KING COUNTY NOXIOUS WEEDS DISTRIBUTION ANALYSIS REPORT

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King County

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Geography 569 Capstone Project

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1 INTRODUCTION

1.1 Background

Home to 1.9 million people, King County (the County) is the most populous county in the State of Washington and encompasses an area of approximately 2,134 square miles (About King County, King County Website). Noxious weeds are ubiquitous throughout the County, appearing in urban, suburban, and rural areas on both developed and undeveloped land, and in aquatic regions as well. Figure 1.1 – All Surveyed Noxious Weed Sites in King County presents the geographic extent of surveyed noxious weed sites throughout the County to give the reader a sense of the magnitude of the problem. The County established a Noxious Weed Control Board to adopt rules and regulations needed for the administration of the County's Noxious Weed Control Program. The goal of the program is "to provide benefits to the environment, recreation, public health and economic resources of King County by preventing and minimizing harmful impacts of noxious weeds" (Noxious Weed Program Objectives, King County Website) . Specific program objectives include:

- Eradicate infestations of Class A noxious weeds;
- Control regulated Class B and Class C noxious weeds to below levels of significant impact;
- Carry out early detection and rapid control response of infestations of new or recently detected noxious weeds with restricted distributions;
- Support the management of widespread noxious weeds, and facilitation of more effective, coordinated landscape-scale control effort;
- Educate the community about prevention and management of noxious weed infestations and increase participation in noxious weeds control activities;
- Assist and educate landowners to be responsible stewards of the land and aquatic resources of the County by eliminating or minimizing the degrading impact of invasive noxious weeds;
- Provide quality, timely, and responsive service to the residents of King County.

(Noxious Weed Program Objectives, King County Website)

In the project questionnaire that the County submitted in response to the University of Washington's request for project sponsor programs, they indicated that their Noxious Weed Control Program could benefit from an analysis of the noxious weed distribution within the County. This analysis would involve examining the distribution across time and space of high priority noxious weeds to show changes that have occurred over time as well as form the basis for modeling future trends and potential spread of these species in the county. As a mechanism of temporal analysis, the County asserted that they were keenly interested in using animations to illustrate the distribution of key noxious weed species across time using data that they have been accumulating since 1996. This, they felt, would facilitate gaging the success of the program's efforts and identify trends in weed distribution or problem areas that require special attention. As a mechanism of spatial analysis, the County asserted that they would be interested examining possible connections between observed weed distributions and geospatial data showing habitat type, soil type, property zoning, elevation, proximity to water, proximity to existing sites, and other variables. Identifying such connections could help the County forecast future weed outbreaks, identify where specific species are likely to occur and spread, and where they should focus their surveying and outreach efforts. As a team, we are assembling a package and implementation plan that consists of information, tools, and media that the County can immediately put to use to help manage noxious weeds. Our group was drawn toward this particular project because many of the geospatial analysis techniques, conceptual frameworks, and resilience practices that we have been learning over the past two years can be directly applied to providing guidance to the County in how to better manage their noxious weed control efforts.

