to improve on the process and results.

5.1 Conclusions

As stated in Chapter 1 the population in Washington is expected to experience a 50% population increase by the year 2060 (Proximity 2014). The major cities, Seattle and Tacoma, and the capital city of Olympia will see the most impact with this growth due to urban sprawl around existing urban centers (Heimlich and Anderson 2001). Subsequently urban development will encroach on agriculture land, conservation land, and areas more susceptible to natural disasters (Heimlich and Anderson 2001; Brauch 2003). The LUCIS model takes into consideration how agriculture, conservation, and urban land use types change over time. Although the LUCIS model focuses on all three land use types, this study concentrates mostly on urban land use. However in order to create a basemap of potential future urban land use, the suitability for all three types of land use must be taken into consideration.

Each land use has its own set of preferred locations which were used to create the future basemap. As described in the Chapter 3 and Appendix A, the preferences were determined based on the existence and distance from select datasets. As was expected and described in the urban suitability analysis, urban preferred land use is closest to the pre-existing areas. Additionally, urban growth supports the hypothesis of urban sprawl. Figure 46 shows a visualization that supports growth surrounding Seattle, Tacoma, and Olympia. As expected the growth is not solely confined to the existing urban region, the future urban area directly east of Mount Rainier is a new urbanized area. This new area is encroaching on agriculture land, conservation land, and Mount Rainer. Due to the proximity of Mount Rainier the hazards increase immensely.

To compensate for new urban development, acreage must be obtained from other land uses. Chapter 4 includes a breakdown of acreage allocated to each land type for the future land use basemap. Urban land is over-allocated due to the slice process, however excess acres can be used as alternative locations for development. These allocated urban cells are newly added urban acres in addition to existing urban areas. Table 9 contains current land use in the study region for comparison. Conservation land in this study area indicates acres added to existing acres whereas agriculture acres can be directly compared. Comparing Table 6 and Table 9 shows a decrease in agricultural land and an increase in conservation and urban lands.

Table 9: Acres and percentage of existing assigned land use types

Land Type	Acres	Percentage
Agriculture	1,552,475	55%
Conservation	507,979	18%
Urban	741,137	27%

The main objective of this study was to determine where the future urban lands come in contact with the volcanic hazards of Mount Rainier. As seen in Chapter 4 many cells already exist in the path of the lahars. According to the USGS many existing urban developments are built on ancient lahar flows (USGS 2015). Combining future urban land and volcanic hazards depicts a future scenario. Buildings and population are put at risk of a volcanic eruption if development occurs in this region. An additional 31,584 urban acres have the potential to be added to the volcanic hazard zones. Unlike the existing affected urban cells, these new cells expand into the pyroclastic flows and are at most risk because of the increased hazards associated with a pyroclastic flow versus a lahar. These results can be used when developers determine where to build, hopefully minimizing the population affected by an eruption. Developers can use the distribution of urban lands and determine if developing in these hazardous areas is the best solution because there is an over allocation of 79,426 urban cells.

A suitability analysis was created for this study to ensure the results are reliable with any weighting of goals the community members might assign. Changing the weights decreased the number of over-allocated urban cells to 54,035, allowing for a more precise distribution of future urban land. The future urban land still remained in conflict with volcanic hazards despite the reduction in future urban land. Since aspects of the model can be changed and still produce the same overall result, the results from this study can be used by developers and insurance companies while developing this region. City planning committees can determine where the most efficient developing should occur to protect the future population. The basemap does assume the current growth rate and therefore the results should only be used as a guide and not a strict outline. Insurance companies will have an advantage by knowing which acres are in the path of volcanic hazards.

5.2 Application and Assumptions of LUCIS Model in this Study

The LUCIS model was introduced by Paul Zwick and Margaret Carr in their 2005 analysis of North Central Florida (Carr and Zwick 2005). This model was then developed into an Esri model, available for broad use. The main benefit of the LUCIS model is that it is flexible, modifiable, and can be edited for almost any regional or international study area (Cotroneo 2015;

Tims 2009). The model is dependent on availability of data, however it can be modified based on the user's data. Additionally Margaret Carr and Paul Zwick (2007) include the distances used within the suitability analysis.

Datasets available in Washington were not as robust as those used in North Central Florida, leading to a modified LUCIS model. The strengths of this study came from modifying the LUCIS model for the available data. Most of the major datasets were available (i.e., land use, hydrology, conservation lands, and crop data), however datasets did not use the exact information from the original LUCIS model. Due to the missing information in datasets, multiple datasets were combined along with the addition of new attributes with interpreted data from external resources. A dataset that was missing from this study was the value of land. Consequently, each economic suitability analysis was restructured and reweighted. In addition to modifying the datasets for compatibility with the LUCIS model, distances of measurement had to be converted from meters to feet to match the projection for this study area. Although this introduced a chance for human calculation error, each value was checked multiple times to ensure the smallest chance of error. Additionally, values were not rounded to ensure precision in conversions.

The main weakness associated with using the LUCIS model is the assumption that comes with modifying the base model. Appropriate distances for suitability parameters were ascertained from vast research conducted by Margaret Carr and Paul Zwick (2005) for the analysis of North Central Florida. These values were used because the data collected for the North Central Florida was not specific to that region of the United States. Since Margaret Carr and Paul Zwick created this model to be easily modified depending on the region, the distances for suitability are subject to change.

An additional assumption that was made in this study was in the combination of SUAs and MUAs. Typically an AHP is used to assign weights for the suitability goals or the involvement of stakeholder involvement. With the exception of the urban residential goal, the suitability goals were equally combined due to the lack of resources for either of these options. The urban residential goal was more heavily weighted because it was assumed that in order to withstand population growth, more residential areas must be built. These assumptions strengthen the argument that the scenario developed in this study should only be used as a guideline. If used for developmental purposes, stakeholders can begin to get involved and decide how to alter the weights of suitability goals.

5.3 Future Work

There are three ways to further this project to create a more accurate representation of the future development in this region. These include obtaining all datasets, determining distances specifically for this region, and using an AHP. This study can also be applied to different regions with volcanos.

The biggest improvement that can be made in the datasets is the addition of the land value. Land cannot be built on if its value is too expensive to purchase. Including this aspect in the analysis addresses a major aspect in development that is left out of this study. The less expensive a piece of land is, the more likely it will be built on. This could be an additional consideration when determining which urban cells to build in due to over-allocation. Further investigation could also be applied to obtaining datasets that contain all of the information without combining more than one dataset. The chance of errors increase every time two datasets are combined.

The original LUCIS model contained distances for suitability analysis that are appropriate for multiple regions, however, using region specific values creates a more accurate representation. This pertains specifically to buffers surrounding water features, allowing for suitable runoff. Slope and soil type vary drastically across the United States, especially from Florida to Washington. Every soil type absorbs water at different rates leading to different distances of runoff, however, slope is the biggest factor because as it increases the speed of water runoff increases. Due to the size of the study area, the slope changes from steep at Mount Rainier and in the Cascades, to relatively flat near the coast. An average would need to be determined due to this variation. The analysis would more accurately represent the situation at hand if regional data were used.

Finally using an AHP could enhance this study. The most sensible AHP would be the stakeholder involvement as it adds the insight of those who will actually be using the data. Stakeholders can determine the weights for each suitability goal allowing for consideration of their priorities and needs. This study represents a situation which is most focused on the expanding residential areas but with the input of the stakeholders, the focus might be on conservation of the National Parks and surrounding areas in this region.

The results of this study could potentially limit the population and number of developments that are damaged in a volcanic eruption. As stated in chapter 1 there are 7 active volcanoes in Washington State alone. Because this study uses a basic modified version of the LUCIS model it can be applied to any other region in Washington. Since Washington State is projected to grow 50% by 2060, applying this model to the other volcanoes could protect the growing population of the western portion of the state. Results from each volcano could be used to have minimal impact on development and population in hazardous regions. Developers can use the results to support the ever-growing population in the safest locations if an over-allocation were found in each analysis. Depending on data availability this model can be applied to regions surrounding all active volcanoes, minimizing the impact on population and developments nationwide.

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Appendix A: Suitability Models

This appendix is a description of the suitability models and results for agriculture, conservation, and urban land use goals, objectives, and subobjectives. This are all derived from the goals stated in Table 2. The maps display one-acre cells with suitability values.

Land use: Agriculture
Goal 1: Identify lands suitable for croplands/row crops
Objective 1.1: Identify lands physically suitable for croplands/row crops
Subobjective 1.1.1: Identify soils most suitable for croplands

Input data layer: Crop layer and State Agriculture Overview
Criteria for value assignment: Cells with yields for individual crops were assigned values of 2-9, based on equal interval classification of crop yield. All cells without crop yield were assigned a value of 1.
Rationale: The higher the crop yield, the higher the suitability.
Output: Crop Yield SUA (AG1O11SO111)

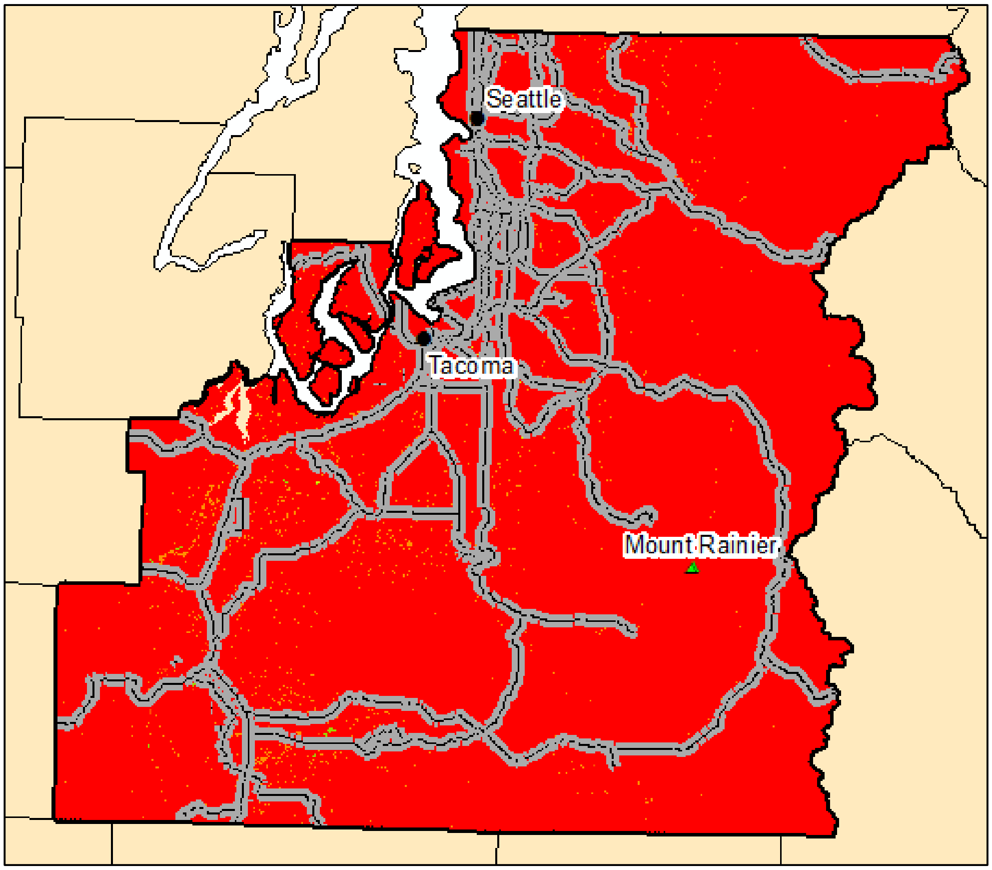

Figure 55: AG1O11SO111

Land use: Agriculture
Goal 1: Identify lands suitable for croplands/row crops
Objective 1.1: Identify lands physically suitable for croplands/row crops
Subobjective 1.1.2: Identify current croplands as suitable

Input data layer: Land use dataset
Criteria for value assignment: Cells with existing croplands were assigned a value of 9, all other areas were assigned a value of 1.
Rationale: If it is currently cropland, it is physically suitable.
Output: Existing Cropland SUA (AG1O11SO112

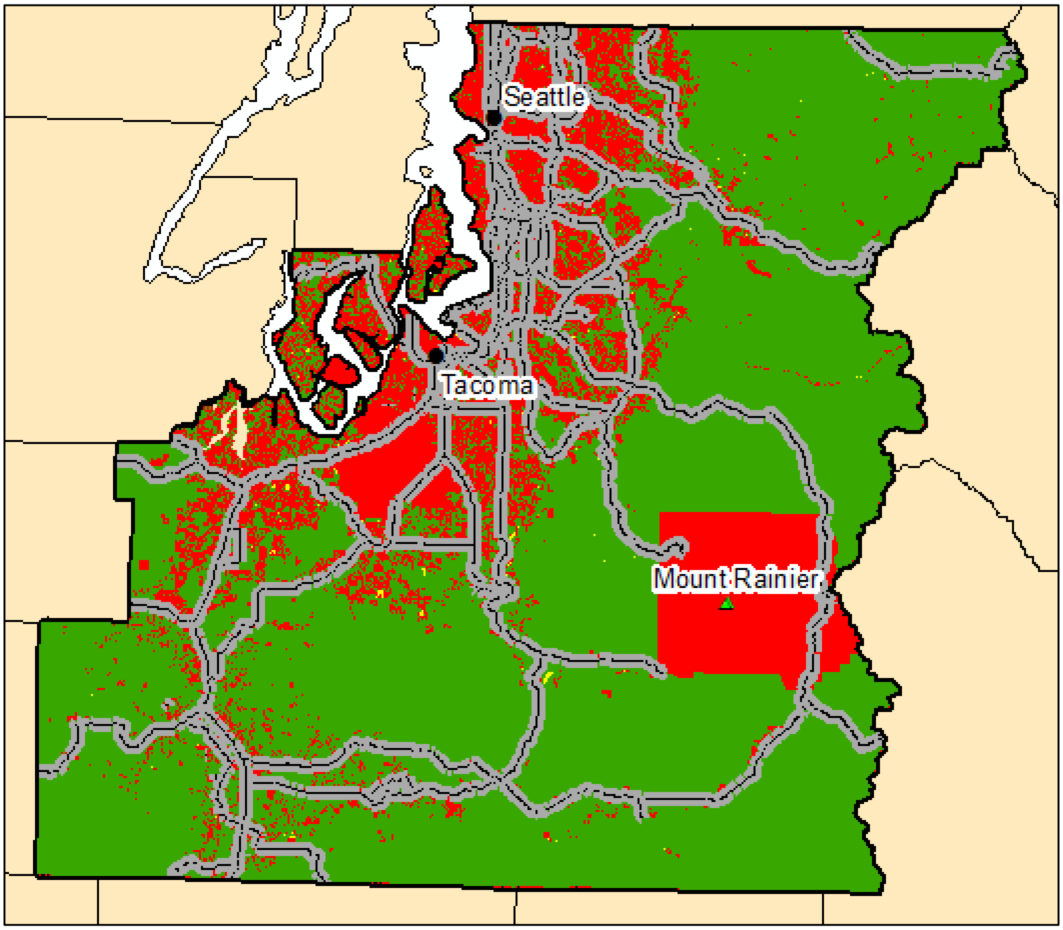

Figure 56: AG1O11SO112

Land use: Agriculture
Goal 1: Identify lands suitable for croplands/row crops
Objective 1.1: Identify lands physically suitable for croplands/row crops

Input data layer: Crop Yield SUA (AG1O11SO111) and Existing Cropland SUA (AG1O11SO112)
Criteria for value assignment: Inputs were combined using a conditional statement; CON (Existing Cropland = 9, 9, Crop Yield). Cells currently used for crops were assigned a value of 9, all others were assigned the value of the Crop Yield.
Rationale: If cells are currently used for crops, then the suitability must be high; all other cells are determined by the crop yield
Output: Cropland Physical Suitability MUA (AG1O11)

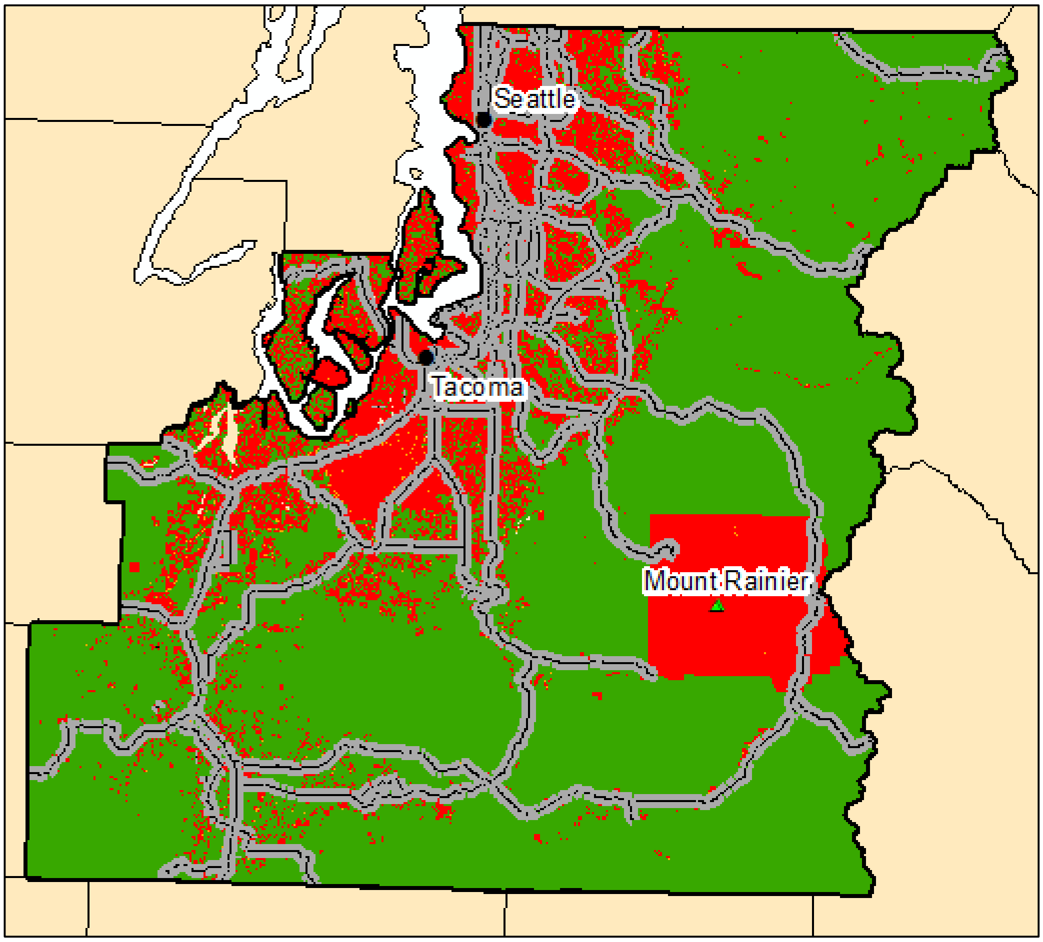

Figure 57: AG1O11

Land use: Agriculture
Goal 1: Identify lands suitable for croplands/row crops
Objective 1.2: Identify lands proximal to markets for croplands/row crops (Economic suitability)

Input data layer: City Limits
Criteria for value assignment: Euclidean distance was run for City Limits. Zonal statistics were run on the Euclidean distance from City Limits to determine the mean and standard deviation. Cells with a Euclidean distance less than or equal to the mean were assigned a value of 9 (0-29,271.1 feet), Cells were assigned values from 8 to 2 within quarter standard deviations. The remaining cells received a value of 1.
Rationale: The closer to markets (city limits) for row crops the better.
Output: Proximity to Cropland Markets SUA (AG1O12)

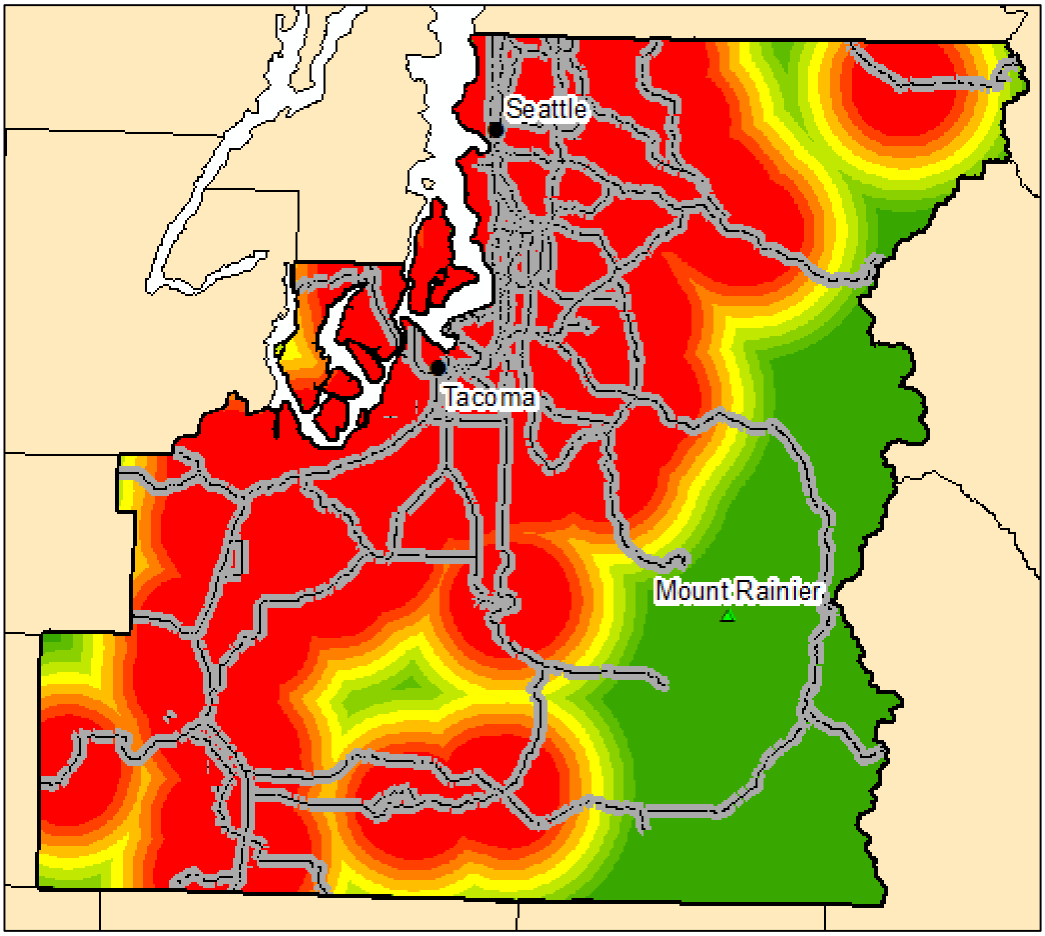

Figure 58: AG1O12

Land use: Agriculture
Goal 1: Identify lands suitable for croplands/row crops

Input data layer: Cropland Physical Suitability MUA and Proximity to Cropland Markets SUA
Criteria for value assignment: The MUA and SUA were equally weighted at 50 percent using map algebra.
Rationale: Physical and economic (proximity to markets) suitability are equally important in determining an overall agricultural suitability.
Output: Cropland Suitability MUA (AG1)

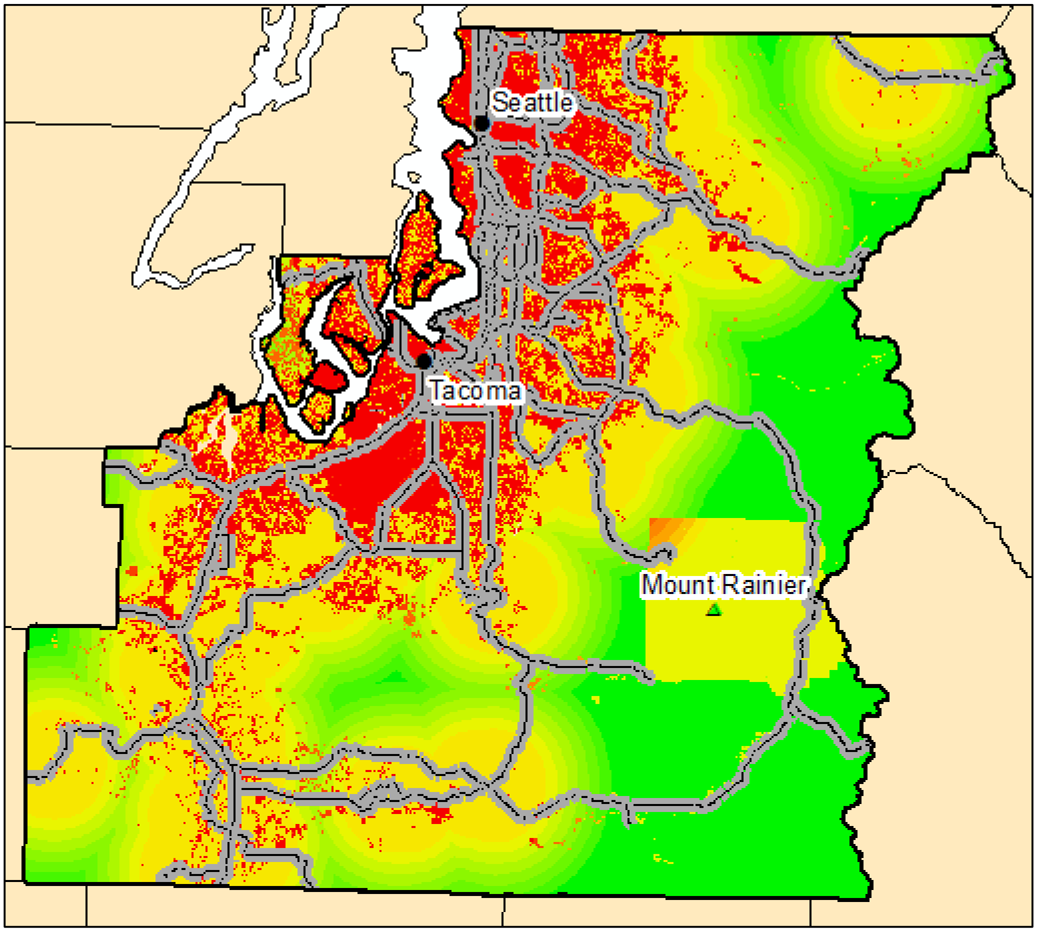

Figure 59: AG1

Land use: Agriculture
Goal 2: Identify lands suitable for managed livestock
Objective 2.2: Identify lands physically suitable for managed livestock
Subobjective 2.2.1: Identify underlying geology suitable for managed livestock

Input data layer: Aquifer
Criteria for value assignment: Cells with the presence of existing aquifer were assigned a value of 9, all other cells were assigned a value of 1.
Rationale: The presence of an aquifer is more suitable for livestock.
Output: Geologic Suitability for Managed Livestock SUA (AG2O21SO211)

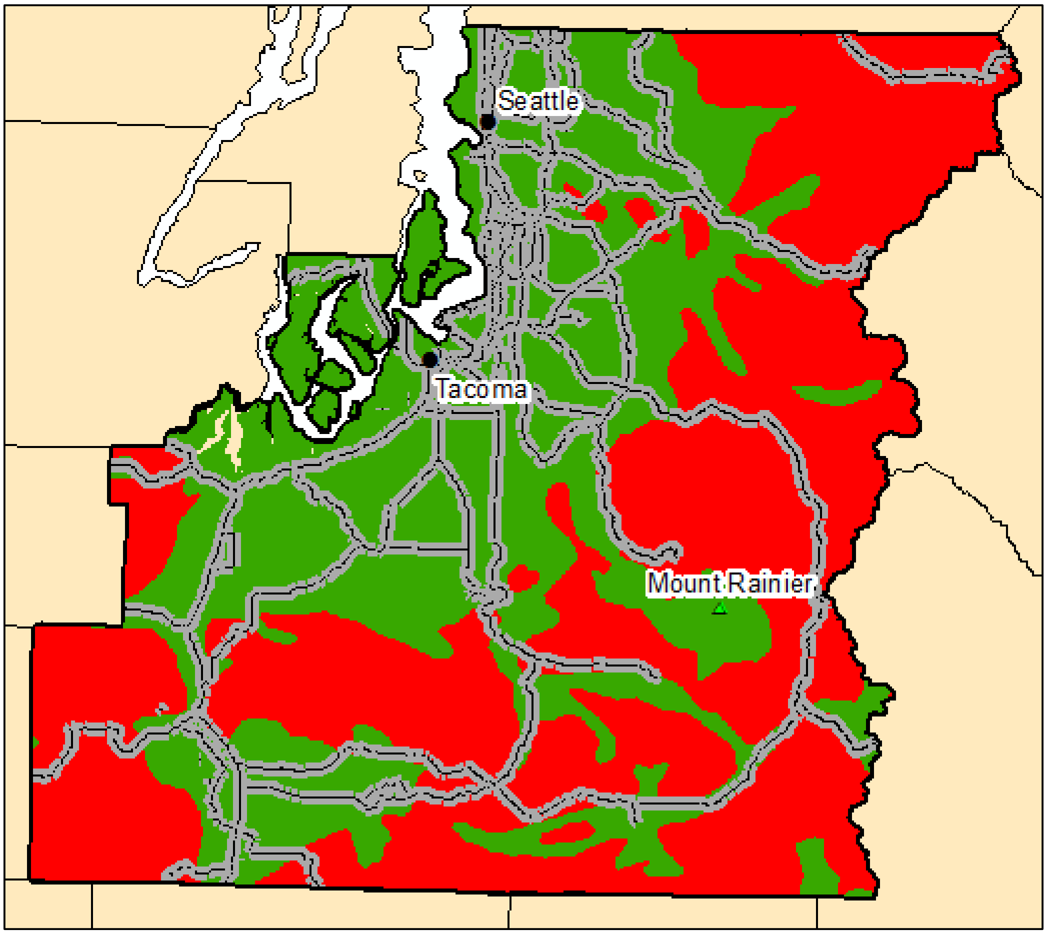

Figure 60: AG2O21SO211

Land use: Agriculture
Goal 2: Identify lands suitable for managed livestock
Objective 2.2: Identify lands physically suitable for managed livestock
Subobjective 2.2.2: Identify existing managed livestock lands as suitable

Input data layer: Land use dataset
Criteria for value assignment: Cells of existing managed livestock were assigned a value of 9, all others were assigned a value of 1.
Rationale: If it is currently used for managed livestock, it is physically suitable.
Output: Existing Managed Livestock Area SUA (AG2O21SO212)

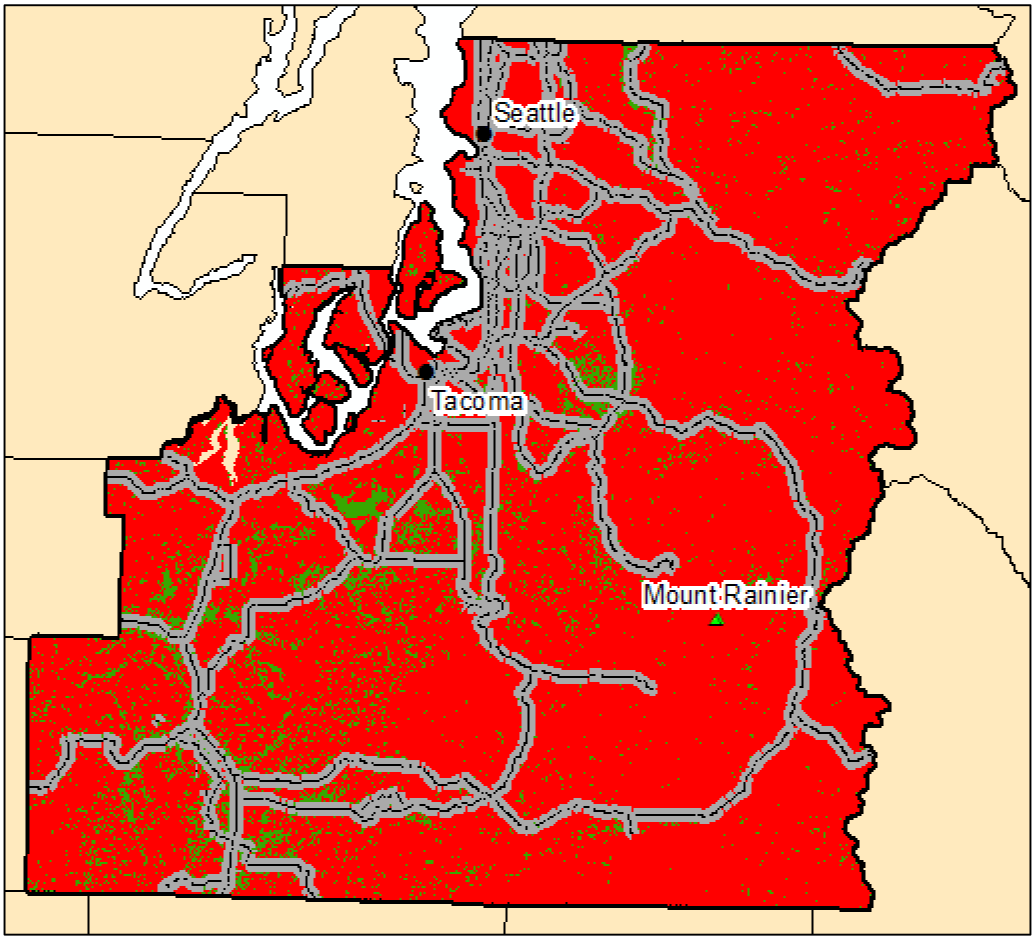

Figure 61: AG2O21SO212

Land use: Agriculture
Goal 2: Identify lands suitable for managed livestock
Objective 2.2: Identify lands physically suitable for managed livestock

Input data layer: Geologic Suitability for Managed Livestock SUA (AG2O21SO211) and Existing Managed Livestock Area SUA (AG2O21SO212)
Criteria for value assignment: The inputs were combined using a conditional statement; CON (Existing Managed Livestock = 9, 9, Geologic Suitability). Cells currently used for managed livestock were assigned the value of 9, all others were assigned the value of geologic suitability.
Rationale: If cells are currently used for managed livestock, then the suitability must be high, for all other cells, the geologic suitability for managed livestock is an adequate indication of suitability.
Output: Managed Livestock Physical Suitability MUA (AG2O21)

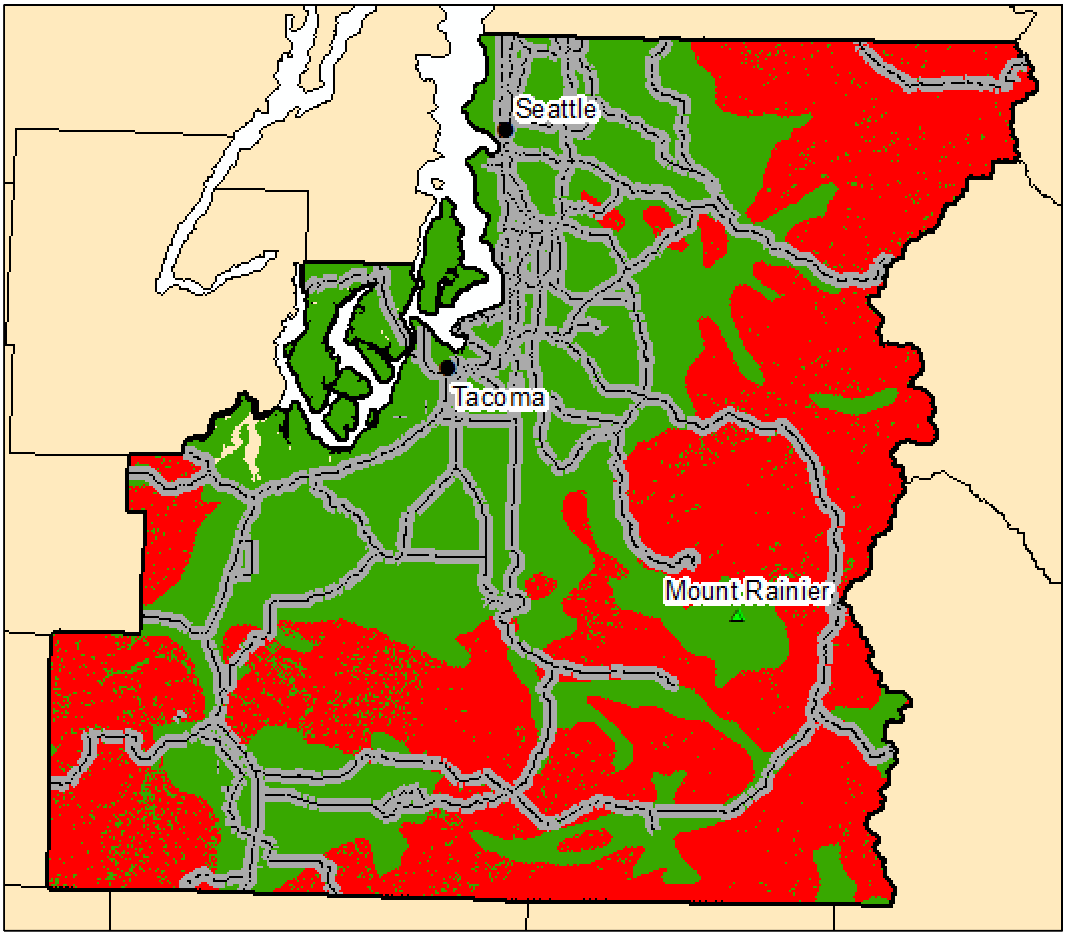

Figure 62: AG2O21

Land use: Agriculture
Goal 2: Identify lands suitable for managed livestock
Objective 2.2: Determine lands economically suitable for managed livestock
Subobjective 2.2.2: Identify lands proximal to markets for intensively managed livestock

Input data layer: City Limits
Criteria for value assignment: Euclidean distance was run for City Limits. Zonal statistics were run on the Euclidean distance from City Limits to determine the mean and standard deviation. Cells with a Euclidean distance less than or equal to the mean were assigned a value of 9 (0-29,271.1 feet), Cells were assigned values from 8 to 2 within quarter standard deviations. The remaining cells received a value of 1.
Rationale: The closer to markets (city limits) for existing managed livestock areas the better.
Output: Proximity to Managed Livestock Markets (AG2O22SO221)

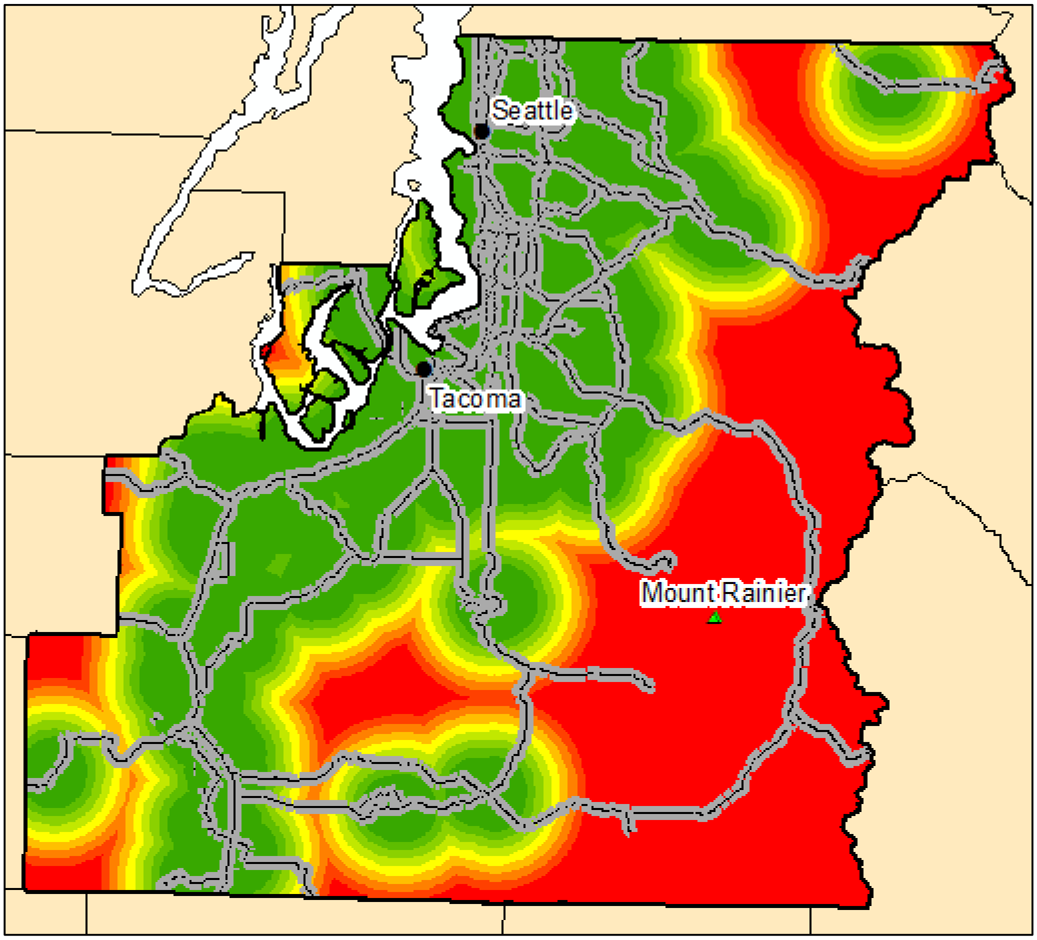

Figure 63: AG2O22SO221

Land use: Agriculture
Goal 2: Identify lands suitable for managed livestock
Objective 2.2: Determine lands economically suitable for managed livestock
Subobjective 2.2.2: Determine proximity to potentially troublesome adjacent land uses

Input data layer: Residential Land Use
Criteria for value assignment: Euclidean distance was run from residential land use to existing managed livestock areas. Zonal statistics were run on the Euclidean distance to determine the mean standard deviation. Cells with values of 0 to the mean were assigned the value of 1 (0-2,389.09). The next set of cells were assigned values of 2-8 in quarter-stand deviation intervals. The remaining cells were assigned a value of 9.
Rationale: Residential areas are disagreeable neighbors for managed livestock areas because of the smell. The further away from residential areas the better.
Output: Proximity to Residential SUA (AG2O22SO222)

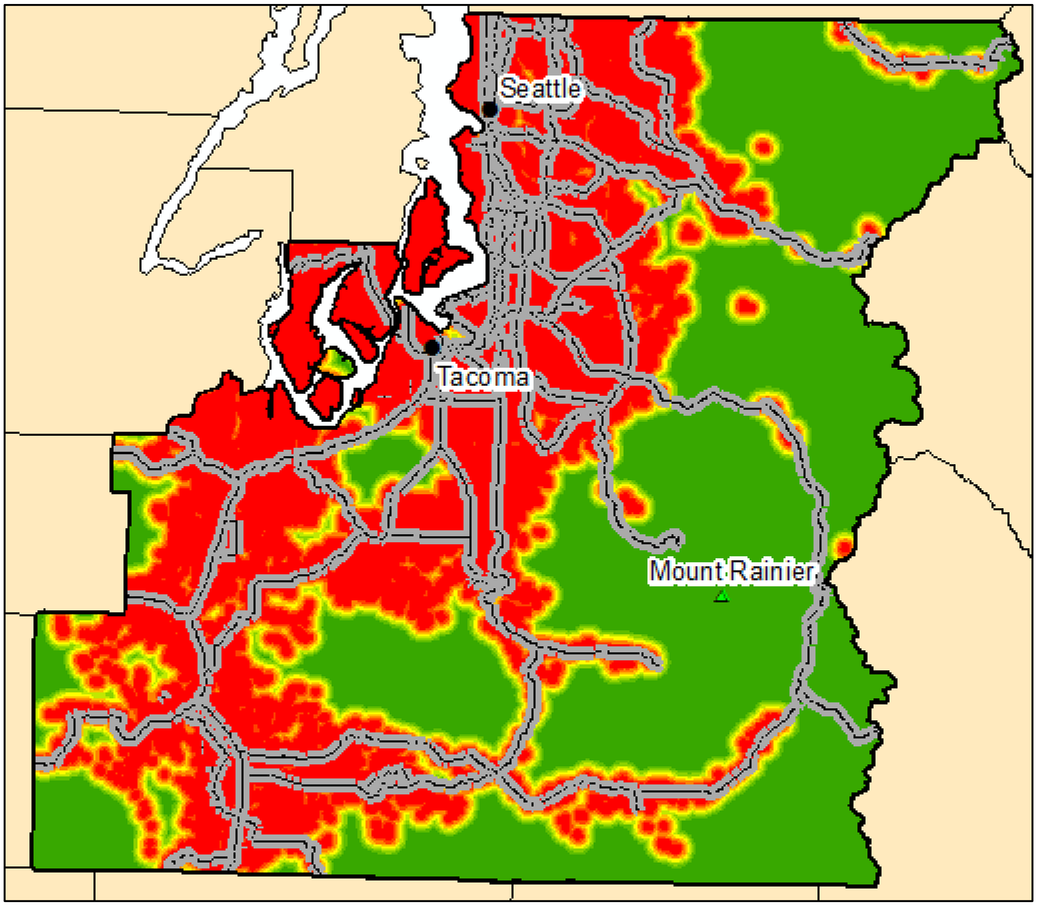

Figure 64: AG2O22SO222

Land use: Agriculture
Goal 2: Identify lands suitable for managed livestock
Objective 2.2: Determine lands economically suitable for managed livestock