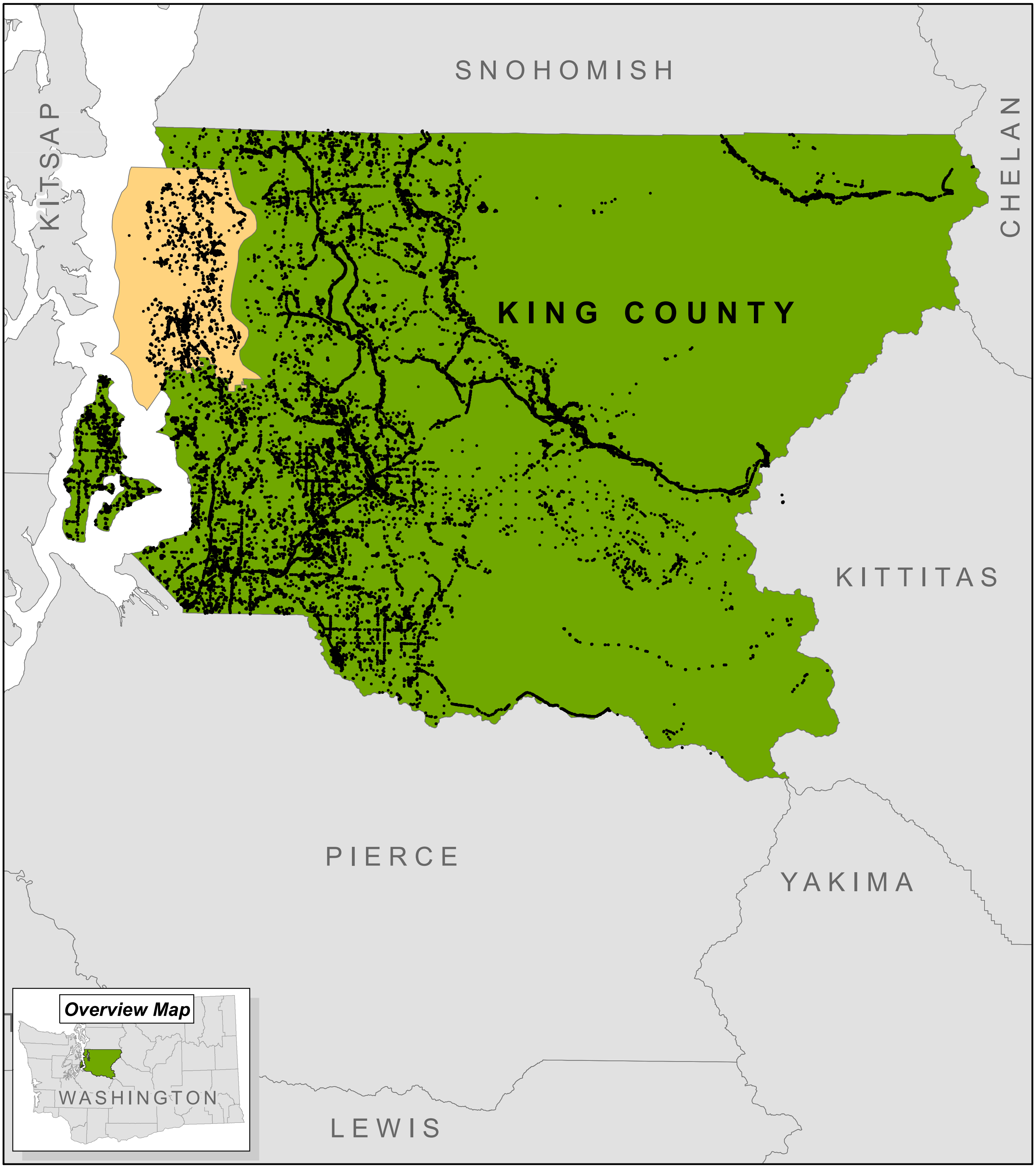
1.2 Problem Statement and Scope

To protect native vegetation species and ensure healthy habitat in King County it's important to curb the spread of noxious weeds. The Noxious Weed Control Program implemented by the County's Noxious Weed Control Board has the responsibility of preventing and minimizing the impacts from these noxious weeds. The County has limited resources and budget to draw upon to help them implement the Noxious Weed Control Program. Their ability to forecast future noxious weed proliferation, strategically apply noxious weed control measures, and provide outreach and education programs to inform and empower the public about the noxious weed problem is hampered by their limited resources and budget.

Our efforts will provide the County with important tools to help them reach their program goals. Specifically, our multi-criteria and geospatial analyses will attempt to identify connections between noxious weed extent and environmental variables such as soil and proximity to water that will help the County identify areas at risk of noxious weed infestation as well as areas where minimal threat exists. The animations that we develop will help visually communicate the current and historical extent of noxious weeds throughout the County during meetings and outreach efforts. In consideration of the limited time that our group has to work on this project, the County has requested that we focus our multi-criteria and geospatial research efforts, animations, and tool development on two Class A noxious weeds that are of specific interest to them, giant hogweed and garlic mustard, rather than spread our efforts broadly over more weed species.

Our multi-criteria analyses will enable the County to strategically respond to noxious weed infestations by looking at an area's noxious weed susceptibility score based on multiple variables relative to other infestation areas – allowing for a form of triage to be applied before noxious weed eradication actions are enacted that deplete precious county resources. Our geospatial analyses will attempt to identify correlations between specific environmental variables and noxious weed distribution, enabling the County to focus attention on potential infestation areas that may emerge based on known infestation proclivities. Our animations will help the County visualize the dynamic extent of noxious weed distributions across time and thus identify areas where noxious weed intervention measures were met with success and failure, helping them to assess the overall success of the program's efforts. The animations will also enable the public to engage with and understand the noxious weed threat via intuitive, visual media rather than through static brochures and literature. Our Python-based ArcGIS Tool will allow the County's GIS personnel to quickly produce infestation summary information and graphics for areas where fine detail is required for sites that require special attention or emphasis during internal and external meetings and/or presentations.

Collectively, our research, analyses, animation, and tool will give the County additional resources with which to continue working sustainably to mitigate the noxious weed problem. Using information and tools that allow the County to make better, more efficient use of their limited budget and resources will increase the County's ability to resiliently manage noxious weeds.



City of Seattle
King County
Surveyed Noxious Weeds Sites

Notes:
· Background data provided by King County.

0 5 10 20
Miles

Figure 1.1
All Surveyed Noxious Weeds Sites
King County, Washington

King County
Noxious Weed Control Program

2 ANIMATION

During our initial “kickoff” meeting with them, the County mentioned that creating animation sequences showing the geographic distribution over time of both garlic mustard and giant hogweed was their top priority among the deliverables that we will provide to them at the conclusion of this project. Although noxious weed data is collected for sites throughout the County, our sponsors suggested that we develop our animations within the extent of the City of Seattle because there is consistent site representation and coverage across a large temporal band within this subset of the entire data set. The County asked that we focus our efforts on these two key Class A noxious weeds for a number of reasons. The first reason is that data coverage for these two species is the most comprehensive and of the best quality in terms of accuracy and precision of all the noxious weeds in the County’s database. Much of the data for giant hogweed, for example, had been validated as a part of porting it to the County’s iMap web mapping application. Secondly, both of these species spread quickly by seed and quickly displace native species in key habitat areas like ravines and stream banks. Third, exposure to giant hogweed followed by sun exposure can cause blisters and scars, making this weed harmful to one’s health (Shaw, S. and Devine, M., 2013, p. 8-11).

The County’s noxious weeds webpage defines Class A noxious weeds as “Non-native species whose distribution in Washington is still limited”, and they continue by stating “Preventing new infestations and eradicating existing infestations are the highest priority. Eradication of all Class A plants is required by law throughout Washington” (Noxious Weeds Lists and Laws, King County Noxious Weeds Webpage). It’s obvious from the tone of these statements that noxious weeds are a concern and need to be mitigated aggressively. Our animations will largely serve as discussion points during both internal and external meetings that the County participates in to discuss approaches to controlling and eradicating these weeds so it’s important that these animations are interesting to watch and that they present meaningful data. Good data is more likely to produce good results, and in working with animations, where large temporal gaps between data records can lead to somewhat ‘jerky’ looking animations, it’s very advantageous to have as complete a dataset as possible. The County recommended the giant hogweed and garlic mustard datasets as their best candidates for this project so we are focusing our efforts on these two Class A weeds.

Our animations will convey a hybrid of quantitative and qualitative information. The underlying data driving the animations is fairly quantitative. Noxious weed infestation field data, which include plant locations, infestation areas, and cover class rating (which describes the percentage of an infestation area footprint that is occupied by the weeds, conveying density) are collected annually in a systematic fashion by trained technicians and are compiled into the County's Microsoft Access database where integrity constraints are enforced at the time of import into the database, ensuring a high degree of data quality. During an animation sequence, infestation areas for specific sites are communicated to the viewer through the use of symbols and colors. However, a visual assessment of quantitative information, which is in-effect what an animation of this data provides, invariably leads to qualitative interpretation. Although qualitative in nature, this type of interpretation has merit because leveraging the animation format enables us to communicate the results of rather dry, compiled scientific observations to a non-scientific audience in a very intuitive manner. Our animations will serve to educate the public about the proliferation of noxious weeds throughout the County, and how efforts are underway to curb this proliferation. These animations, because they are non-technical, will provide tremendous value in conveying to a non-scientific audience the extent and magnitude of the infestations of these two key noxious weed species. Additionally, the animations will draw attention to areas where eradication efforts have succeeded in curbing noxious weeds proliferation. Finally, these animations can easily be disseminated via uploading them to a Vimeo or YouTube account and embedding links to them within the County's existing noxious weed program web page. Additionally, some of the animations will be created using temporally-enabled Google keyhole markup language (KML) files that can easily be downloaded directly from the County's web site because of their small file size.