Input data layer: Proximity to Managed Livestock Markets (AG2O22SO221) and Proximity to Residential SUA (AG2O22SO222)
Criteria for value assignment: The SUAs were equally weighted at 50 percent and combined using map algebra.
Rationale: The proximity to markets and residential area are equally important.
Output: Managed Livestock Economic Suitability SUA (AG2O22)

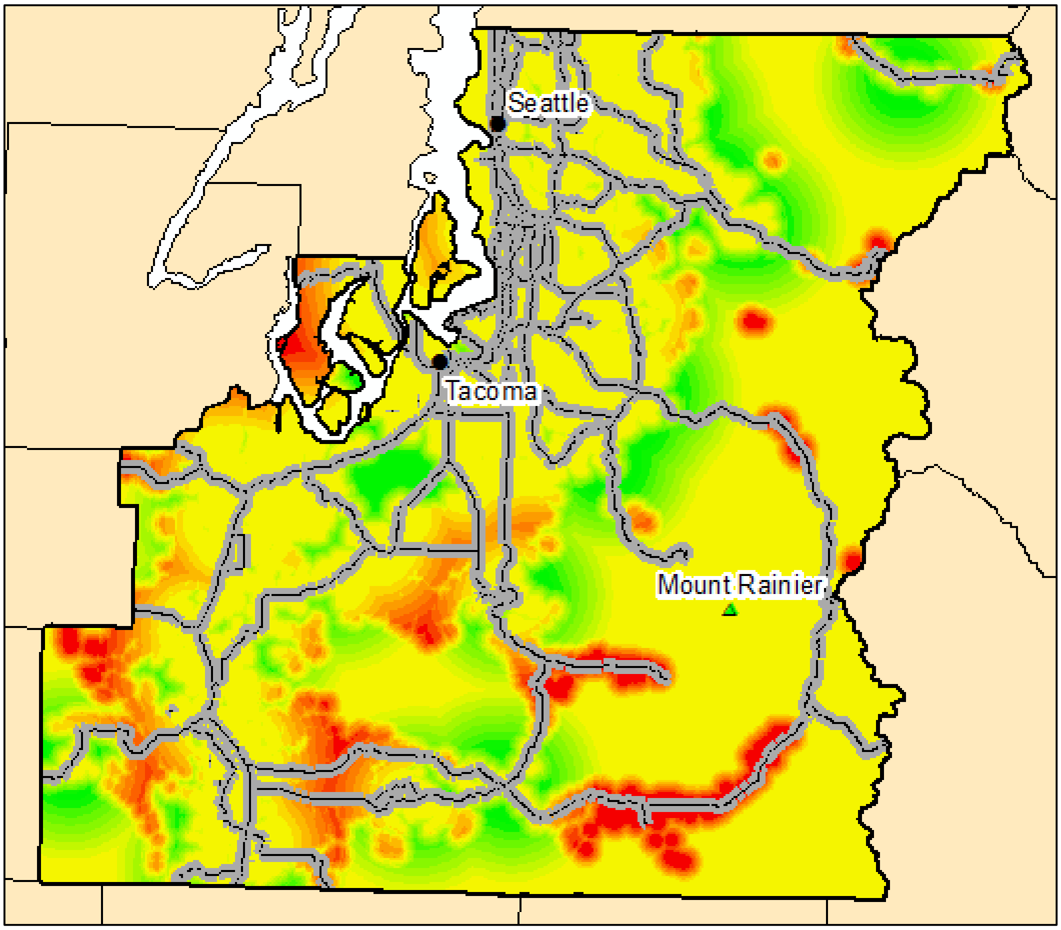

Figure 65: AG2O22

Land use: Agriculture
Goal 2: Identify lands suitable for managed livestock

Input data layer: Managed Livestock Physical Suitability MUA and Managed Livestock Economic Suitability SUA
Criteria for value assignment: MUA and SUA were equally weighted at 50 percent and combined using map algebra.
Rationale: Physical and economic suitability are equally important in determining an overall agricultural suitability.
Output: Managed Livestock Suitability MUA (AG2)

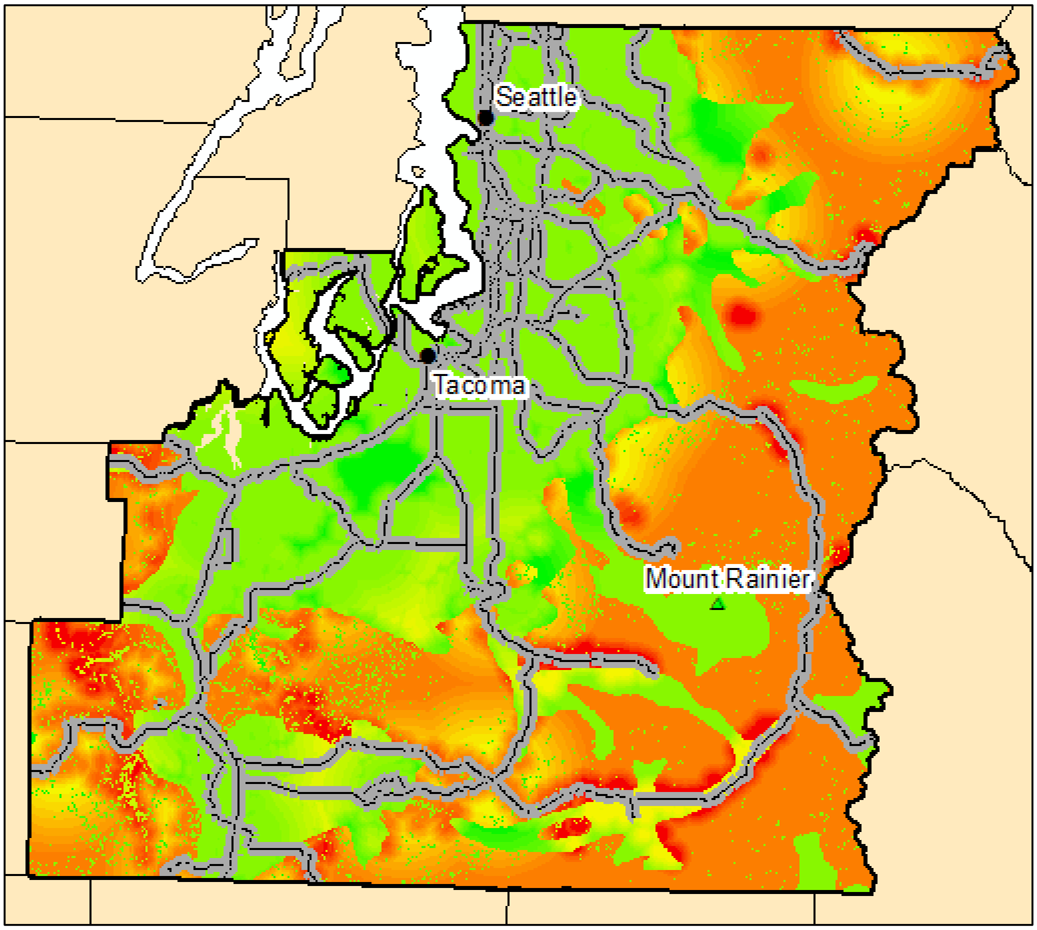

Figure 66: AG2

Land use: Agriculture
Goal 3: Identify lands suitable for Timber/Silviculture
Objective 3.1: Determine lands physically suitable for timber
Subobjective 3.1.1: Identify soils most suitable for timber

Input data layer: Soil
Criteria for value assignment: All cells with timber soils were assigned a value of 9, all others were assigned a value of 1.
Rationale: Existing soils being used for timber are suitable.
Output: Timber Soils SUA (AG3O31SO311)

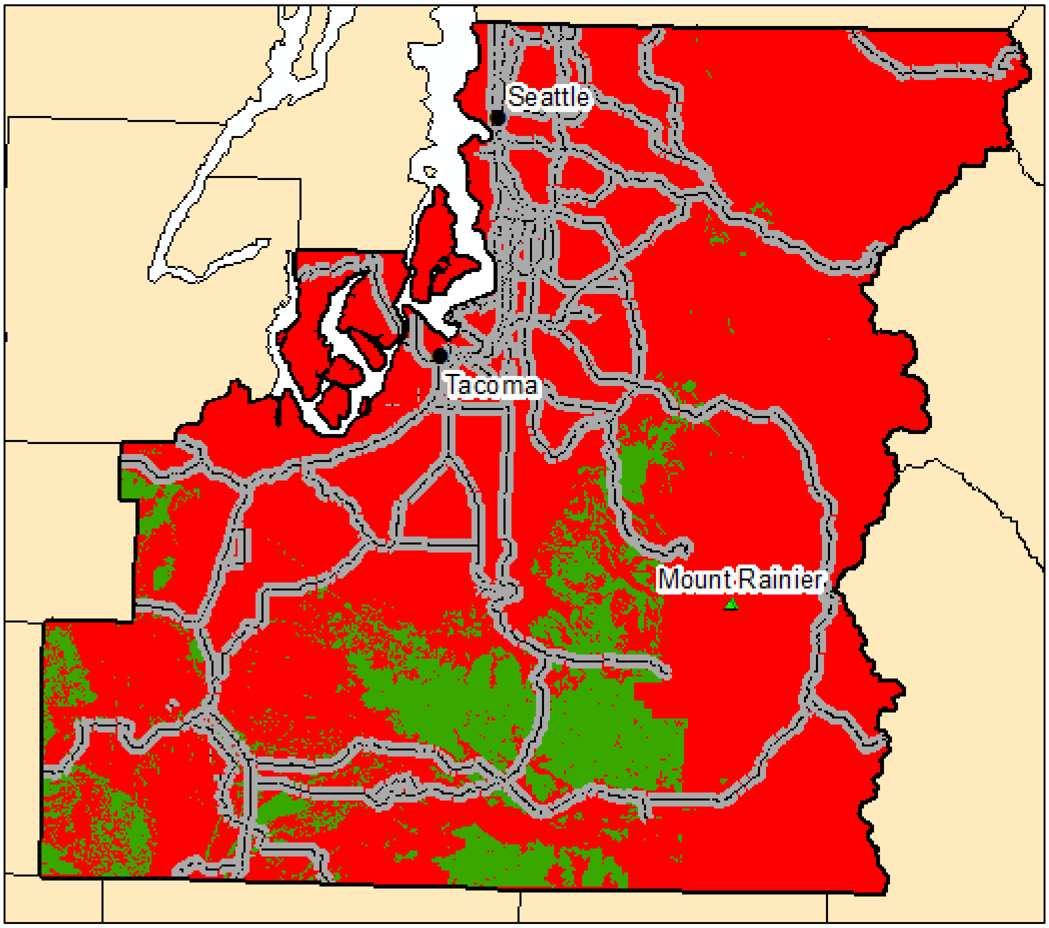

Figure 67: AG3O31SO311

Land use: Agriculture
Goal 3: Identify lands suitable for Timber/Silviculture
Objective 3.1: Determine lands physically suitable for timber
Subobjective 3.1.2: Identify current timberlands as suitable

Input data layer: Land use dataset
Criteria for value assignment: Cells of existing timberlands were assigned a value of 9, all other cells were assigned a value of 1.
Rationale: If it is currently being used for timber, it is physically suitable.
Output: Existing Timber Areas SUA (AG3O31SO312)

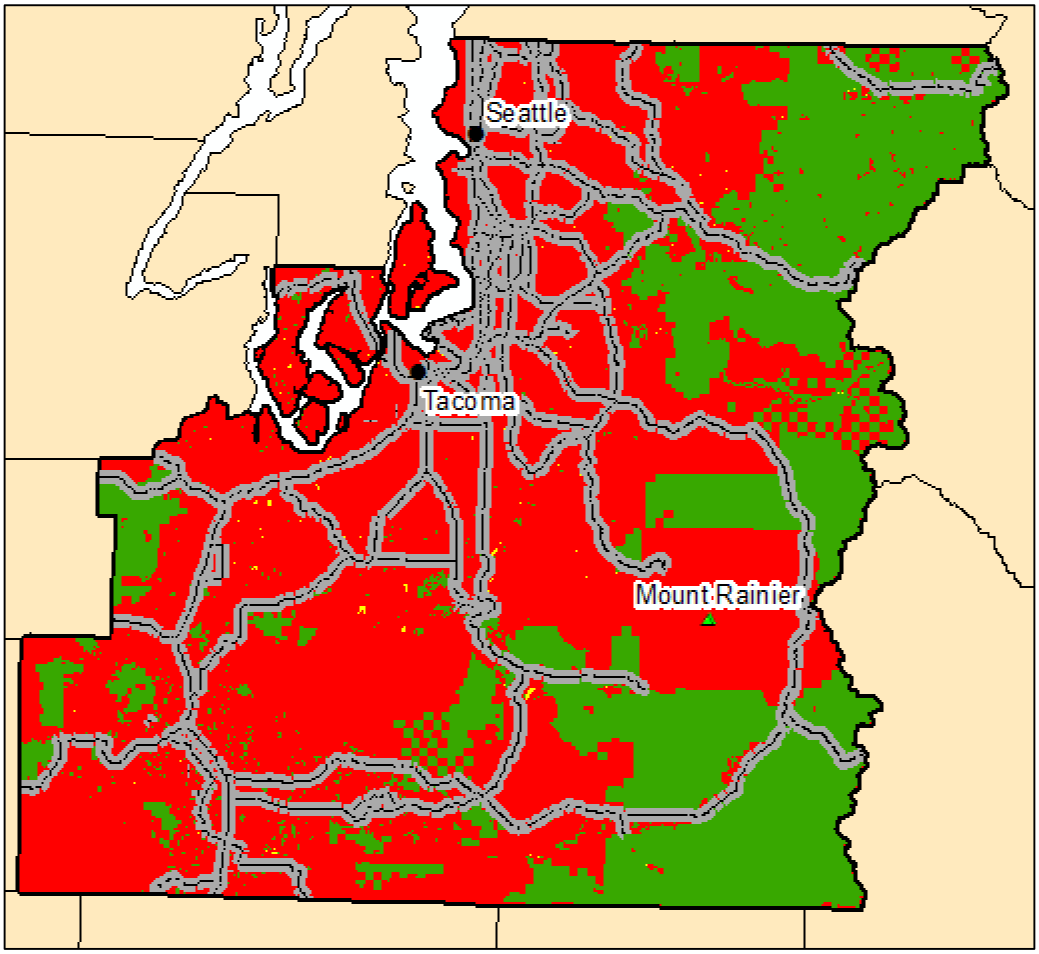

Figure 68: AG3O31SO312

Land use: Agriculture
Goal 3: Identify lands suitable for Timber/Silviculture
Objective 3.1: Determine lands physically suitable for timber

Input data layer: Timber Soils SUA (AG3O31SO311) and Existing Timber Areas SUA (AG3O31SO312)
Criteria for value assignment: The inputs were combined using a conditional statement; CON (Existing Timber Areas = 9, 9, Timber Soil). Cells currently used for timber were assigned a value of 9, all other cells were assigned the timber soil value.
Rationale: If cells are currently being used for timber/silviculture, then the suitability is high, and the yield is a good indication of suitability for other cells.
Output: Timber/Silviculture Physical Suitability MUA (AG3O31)

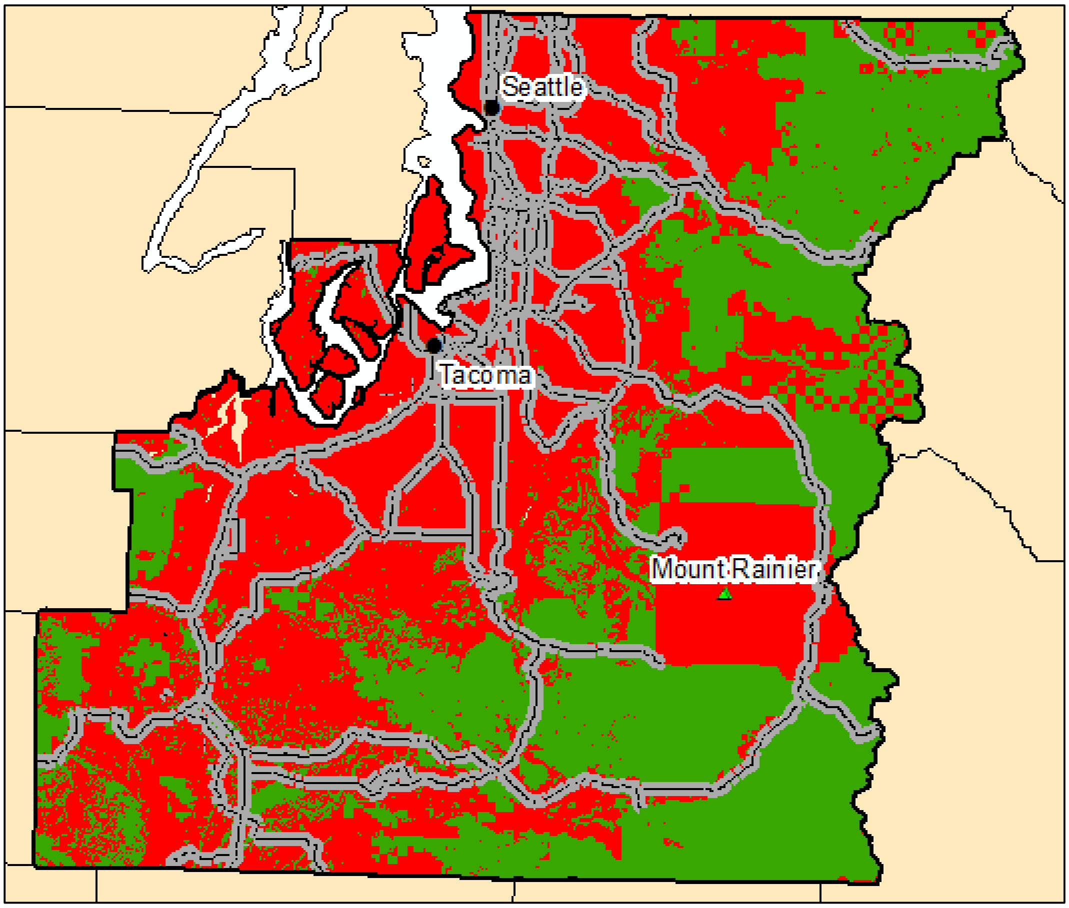

Figure 69: AG3O31

Land use: Agriculture
Goal 3: Identify lands suitable for Timber/Silviculture
Objective 3.2: Identify lands proximal to markets for timber and pulpwood (Economic suitability)

Input data layer: City Limits
Criteria for value assignment: Euclidean distance was run for City Limits. Zonal statistics were run on the Euclidean distance from City Limits to existing timber areas to determine the mean and standard deviation. Cells with a Euclidean distance less than or equal to the mean were assigned a value of 9 (0-45,830.72 feet), Cells were assigned values from 8 to 2 within quarter standard deviations. The remaining cells received a value of 1.
Rationale: The closer to markets (city limits) from existing timber areas the better
Output: Proximity to Timber Markets SUA (AG3O32)

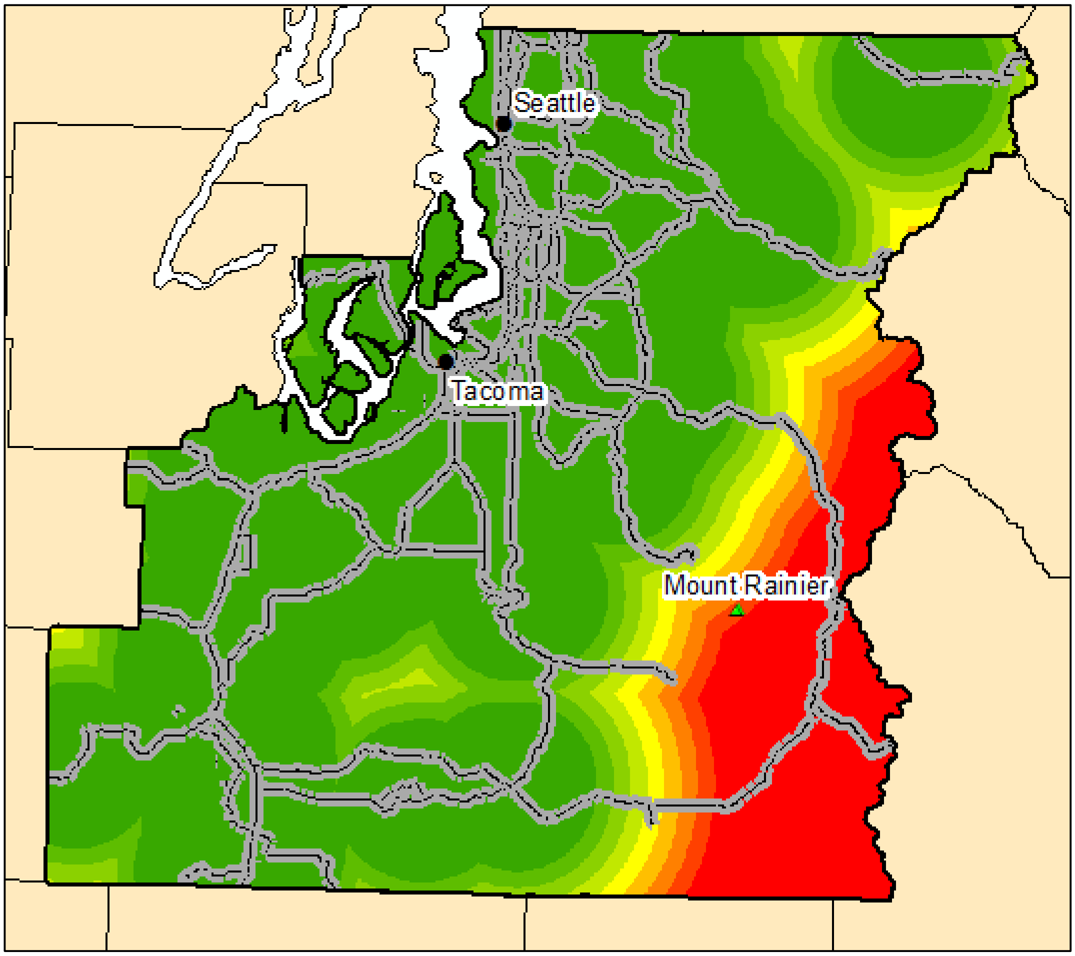

Figure 70: AG3O32

Land use: Agriculture
Goal 3: Identify lands suitable for Timber/Silviculture

Input data layer: Timber/Silviculture Physical Suitability MUA and Proximity to Timber Markets SUA (Economic Suitability)
Criteria for value assignment: The MUA and SUA were equally weighted at 50 percent and combined using map algebra.
Rationale: Physical and economic suitability are equally important in determining an overall agricultural suitability.
Output: Timber/Silviculture Suitability MUA (AG3)

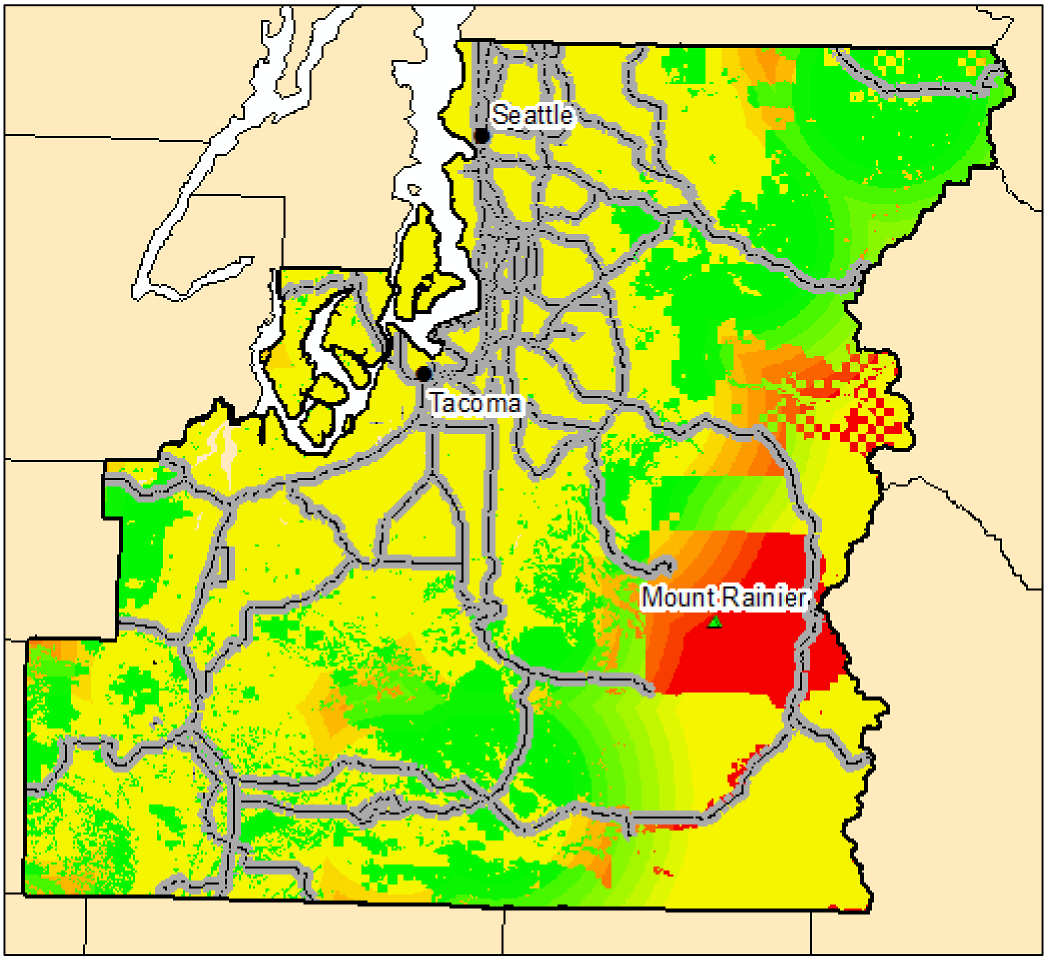

Figure 71: AG3

Land use: Conservation
Goal 1: Identify lands suitable for protecting native biodiversity
Objective 1.1: Identify lands with high native biodiversity
Subobjective 1.1.1: Identify priority wetland habitats

Input data layer: Wetlands
Criteria for value assignment: Values were assigned based on the percentage and acreage of tree crown cover. Definition of wetland types were derived from WAC 222-16-035 (Washington State Legislature). The value of 9 was assigned to Forested wetland (>30% crown closure), a value of 8 was assigned to Type A nonforested wetland (<30% crown closure with >0.5 acres), a value of 7 was assigned to Type B nonforested wetland (<30% crown closure and >0.25 acres), a value of 6 was assigned to all other wetlands. The remaining cells were assigned a value of 1.
Rationale: The better habitat for tree canopy the higher the priority
Output: Wetland Biodiversity SUA (CG1O11SO111)

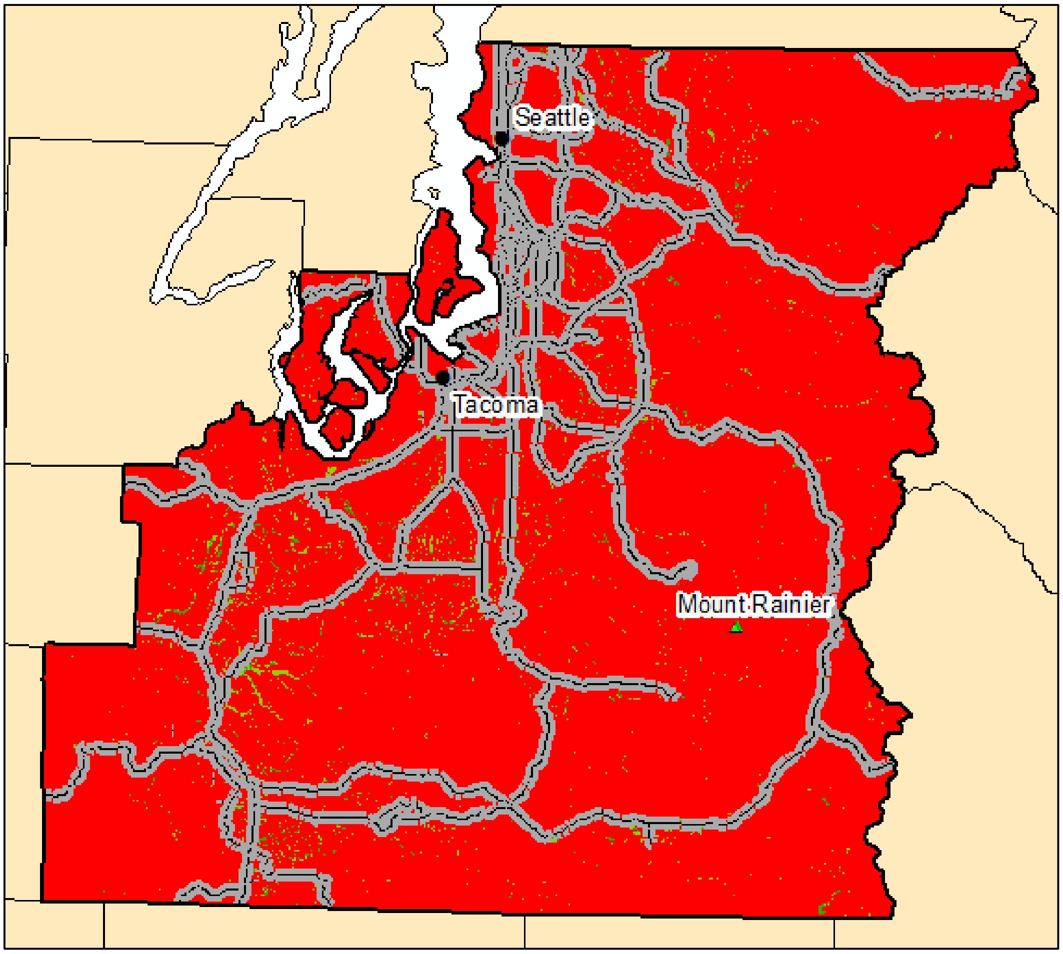

Figure 72: CG1O11SO111

Land use: Conservation
Goal 1: Identify lands suitable for protecting native biodiversity
Objective 1.1: Identify lands with high native biodiversity
Subobjective 1.1.2: Identify strategic habitat conservation areas

Input data layer: Habitat Conservation Plan Lands
Criteria for value assignment: Cells with existing conservation lands were assigned a value of 9, all other cells were assigned a value of 1.
Rationale: Existing conservation lands all have potentially high biodiversity and are suitable for inclusion in a high suitability biodiversity data product.
Output: Strategic Habitat Conservation Areas SUA (CG1O11SO112)

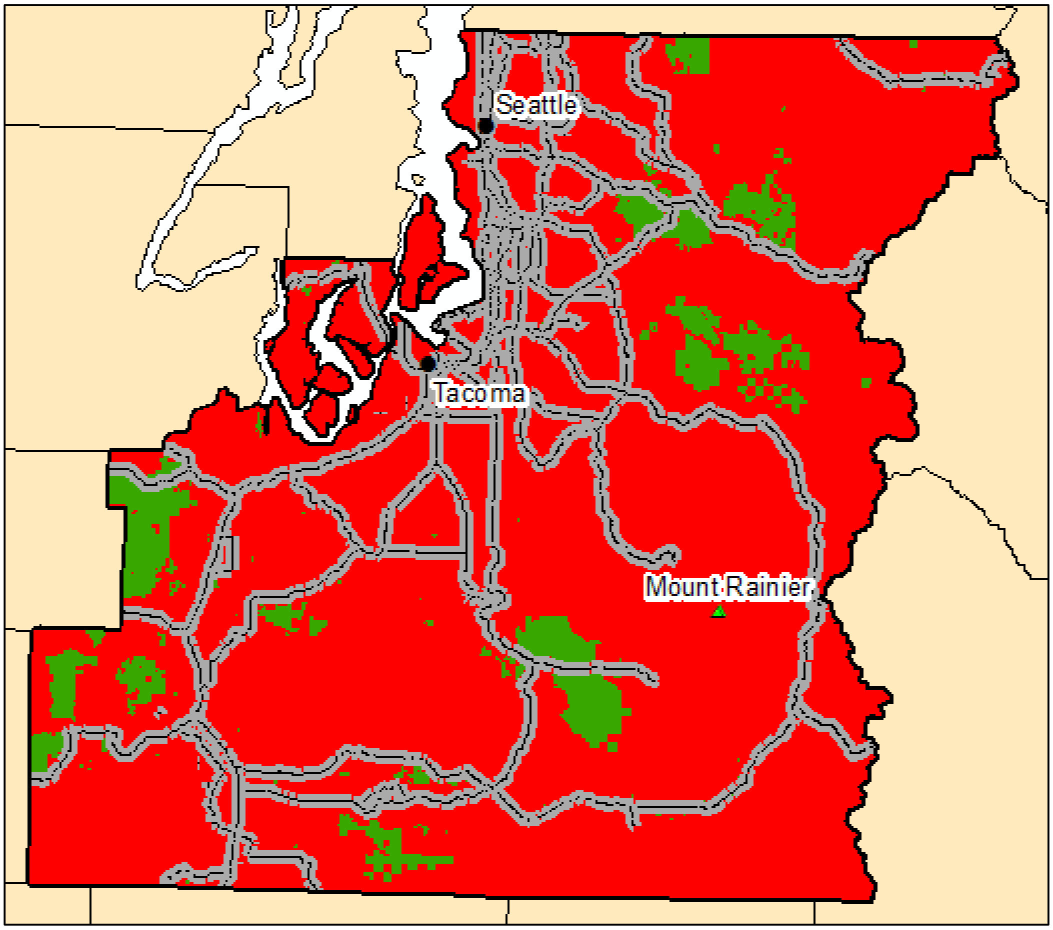

Figure 73: CG1O11SO112

Land use: Conservation
Goal 1: Identify lands suitable for protecting native biodiversity
Objective 1.1: Identify lands with high native biodiversity
Subobjective 1.1.3: Identify habitats with high biodiversity

Input data layer: Habitat
Criteria for value assignment: Habitat ranked by the Natural Heritage Program as having high native biodiversity were given a value of 9. Habitat ranked as moderately high native biodiversity was given a value of 7. Habitat ranked as moderate native biodiversity was given a value of 5. Habitat ranked as moderately low native biodiversity was given a value of 3, all others were assigned a value of 1.
Rationale: Certain habitat types are known to have higher native biodiversity than others, therefore those with higher biodiversity were given a higher suitability value.
Output: Habitat Biodiversity SUA (CG1O11SO113)

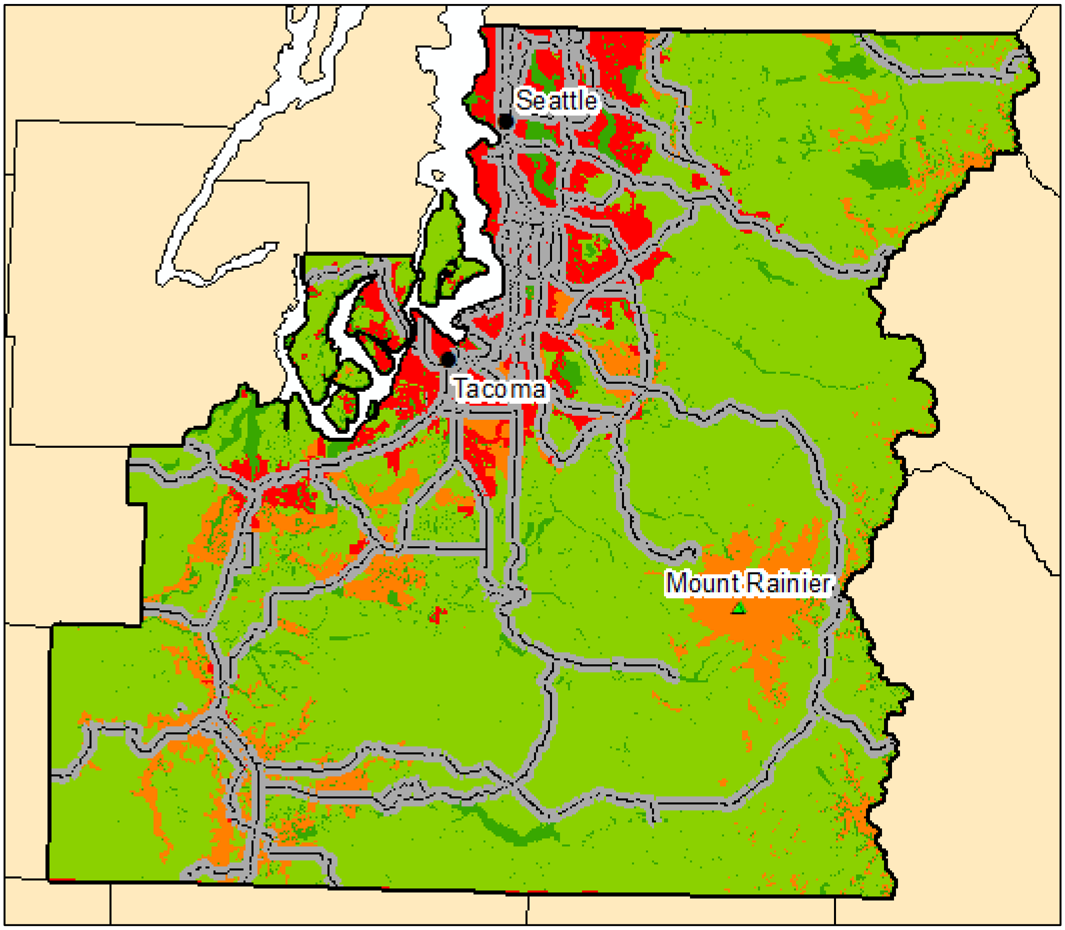

Figure 74: CG1O11SO113

Land use: Conservation
Goal 1: Identify lands suitable for protecting native biodiversity
Objective 1.1: Identify lands with high native biodiversity

Input data layer: Wetland Biodiversity SUA (CG1O11SO111), Strategic Habitat Conservation Areas SUA (CG1O11SO112), and Habitat Biodiversity SUA (CG1O11SO113)
Criteria for value assignment: The SUAs were weighted and combined using map algebra as follows: Wetland Biodiversity 25 percent, Strategic Habitat Conservation 25 percent, and Habitat Biodiversity 50 percent.
Rationale: The most complete representation of biodiversity suitability is captured through the reclassification of the current habitat therefore receives the highest weight.
Output: Native Biodiversity MUA (CG1O11)

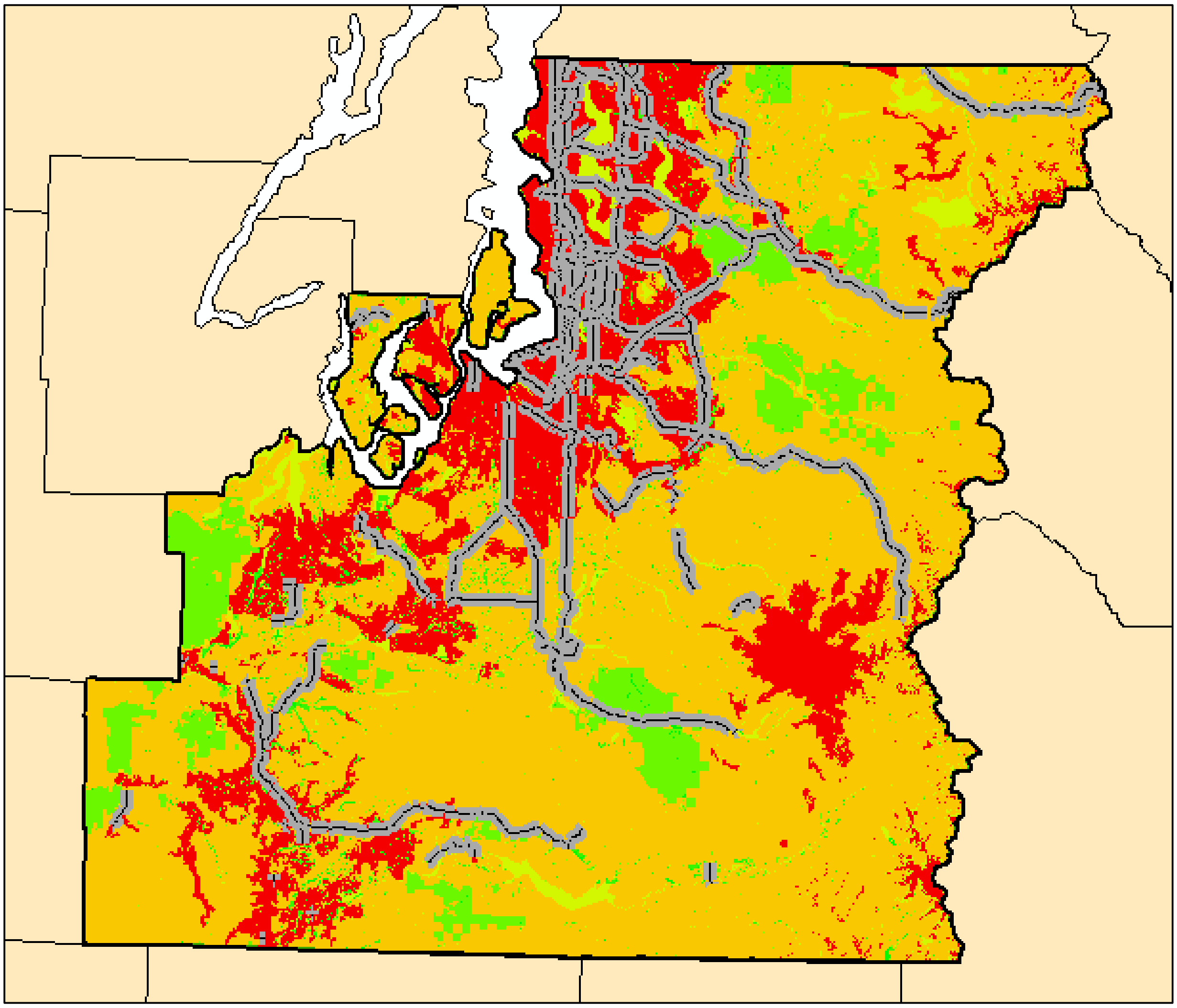

Figure 75: CG1O11

Land use: Conservation
Goal 1: Identify lands suitable for protecting native biodiversity
Objective 1.2: Identify lands with relatively low road density

Input data layer: Road Density
Criteria for value assignment: Road densities per square mile were assigned values of 9-1 based on 9 equal intervals, with the lowest road density being assigned a value of 9 and the highest being assigned a value of 1.
Rationale: The lower the road density, the less disturbance in an area will have due to human interactions. The less disturbance, the more protected the biodiversity will be.
Output: Low Road Density SUA (CG1O12)

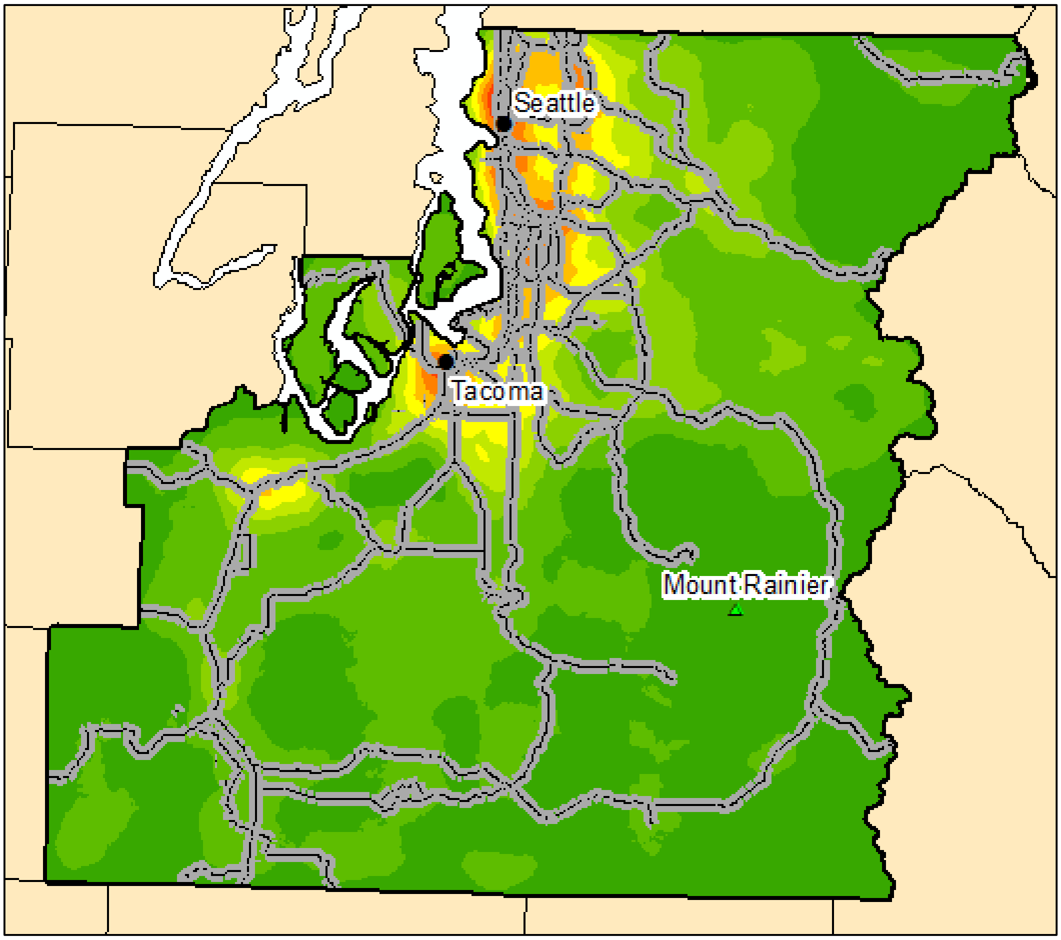

Figure 76: CG1O12

Land use: Conservation
Goal 1: Identify lands suitable for protecting native biodiversity
Objective 1.3: Identify existing conservation lands and areas proximate to those lands

Input data layer: Habitat Conservation Plan Lands
Criteria for value assignment: A Euclidean distance was run and reclassified with the new values of 9 assigned to cells from 0 ft. to 206.69 ft., 8 to cells from 206.69 ft. to 1,640.42 ft., 7 to cells from 1,640.42 ft. to 3,280.84 ft., 6 to cells 3,280.84 ft. to 5,741.47 ft., 5 to cells 5,741.47 ft. to 9,022.31 ft., 4 to cells 9,022.31 ft. to 12,303.15 ft., 3 to cells 12,303.15 ft. to 15,583.99 ft., 2 to cells 15,583.99 ft. to 18,044.62 ft., and the remaining cells were assigned a value of 1.
Rationale: Existing conservation lands have biodiversity value, otherwise they would not be given a protective status. The closer to the existing conservation lands, the higher the likelihood the area has a higher biodiversity.
Output: Proximity to Existing Conservation Lands SUA (CG1O13)

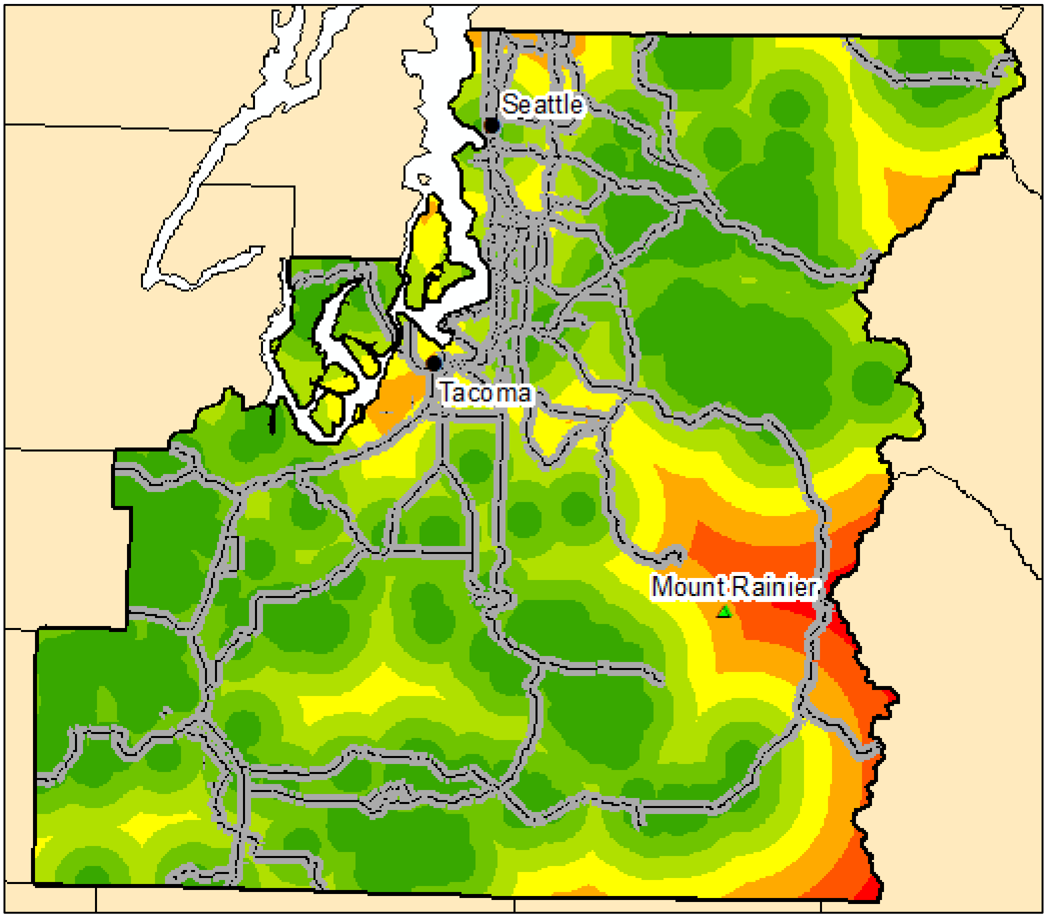

Figure 77: CG1O13

Land use: Conservation
Goal 1: Identify lands suitable for protecting native biodiversity

Input data layer: Native Biodiversity MUA (CG1O11), Low Road Density SUA (CG1O12), and Proximity to Existing Conservation Lands SUA (CG1O13)
Criteria for value assignment: The MUAs were weighted and combined using map algebra. Native biodiversity was weighted 33 percent, lower road density was weighted 33 percent, and proximity to existing conservation lands was weighted 34 percent.
Rationale: All measures of suitability are equally valid measures of native biodiversity.
Output: Native Biodiversity Protection Suitability SUA (CG1)

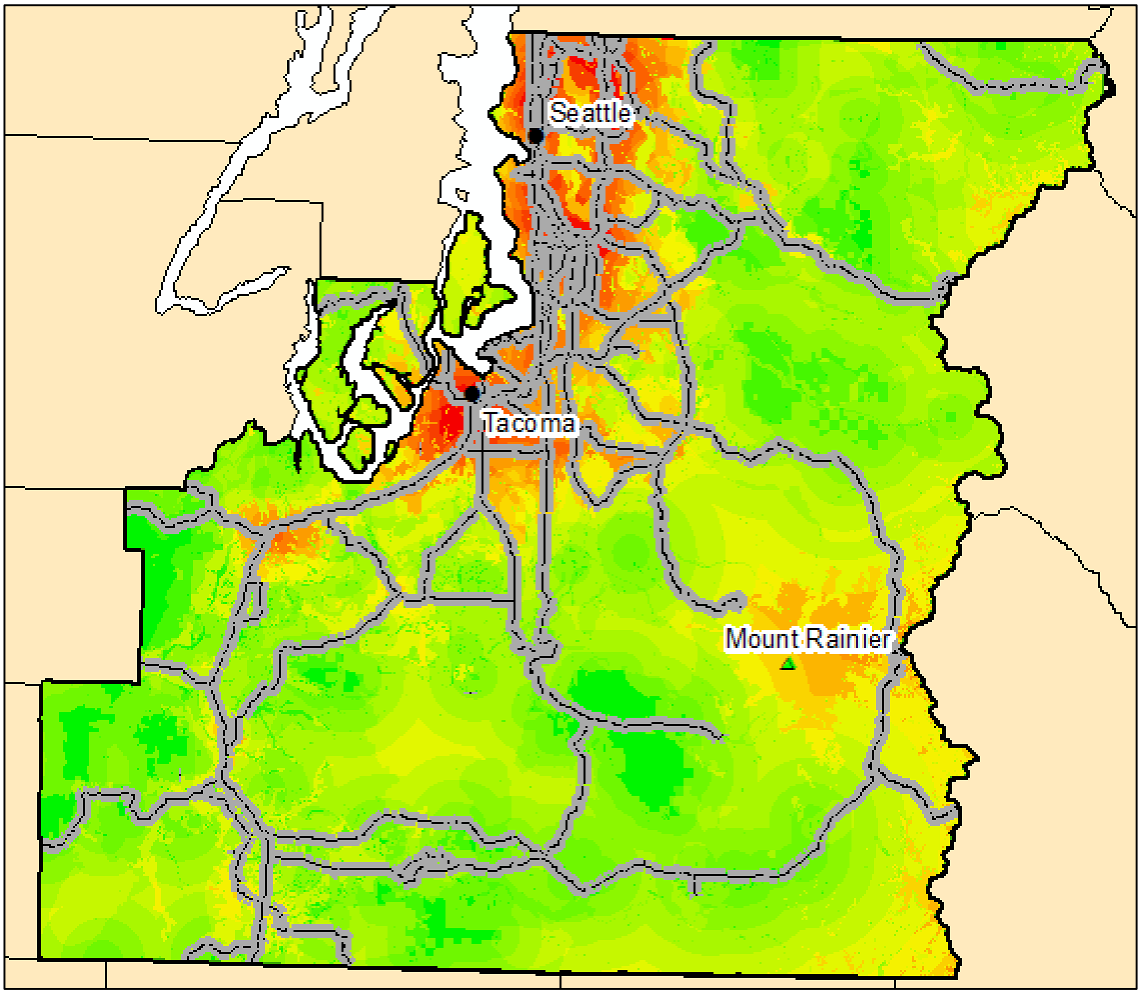

Figure 78: CG1

Land use: Conservation
Goal 2: Identify lands suitable for protecting water quality
Objective 2.2: Identify lakes, wetlands, rivers, streams, and associated buffers.

Input data layer: Hydrology
Criteria for value assignment: Surface water features were selected and a Euclidean distance was run. These were reclassified as follows: 0- 393.70ft was assigned a 9, 393.70- 787.40ft was assigned an 8, and all other cells were assigned a value of 1.
Rationale: If surface water quality is to be maintained, runoff into surface water features needs to be free from contamination and particulates. The buffers go into the neighboring vegetation and it serves as a filter for the runoff before it reaches the surface locations.
Output: Surface Water Feature Buffer SUA (CG2O21)

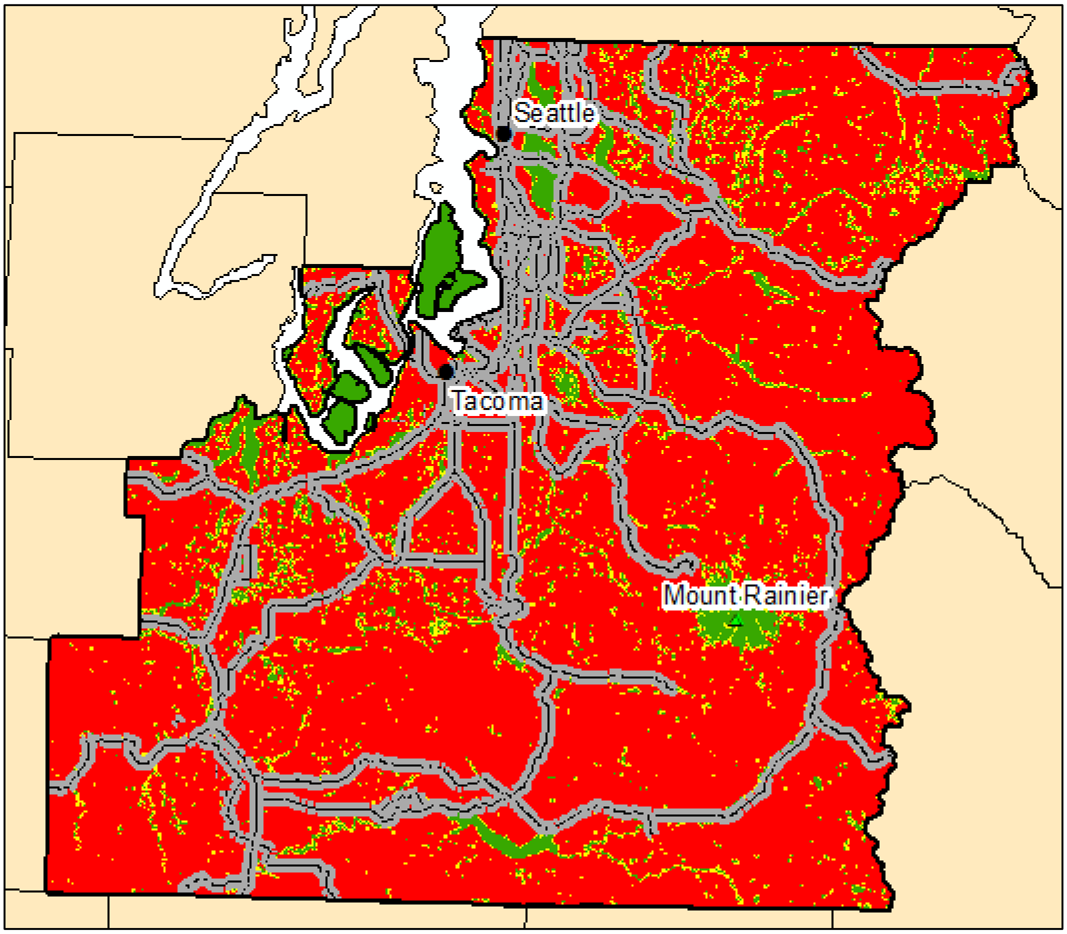

Figure 79: CG2O21

Land use: Conservation
Goal 2: Identify lands suitable for protecting water quality
Objective 2.2: Identify springs and associated buffers

Input data layer: Springs
Criteria for value assignment: Surface water features were selected and a Euclidean distance was run. These were reclassified as follows: 0- 393.70ft was assigned a 9, 393.70- 787.40ft was assigned an 8, and all other cells were assigned a value of 1.
Rationale: If surface water quality is to be maintained, runoff into springs needs to be free from contaminates and particulates. The buffers go into the neighboring vegetation and it serves as a filter for the runoff before it reaches the surface locations. Springs are worth greater protections than other surface water features because they are usually the primary or signification contribution source for surface water.
Output: Springs Buffer SUA (CG2O22)

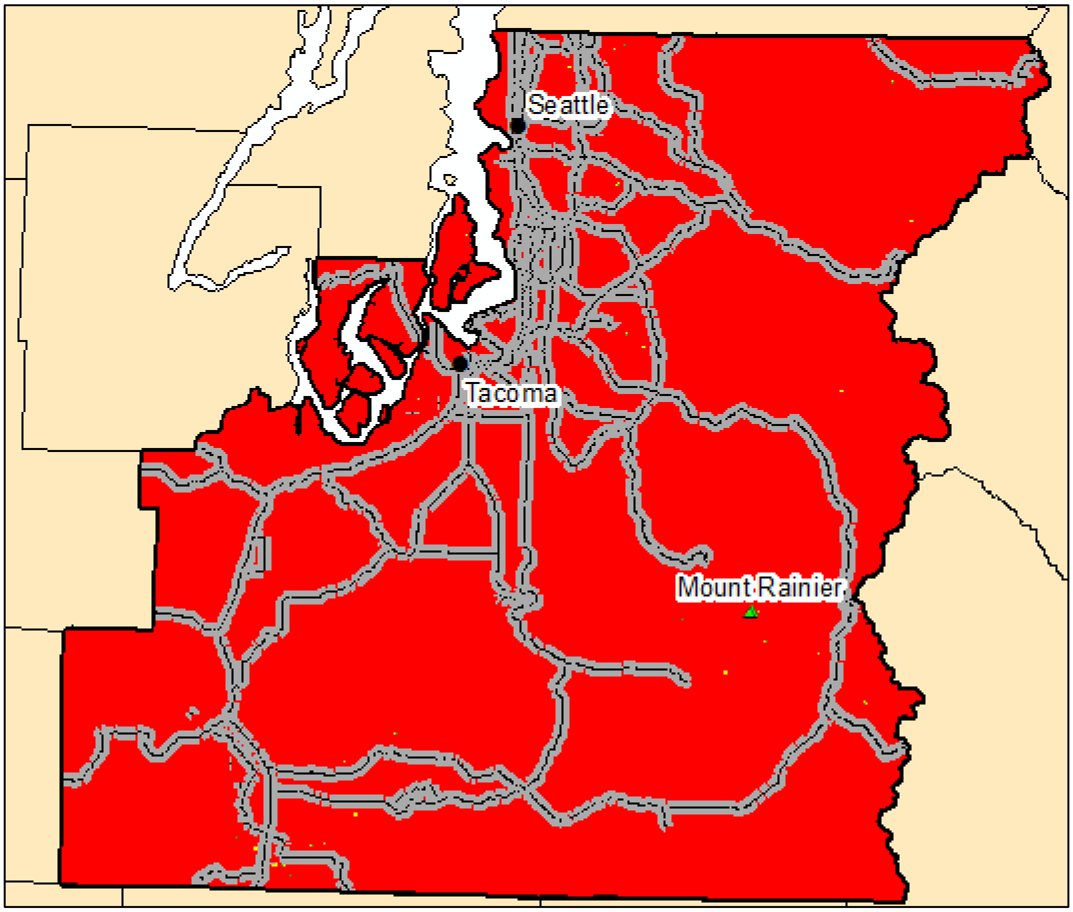

Figure 80: CG2O22

Land use: Conservation
Goal 2: Identify lands suitable for protecting water quality

Input data layer: Surface Water Feature Buffer SUA (CG2O21) and Springs Buffer SUA (CG2O22)
Criteria for value assignment: The input SUAs were combined using a conditional statement; CON (Surface Water Feature Buffer > Spring Buffer, Surface Water Feature Buffer, Spring Buffer). The highest value from either SUA was assigned suitability value.
Rationale: Combined the two buffers to create buffers around all surface waters in order to protect water quality.
Output: Surface Water Protection SUA (CG2)

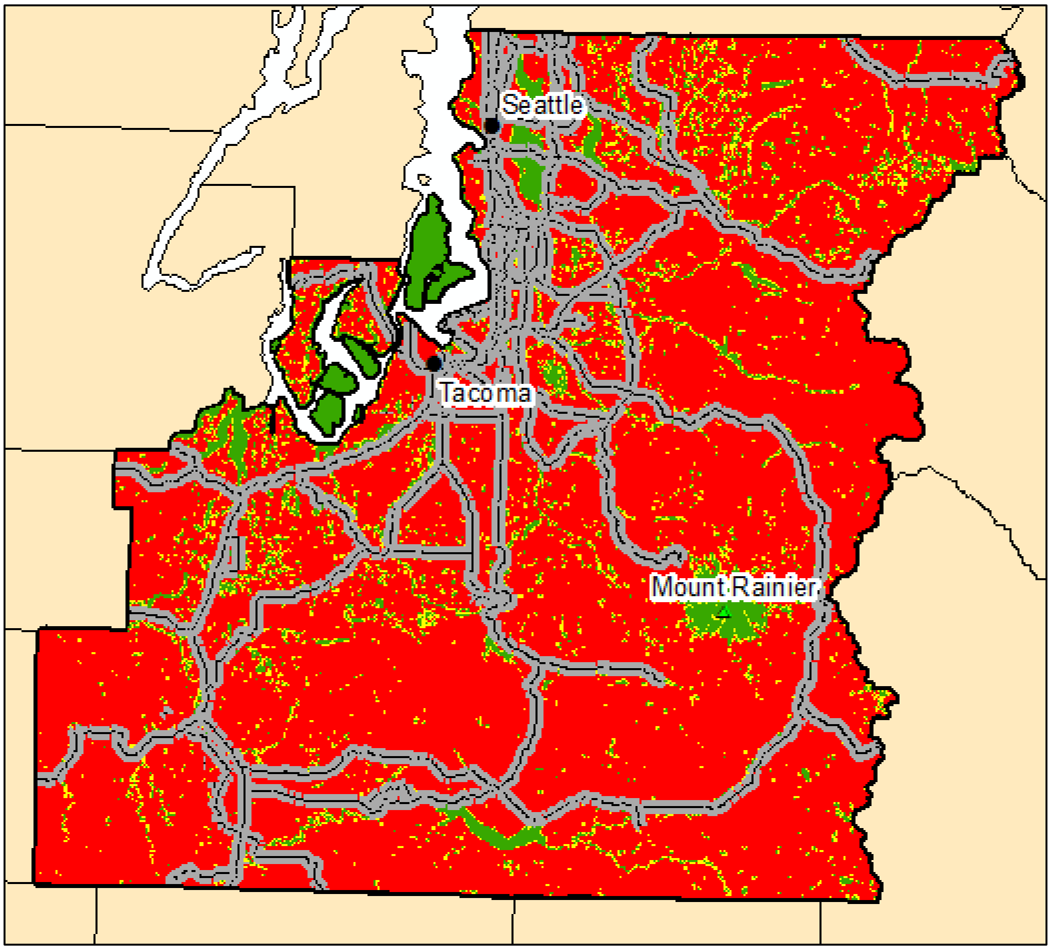

Figure 81: CG2

Land use: Conservation
Goal 3: Identify lands suitable for protection of important ecological processes
Objective 3.1: Identify lands important for the movement of fire across the landscape
Subobjective 3.1.1: Identify fire-maintained communities

Input data layer: Habitat
Criteria for value assignment: Fire-maintained plant communities were assigned a value of 9 and all other plant communities were assigned a value of 1.
Rationale: Protection for the remaining fire-maintained communities is critical to the survival of the role played by fire in the landscape.
Output: Fire-maintained Communities SUA (CG3O31SO311)

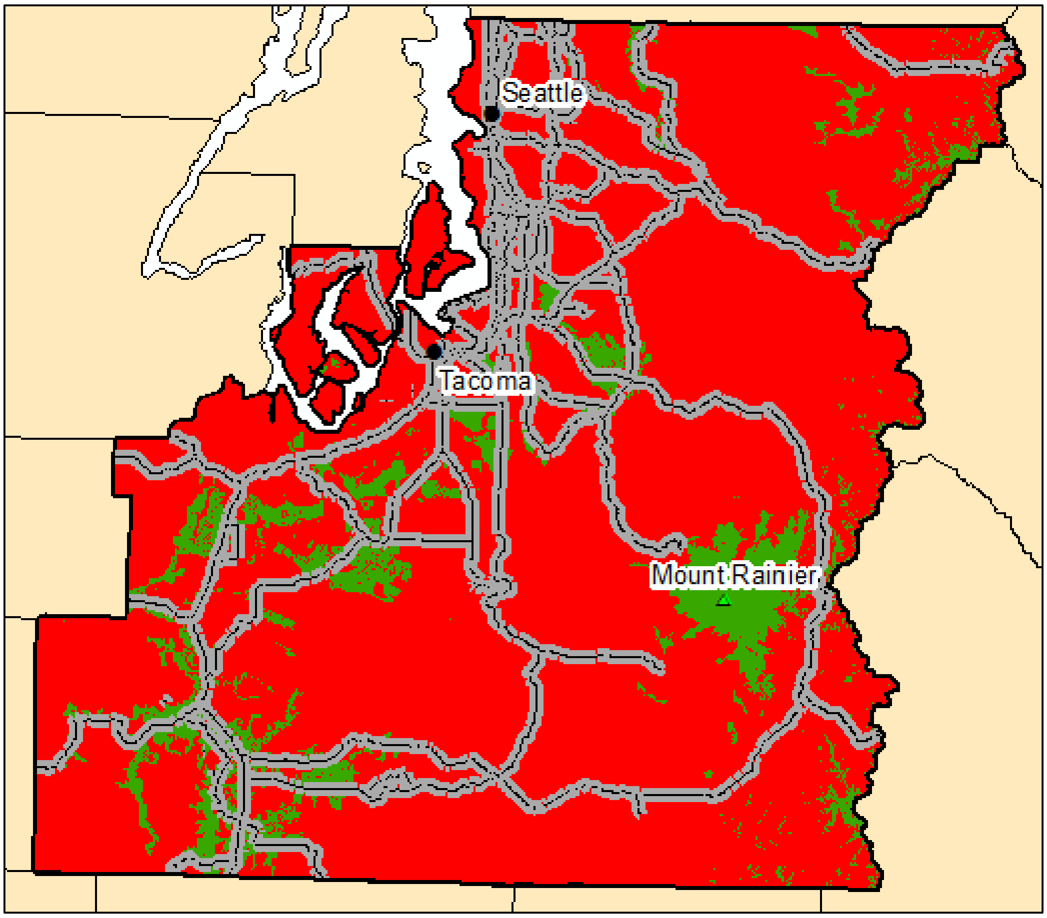

Figure 82: CG3O31SO311

Land use: Conservation
Goal 3: Identify lands suitable for protection of important ecological processes
Objective 3.1: Identify lands important for the movement of fire across the landscape
Subobjective 3.1.2: Identify nonburnable areas and associated buffers

Input data layer: Nonburnable areas (Preprocessed from land use dataset)
Criteria for value assignment: Euclidean distance was run from nonburnable areas. The Euclidean distance results were reclassed as follows: 1 was assigned to 0- 328.08ft (not suitable for fire), 2 was assigned to 328.08- 656.17ft, and so on in 328.08ft intervals until 2,624.67ft. 2,624.67ft and above were assigned a value of 9.
Rationale: Nonburnable areas will be protected from fire, and the further away one is from a nonburnable area, the more likely fire will be allowed to go through that area.
Output: Nonburnable Areas SUA (CG3O31SO312)

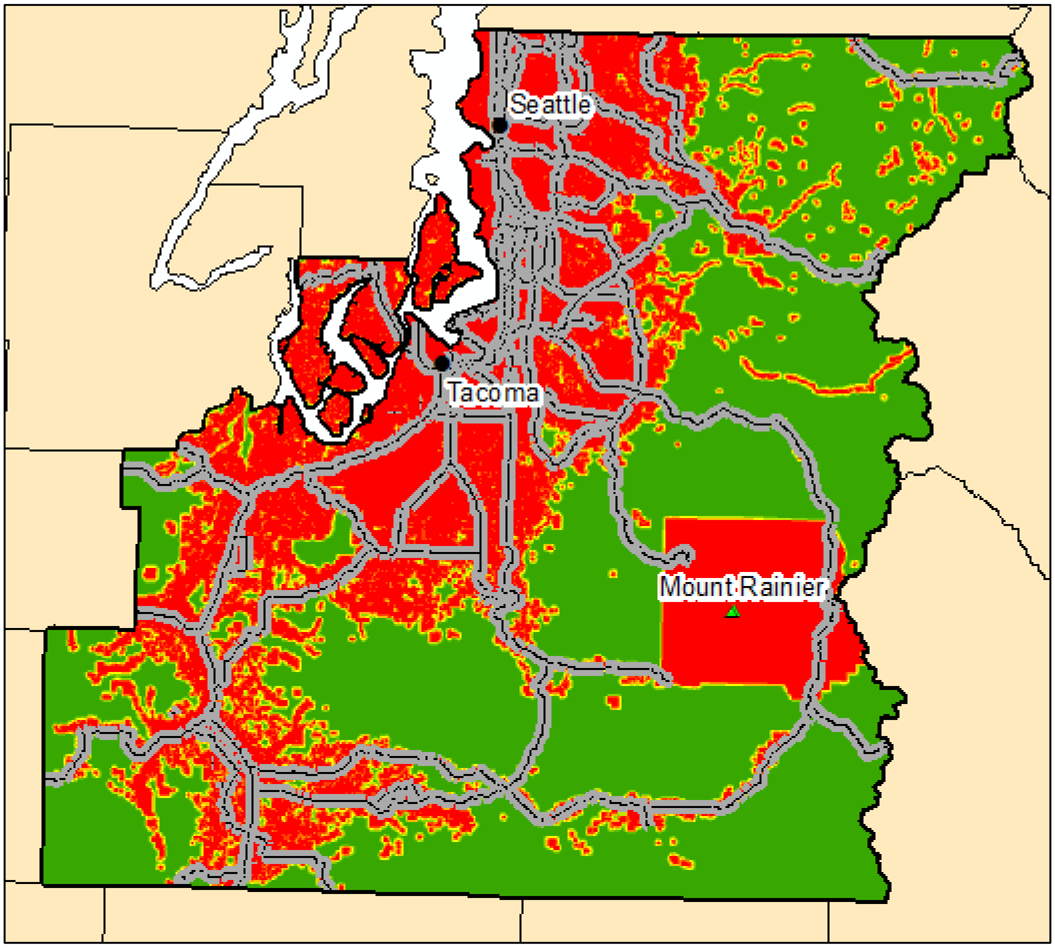

Figure 83: CG3O31SO312

Land use: Conservation
Goal 3: Identify lands suitable for protection of important ecological processes
Objective 3.1: Identify lands important for the movement of fire across the landscape

Input data layer: Fire-maintained Communities SUA (CG3O31SO311) and Nonburnable Areas SUA (CG3O31SO312)
Criteria for value assignment: The two SUAs were combined using a conditional statement, CON (Fire-maintained = 9 AND Nonburnable = 9, 9, Nonburnable). Where the fire-maintained communities value and nonburnable area value was equal to 9, make the cell a nine, otherwise give the cell the value from the nonburnable area.
Rationale: Fire-maintained communities are essential for the movement of fire through landscape, but the likelihood that fire will be allowed in a fire-maintained community decrease with proximity to nonburnable areas.
Output: Fire Process MUA (CG3O31)

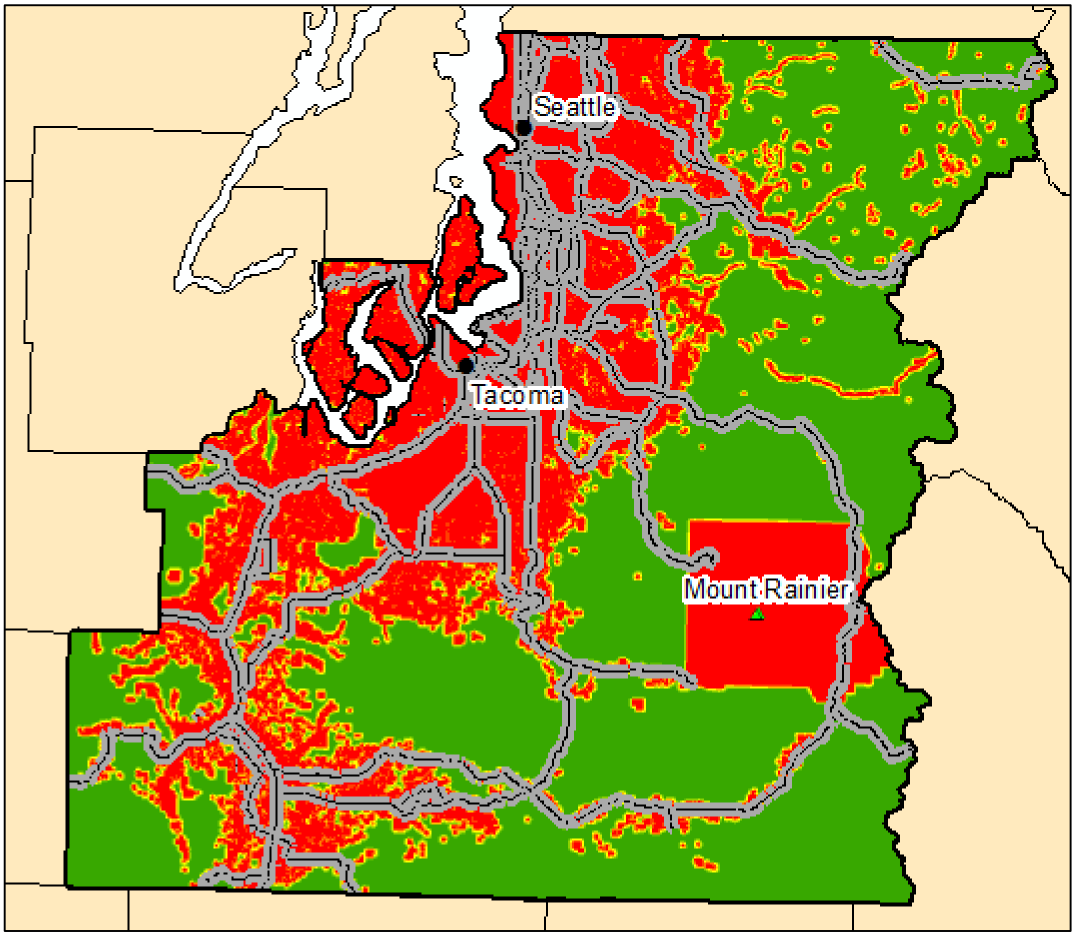

Figure 84: CG3O31

Land use: Conservation
Goal 3: Identify lands suitable for protection of important ecological processes
Objective 3.2: Identify lands important for maintenance of the process of flooding and flood storage in the landscape
Subobjective 3.2.2: Identify wetlands

Input data layer: Habitat
Criteria for value assignment: Wetland habitats were assigned a value of 9, all other habitats were assigned a value of 1.
Rationale: Wetlands are important component in the flooding process.
Output: Wetlands SUA (CG3O32SO321)

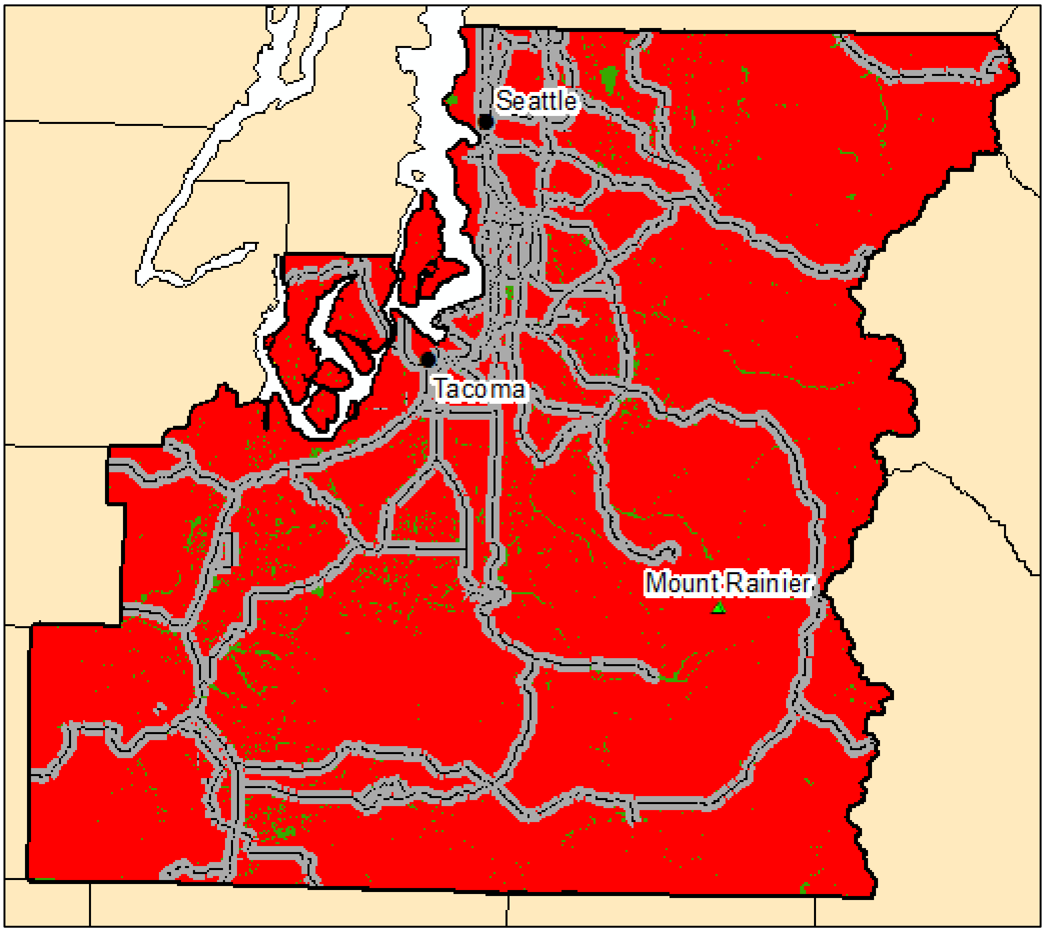

Figure 85: CG3O32SO321

Land use: Conservation
Goal 3: Identify lands suitable for protection of important ecological processes
Objective 3.2: Identify lands important for maintenance of the process of flooding and flood storage in the landscape
Subobjective 3.2.2: Identify rivers and associated buffers

Input data layer: Rivers
Criteria for value assignment: Euclidean distance was run from rivers. The results were reclassified as follows; areas within 393.70 ft. of a river were assigned a value of 9 and all other areas were assigned a value of 1.
Rationale: Rivers and buffers adjacent to rivers are important for protecting the process of flooding.
Output: Rivers SUA (CG3O32SO322)

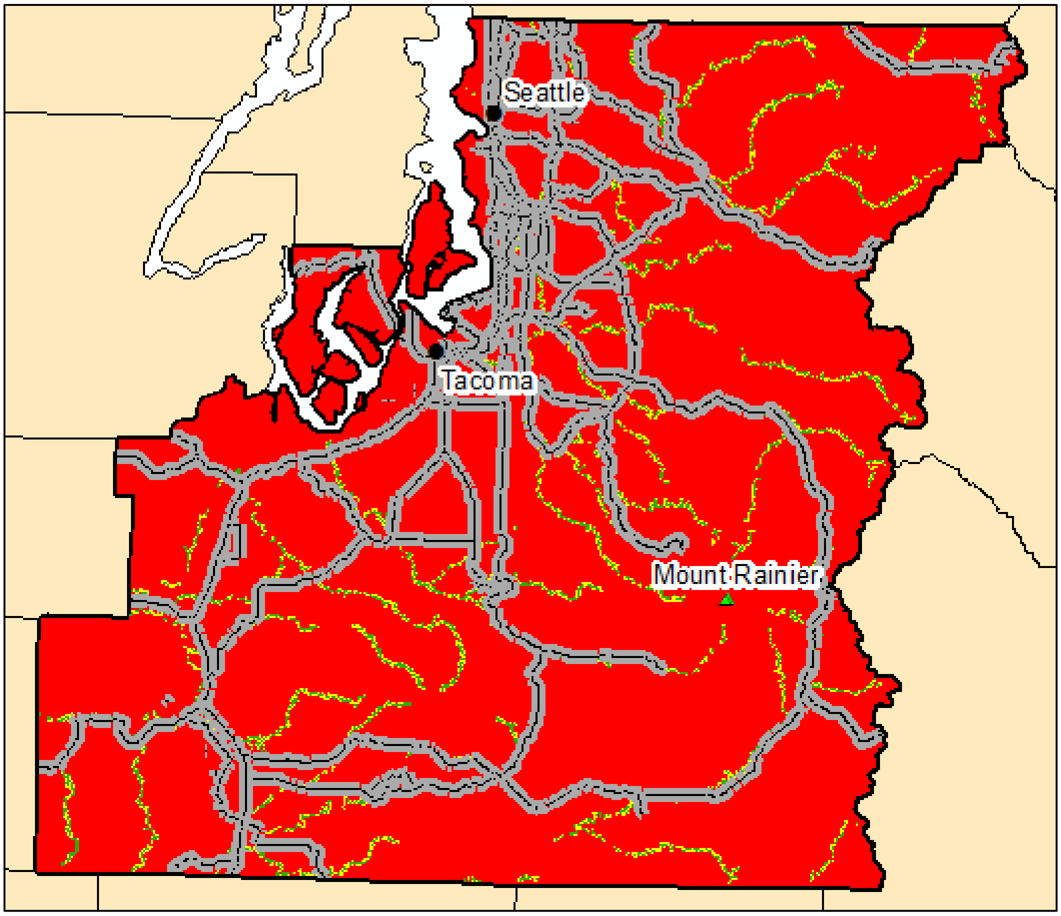

Figure 86: CG3O32SO322

Land use: Conservation
Goal 3: Identify lands suitable for protection of important ecological processes
Objective 3.2: Identify lands important for maintenance of the process of flooding and flood storage in the landscape
Subobjective 3.2.3: Identify open water and associated buffer

Input data layer: Hydrology
Criteria for value assignment: Euclidean distance was run from all open water features. Areas within 393.70 ft. of an open water feature were assigned a value of 9 and all others were assigned a value of 1.
Rationale: Open water and buffers adjacent to open water are important for protecting the process of flooding.
Output: Open Water SUA (CG3O32SO323)

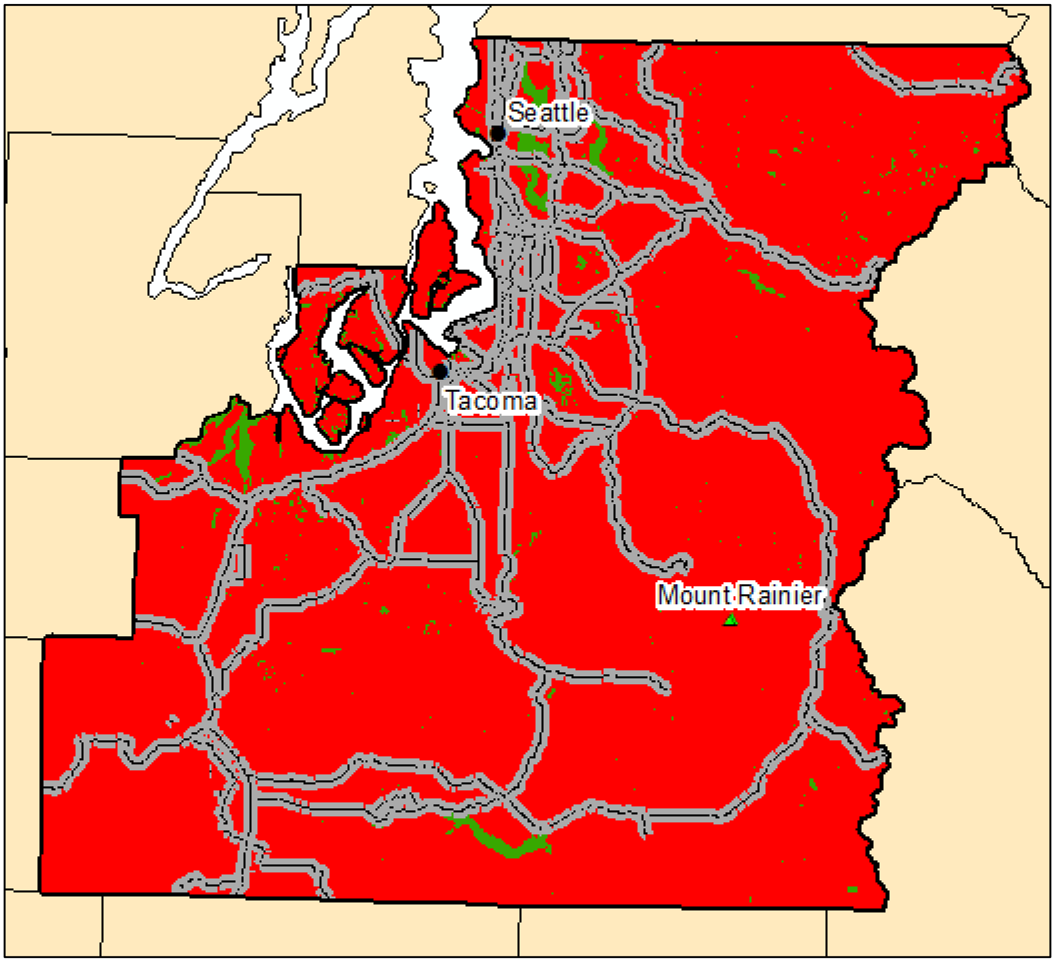

Figure 87: CG3O32SO323

Land use: Conservation
Goal 3: Identify lands suitable for protection of important ecological processes
Objective 3.2: Identify lands important for maintenance of the process of flooding and flood storage in the landscape

Input data layer: Wetlands SUA (CG3O32SO321), Rivers SUA (CG3O32SO322), and Open Water SUA (CG3O32SO323)
Criteria for value assignment: The three SUAs were combined using a conditional statement, CON (Wetlands = 9) | (Rivers = 9) | (Open Water = 9), 9, 1). If any one of the input cells is equal to 9, assign the cell a value of 9, otherwise assign a value of 1.
Rationale: People and natural organism benefit from the protection of feature that provide storm storage or allow natural flooding processes to function.
Output: Flood Process MUA (CG3O32)

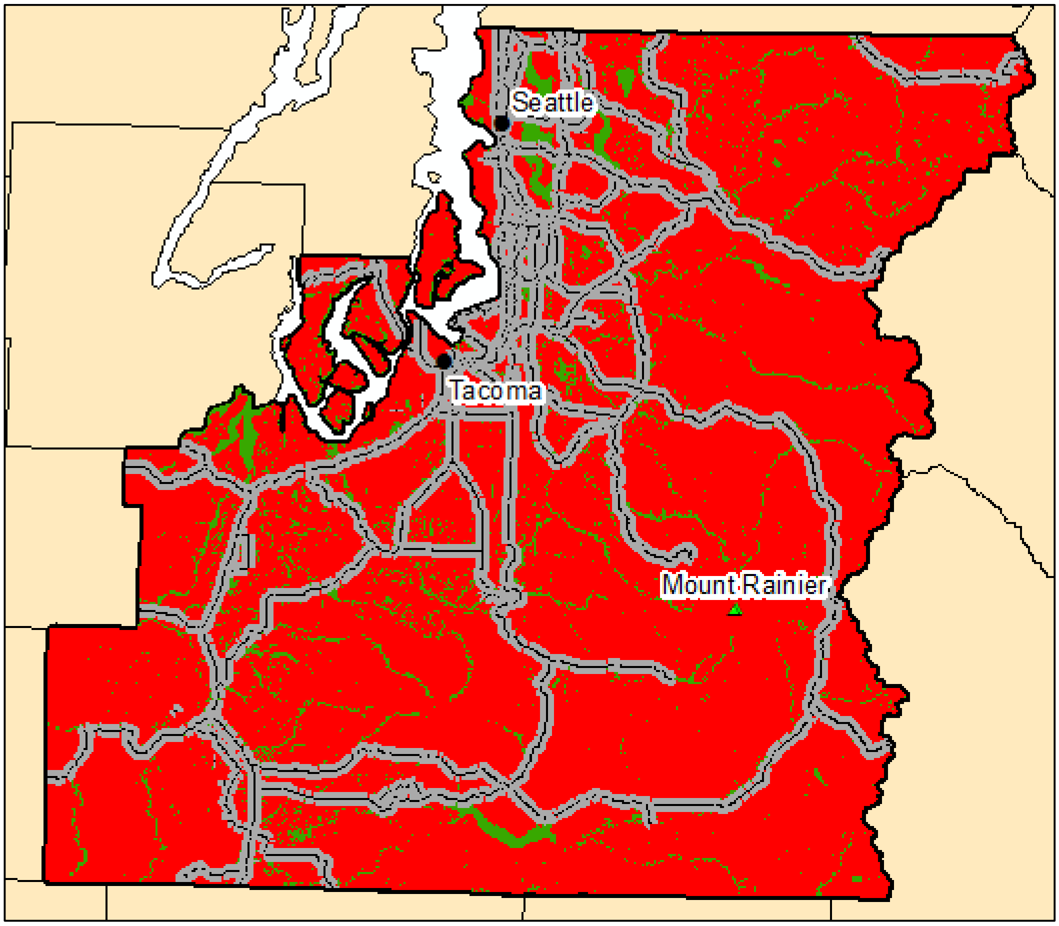

Figure 88: CG3O32

Land use: Conservation
Goal 3: Identify lands suitable for protection of important ecological processes

Input data layer: Fire Process MUA (CG3O31) and Flood Process MUA (CG3O32)
Criteria for value assignment: The MUAs were combined using a conditional statement, CON (Fire Process = 9) | (Flood Process = 9), 9, Fire Process). If either of the MUAs was equal to 9, assign the cell a value of 9, otherwise assign the cell the value of the fire process MUA.
Rationale: If either MUA was highly suitable, then that suitability ranking should be pass forward. If the value is not highly suitable, the value of fire process is appropriate.
Output: Ecological Process Suitability MUA (CG3)

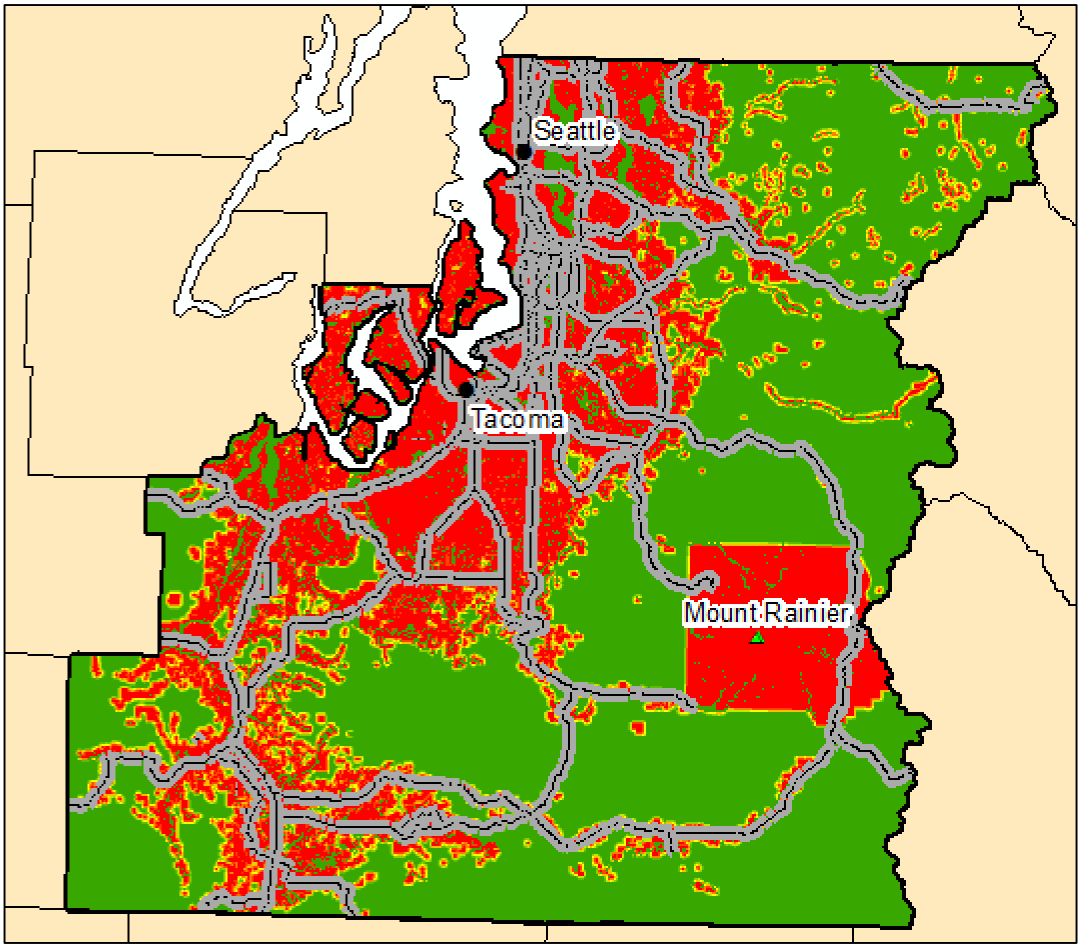

Figure 89: CG3

Land use: Conservation
Goal 4: Identify lands suitable for resource-based recreation
Objective 4.1: Identify existing areas used for resource-based recreation
Subobjective 4.1.1: Identify existing resource-based parks and recreation areas

Input data layer: Parks (Preprocessed from Land use dataset)
Criteria for value assignment: Existing resource-based parks and recreation areas were selected and assigned a value of 9, all other cells were assigned a value of 1.
Rationale: All existing resource-based parks and recreation areas should be protected.
Output: Existing Recreation Areas SUA (CG4O41SO411)

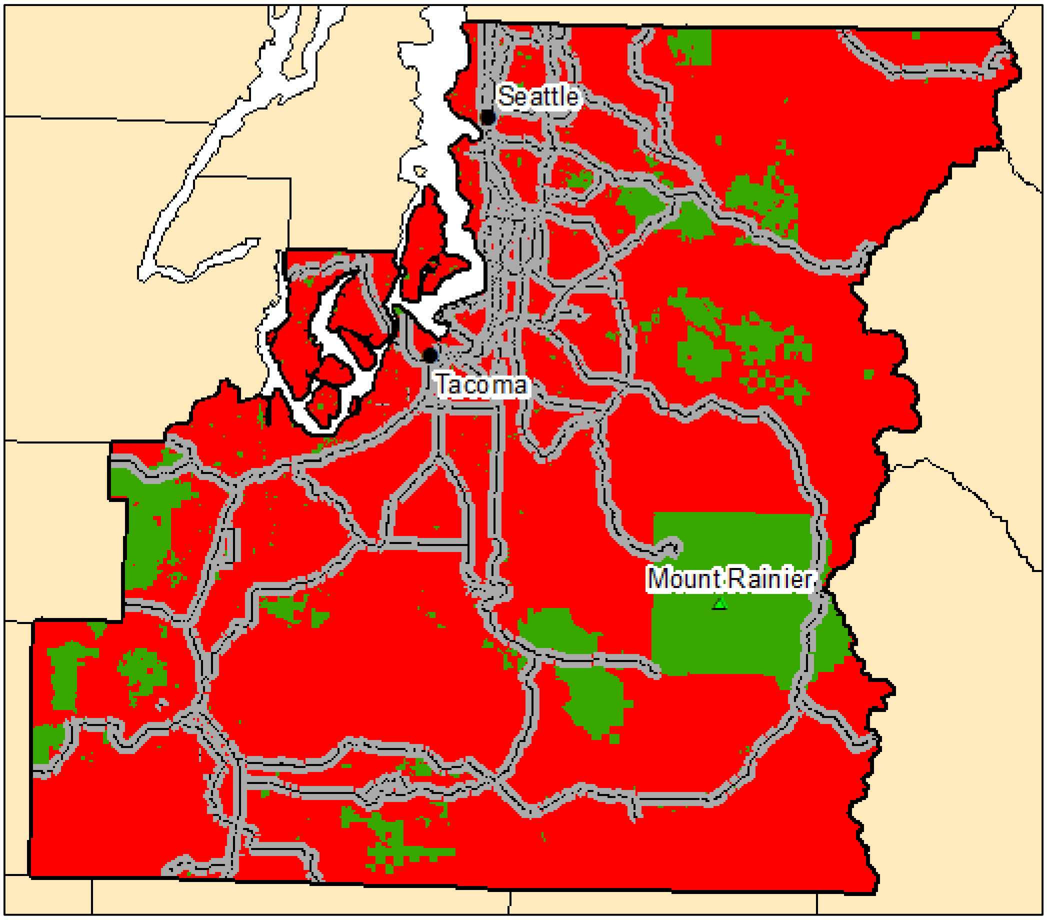

Figure 90: CG4O41SO411

Land use: Conservation
Goal 4: Identify lands suitable for resource-based recreation
Objective 4.1: Identify existing areas used for resource-based recreation
Subobjective 4.1.2: Identify existing and potential trail corridors

Input data layer: Existing Trails
Criteria for value assignment: Existing rails were selected from the dataset and were assigned a value of 9, all other cells were assigned a value of 1.
Rationale: Trails are compatible with conservation goals, and protection of these trails will further the goals of conservation.
Output: Trail Corridors SUA (CG4O41SO412)

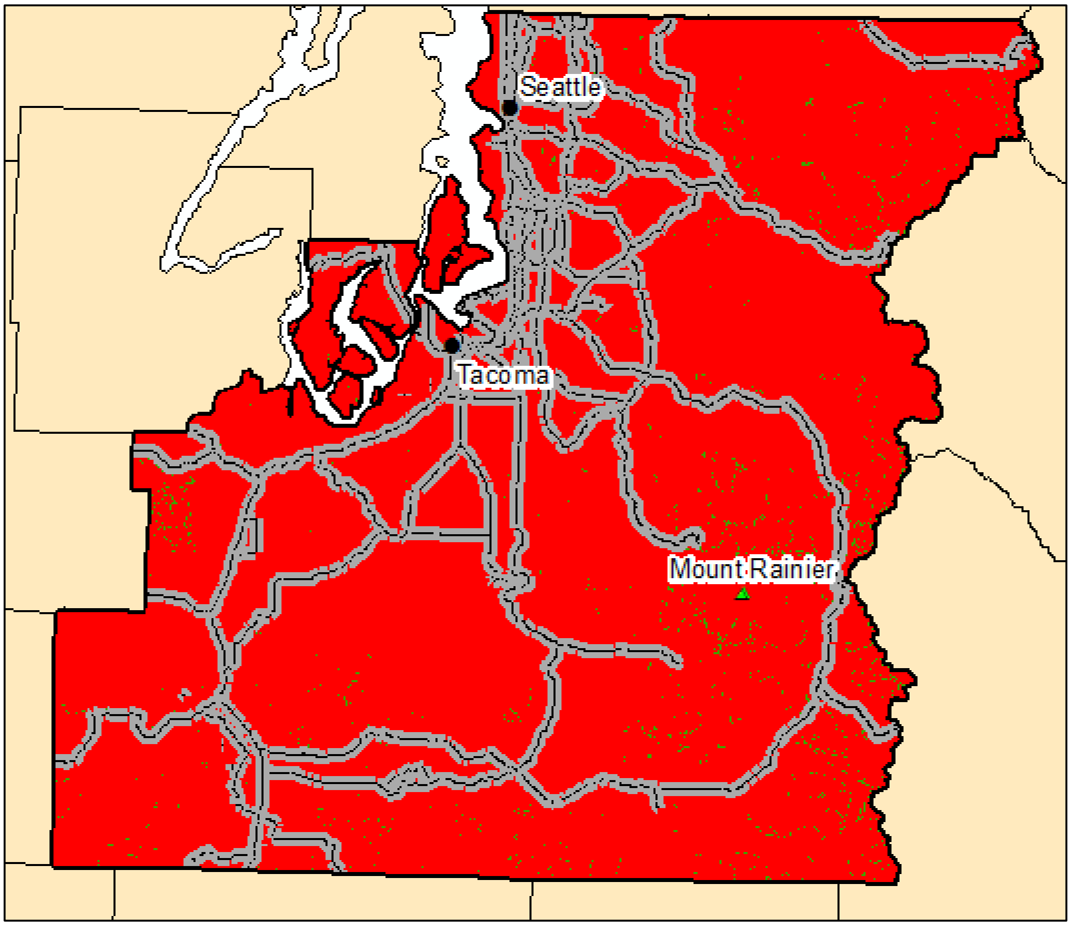

Figure 91: CG4O41SO412

Land use: Conservation
Goal 4: Identify lands suitable for resource-based recreation
Objective 4.1: Identify existing areas used for resource-based recreation
Subobjective 4.1.3: Identify cultural and historic sites

Input data layer: Historic Sites
Criteria for value assignment: Existing historical sites were assigned a value of 9 and all other cells were assigned a value of 1.
Rationale: Protection of cultural and historic sites is consistent with conservation goals. Protecting these sites further the goals of conservation.
Output: Cultural/Historic Sites SUA (CG4O41SO413)

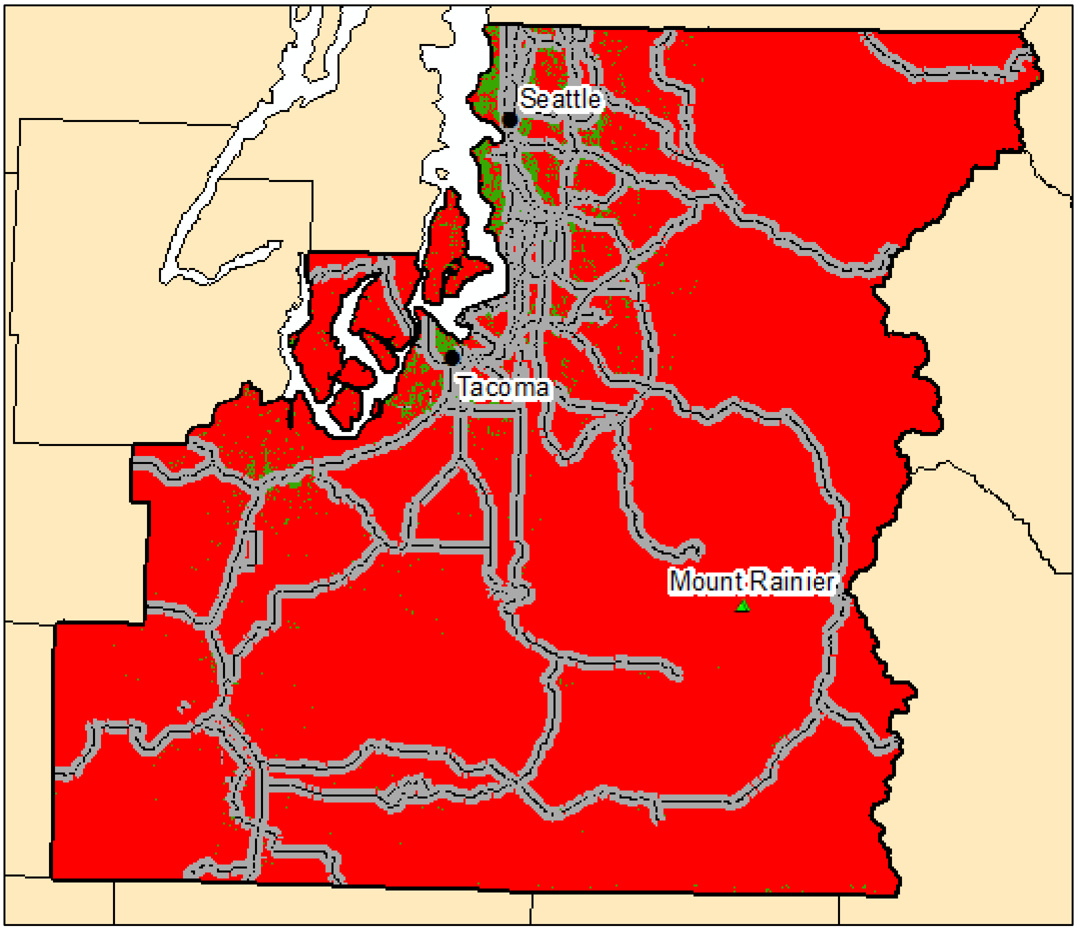

Figure 92: CG4O41SO413

Land use: Conservation
Goal 4: Identify lands suitable for resource-based recreation
Objective 4.1: Identify existing areas used for resource-based recreation

Input data layer: Existing Recreation Areas SUA (CG4O41SO411), Trail Corridors SUA (CG4O41SO412), and Cultural/Historic Sites SUA (CG4O41SO413)
Criteria for value assignment: The three SUAs were combined using a conditional statement, CON (Existing Recreation Areas = 9) | (Trail Corridors = 9) | (Cultural/Historic Sites= 9), 9, 1). If any of the inputs have a value of 9, the cell was assigned a value of 9, otherwise it was assigned a value of 1.
Rationale: All of these inputs are consistent with the goals of conservation and contribute to a quality recreational experience.
Output: Existing Recreation Features MUA (CG4O41)

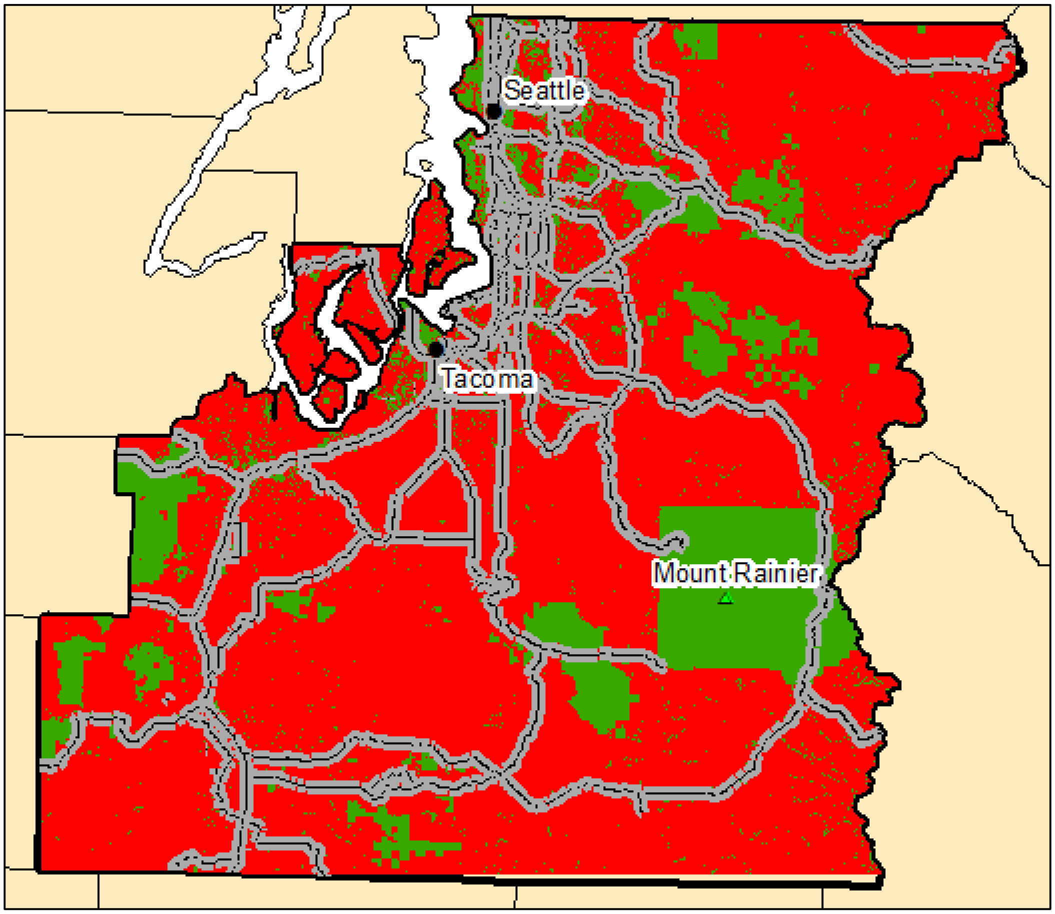

Figure 93: CG4O41

Land use: Conservation
Goal 4: Identify lands suitable for resource-based recreation
Objective 4.1: Identify all surface water features with the potential for use for outdoor recreation

Input data layer: Hydrology
Criteria for value assignment: The hydrology layer was rasterized and reclassified such that all open water features were assigned a value of 9 and all others were assigned a value of 1.
Rationale: Rivers, streams, lakes, bays, etc. are important for water-based recreation and should therefore be conserved.
Output: Open Water Recreation SUA (CG4O42)

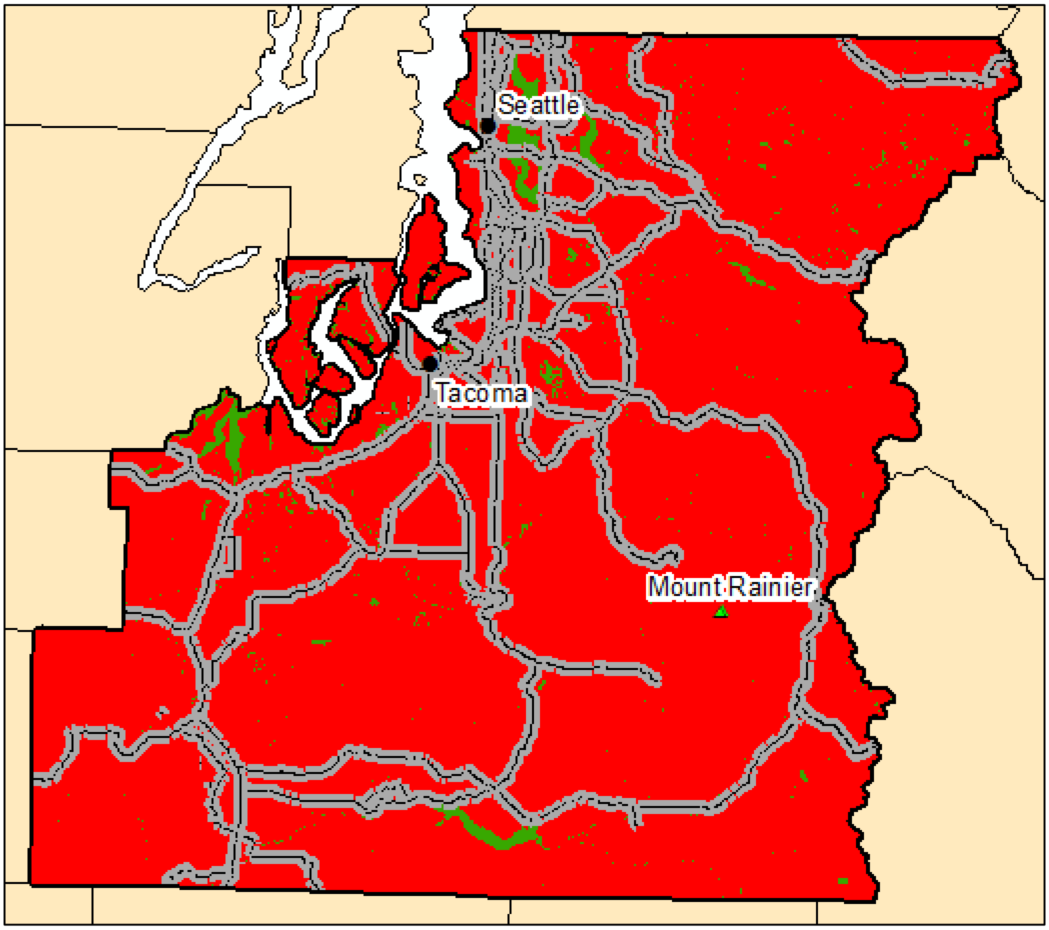

Figure 94: CG4O42

Land use: Conservation
Goal 4: Identify lands suitable for resource-based recreation
Objective 4.3: Identify existing linear infrastructure with the potential for use as trail corridors
Subobjective 4.3.1: Identify utility rights of way with the potential for us as trial corridors

Input data layer: Land use dataset
Criteria for value assignment: Utility corridors were selected from the land use dataset and a Euclidean distance was run. Areas 0-393.70 ft. from the utility were assigned a value of 9 and all other cells were assigned a value of 1.
Rationale: Utility corridors have the potential to become trail corridors due to the linear characteristics and common ownership.
Output: Utility Corridors SUA (CG4O43SO431)

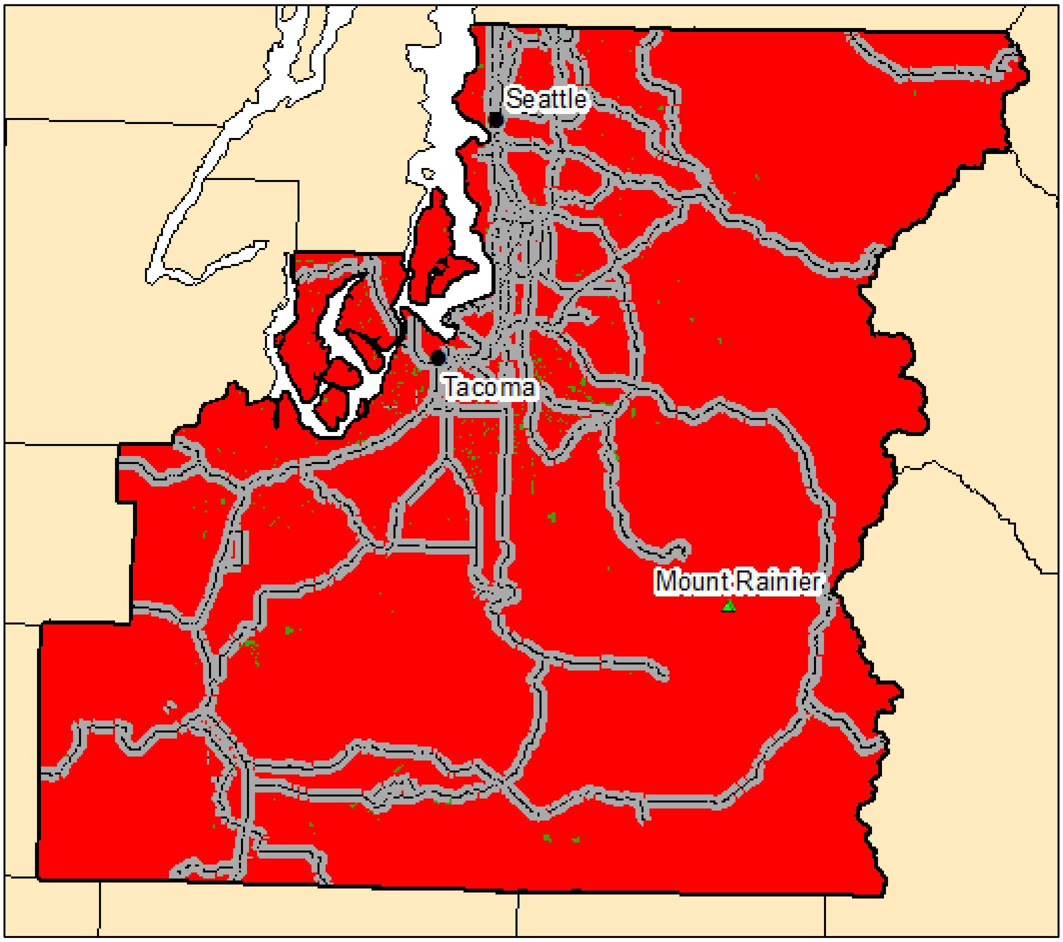

Figure 95: CG4O43SO431

Land use: Conservation
Goal 4: Identify lands suitable for resource-based recreation
Objective 4.3: Identify existing linear infrastructure with the potential for use as trail corridors
Subobjective 4.3.2: Identify railroad rights of way with the potential for use as trail corridors

Input data layer: Railroads
Criteria for value assignment: Euclidean distance was run and areas within 393.70 feet were assigned a value of 9 and all other areas were assigned a value of 1.
Rationale: Railroad corridors have the potential to become trail corridors because of their linear character and the common ownership.
Output: Railroad Corridors SUA (CG4O43SO432)

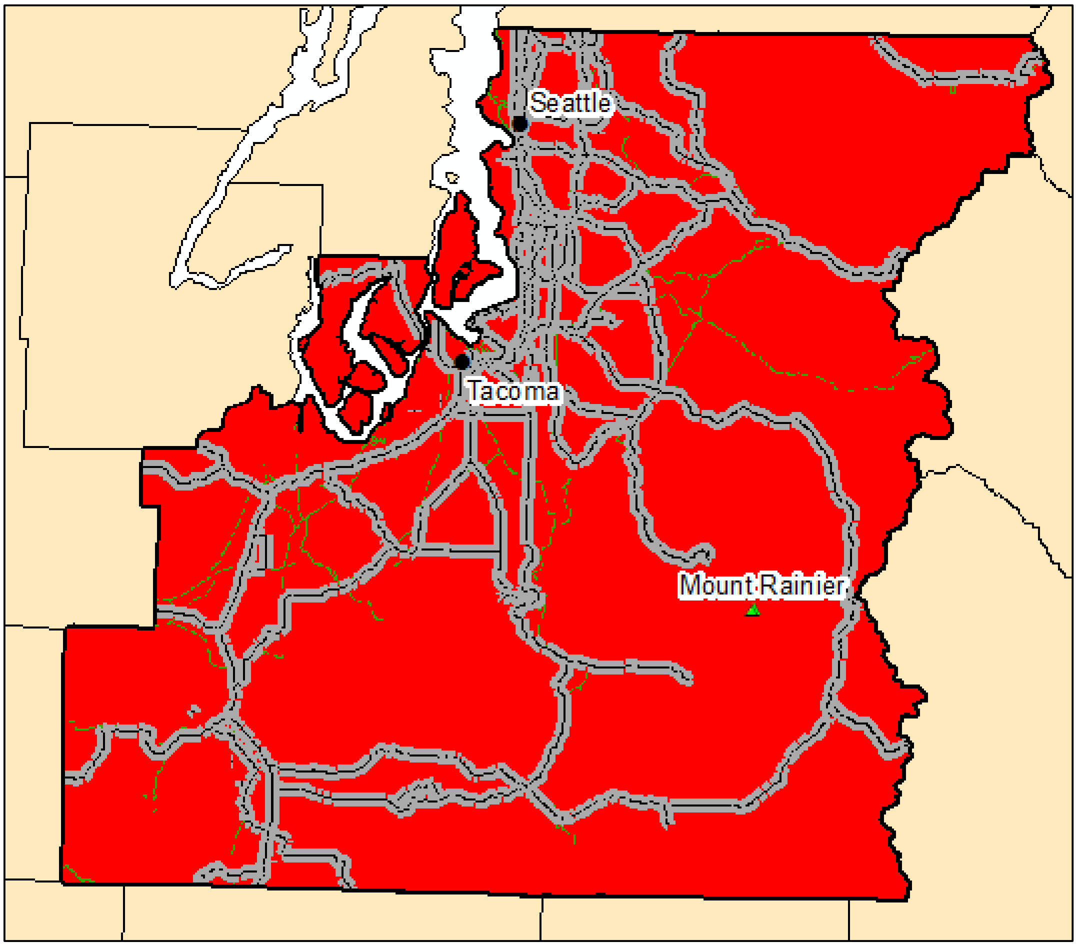

Figure 96: CG4O43SO432

Land use: Conservation
Goal 4: Identify lands suitable for resource-based recreation
Objective 4.3: Identify existing linear infrastructure with the potential for use as trail corridors

Input data layer: Utility Corridors SUA (CG4O43SO431) and Railroad Corridors SUA (CG4O43SO432)
Criteria for value assignment: The two SUAs were combined using a conditional statement CON (Utility = 9 | Railroad = 9, 9, 1). If a cell from either SUA has a value of 9, assign the cell a value of 9, otherwise assign a value of 1.
Rationale: Either corridor has a potential to create a trail corridor, creating a quality recreational experience.
Output: Linear Facilities MUA (CG4O43)

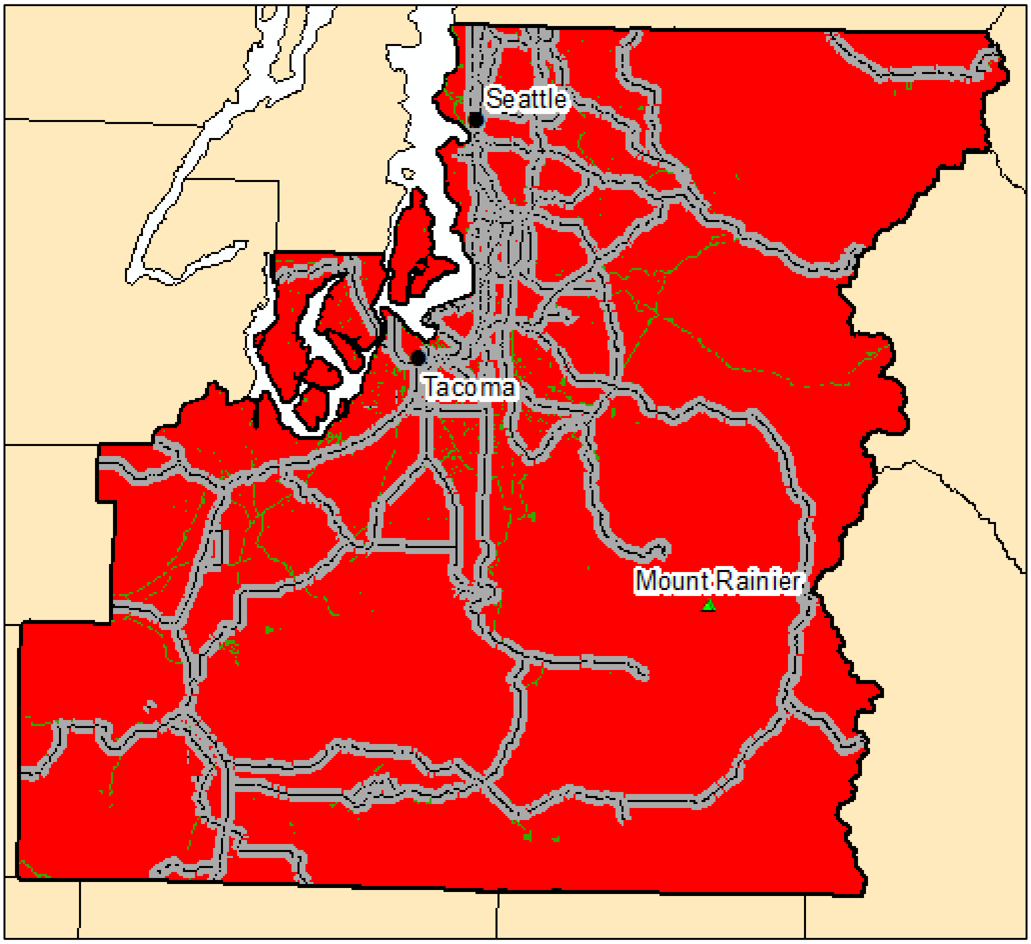

Figure 97: CG4O43

Land use: Conservation
Goal 4: Identify lands suitable for resource-based recreation
Objective 4.4: Identify native habitat suitable for resource-based recreation

Input data layer: Habitat
Criteria for value assignment: Ares with upland native habitat were assigned a value of 9, wetland native habitats were assigned a value of 7, areas of exotic plant communities were assigned a value of 5, and barren areas were assigned a value of 1.
Rationale: Any area of native habitat has the potential to be used for resource-based recreation such as hiking, camping, but upland habitats are more user-friendly.
Output: Native Habitat/Recreation SUA (CG4O44)

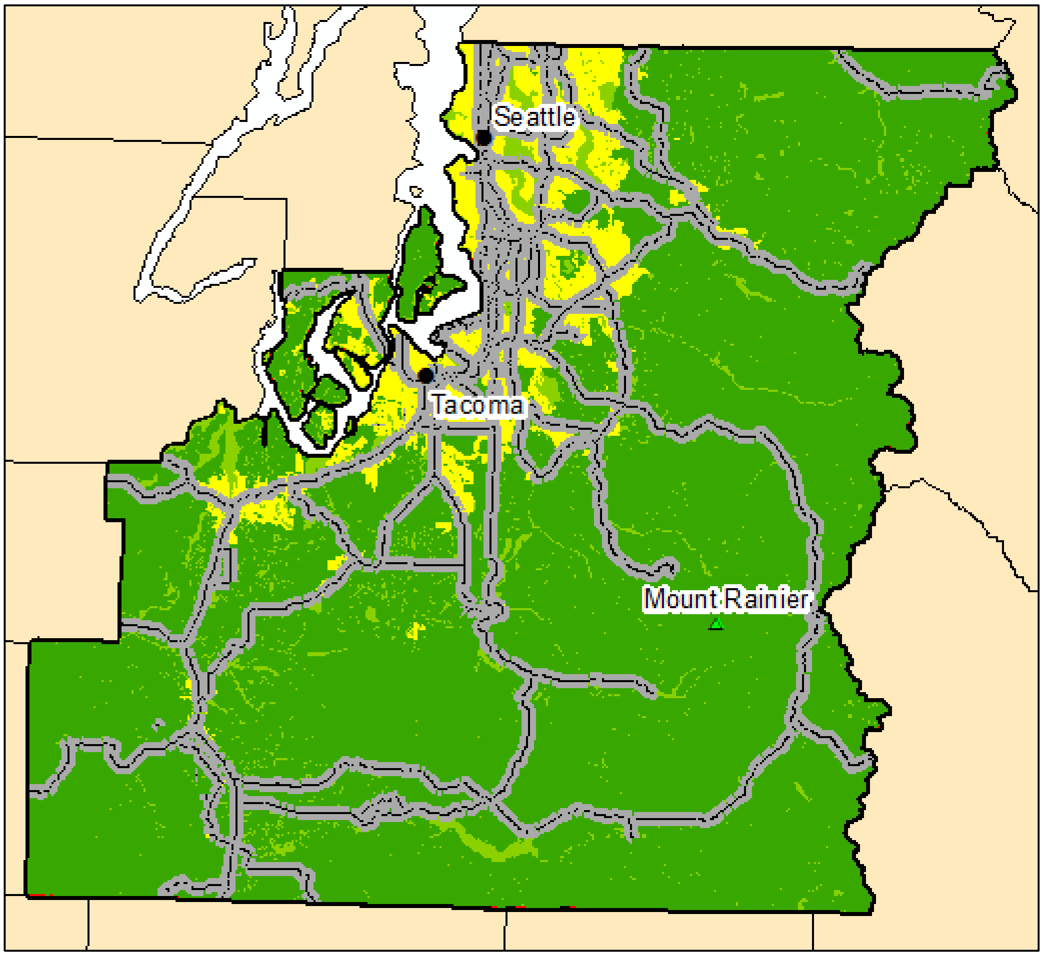

Figure 98: CG4O44

Land use: Conservation
Goal 4: Identify lands suitable for resource-based recreation

Input data layer: Existing Recreation Features MUA (CG4O41), Open Water Recreation SUA (CG4O42), Linear Facilities MUA (CG4O43), and Native Habitat/Recreation SUA (CG4O44)
Criteria for value assignment: The four MUAs were combined using a conditional statement, CON ((Existing Recreation = 9) | (Open Water Recreation = 9) | (Linear Facilities = 9), 9, Native Habitat). If the existing recreation feature, open water, or linear facilities value were equal to 9, assign the cell a value of 9, otherwise assign the cell a value of 1.
Rationale: If any MUA is highly suitable then that value is passed on to create a high quality recreation area.
Output: Recreation Suitability MUA (CG4)

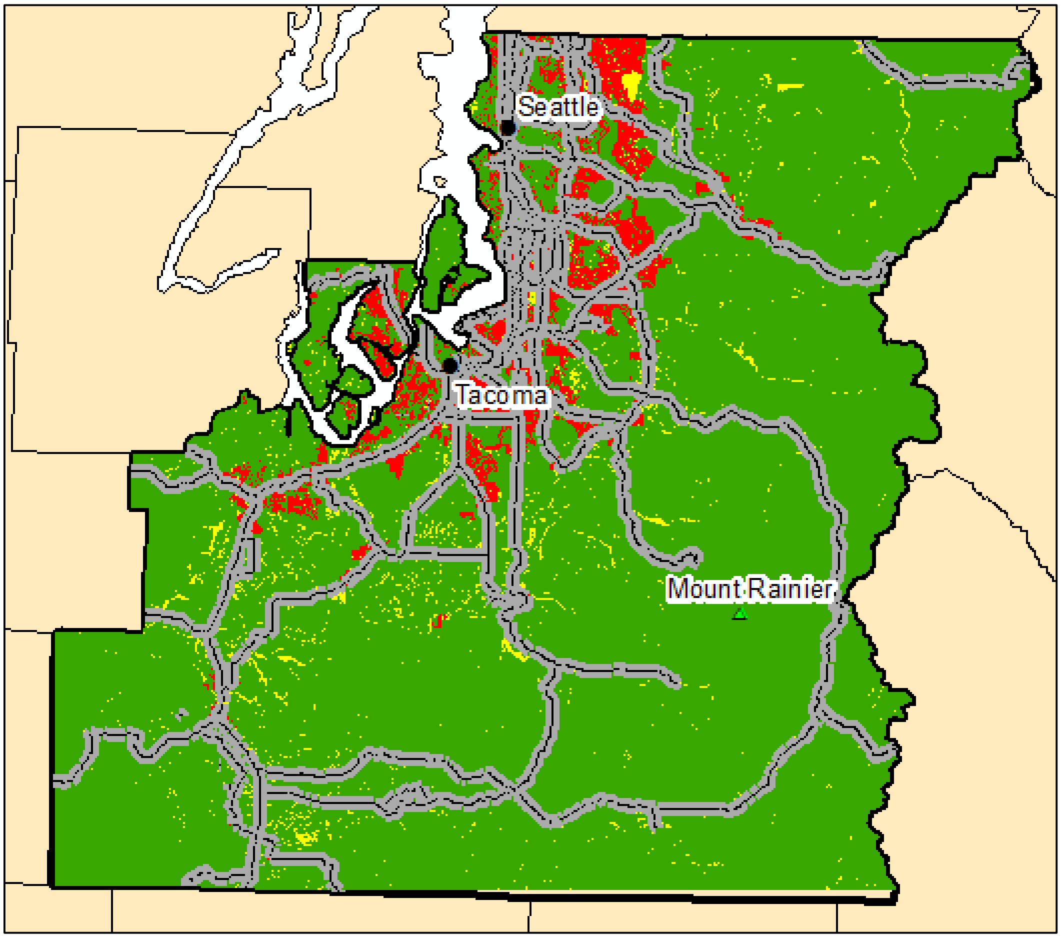

Figure 99: CG4

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.1: Determine lands physically suitable for residential land use
Subobjective 1.1.1: Identify lands free of flood potential

Input data layer: Habitat
Criteria for value assignment: Wetland habitats and open water were reclassified with a value of 1 and all other cells were assigned a value of 9.
Rationale: Building within wetlands or open water is more costly and discouraged by insurance companies.
Output: Flood Construction Suitability SUA (UG1O11SO111)

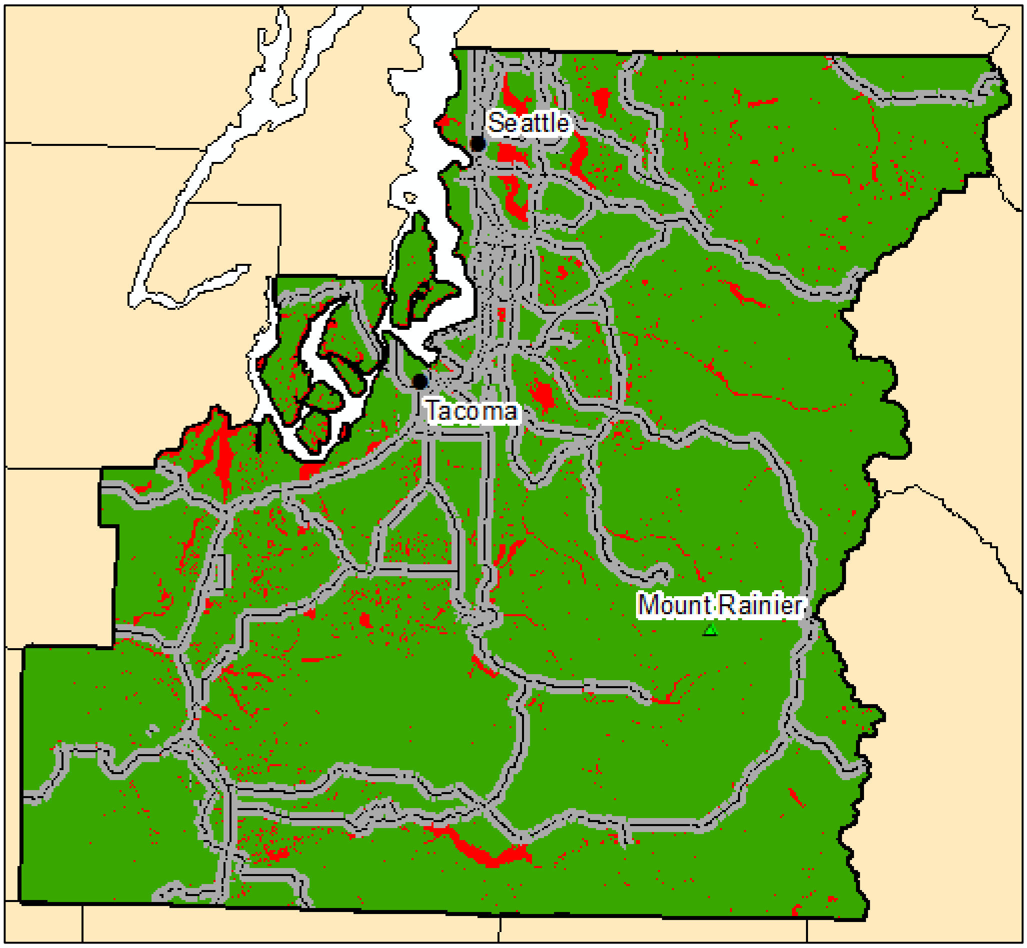

Figure 100: UG1O11SO111

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.1: Determine lands physically suitable for residential land use
Subobjective 1.1.2: Identify quiet areas

Input data layer: Major Roads, Airports, Railroads
Criteria for value assignment: Highways were selected from the road dataset and Euclidean distance was run from each of the three inputs. Highways were reclassed as follows: 0-656.17 ft. were assigned a value of 1, 656.17-1,148.29 ft. were assigned a value of 2, and all other cells were assigned a value of 9. Airports were reclassed in 3,280.84 ft. intervals with the closest range being assigned a value of 1 and anything beyond 26,246.72 ft. were assigned a value of 9. Railroads were reclassed as follow: 0-1,640.42 ft. were assigned a value of 1, 1,640.42-3,280.84 ft. were assigned a value of 6, and all others were assigned a value of 9. The resulting SUAs were combined using map algebra. The highways were weighed as 15 percent, airports as 50 percent, and railroads were 35 percent.
Rationale: The further from all locations the quieter the area which is more desirable or residential development.
Output: Residential Quiet MUA (UG1O11SO112)

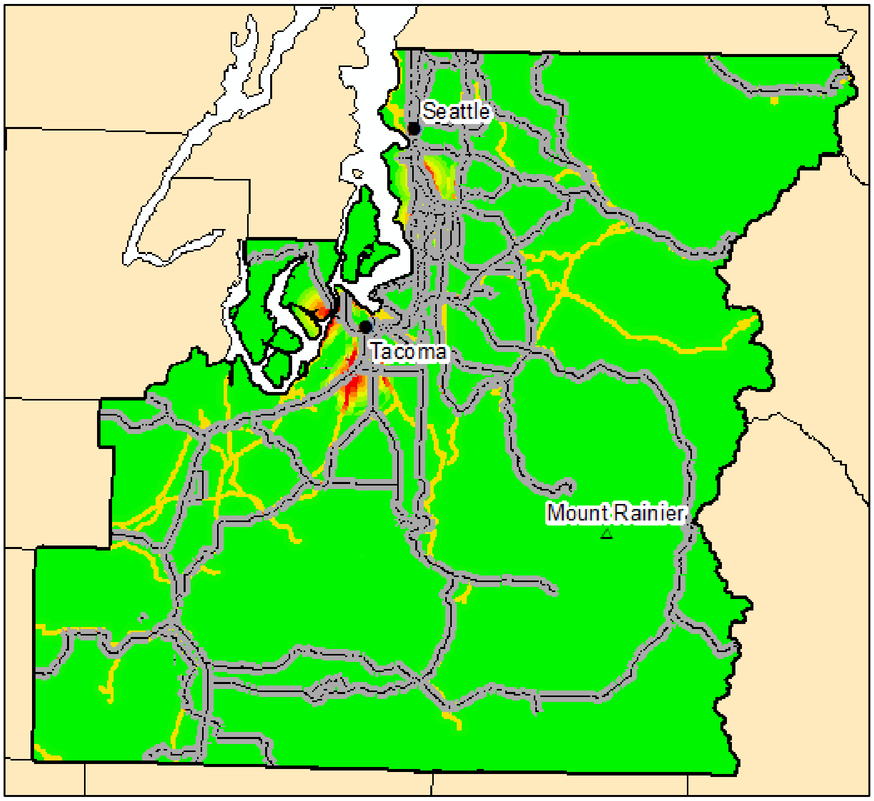

Figure 101: UG1O11SO112

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.1: Determine lands physically suitable for residential land use
Subobjective 1.1.3: Identify lands free of hazardous waste

Input data layer: Arsenic, Asbestos, and Mercury Hazardous Site
Criteria for value assignment: Euclidean distance was run from hazardous sites and zonal statistics were run to determine the mean distance of existing residential areas from hazardous sites and the standard deviation. Cells with values from 0 to the mean (80,167.87) were assigned a value of 1. The next areas were assigned values of 2-8 in quarter-standard deviation intervals and the remaining areas were assigned a value of 9.
Rationale: A healthy environment free of hazards is more desirable for residential developments.
Output: Residential Hazard MUA (UG1O11SO113)

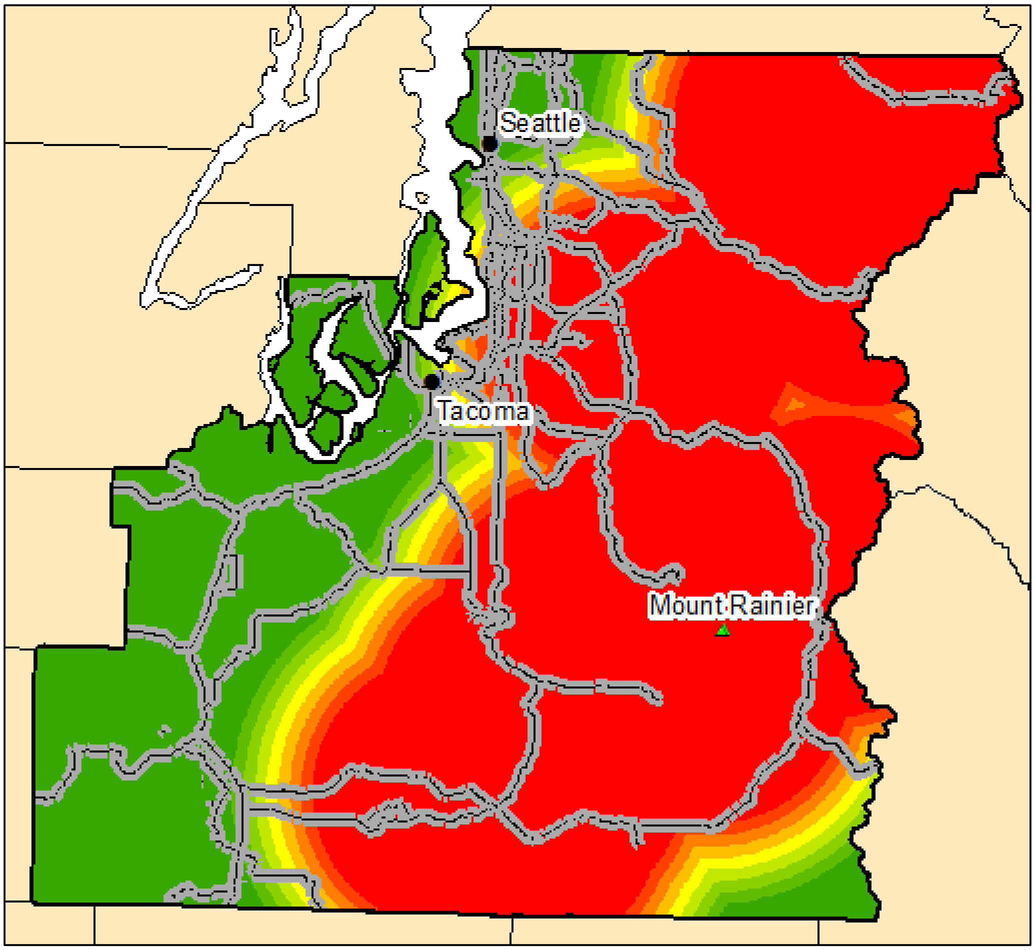

Figure 102: UG1O11SO113

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.1: Determine lands physically suitable for residential land use
Subobjective 1.1.4: Identify lands with good air quality

Input data layer: Sewage Treatment Plants and Power Plants
Criteria for value assignment: Euclidean distance was run for both sewage treatment plants and power plants. The results for sewage treatment plants were reclassified as follows: 0-4,921.26 ft. was assigned as a value of 1, 4,921.26-16,404.2 ft. was assigned a value of 7, and all areas greater than 16,404.2 ft. was assigned a value of 9. The power plant results were reclassified as follows: 0-29,527.56 ft. was assigned a value of 1 and anything beyond was assigned a value of 9. These reclassified outputs were equally weighted and combined using map algebra.
Rationale: A healthy environment with good air quality is more desirable for residential development.
Output: Residential Air Quality MUA (UG1O11SO114)

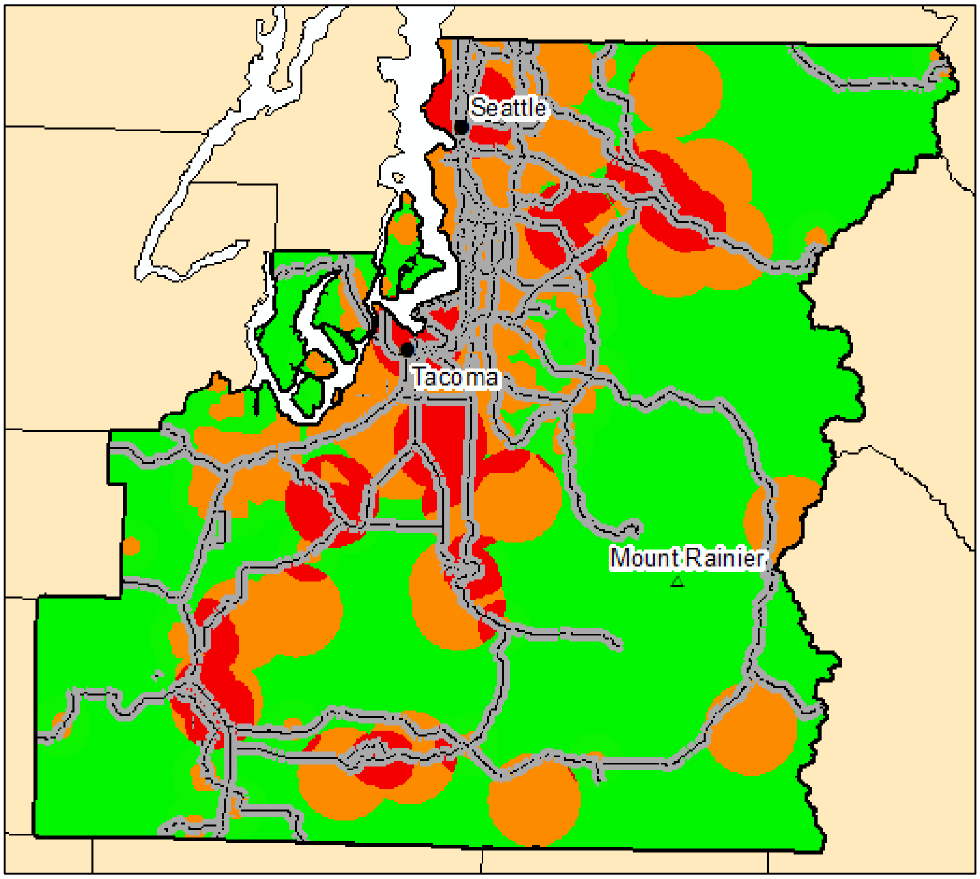

Figure 103: UG1O11SO114

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.1: Determine lands physically suitable for residential land use

Input data layer: Flood Construction Suitability SUA (UG1O11SO111), Residential Quiet MUA (UG1O11SO112), Residential Hazard MUA (UG1O11SO113), and Residential Air Quality MUA (UG1O11SO114)
Criteria for value assignment: The SUA and MUAs were weighted and combined as follows using map algebra: Flood at 40 percent, Quiet at 30 percent, Hazard at 20 percent, and Air Quality at 10 percent.
Rationale: The areas physically most suitable for residential development are those without hazardous features that are quiet, have good air quality, and are outside poorly drained areas. Flooding was considered most critical to determining physical suitability because of its direct correlation to increased construction costs and difficulty with insurance.
Output: Residential Physical Suitability MUA (UG1O11)

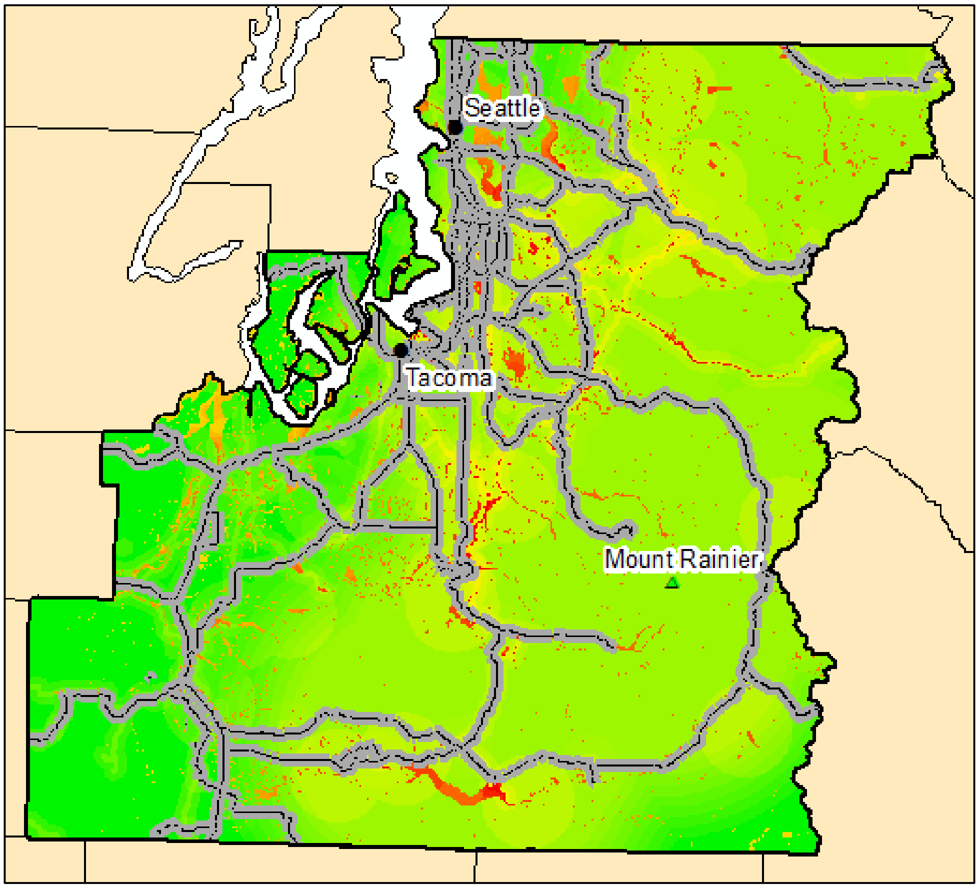

Figure 104: UG1O11

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.2: Determine lands economically suitable for residential land use
Subobjective 1.2.2: Identify lands proximal to existing residential development

Input data layer: Distance to Existing Residential Land Uses (Preprocessed from land use)
Criteria for value assignment: Results of the Euclidean distance from existing residential areas were reclassified in 492.23 ft. intervals with the closest existing residential areas assigned a value of 9, and anything beyond 3,937.09 ft. were assigned a value of 1.
Rationale: Generally people prefer to live closer to one another.
Output: Residential Proximity to Residential SUA (UG1O12SO121)

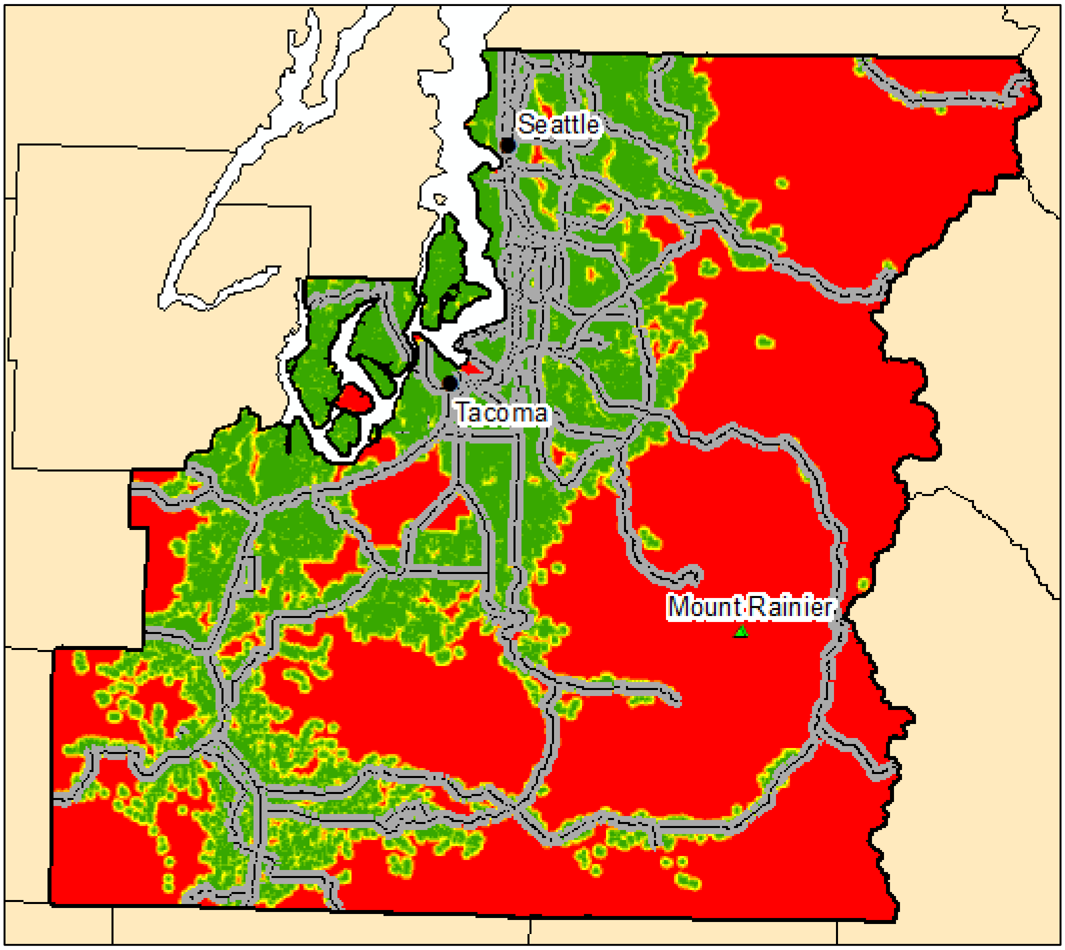

Figure 105: UG1O12SO121

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.2: Determine lands economically suitable for residential land use
Subobjective 1.2.2: Identify lands proximal to schools

Input data layer: Schools
Criteria for value assignment: Euclidean distance was run and then zonal statistics were run to determine the mean distance of existing residential areas from schools and the standard deviation. Cells with values of 0 to the mean (6,469.41) were assigned a value of 9. The next areas were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: Generally people prefer to live near schools.
Output: Residential Proximity to Schools SUA (UG1O12SO122)

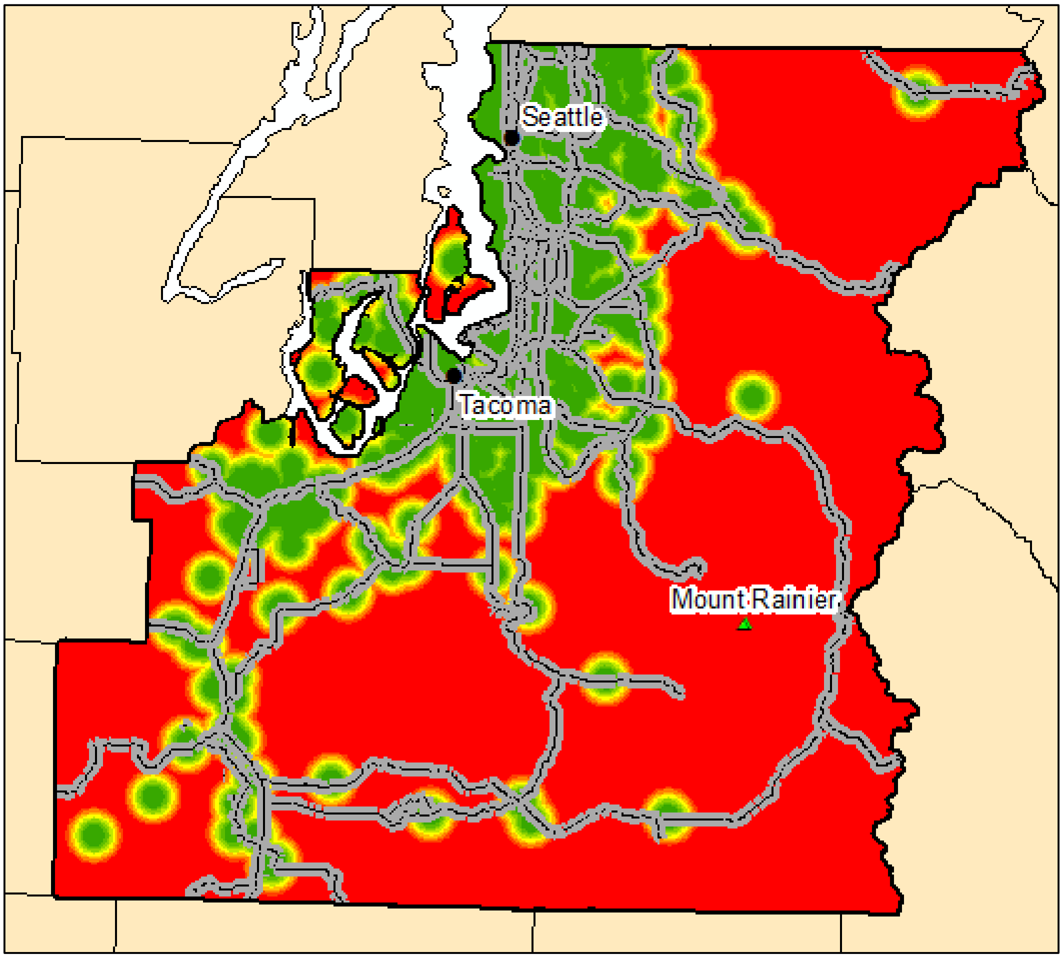

Figure 106: UG1O12SO122

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.2: Determine lands economically suitable for residential land use
Subobjective 1.2.3: Identify lands proximal to hospitals

Input data layer: Hospitals
Criteria for value assignment: Euclidean distance was run and then zonal statistics were run to determine the mean distance of existing residential areas from hospitals and the standard deviation. Cells with values of 0 to the mean (25,502.91) were assigned a value of 9. The next areas were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: Generally people prefer to live near hospitals.
Output: Residential Proximity to Hospitals SUA (UG1O12SO123)

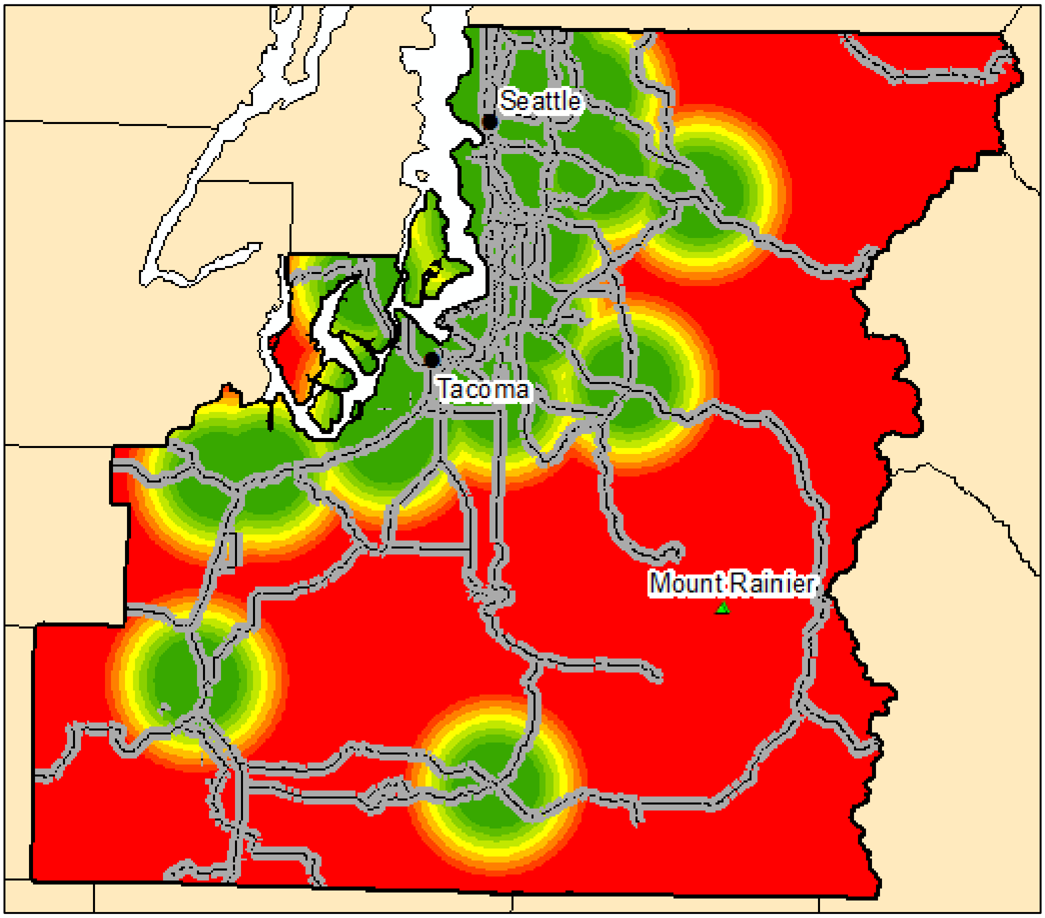

Figure 107: UG1O12SO123

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.2: Determine lands economically suitable for residential land use
Subobjective 1.2.4: Identify lands proximal to roads

Input data layer: Highways
Criteria for value assignment: Euclidean distance was run and then zonal statistics were run to determine the mean distance of existing residential areas from highways and the standard deviation. Cells with values of 0 to the mean (5,809.94) were assigned a value of 9. The next areas were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: It is convenient to be close to highways.
Output: Residential Proximity to Highways SUA (UG1O12SO124)

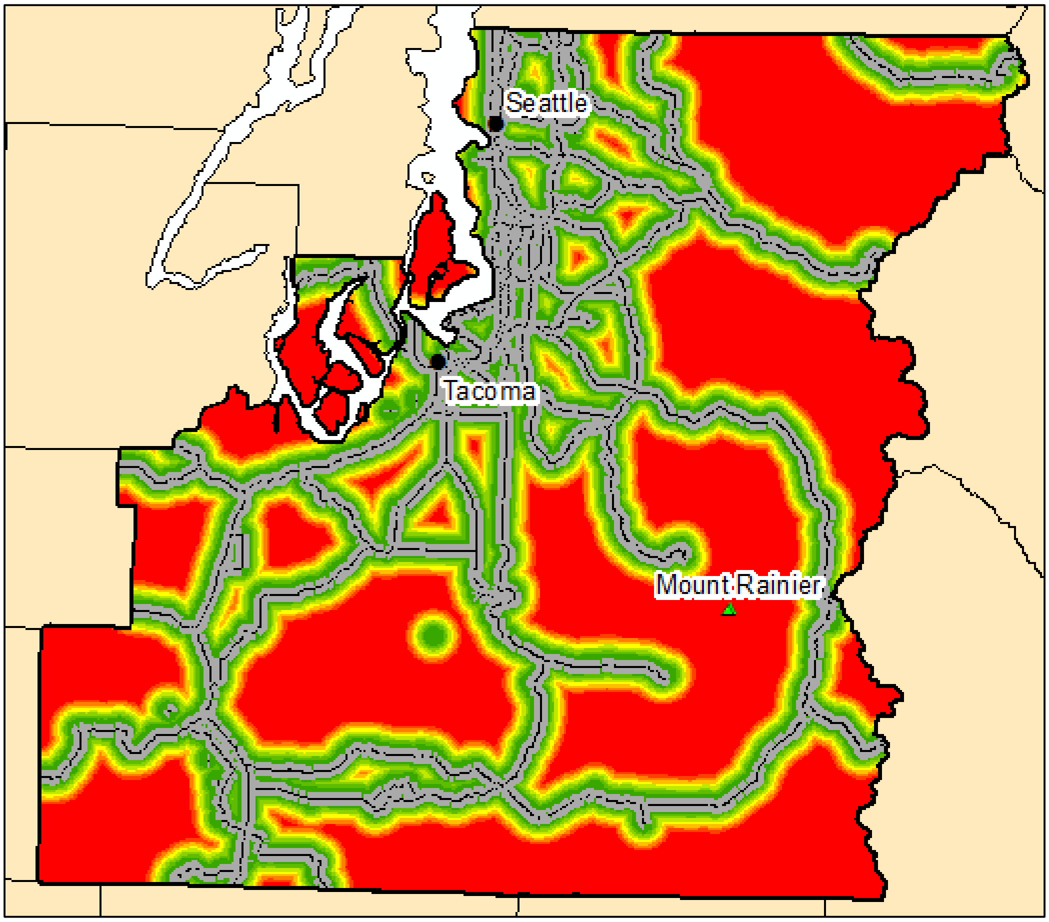

Figure 108: UG1O12SO124

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.2: Determine lands economically suitable for residential land use
Subobjective 1.2.5: Identify lands proximal to airports

Input data layer: Airports
Criteria for value assignment: Euclidean distance was run and then zonal statistics were run to determine the mean distance of existing residential areas from airports and the standard deviation. Cells with values of 0 to the mean (30,277.79) were assigned a value of 9. The next areas were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: It is convenient to be near regionally airports but it is not preferred to be immediately adjacent.
Output: Residential Proximity to Airports SUA (UG1O12SO125)

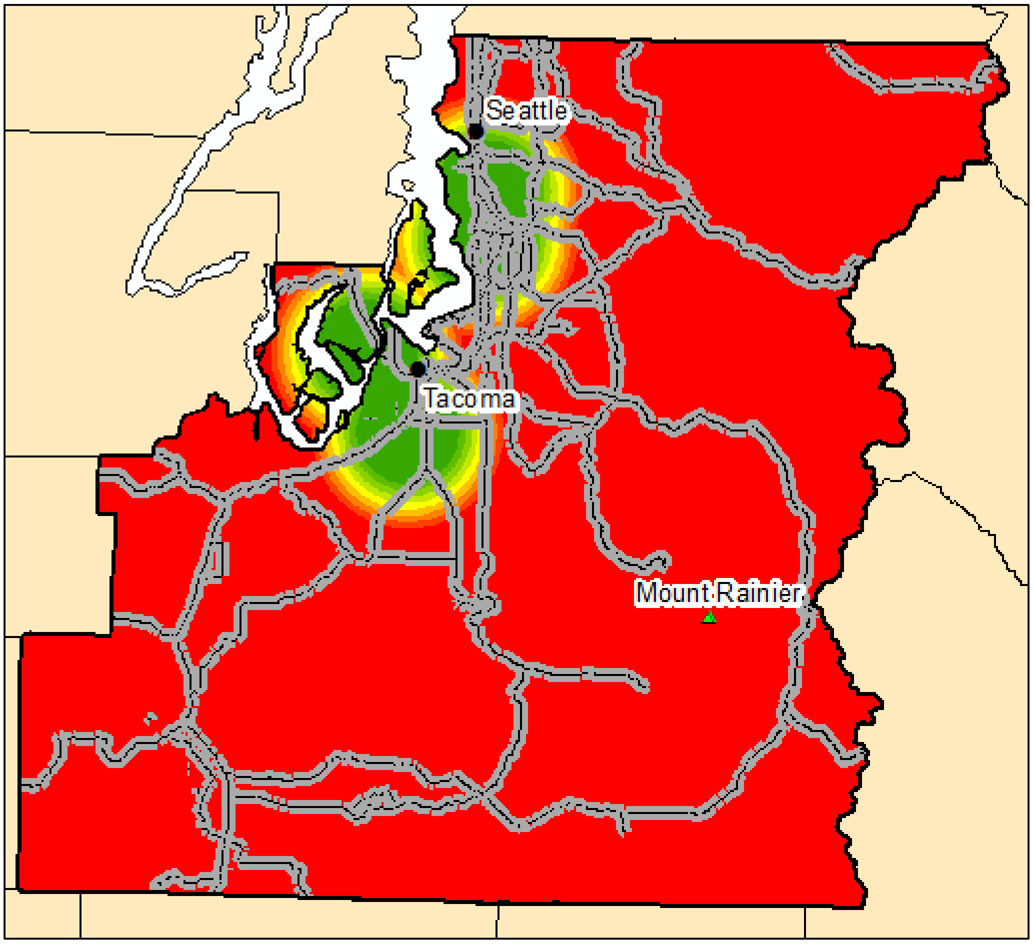

Figure 109: UG1O12SO125

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.2: Determine lands economically suitable for residential land use
Subobjective 1.2.6: Identify lands proximal to parks, recreational opportunities, protected conservation lands, or historic sites.

Input data layer: Parks, recreation lands (preprocessed from land use), Habitat Conservation Plan lands, and Historical Sites.
Criteria for value assignment: Euclidean distance was run and then zonal statistics were run separately for each input to determine the mean distance of existing residential areas from each parameter and the standard deviation. Cells with values of 0 to the mean (4,168.33 (Parks), 6,343.03 (Recreation), 27,670.62 (Habitat Conservation Plan Lands), and 792.63 (Historical Sites)) were assigned a value of 9. The next areas were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1. The resulting SUAs were weighted and combined as follows: Parks at 10 percent, Recreation Areas at 20 percent, Habitat Conservation Plan Lands at 40 percent, and Historical Sites at 30 percent.
Rationale: People like to be near amenities such as parks and cultural sites.
Output: Residential Proximity to Parks/Historical Sites SUA (UG1O12SO126)

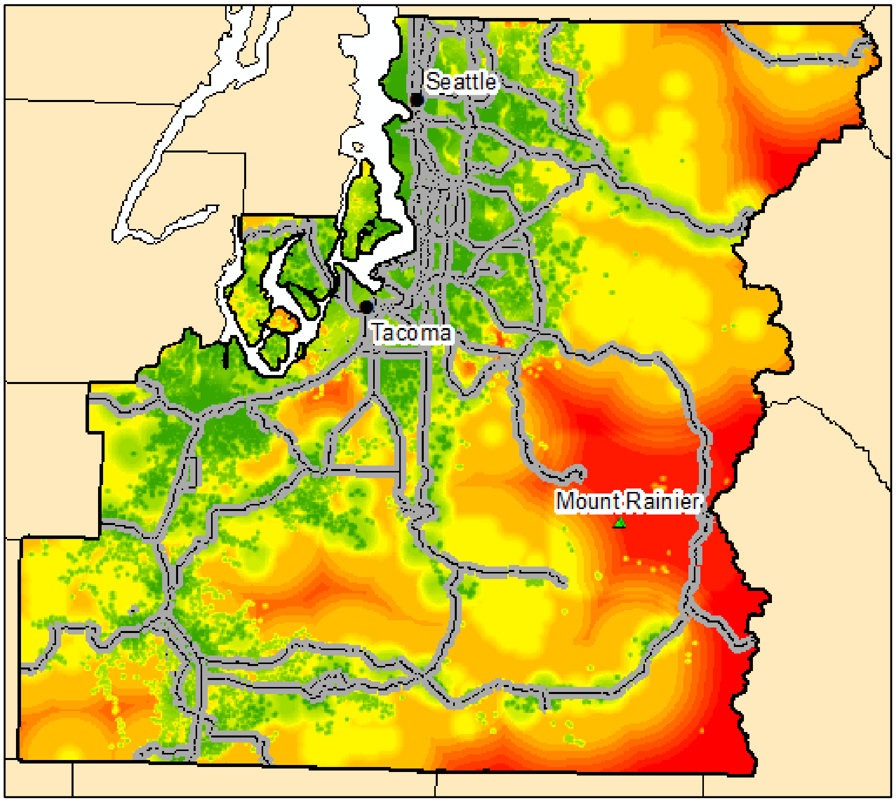

Figure 110: UG1O12SO126

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.2: Determine lands economically suitable for residential land use
Subobjective 1.2.7: Identify lands proximal to existing public water and sewer service

Input data layer: Water Treatment Plants, Sewage Treatment Plants
Criteria for value assignment: Euclidean distance was run and then zonal statistics were run separately to determine the mean distance of existing residential areas from each utility and the standard deviation. Cells with values of 0 to the mean (50,319.16 (water) and 5,187.21 (sewage)) were assigned a value of 9. The next areas were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1. The two SUAs were equally weighted and combined using map algebra.
Rationale: It is cost-effective to live near the existing utility services.
Output: Residential Proximity to Utilities SUA (UG1O12SO127)

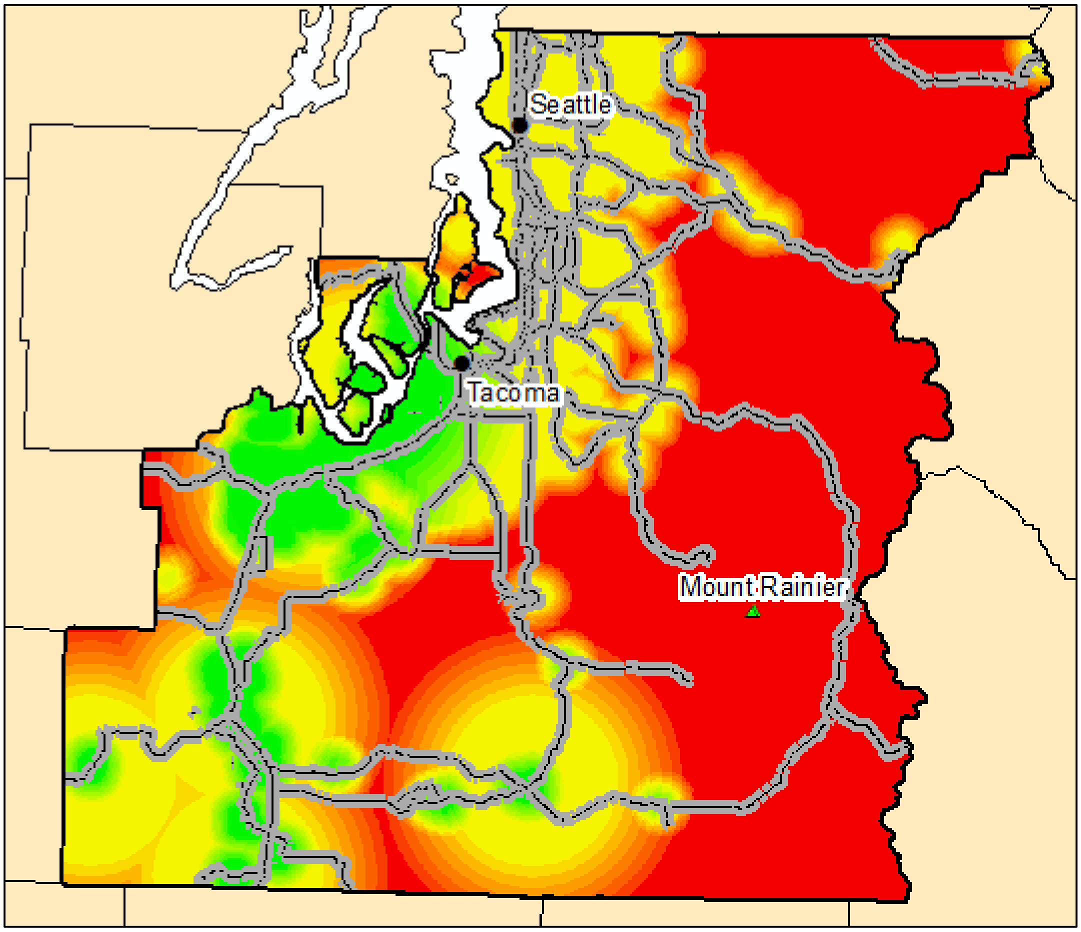

Figure 111: UG1O12SO127

Land use: Urban
Goal 1: Identify lands suitable for residential land use
Objective 1.2: Determine lands economically suitable for residential land use

Input data layer: Residential Proximity to Residential SUA (UG1O12SO121), Residential Proximity to Schools SUA (UG1O12SO122), Residential Proximity to Hospitals SUA (UG1O12SO123), Residential Proximity to Highways SUA (UG1O12SO124), Residential Proximity to Airports SUA (UG1O12SO125), Residential Proximity to Parks/Historical Sites SUA (UG1O12SO126), and Residential Proximity to Utilities SUA (UG1O12SO127)
Criteria for value assignment: The input SUAs were weighted and combined using map algebra as follows: Residential Proximity to Residential at 16 percent, Residential Proximity to Schools at 14 percent, Residential Proximity to Hospitals at 14 percent, Residential Proximity to Highways at 14 percent Residential Proximity to Airports at 14 percent, Residential Proximity to Parks/Historical Sites at 14 percent, and Residential Proximity to Utilities at 14 percent.
Rationale: The areas economically most suitable for residential development are close to existing residential areas, schools, hospitals, highways, airports, parks/historical sites, and public utilities.
Output: Residential Economic Suitability MUA (UG1O12)

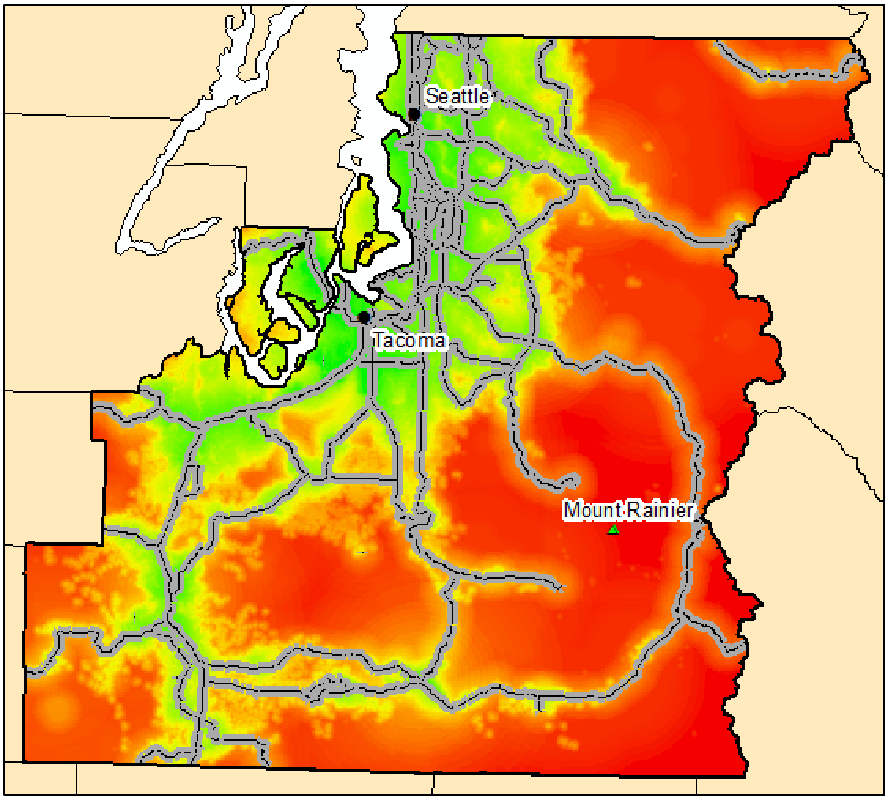

Figure 112: UG1O12

Land use: Urban
Goal 1: Identify lands suitable for residential land use

Input data layer: Residential Physical Suitability MUA (UG1O11), Residential Economic Suitability MUA (UG1O12), and Existing Residential Areas
Criteria for value assignment: The MUAs were combined and equally weighted and combined using map algebra. Existing residential land was reclassified with all existing residential lands being assigned a value of 9 and all other values assigned a value of 1. The resulting MUA and reclassified residential land was combined using a conditional statement, CON (Residential = 9, 9, MUA). If a cell is an existing residential area, it is retained as a value of 9, otherwise it is assigned the value of the combined MUAs.
Rationale: If an area is already residential it will remain residential and is highly suitable. If not the most suitable area is derived from equally weighted physical and economic suitability.
Output: Residential Suitability MUA (UG1)

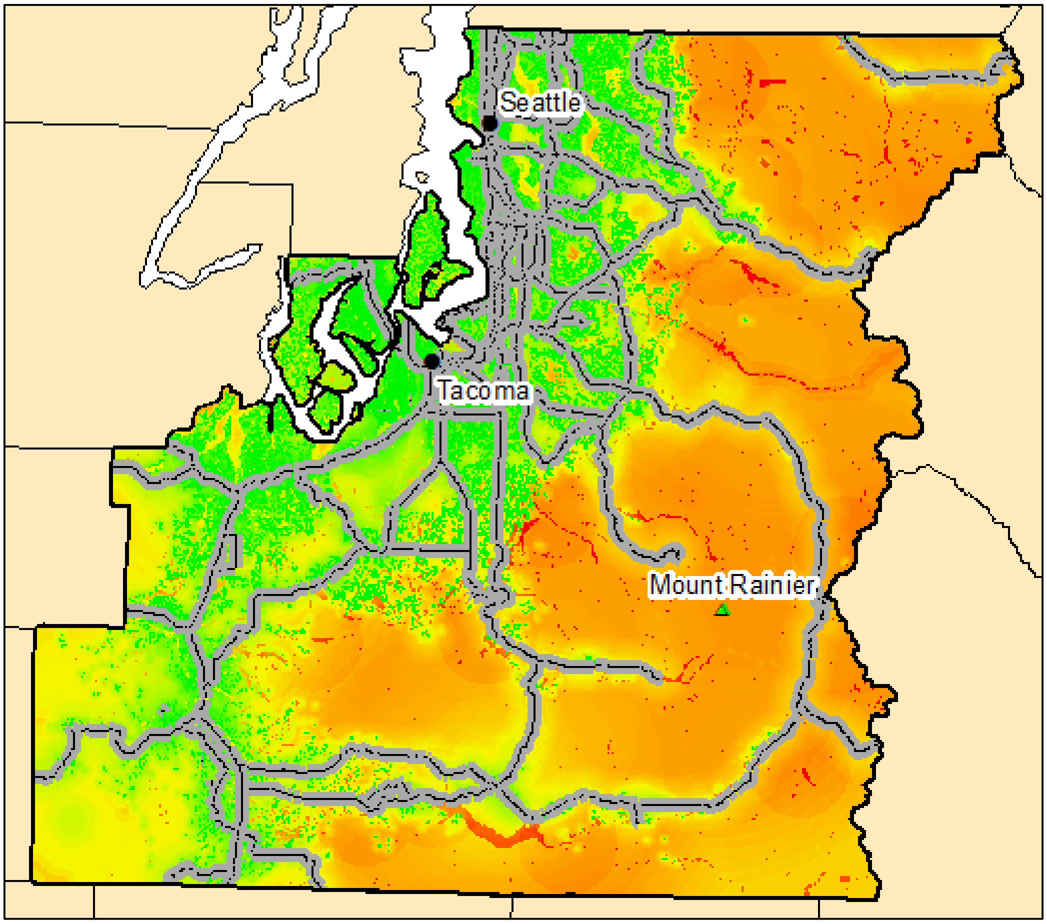

Figure 113: UG1

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.1: Determine lands physically suitable for office/commercial land use
Subobjective 2.1.1: Identify lands free of flood potential

Input data layer: Habitat
Criteria for value assignment: Wetland habitats were reclassified with a value of 1 and all other values were assigned a value of 9.
Rationale: Building within wetlands is more costly and is discouraged by insurance companies.
Output: Flood Construction Suitability SUA (UG2O21SO211)

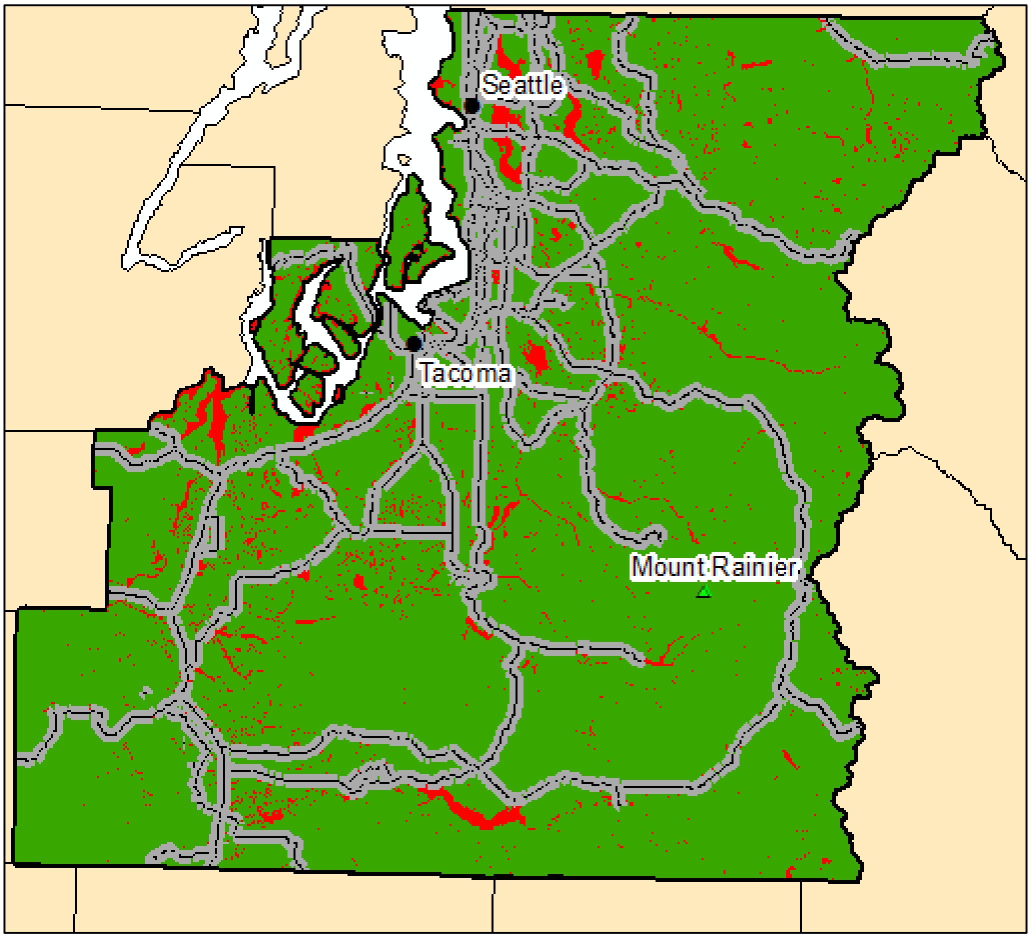

Figure 114: UG2O21SO211

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.1: Determine lands physically suitable for office/commercial land use
Subobjective 2.1.2: Identify quiet areas

Input data layer: Highways, Airports, Railroads
Criteria for value assignment: Highways were selected from the road dataset and Euclidean distance was run from each of the three inputs. Highways were reclassed as follows: 0-656.17 ft. were assigned a value of 1, 656.17-1,148.29 ft. were assigned a value of 2, and all other cells were assigned a value of 9. Airports were reclassed in 3,280.84 ft. intervals with the closest range being assigned a value of 1 and anything beyond 26,246.72 ft. were assigned a value of 9. Railroads were reclassed as follow: 0-1,640.42 ft. were assigned a value of 1, 1,640.42-3,280.84 ft. were assigned a value of 6, and all others were assigned a value of 9. The resulting SUAs were combined using map algebra. The highways were weighed as 15 percent, airports as 50 percent, and railroads were 35 percent.
Rationale: The further from all locations the quieter the area which is more desirable or office/commercial development.
Output: Office/Commercial Quiet SUA (UG2O21SO212)

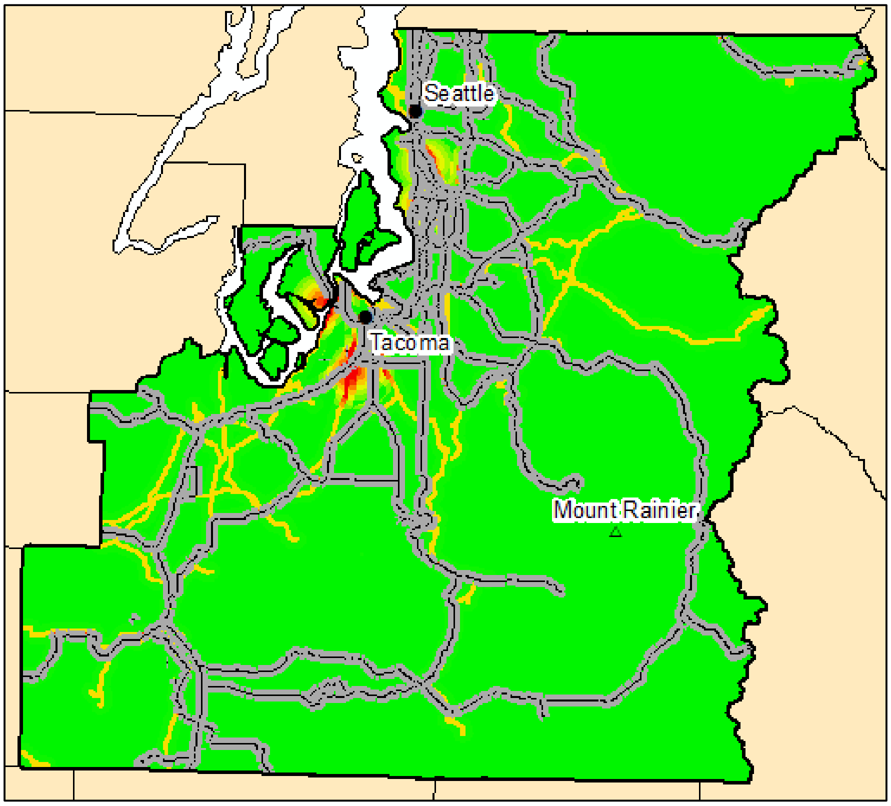

Figure 115: UG2O21SO212

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.1: Determine lands physically suitable for office/commercial land use
Subobjective 2.1.3: Identify lands free of hazardous waste

Input data layer: Arsenic, Asbestos, and Mercury Hazardous Site
Criteria for value assignment: Euclidean distance was run from hazardous sites and zonal statistics were run to determine the mean distance of existing residential areas from hazardous sites and the standard deviation. Cells with values from 0 to the mean (79,590.59) were assigned a value of 1. The next areas were assigned values of 2-8 in quarter-standard deviation intervals and the remaining areas were assigned a value of 9.
Rationale: A healthy environment free of hazards is more desirable for office/commercial developments.
Output: Office/Commercial Hazard SUA (UG2O21SO213)

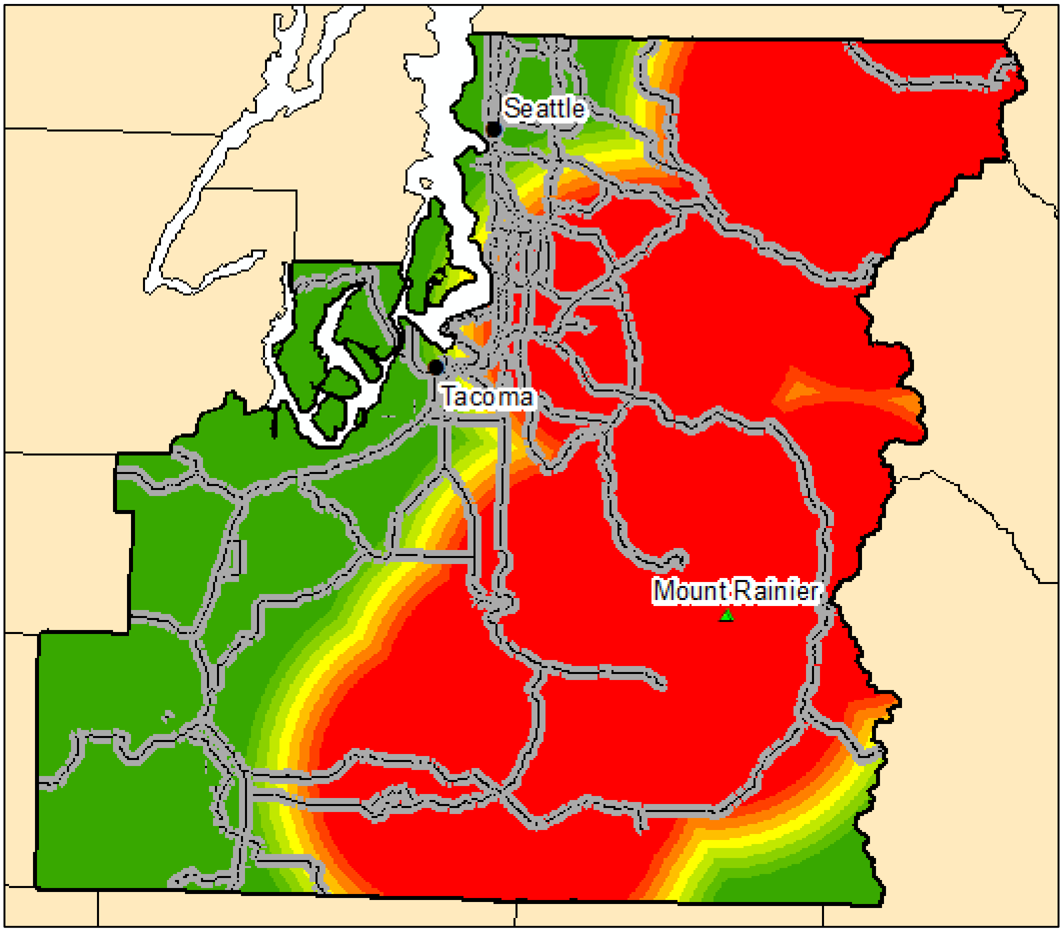

Figure 116: UG2O21SO213

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.1: Determine lands physically suitable for office/commercial land use
Subobjective 2.1.4: Identify lands with good air quality

Input data layer: Sewage Treatment Plants and Power Plants
Criteria for value assignment: Euclidean distance was run for both sewage treatment plants and power plants. The results for sewage treatment plants were reclassified as follows: 0-4,921.26 ft. was assigned as a value of 1, 4,921.26-16,404.2 ft. was assigned a value of 7, and all areas greater than 16,404.2 ft. was assigned a value of 9. The power plant results were reclassified as follows: 0-29,527.56 ft. was assigned a value of 1 and anything beyond was assigned a value of 9. These reclassified outputs were equally weighted and combined using map algebra.
Rationale: A healthy environment with good air quality is more desirable for office/commercial development.
Output: Residential Air Quality MUA (UG2O21SO214)

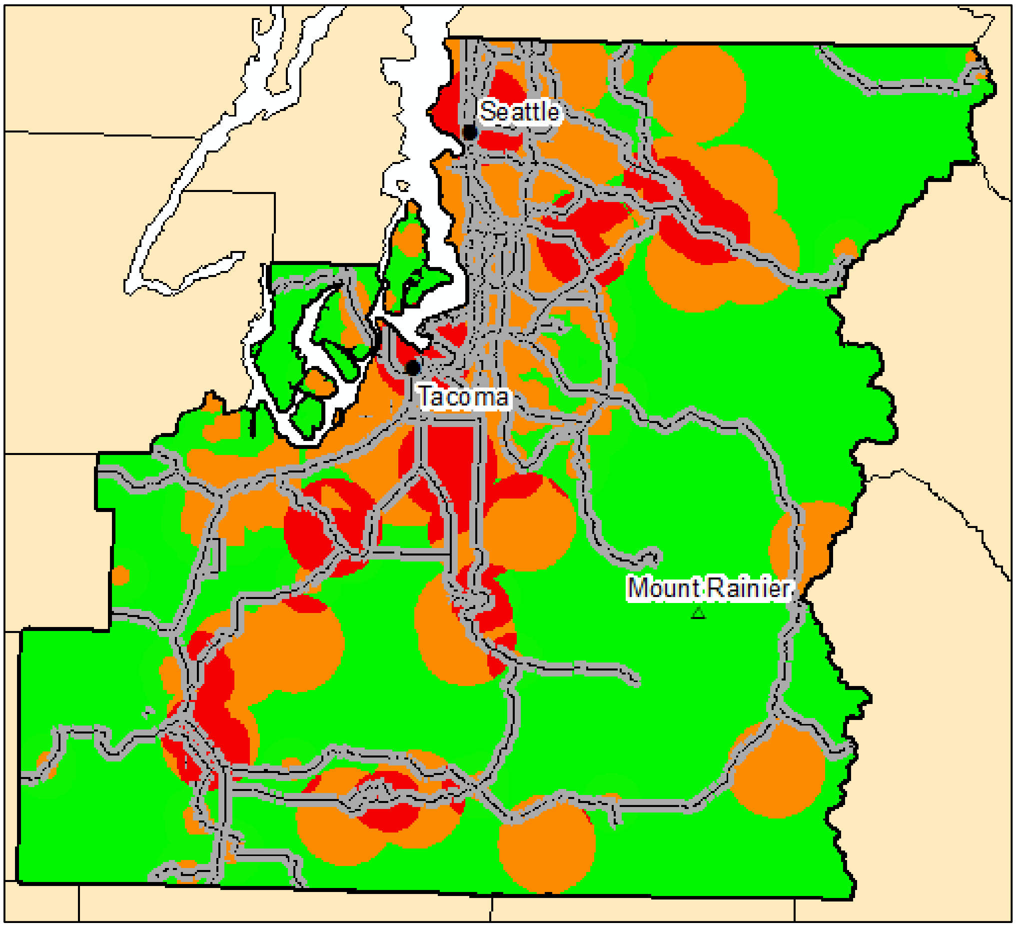

Figure 117: UG2O21SO214

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.1: Determine lands physically suitable for office/commercial land use

Input data layer: Flood Construction Suitability SUA (UG2O21SO211), Office/Commercial Quiet SUA (UG2O21SO212), Office/Commercial Hazard SUA (UG2O21SO213), and Residential Air Quality MUA (UG2O21SO214)
Criteria for value assignment: The SUAs and MUA were weighted and combined as follows using map algebra: Flood at 42 percent, Quiet at 26 percent, Hazard at 16 percent, and Air Quality at 16 percent.
Rationale: The areas physically most suitable for office/commercial development are those outside of poorly drained areas, without hazards features, that are quiet, and have good air quality.
Output: Office/Commercial Physical Suitability MUA (UG2O21)

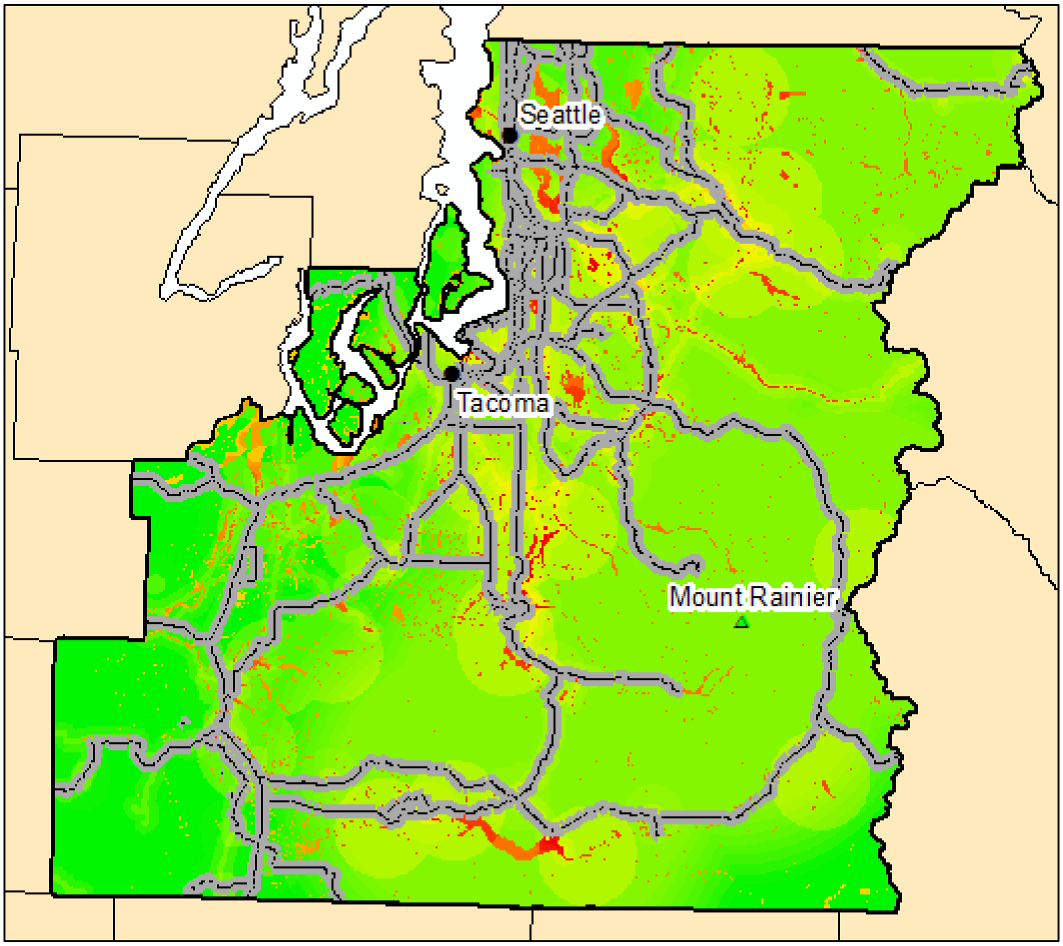

Figure 118: UG2O21

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.2: Determine lands economically suitable for office/commercial land use
Subobjective 2.2.1: Identify lands proximal to existing residential development

Input data layer: Distance to Existing Residential Land Uses (Preprocessed from land use)
Criteria for value assignment: Zonal statistics were run to determine the mean distance of existing office/commercial areas from existing residential areas and the standard deviation. Cells with values 0 to mean (2,254.75) were assigned the value of 9, the next set of cells were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned the value of 1.
Rationale: Success of Office/Commercial developments increase with the proximity to residential areas.
Output: Office/Commercial Proximity to Residential SUA (UG2O22SO221)

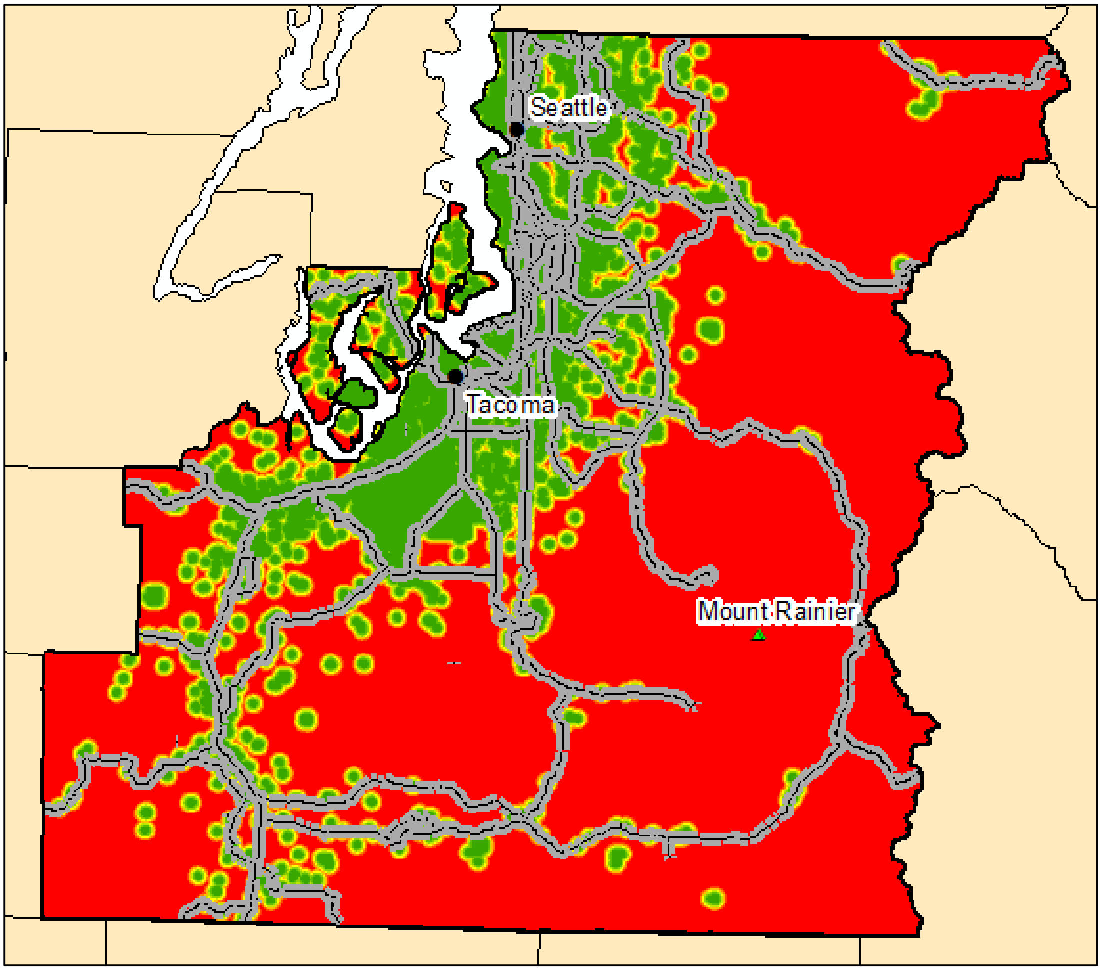

Figure 119: UG2O22SO221

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.2: Determine lands economically suitable for office/commercial land use
Subobjective 2.2.2: Identify lands within and proximal to existing city limits

Input data layer: City Limits
Criteria for value assignment: Euclidean distance was run from City Limits and the results were reclassified using zonal statistics. Cells with values less than or equal to the mean (5,180.48) were assigned a value of 9, the next set of cells were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: Success of office/commercial developments increases in urbanized areas.
Output: Office/Commercial Proximity to City Limits SUA (UG2O22SO222)

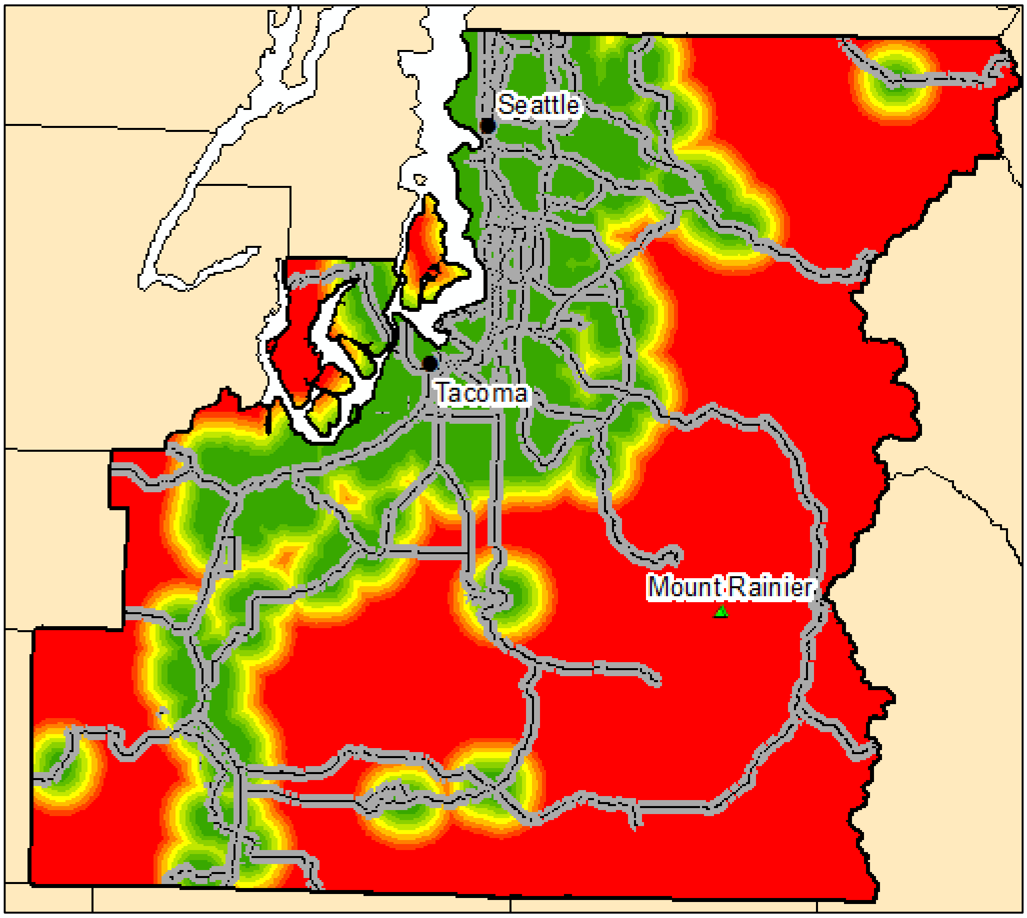

Figure 120: UG2O22SO222

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.2: Determine lands economically suitable for office/commercial land use
Subobjective 2.2.3: Identify lands proximal to roads

Input data layer: Euclidean distance from highways (preprocessed in residential model UG1O12SO124)
Criteria for value assignment: Zonal statistics were run to determine the mean distance of existing office/commercial areas from highways and the standard deviation. Cells with values of 0 to the mean (4,984.32) were assigned a value of 9. The next areas were assigned values of 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: It is convenient to be near highways.
Output: Office/Commercial Proximity to Highways SUA (UG2O22SO223)

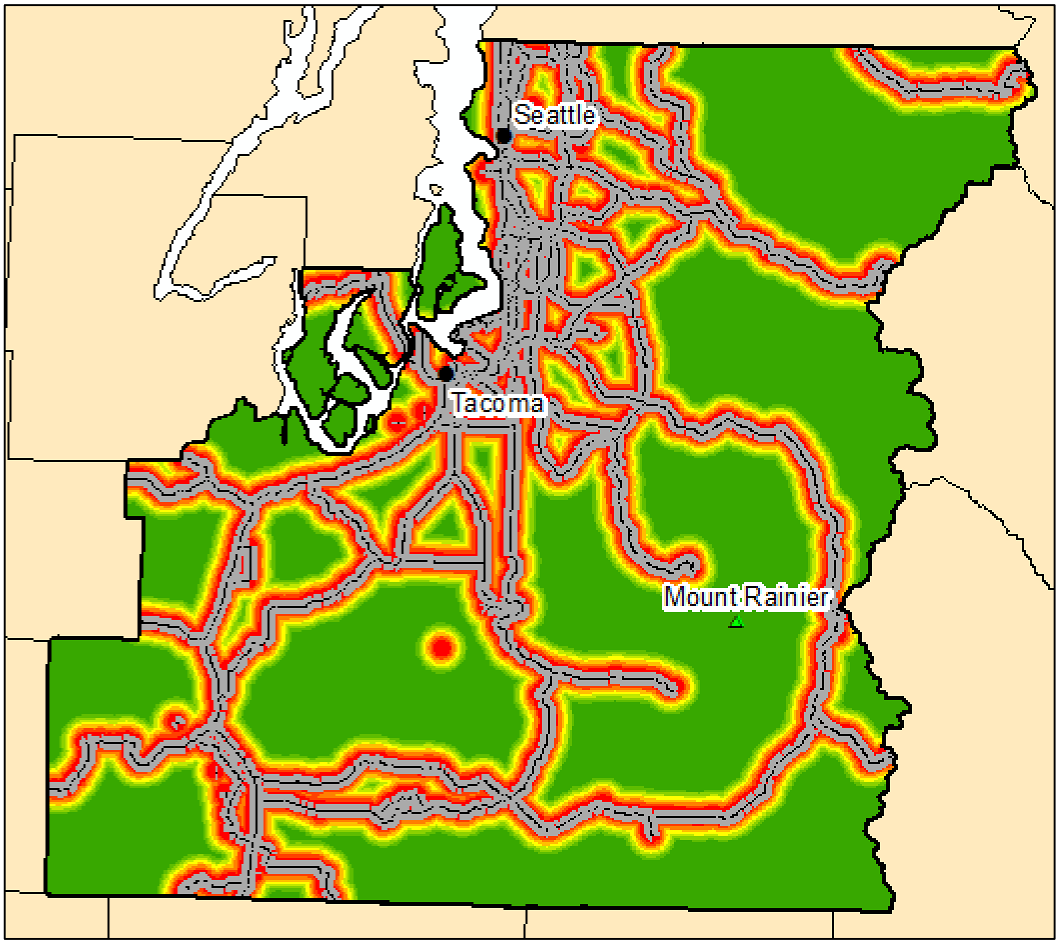

Figure 121: UG2O22SO223

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.2: Determine lands economically suitable for office/commercial land use
Subobjective 2.2.4: Identify lands proximal to airports

Input data layer: Airports
Criteria for value assignment: Euclidean distance was run from airports and zonal statistics were run to determine the mean distance of existing office/commercial areas from airports and the standard deviation. Cells with values of 0 to the mean (29,576.78) were assigned a value of 9. The next set of cells were assigned values of 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: It is convenient for office/commercial areas to be close to airports.
Output: Office/Commercial Proximity to Airports SUA (UG2O22SO224)

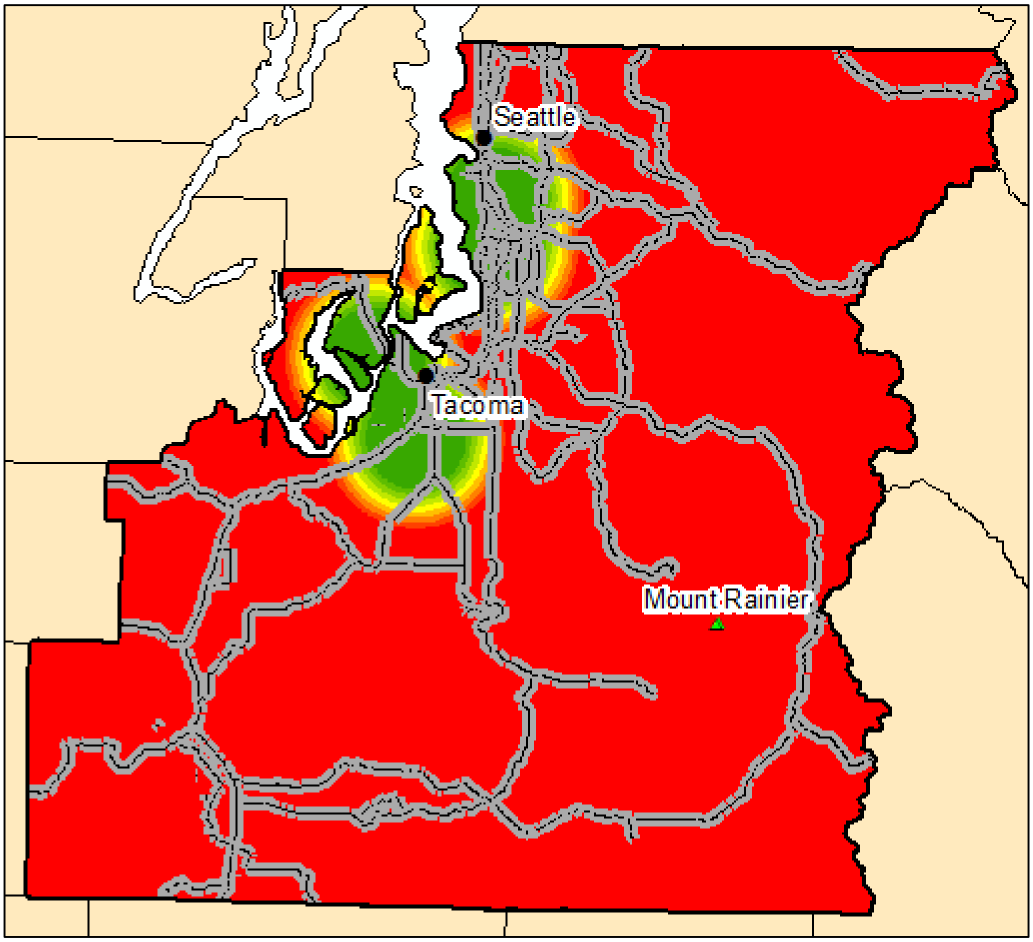

Figure 122: UG2O22SO224

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.2: Determine lands economically suitable for office/commercial land use
Subobjective 2.2.5: Identify lands proximal to parks, recreational opportunities, protected conservation lands, or historic sites.

Input data layer: Parks, recreation lands (preprocessed from land use), Habitat Conservation Plan lands, and Historical Sites.
Criteria for value assignment: Euclidean distance was run and then zonal statistics were run separately for each input to determine the mean distance of existing office/commercial areas from each parameter and the standard deviation. Cells with values of 0 to the mean (4,311.93 (Parks), 6,759.33 (Recreation), 28,636.75 (Habitat Conservation Plan Lands), and 1,302.66 (Historical Sites)) were assigned a value of 9. The next areas were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1. The resulting SUAs were weighted and combined as follows: Parks at 40 percent, Recreation Areas at 30 percent, Habitat Conservation Plan Lands at 20 percent, and Historical Sites at 10 percent.
Rationale: Proximity to parks and historical sites is a desirable amenity for office/commercial developments.
Output: Office/Commercial Proximity to Parks/Historical Sites MUA (UG2O22SO225)

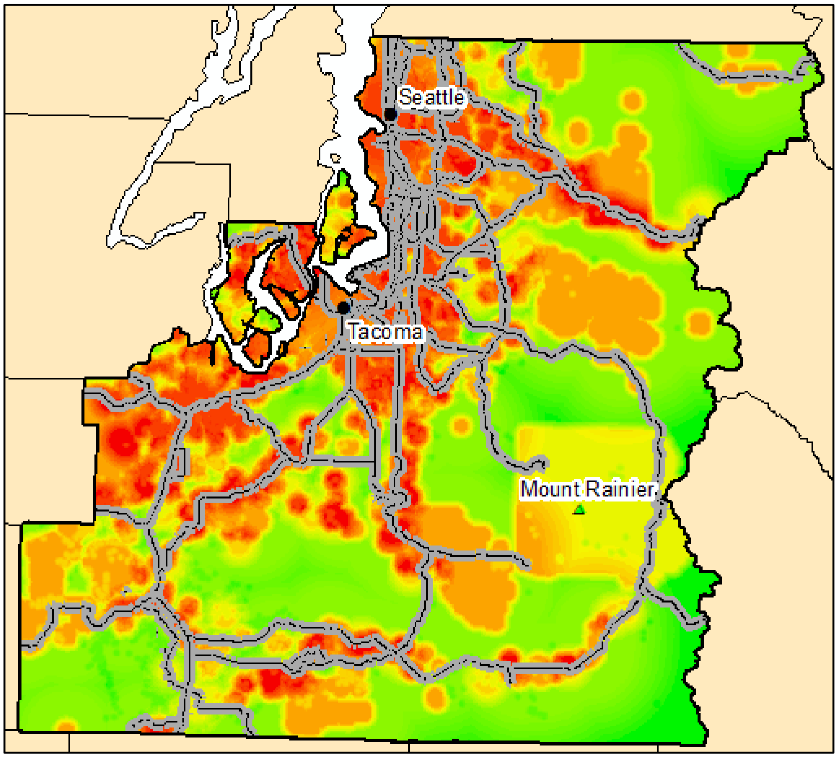

Figure 123: UG2O22SO225

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.2: Determine lands economically suitable for office/commercial land use
Subobjective 2.2.6: Identify lands proximal to existing public water and sewer services

Input data layer: Water Treatment Plants, Sewage Treatment Plants
Criteria for value assignment: Euclidean distance was run and then zonal statistics were run separately to determine the mean distance of existing office/commercial areas from each utility and the standard deviation. Cells with values of 0 to the mean (52,869.64 (water) and 4,766.68 (sewage)) were assigned a value of 9. The next areas were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1. The two SUAs were equally weighted and combined using map algebra.
Rationale: It is cost-effective to develop office/commercial near the existing utility services.
Output: Office/Commercial Proximity to Utilities MUA (UG2O22SO226)

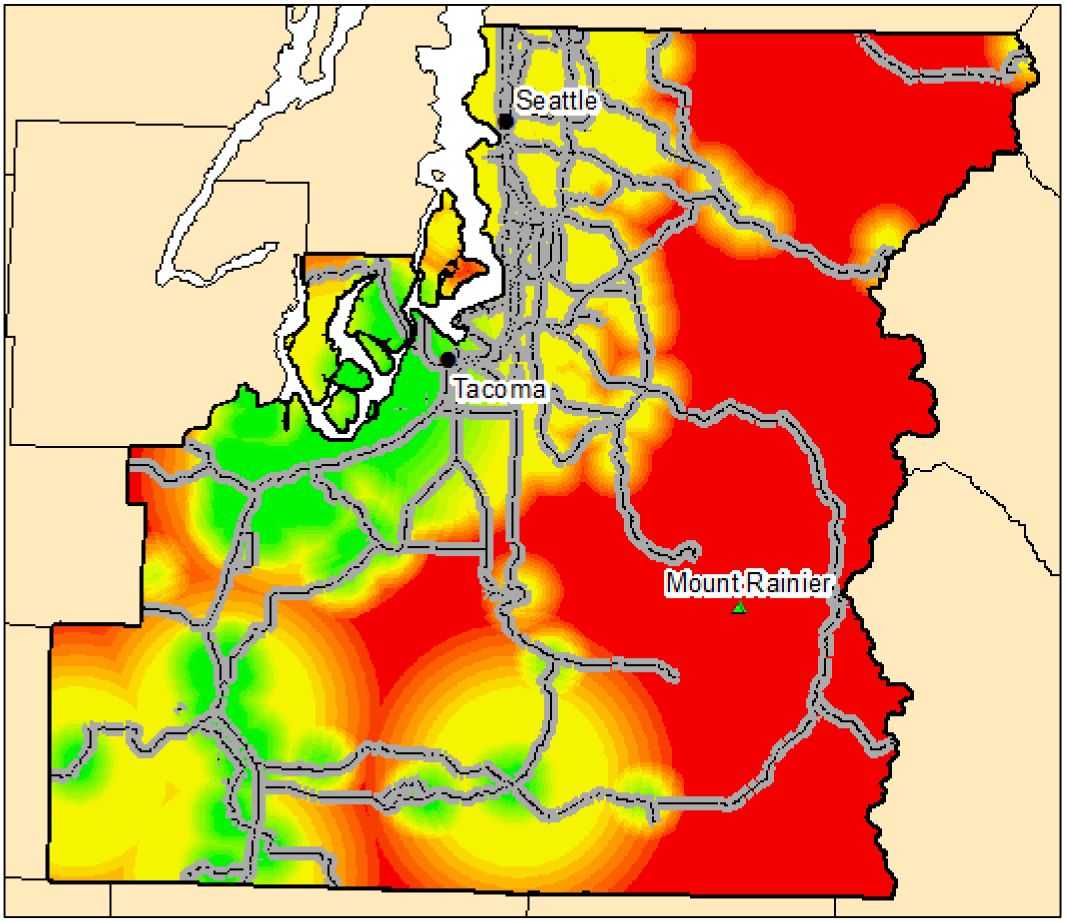

Figure 124: UG2O22SO226

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.2: Determine lands economically suitable for office/commercial land use
Subobjective 2.2.7: Identify lands proximal to existing office/commercial land use

Input data layer: Office/Commercial land use (Preprocessed from land use datasets)
Criteria for value assignment: Euclidean distance was run from existing office/commercial areas and reclassified in 9 classes as follows: 0-393.70 ft. as a value of 9, 393.70-590.55 ft. as a value of 8, 590.55-787.40 ft. as a value of 7, 787.40-984.25 ft. as a value of 6, 984.25-1,181.10 ft. as a value of 5, 1,181.10-1,345.14 as a value of 4, 1,345.14-1,509.19 ft. as a value of 3, 1,509.19-1,640.42 ft. as a value of 2, and all values outside of 1,640.42 ft. as a value of 1.
Rationale: Office/Commercial developments benefit from being near existing developments.
Output: Office/Commercial Proximity to Office/Commercial SUA (UG2O22SO227)

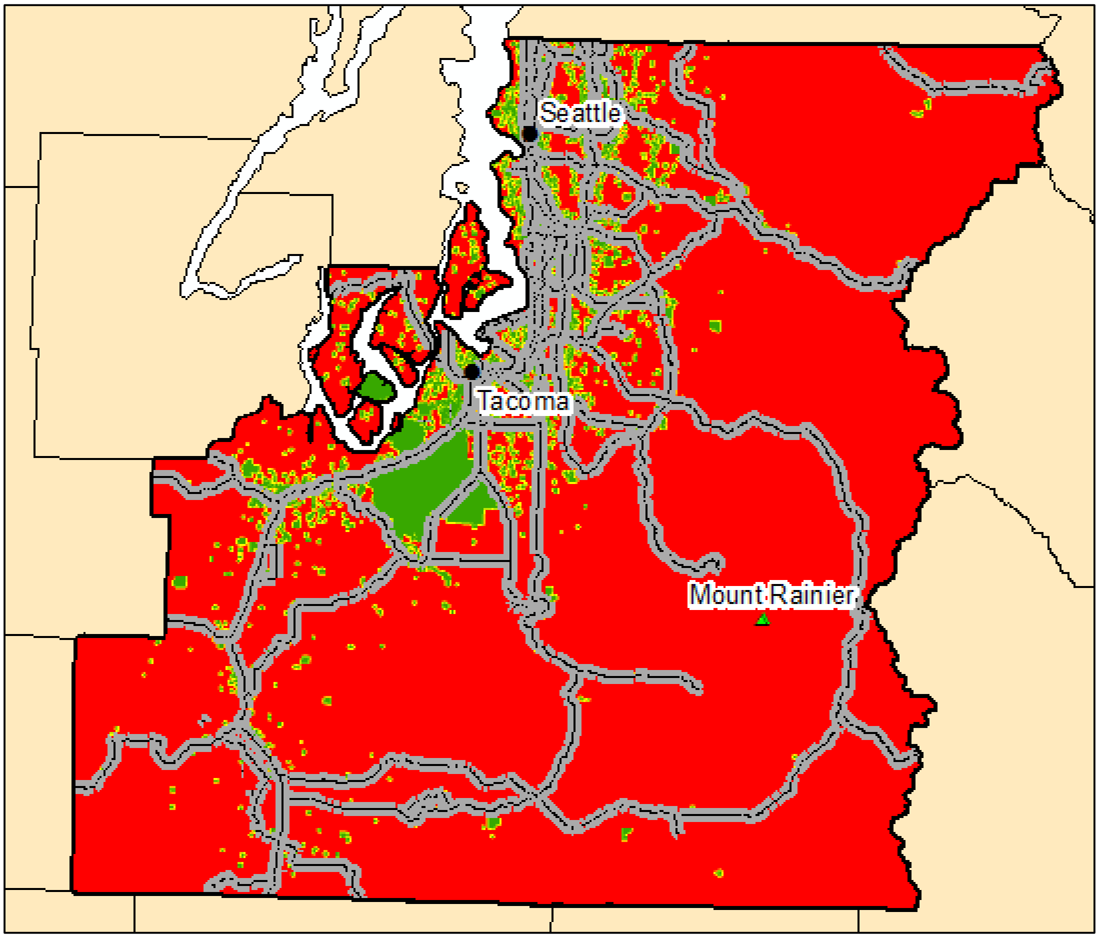

Figure 125: UG2O22SO227

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use
Objective 2.2: Determine lands economically suitable for office/commercial land use

Input data layer: Office/Commercial Proximity to Residential SUA (UG2O22SO221), Office/Commercial Proximity to City Limits SUA (UG2O22SO222), Office/Commercial Proximity to Highways SUA (UG2O22SO223), Office/Commercial Proximity to Airports SUA (UG2O22SO224), Office/Commercial Proximity to Parks/Historical Sites MUA (UG2O22SO225), Office/Commercial Proximity to Utilities MUA (UG2O22SO226), Office/Commercial Proximity to Office/Commercial SUA (UG2O22SO227)
Criteria for value assignment: The SUAs and MUAs were weighted and combined using map algebra as follows: Office/Commercial Proximity to Residential at 14 percent, Office/Commercial Proximity to City Limits at 14 percent, Office/Commercial Proximity to Highways at 14 percent, Office/Commercial Proximity to Airports at 14 percent, Office/Commercial Proximity to Parks/Historical Sites at 14 percent, Office/Commercial Proximity to Utilities at 14 percent, and Office/Commercial Proximity to Office/Commercial at 16 percent.
Rationale: The areas economically suitable for office/commercial development are close to city limits, close to existing residential areas, highways, airports, parks, cultural sites, public utilities, and existing office/commercial areas.
Output: Office/Commercial Economic Suitability MUA (UG2O22)

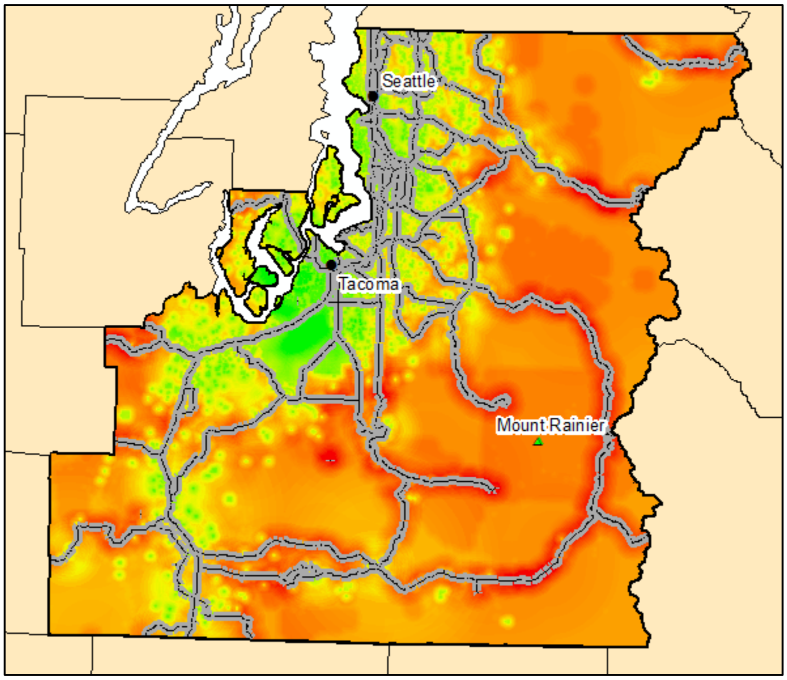

Figure 126: UG2O22

Land use: Urban
Goal 2: Identify lands suitable for office/commercial land use

Input data layer: Office/Commercial Physical Suitability MUA (UG2O21), Office/Commercial Economic Suitability MUA (UG2O22), and existing Office/Commercial Areas (Preprocessed from land use datasets)
Criteria for value assignment: The MUAs were equally weighted and combined using map algebra. Existing Office/Commercial areas were reclassified with a value of 9 and all other areas were assigned a value of 1. The combined MUAs and office/commercial areas were combined using a conditional statement CON (Office/Commercial = 9, 9, Combined MUAs). If an existing office/commercial area is present it was assigned a value of 9, otherwise it was assigned a value of the combined MUA.
Rationale: Both physical and economic criteria are equally important for determining the location of office/commercial developments and if there is an existing development it is already highly suitable.
Output: Office/Commercial Suitability MUA (UG2)

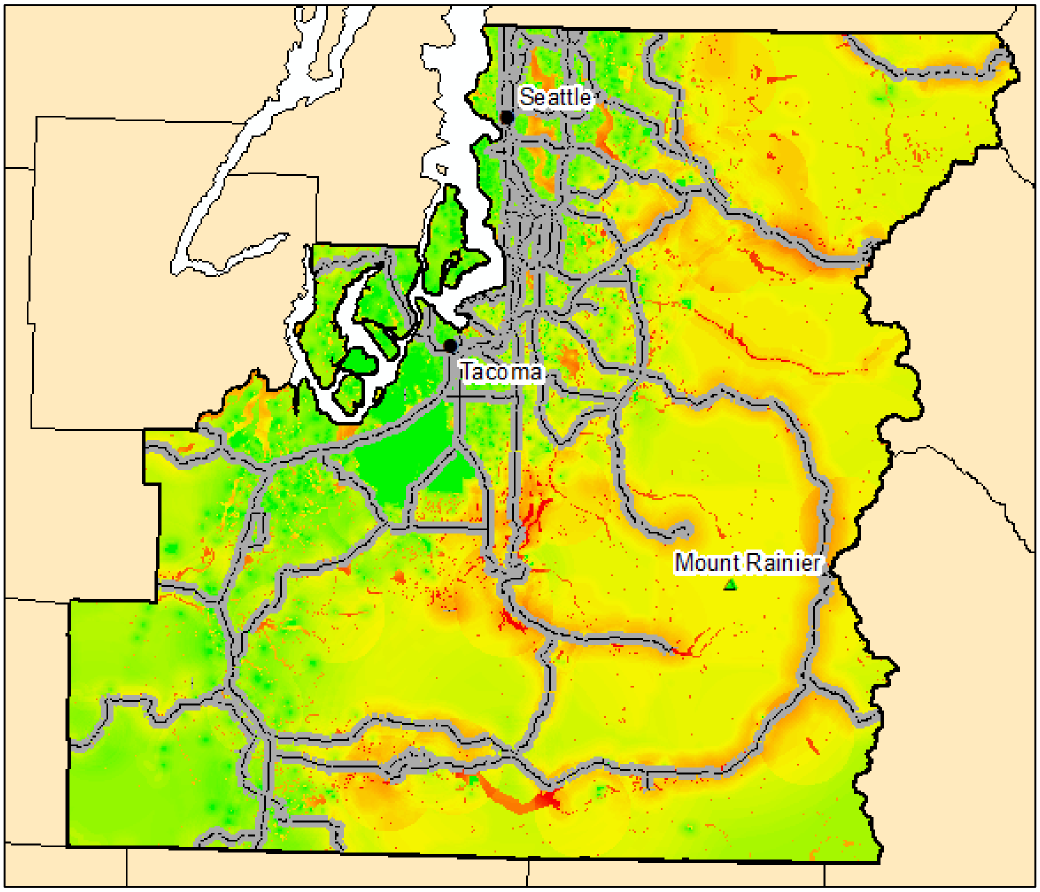

Figure 127: UG2

Land use: Urban
Goal 3: Identify lands suitable for retail land use
Objective 3.1: Determine lands physically suitable for retail land use
Subobjective 3.1.1: Identify soils most suitable for croplands

Input data layer: Habitat
Criteria for value assignment: Wetland habitats were reclassified with a value of 1 and all other values were assigned a value of 9.
Rationale: Building within wetlands is more costly and is discouraged by insurance companies.
Output: Flood Construction Suitability SUA (UG3O31SO311)

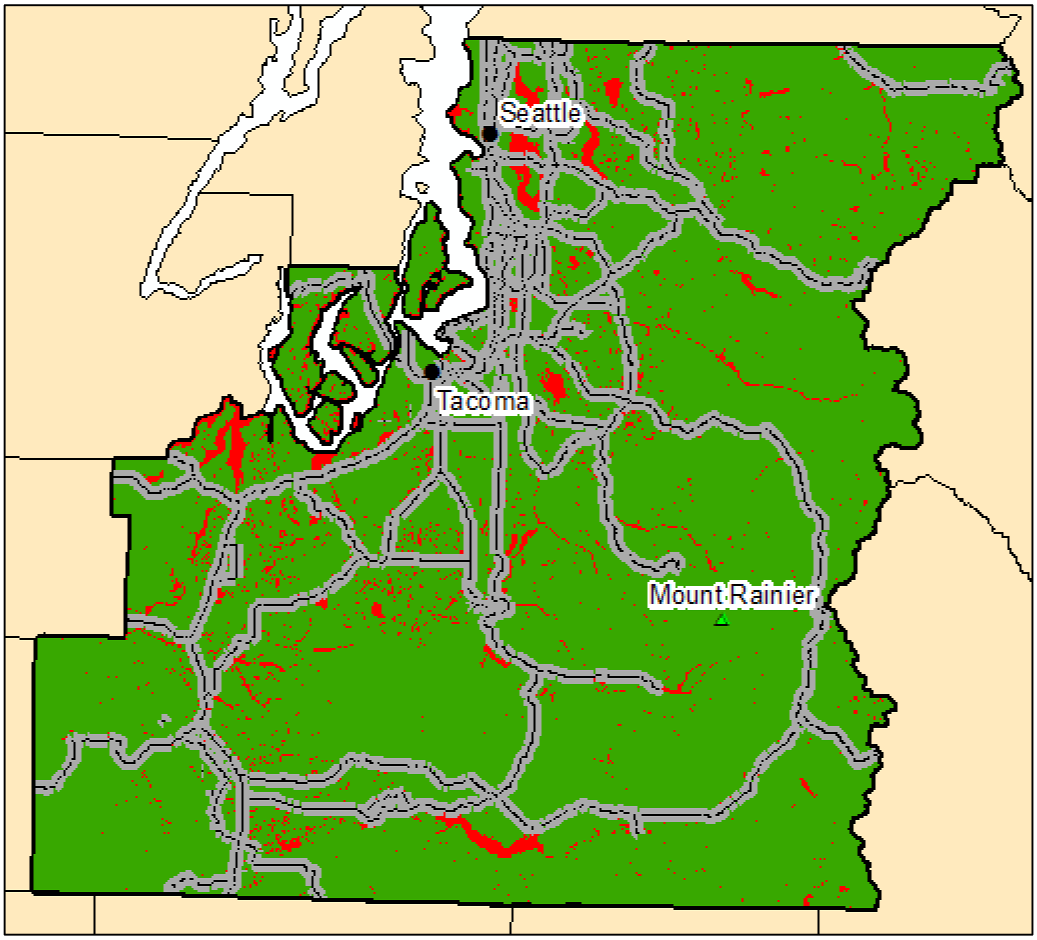

Figure 128: UG3O31SO311

Land use: Urban
Goal 3: Identify lands suitable for retail land use
Objective 3.1: Determine lands physically suitable for retail land use
Subobjective 3.1.2: Identify lands free of hazardous waste

Input data layer: Arsenic, Asbestos, and Mercury Hazardous Site
Criteria for value assignment: Euclidean distance was run from hazardous sites and zonal statistics were run to determine the mean distance of existing residential areas from hazardous sites and the standard deviation. Cells with values from 0 to the mean (85,309.61) were assigned a value of 1. The next areas were assigned values of 2-8 in quarter-standard deviation intervals and the remaining areas were assigned a value of 9.
Rationale: A healthy environment free of hazards is more desirable for retail developments.
Output: Retail Hazard SUA (UG3O31SO312)

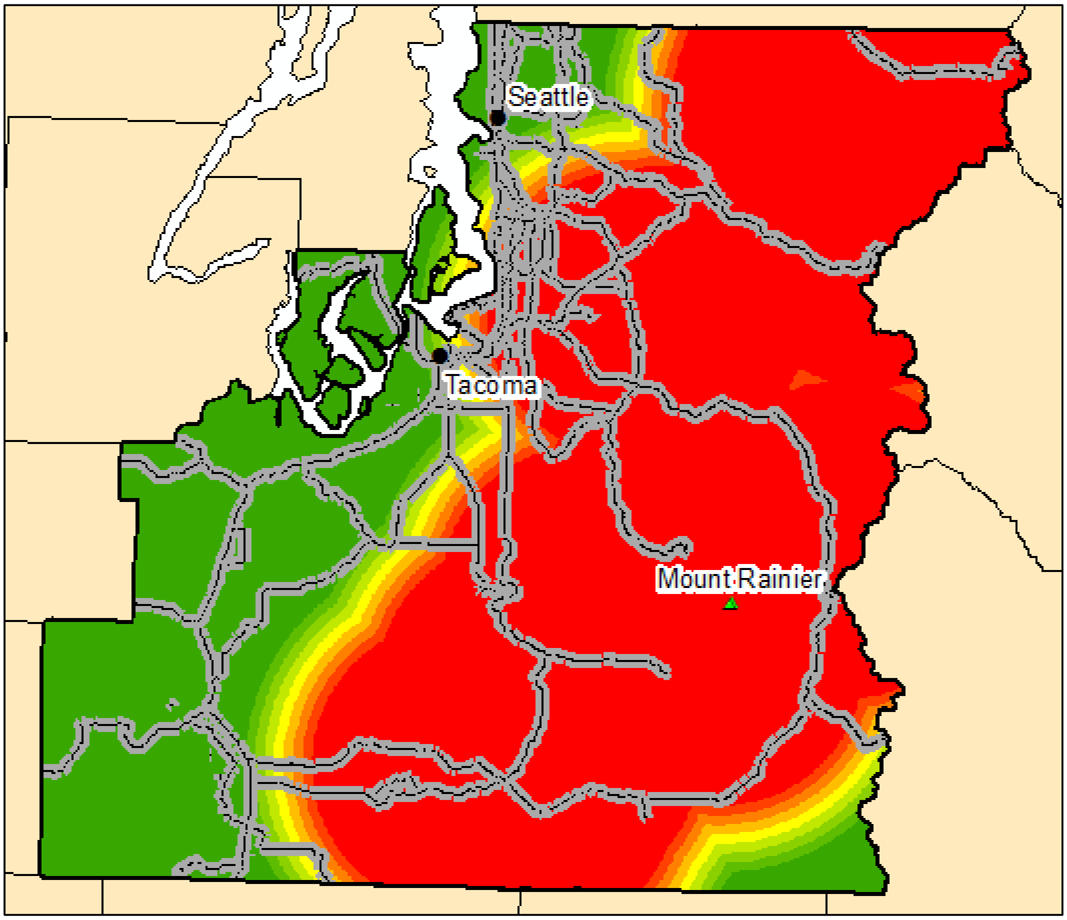

Figure 129: UG3O31SO312

Land use: Urban
Goal 3: Identify lands suitable for retail land use
Objective 3.1: Determine lands physically suitable for retail land use

Input data layer: Flood Construction Suitability SUA (UG3O31SO311) and Retail Hazard SUA (UG3O31SO312)
Criteria for value assignment: The two SUAs were equally weighted and combined using map algebra.
Rationale: The areas physically most suitable for retail development are those outside of the flood zone and without hazardous features.
Output: Retail Physical Suitability MUA (UG3O31)

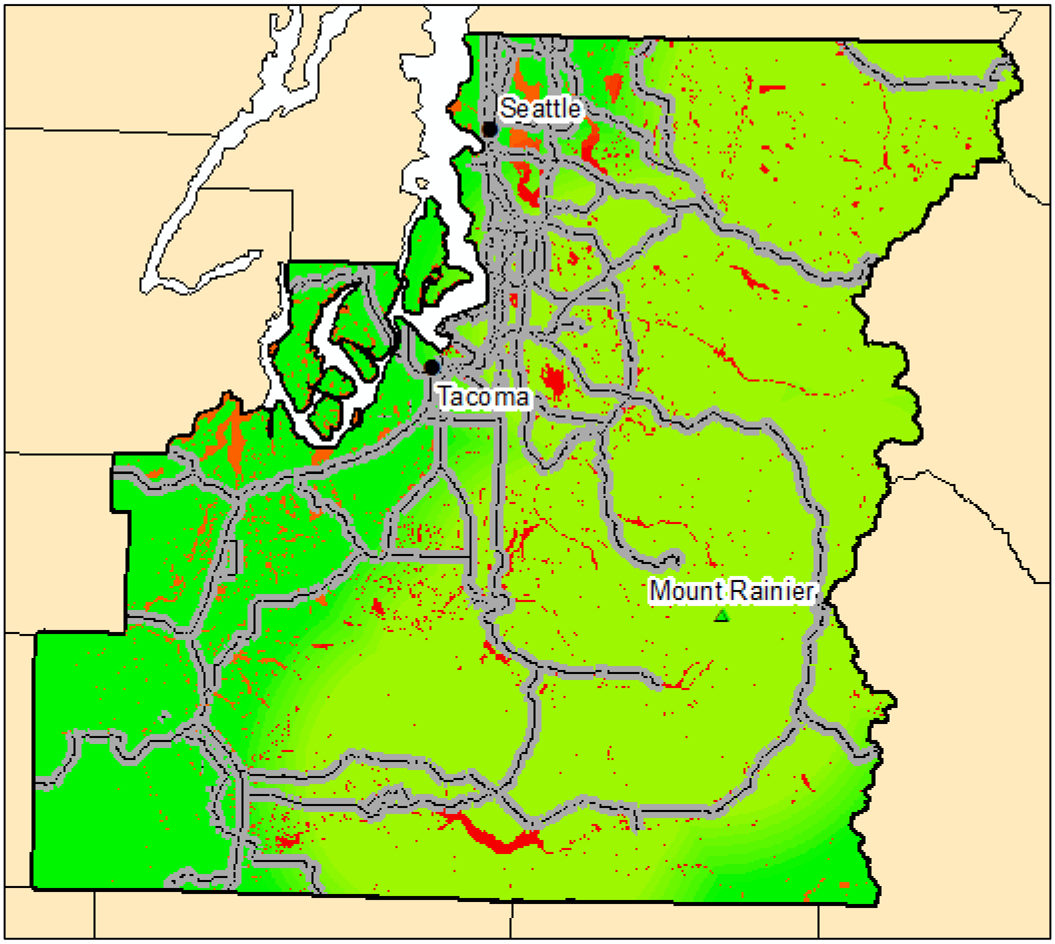

Figure 130: UG3O31

Land use: Urban
Goal 3: Identify lands suitable for retail land use
Objective 3.2: Determine lands economically suitable for retail land use
Subobjective 3.2.1: Identify lands proximal to existing residential development

Input data layer: Distance to Existing Residential Land Use (Preprocessed from land use data in the Agriculture model)
Criteria for value assignment: Zonal statistics were run to determine the mean distance of existing retail areas from existing residential areas and the standard deviation. Cells with values of 0 to the mean (4,268.96) were assigned a value of 9. The next set of cells were assigned values of 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: Retail developments having higher success rates when near to residential land use.
Output: Retail Proximity to Residential SUA (UG3O32SO321)

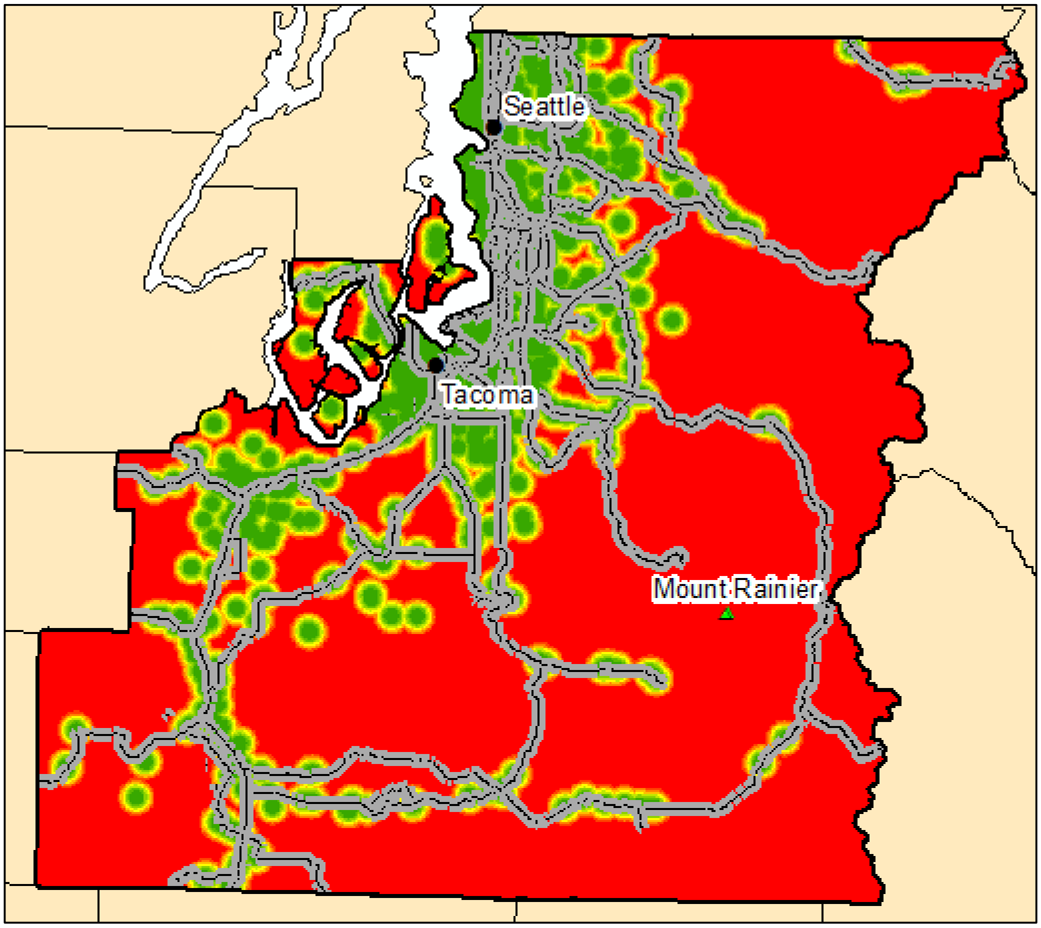

Figure 131: UG3O32SO321

Land use: Urban
Goal 3: Identify lands suitable for retail land use
Objective 3.2: Determine lands economically suitable for retail land use
Subobjective 3.2.2: Identify lands proximal to existing retail land use

Input data layer: Existing retail land use (Preprocessed from land use datasets)
Euclidean distance was run from existing retail areas and reclassified in 9 classes as follows: 0-393.70 ft. as a value of 9, 393.70-590.55 ft. as a value of 8, 590.55-787.40 ft. as a value of 7, 787.40-984.25 ft. as a value of 6, 984.25-1,181.10 ft. as a value of 5, 1,181.10-1,345.14 as a value of 4, 1,345.14-1,509.19 ft. as a value of 3, 1,509.19-1,640.42 ft. as a value of 2, and all values outside of 1,640.42 ft. as a value of 1.
Rationale: Retail developments benefit from being near existing developments.
Output: Retail Proximity to Retail SUA (UG3O32SO322)

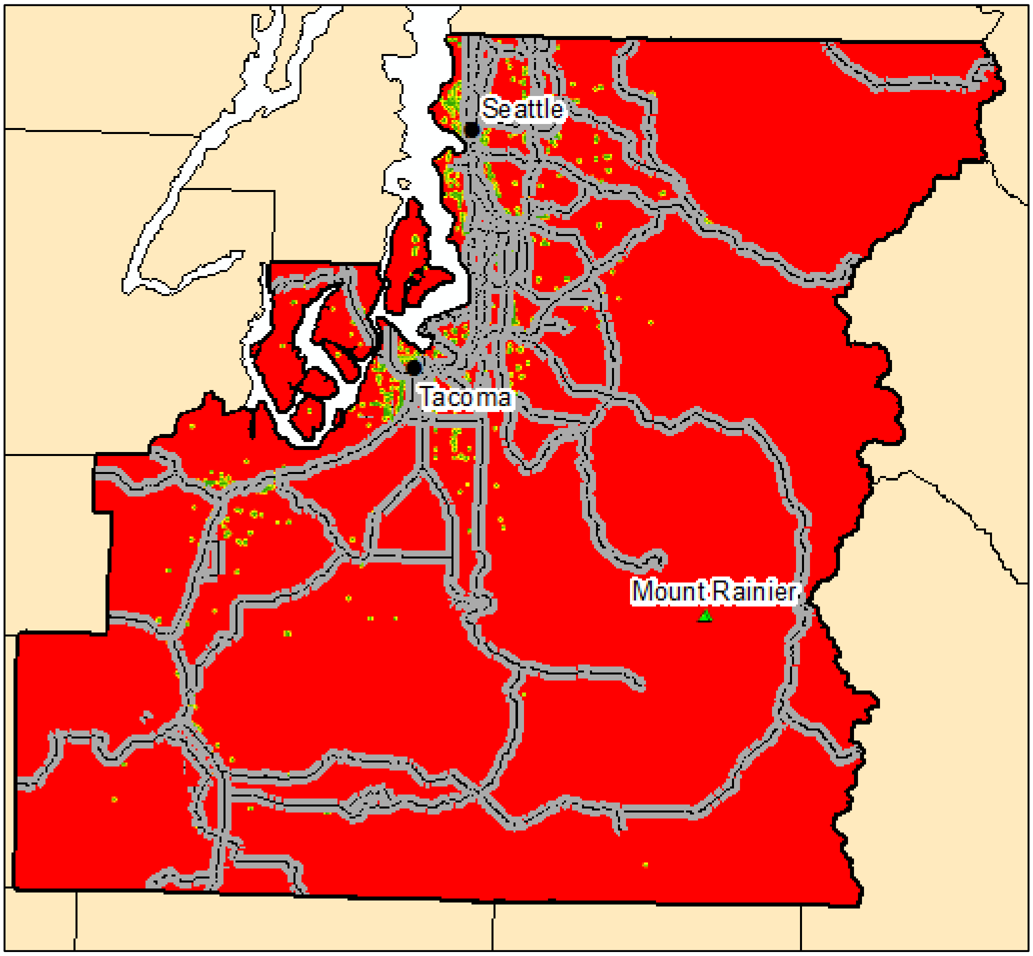

Figure 132: UG3O32SO322

Land use: Urban
Goal 3: Identify lands suitable for retail land use
Objective 3.2: Determine lands economically suitable for retail land use
Subobjective 3.2.3: Identify lands proximal to roads

Input data layer: Euclidean distance from highways (preprocessed in residential model UG1O12SO124)
Criteria for value assignment: Zonal statistics were run to determine the mean distance of existing retail areas from highways and the standard deviation. Cells with values of 0 to the mean (2,058.94) were assigned a value of 9. The next areas were assigned values of 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: It is convenient to be near highways.
Output: Retail Proximity to Highways SUA (UG3O32SO323)

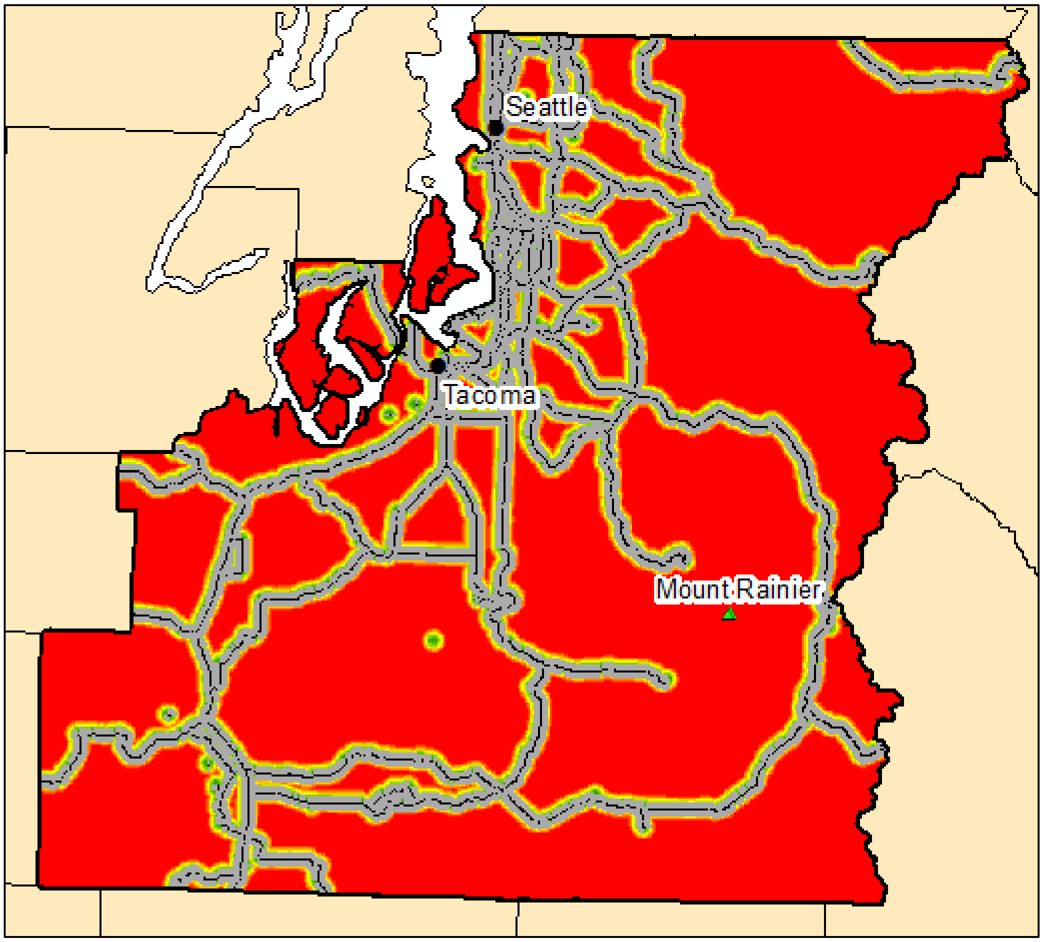

Figure 133: UG3O32SO323

Land use: Urban
Goal 3: Identify lands suitable for retail land use
Objective 3.2: Determine lands economically suitable for retail land use
Subobjective 3.2.4: Identify lands proximal to existing public water and sewer service

Input data layer: Water Treatment Plants, Sewage Treatment Plants
Criteria for value assignment: Euclidean distance was run and then zonal statistics were run separately to determine the mean distance of existing retail areas from each utility and the standard deviation. Cells with values of 0 to the mean (52,043.04 (water) and 1,608.84 (sewage)) were assigned a value of 9. The next areas were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1. The two SUAs were equally weighted and combined using map algebra.
Rationale: It is cost-effective to develop retail near the existing utility services.
Output: Retail Proximity to Utilities MUA (UG3O32SO324)

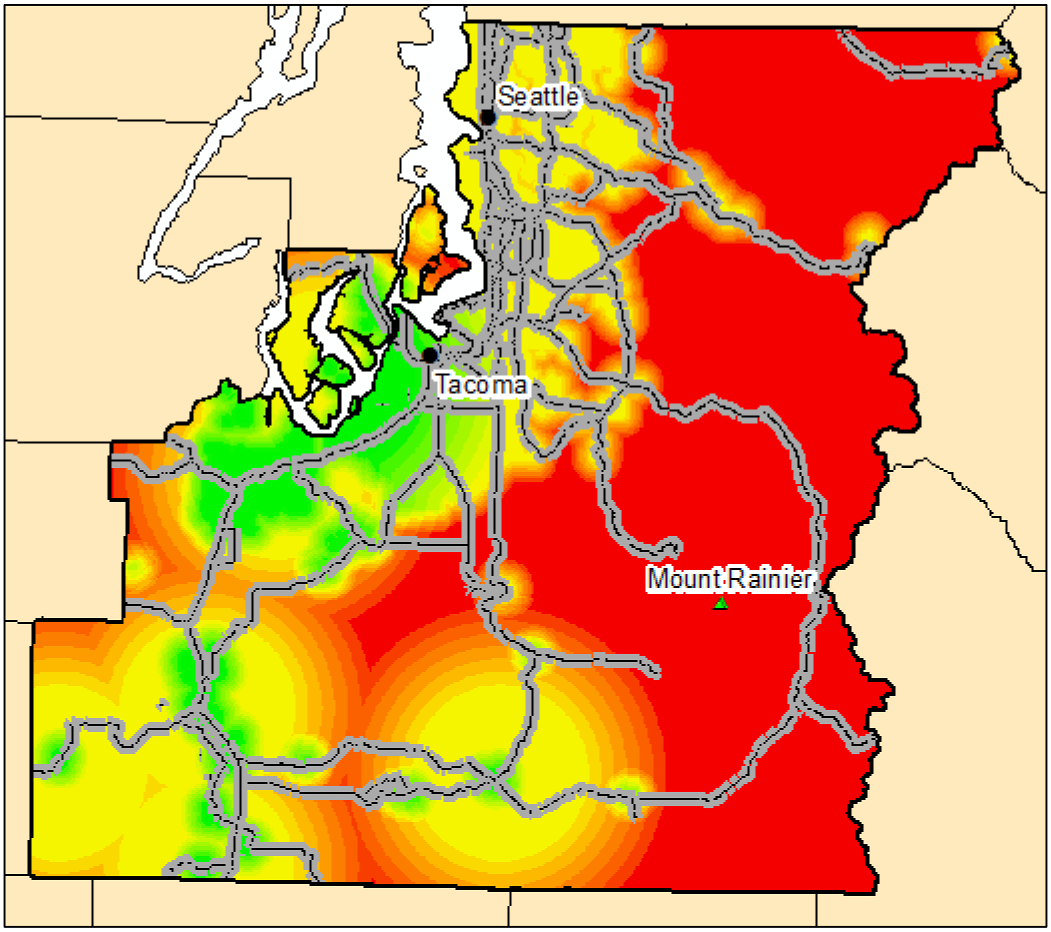

Figure 134: UG3O32SO324

Land use: Urban
Goal 3: Identify lands suitable for retail land use
Objective 3.2: Determine lands economically suitable for retail land use
Subobjective 3.2.5: Identify lands within and proximal to existing city limits

Input data layer: City Limits
Criteria for value assignment: Euclidean distance was run for City Limits. Zonal statistics were run on the Euclidean distance from City Limits to determine the mean and standard deviation. Cells with a Euclidean distance less than or equal to the mean were assigned a value of 9 (0-29,271.1 feet), Cells were assigned values from 8 to 2 within quarter standard deviations. The remaining cells received a value of 1.
Rationale: Retail developments are more successful if in urbanized areas.
Output: Proximity to City Limits SUA (UG3O32SO325)

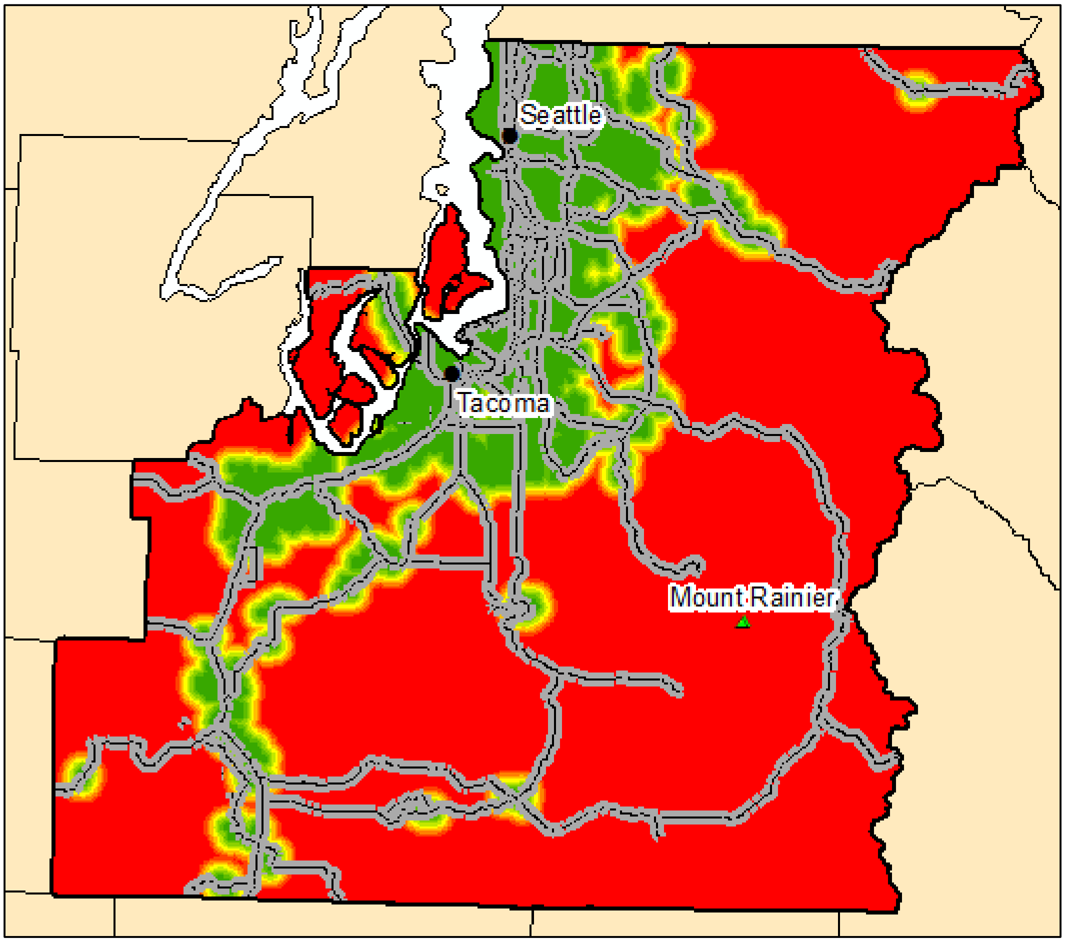

Figure 135: UG3O32SO325

Land use: Urban
Goal 3: Identify lands suitable for retail land use
Objective 3.2: Determine lands economically suitable for retail land use

Input data layer: Retail Proximity to Residential SUA (UG3O32SO321), Retail Proximity to Retail SUA (UG3O32SO322), Retail Proximity to Highways SUA (UG3O32SO323), Retail Proximity to Utilities MUA (UG3O32SO324), and Proximity to City Limits SUA (UG3O32SO325)
Criteria for value assignment: The SUAs and MUA were equally weighted at 20 percent and combined using map algebra.
Rationale: The areas economically most suitable for retail development are those which are within or close to city limits, close to existing residential areas, highways, existing retail, and public utilities.
Output: Retail Economic Suitability MUA (UG3O32)

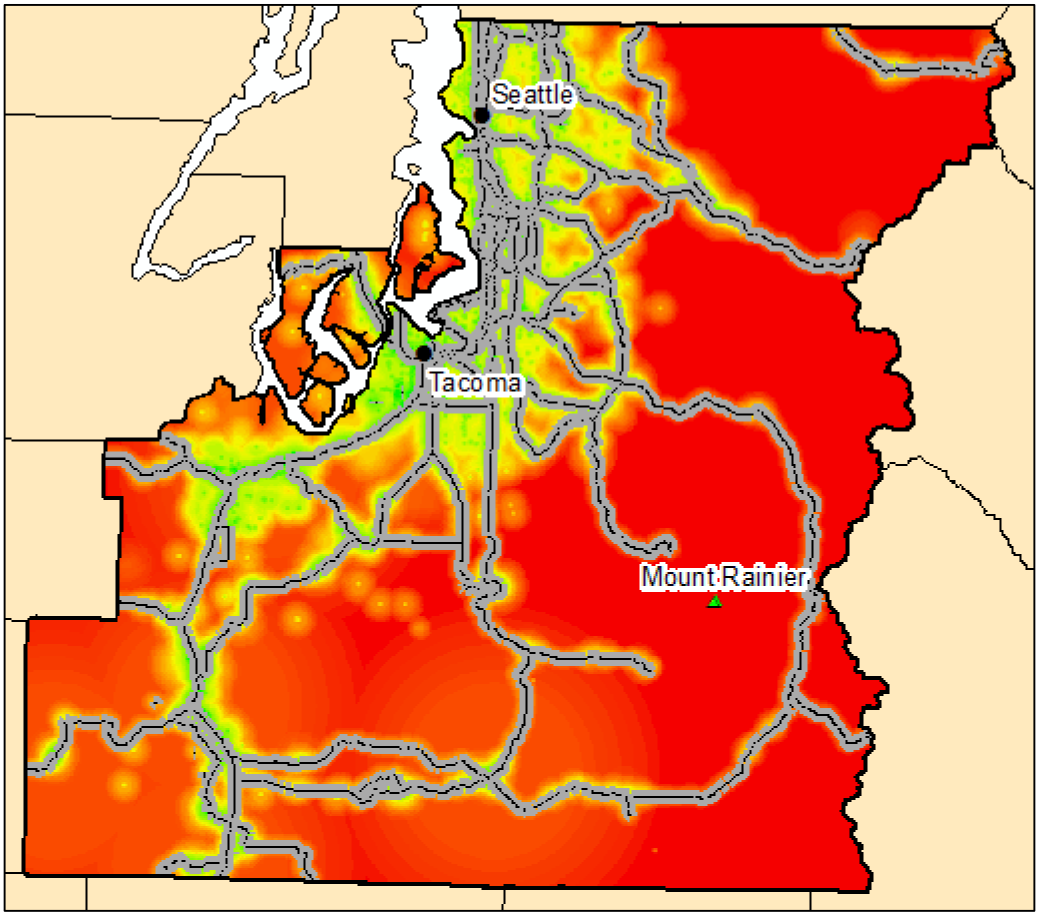

Figure 136: UG3O32

Land use: Urban
Goal 3: Identify lands suitable for retail land use

Input data layer: Retail Physical Suitability MUA (UG2O21), Retail Economic Suitability MUA (UG2O22), and Existing Retail Areas (Preprocessed from land use datasets)
Criteria for value assignment: The MUAs were equally weighted and combined using map algebra. Existing retail areas were reclassified with a value of 9 and all other areas were assigned a value of 1. The combined MUAs and retail areas were combined using a conditional statement CON (Retail = 9, 9, Combined MUAs). If an existing retail area is present it was assigned a value of 9, otherwise it was assigned a value of the combined MUA.
Rationale: Both physical and economic criteria are equally important for determining the location of retail developments and if there is an existing development it is already highly suitable.
Output: Retail Suitability MUA (UG3)

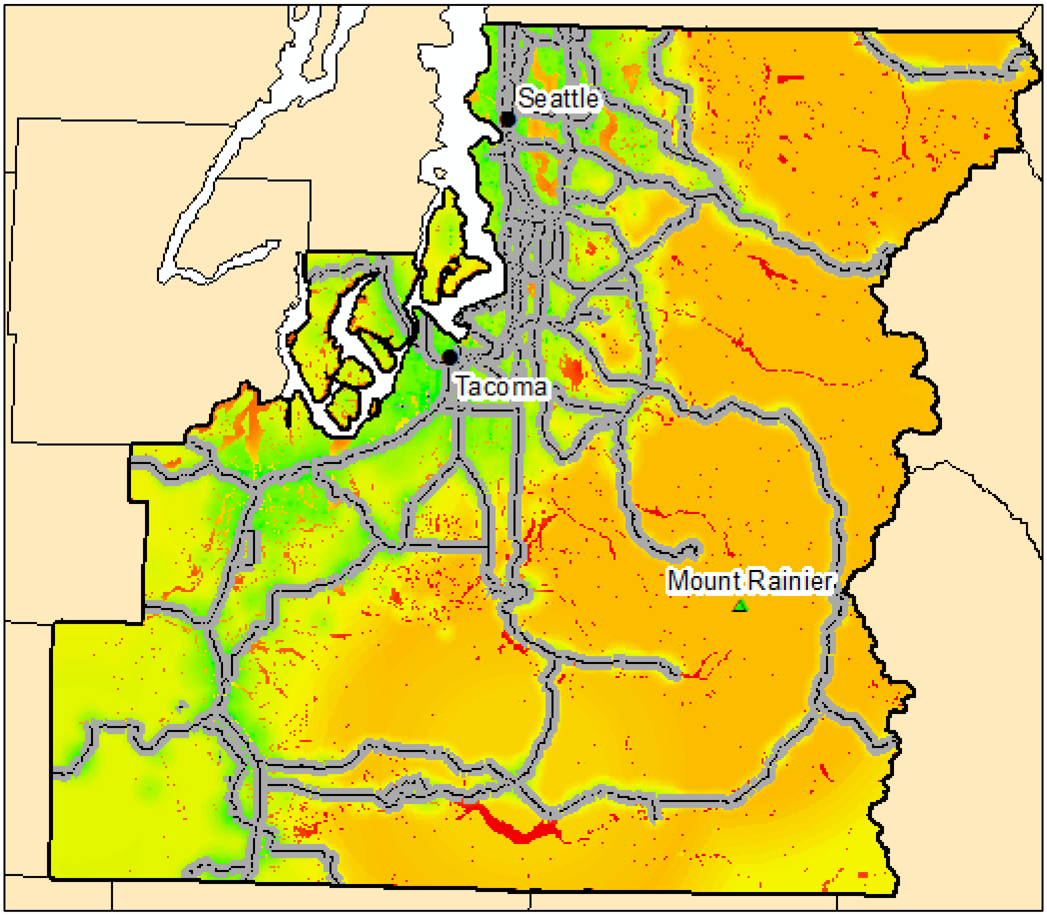

Figure 137: UG3

Land use: Urban
Goal 4: Identify lands suitable for industrial land use
Objective 4.1: Identify lands free of flood potential (Identify lands physically suitable for industrial use)

Input data layer: Habitat
Criteria for value assignment: Wetland habitats were reclassified with a value of 1 and all other values were assigned a value of 9.
Rationale: Building within wetlands is more costly and is discouraged by insurance companies.
Output: Industrial Physical Suitability SUA (UG4O41)

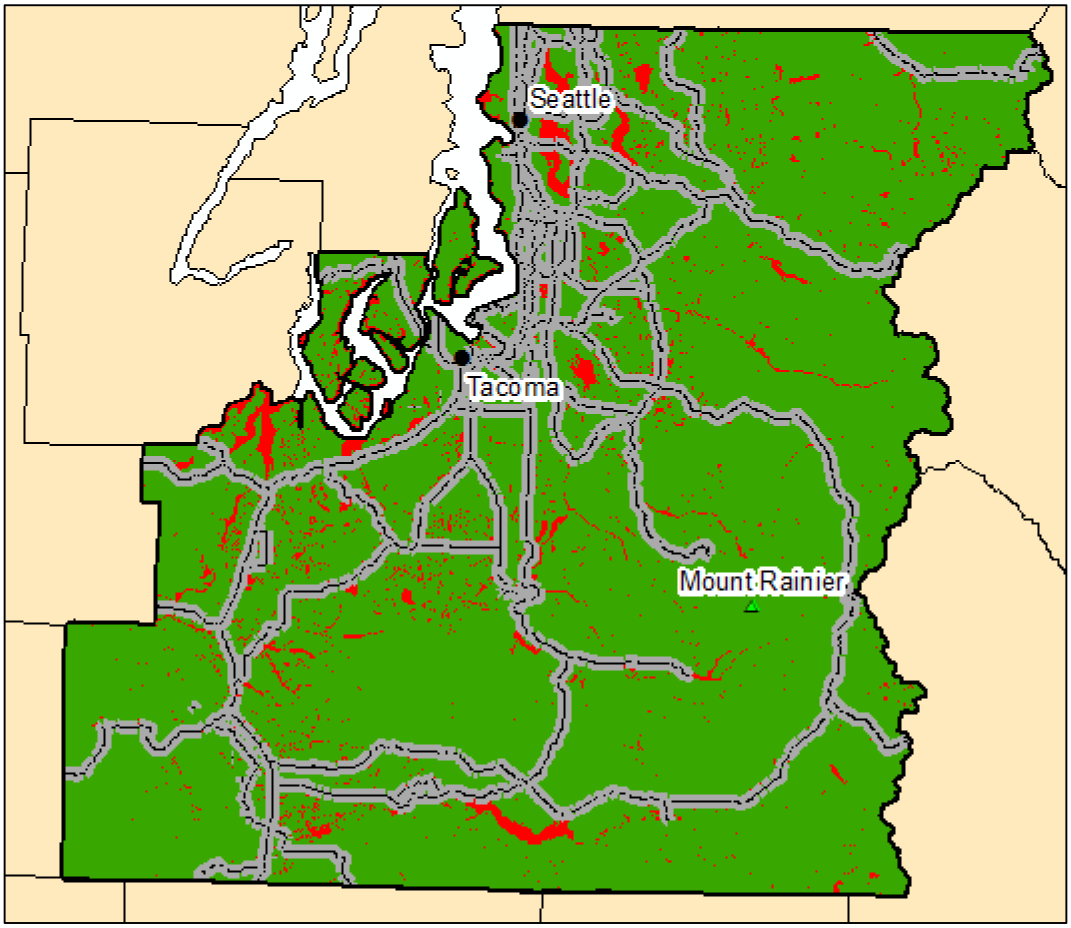

Figure 138: UG4O41

Land use: Urban
Goal 4: Identify lands suitable for industrial land use
Objective 4.2: Identify lands economically suitable for industrial use
Subobjective 4.2.1: Identify lands away from existing residential development

Input data layer: Distance to Existing Residential Land Use (Preprocessed from land use data in the Agriculture model)
Criteria for value assignment: Zonal statistics were run to determine the mean distance of existing retail areas from existing residential areas and the standard deviation. Cells with values of 0 to the mean (9,449.12) were assigned a value of 1. The next set of cells were assigned values of 2-8 in quarter standard deviation intervals. The remaining cells were assigned a value of 9.
Rationale: Industrial developments are more successful as the distance from residential land use increases.
Output: Industrial Distance to Residential SUA (UG4O42SO421)

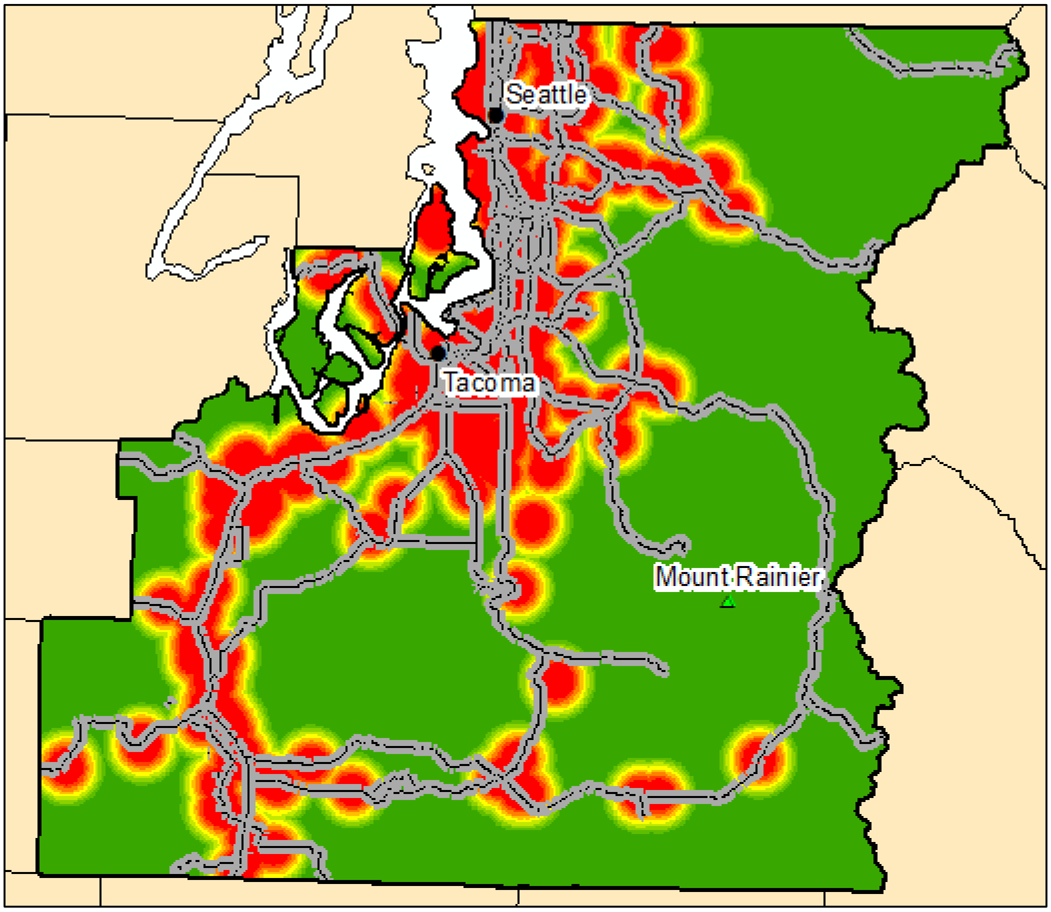

Figure 139: UG4O42SO421

Land use: Urban
Goal 4: Identify lands suitable for industrial land use
Objective 4.2: Identify lands economically suitable for industrial use
Subobjective 4.2.2: Identify lands proximal to existing industrial land use

Input data layer: Industrial land use (Preprocessed from land use datasets)
Criteria for value assignment: The Euclidean distance was run from existing industrial areas and was reclassified in 26,574.80 ft. intervals with a value of 9 being assigned to the closest cells until 2. All remaining cells were assigned a value of 1.
Rationale: Industrial developments are more successful with near existing developments.
Output: Industrial Proximity to Industrial SUA (UG4O42SO422)

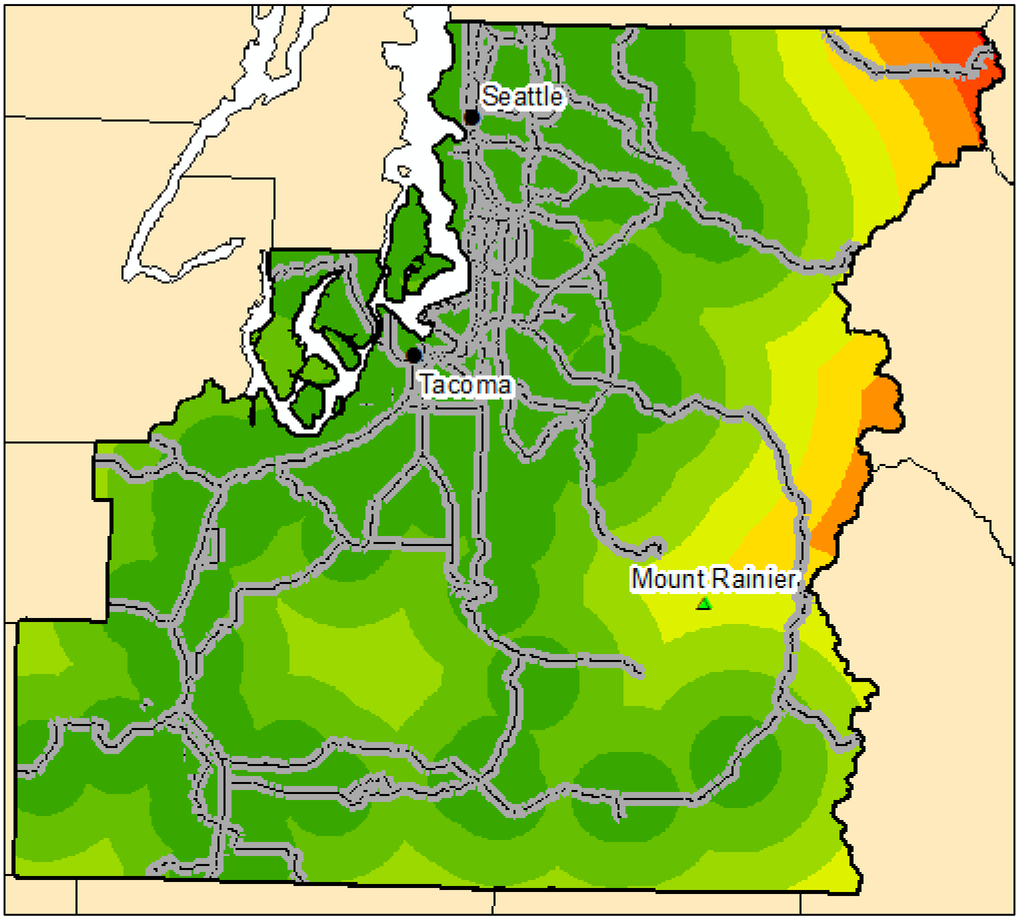

Figure 140: UG4O42SO422

Land use: Urban
Goal 4: Identify lands suitable for industrial land use
Objective 4.2: Identify lands economically suitable for industrial use
Subobjective 4.2.3: Identify lands proximal to roads

Input data layer: Euclidean distance from highways (preprocessed in residential model UG1O12SO124)
Criteria for value assignment: Zonal statistics were run to determine the mean distance of existing industrial areas from highways and the standard deviation. Cells with values of 0 to the mean (3,301.63) were assigned a value of 9. The next areas were assigned values of 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: It is convenient to be near highways.
Output: Industrial Proximity to Highways SUA (UG4O42SO423)

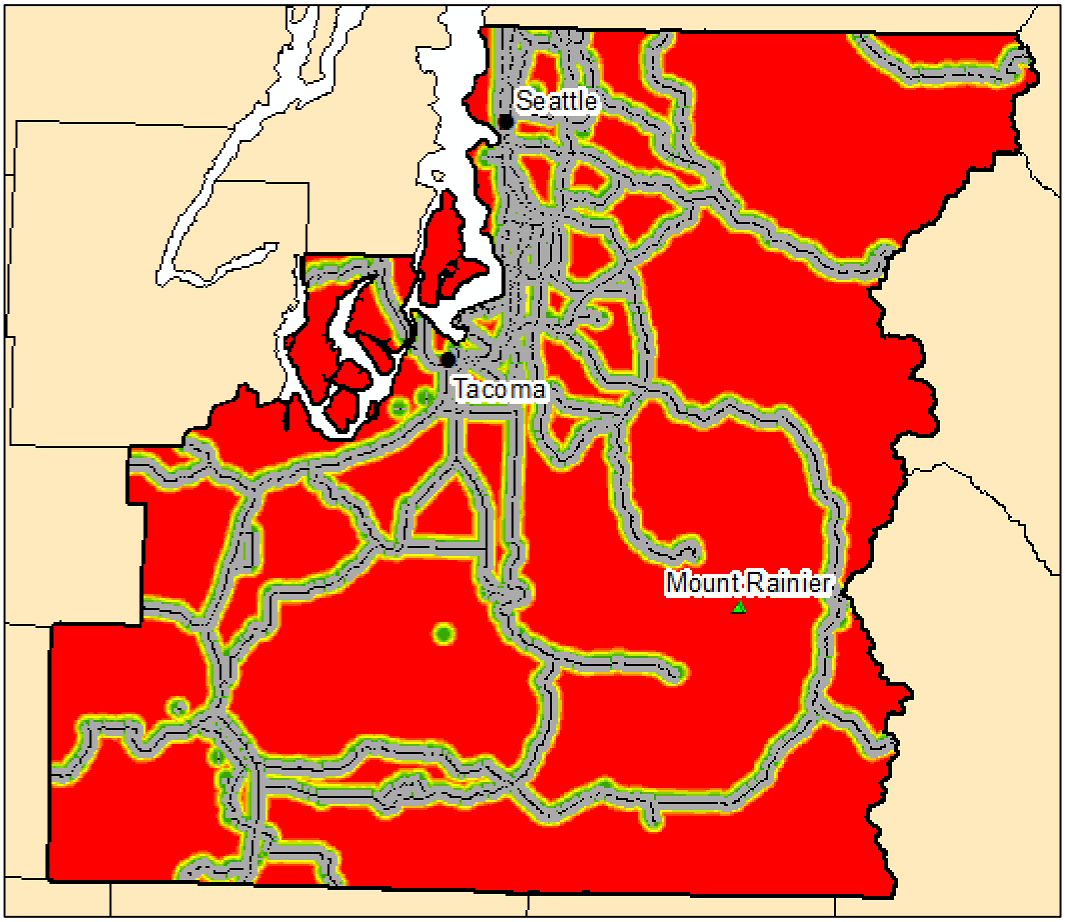

Figure 141: UG4O42SO423

Land use: Urban
Goal 4: Identify lands suitable for industrial land use
Objective 4.2: Identify lands economically suitable for industrial use
Subobjective 4.2.4: Identify lands proximal to railroads

Input data layer: Distance from Railroads (preprocessed in urban model UG1O11SO112)
Criteria for value assignment: Zonal statistics were run to determine the mean distance of existing industrial areas from railroads and the standard deviation. Cells with values of 0 to the mean (3,589.81) were assigned a value of 9. The next set of cells were assigned values of 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: It is convenient to be close to railroads in order to ship the goods.
Output: Industrial Proximity to Railroads SUA (UG4O42SO424)

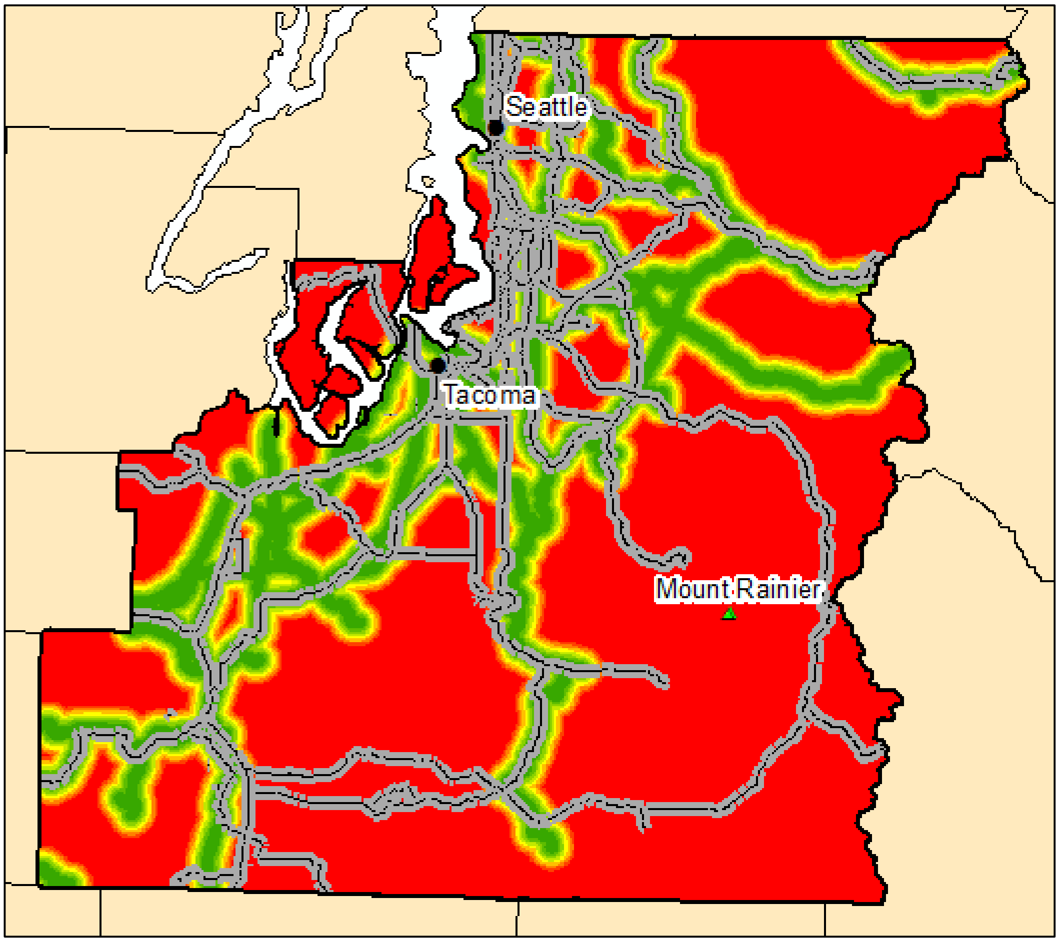

Figure 142: UG4O42SO424

Land use: Urban
Goal 4: Identify lands suitable for industrial land use
Objective 4.2: Identify lands economically suitable for industrial use
Subobjective 4.2.5: Identify lands proximal to airports

Input data layer: Airports
Criteria for value assignment: Euclidean distance was run from airports and zonal statistics were run to determine the mean distance of existing industrial areas from airports and the standard deviation. Cells with values of 0 to the mean (36,359.43) were assigned a value of 9. The next set of cells were assigned values of 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1.
Rationale: It is convenient for industrial areas to be close to airports to ship goods.
Output: Industrial Proximity to Airport SUA (UG4O42SO425)

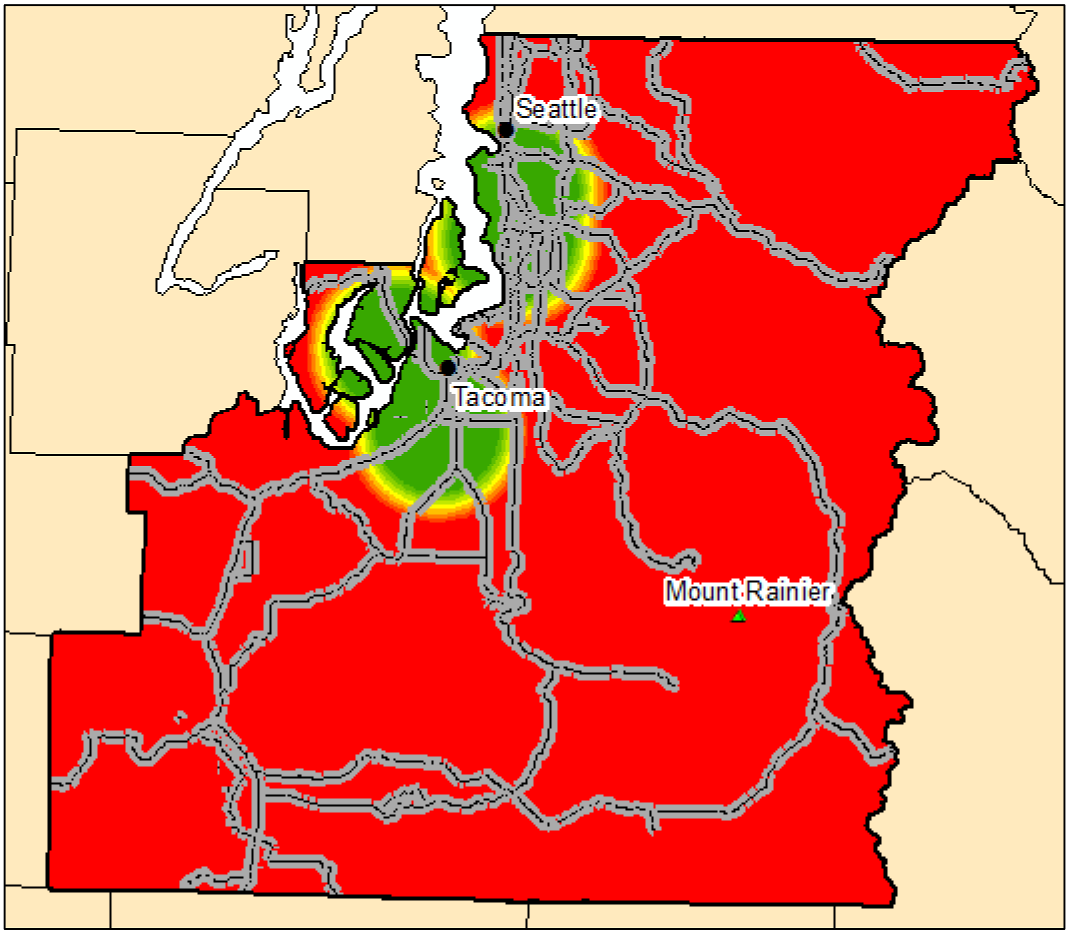

Figure 143: UG4O42SO425

Land use: Urban
Goal 4: Identify lands suitable for industrial land use
Objective 4.2: Identify lands economically suitable for industrial use
Subobjective 4.2.6: Identify lands proximal to existing public water and sewer service

Input data layer: Water Treatment Plants, Sewage Treatment Plants
Criteria for value assignment: Euclidean distance was run and then zonal statistics were run separately to determine the mean distance of existing industrial areas from each utility and the standard deviation. Cells with values of 0 to the mean (48,894.37 (water) and 1,343.25 (sewage)) were assigned a value of 9. The next areas were assigned values 8-2 in quarter standard deviation intervals. The remaining cells were assigned a value of 1. The two SUAs were equally weighted and combined using map algebra.
Rationale: It is cost-effective to develop industrial near the existing utility services.
Output: Industrial Proximity to Utilities MUA (UG4O42SO426)

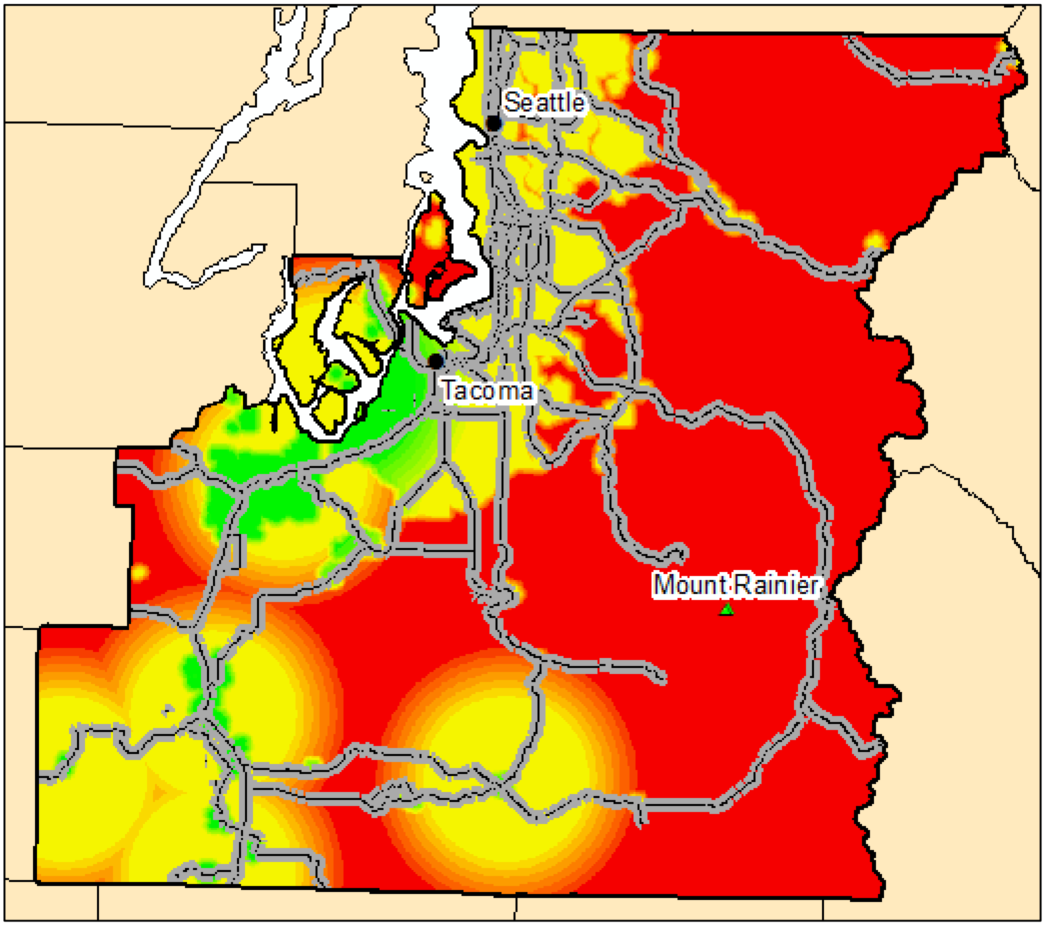

Figure 144: UG4O42SO426

Land use: Urban
Goal 4: Identify lands suitable for industrial land use
Objective 4.2: Identify lands economically suitable for industrial use

Input data layer: Industrial Distance to Residential SUA (UG4O42SO421), Industrial Proximity to Industrial SUA (UG4O42SO422), Industrial Proximity to Highways SUA (UG4O42SO423), Industrial Proximity to Railroads SUA (UG4O42SO424), Industrial Proximity to Airport SUA (UG4O42SO425), and Industrial Proximity to Utilities MUA (UG4O42SO426)
Criteria for value assignment: The SUAs and MUA were weighted and combined using map algebra as follows: Industrial Distance to Residential at 16 percent, Industrial Proximity to Industrial at 20 percent, Industrial Proximity to Highways at 16 percent, Industrial Proximity to Railroads SUA at 16 percent, Industrial Proximity to Airport at 16 percent, and Industrial Proximity to Utilities at 16 percent.
Rationale: The areas economically most suitability for industrial development are those close to highways, shipping locations, public utilities, existing industrial areas, and at a distance from existing residential areas.
Output: Industrial Economic Suitability MUA (UG4O42)

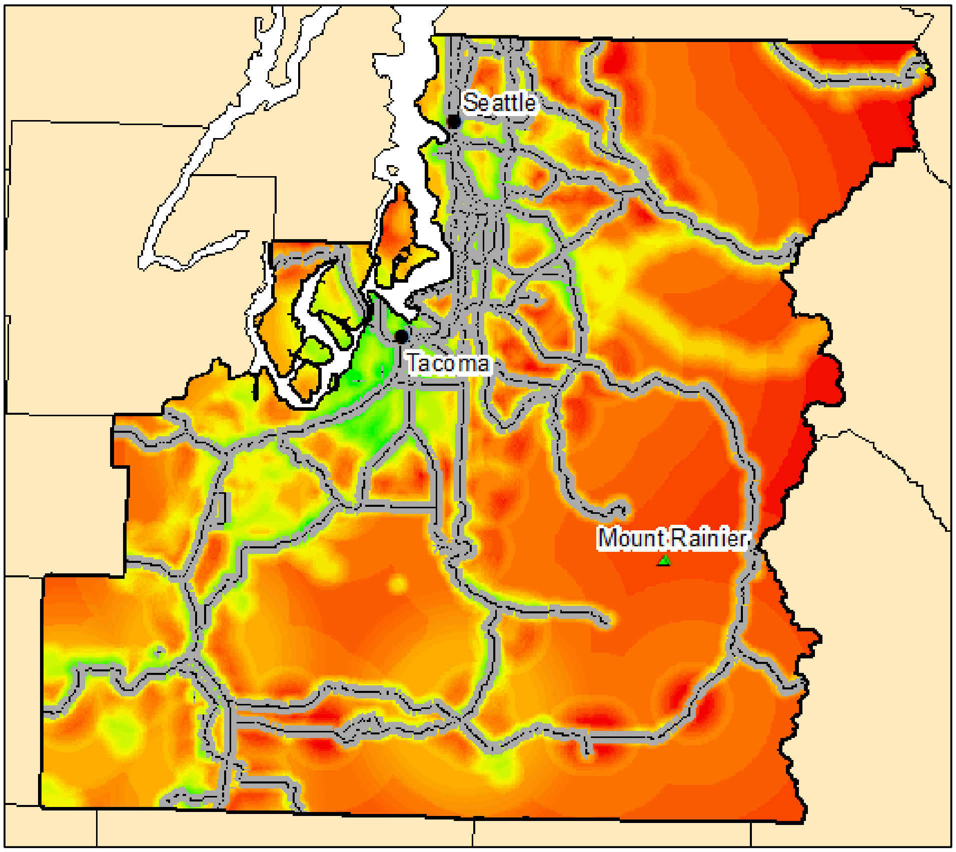

Figure 145: UG4O42

Land use: Urban
Goal 4: Identify lands suitable for industrial land use
Input data layer: Industrial Physical Suitability SUA (UG4O41), Industrial Economic Suitability MUA (UG4O42), and Existing Industrial Areas (Preprocessed from land use datasets)

Criteria for value assignment: The MUAs were equally weighted and combined using map algebra. Existing industrial areas were reclassified with a value of 9 and all other areas were assigned a value of 1. The combined MUAs and industrial areas were combined using a conditional statement CON (Industrial = 9, 9, Combined MUAs). If an existing industrial area is present it was assigned a value of 9, otherwise it was assigned a value of the combined MUA.
Rationale: Both physical and economic criteria are equally important for determining the location of industrial developments and if there is an existing development it is already highly suitable.
Output: Industrial Suitability MUA (UG4)

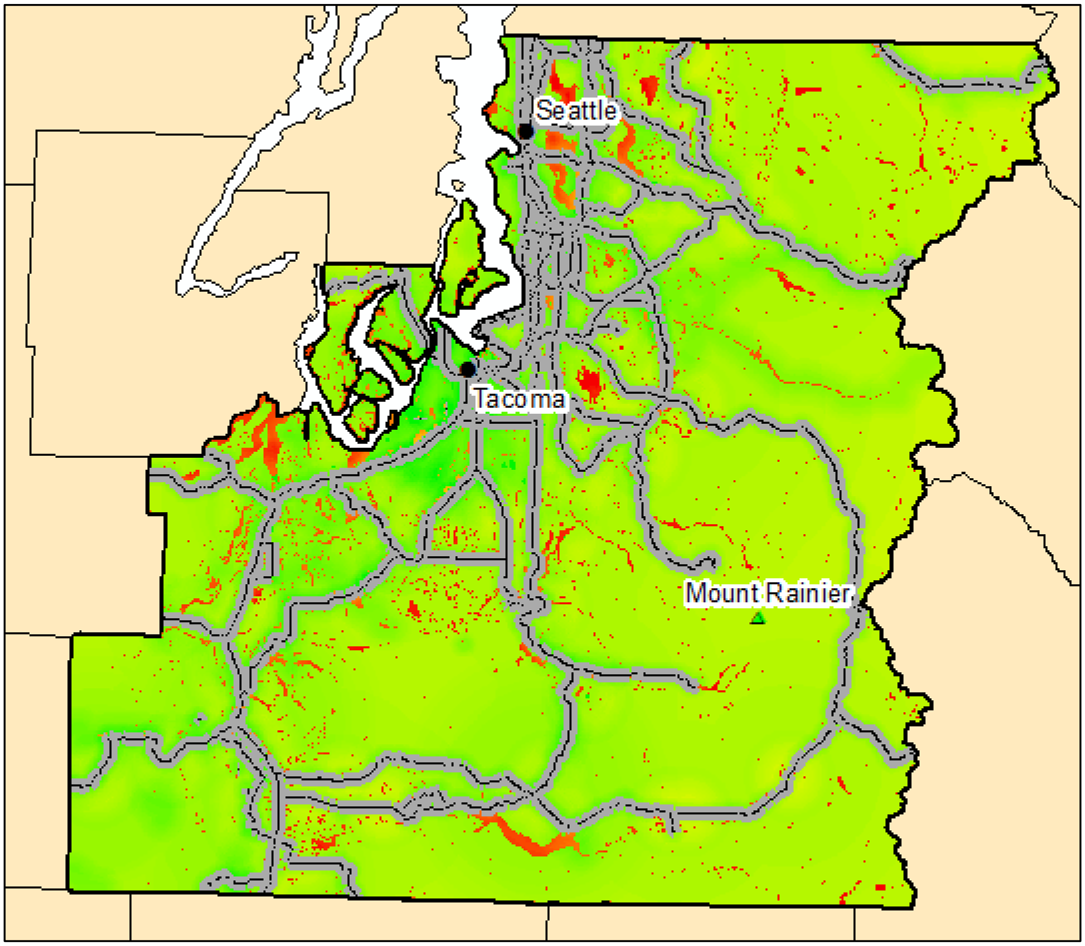

Figure 146: UG4