2.1 Animation Design

Animations must be carefully planned, designed, and tested to be effective in communicating patterns of geographic distribution and careful consideration must be given to several parameters that determine the resulting look and feel of the animation product. For example, animation speed or frame rate needs to be selected to present the dynamic phenomena of interest at a rate that allows the viewer to see the change that is occurring in the phenomena over time while still captivating the viewer's interest. Imagine you create an animation that presents the spread of giant hogweed over a one year period with a data spacing of one measurement per day and a frame rate of 5 frames per minute – it would be nearly impossible for the viewers to register the changes occurring from frame-to-frame and they would lose interest quickly because the animation would show change so slowly that it would be rather dull to watch. This is an extreme example but it illustrates the need to select a data resolution that ideally captures noticeable change between frames and can be compiled into an animation clip that depicts meaningful dynamic movement of a phenomenon across time.

Time allocation is another important animation consideration. Wang, Yu, and Ma mention the importance of allocating time in relation to the values of the time steps in an in an animation sequence. They assert that time steps that show a greater degree of change in the subject variable(s) should be allocated more time while time steps showing a lesser degree of change should be allocated less time (Wang et. al., 2008, p. 4). In the case of our analysis of garlic mustard, we have data coverage of the distribution of this weed that spans the years 1998-2012. Partitioning this data set into annual subsets, whereupon each subset contains the surveyed garlic mustard distribution in King County for a single calendar year, will enable us to compare the relative distributions of garlic mustard between years. The years within this partitioned coverage that show less common information with other years' data will convey more information than the years having more common information, and these may be allocated more time in the animation sequence (Wang et. al., 2008, p. 2). One means of accomplishing this is to slow down the animation frame rate during important time steps and speed up the frame rate during less important time steps (Wang et. al., 2008, p. 4). This same approach can be mirrored with the giant hogweed data set as well to produce more meaningful animation results.

Animation quality and file size are two distinct considerations that are closely related. Capturing higher quality frames for an animation sequence will invariably increase the size of the resulting animation file. Because of this, careful consideration must be made regarding the planned use of the animation and any space limitations that might exist on the host server before the image quality of the animation is selected. Additionally, the file format of the exported animation should be selected to match the needs and software available to the target audience. Proprietary, non-mainstream video formats should be avoided because they may limit consumption of the animation product to a select few that have the specialized software needed to view the animation. Formats like Microsoft's audio video interleave format (.avi extension), Apple's QuickTime format (.mov extension), Moving Pictures Expert Group (MPEG) MP4 format (.mp4 extension), and Adobe's Flash format (.flv extension) are good export options to use if one intends to make their animation products accessible to a wide audience. In our research it was discovered rather late into the project that the animation option offering the smallest possible file size (facilitating file distribution via email) was using Google Earth (GE) with temporally-aware KML files. Because Google hosts all of the imagery data on their servers and makes this data readily available, cached at multiple resolutions for fast drawing performance, the only files required to run an animation sequence by the end user are the KML files that contain the temporally-aware data. This approach does require that the end user install GE on their machine (free software) and have access to the internet. For our animation study area (the City of Seattle) these KML files were very small, making this approach very attractive.

The County has provided us with noxious weed infestation data for two Class A noxious weed species: garlic mustard and giant hogweed. They have directed us to use as much of the supplied dataset as practicable such that the infestations of these two key weed species can be visually observed over as many years and in as much detail as possible. To consolidate all of the available years of data coverage into the animations that we produced, we visually compared consecutive years of data coverage for both giant hogweed and garlic mustard to determine which years of coverage for each species showed the most unique and perhaps dynamic data distributions relative to other years. We also compiled some basic statistics for the noxious weeds areal infestation data, calculating mean, maximum, minimum, and standard deviation values for garlic mustard and giant hogweed normalized infestation areas for the years 2001 to 2012 to help us quantify trends in the data and make informed decisions about how to best present the data within the animation sequences. These statistics are presented in Table 2.1 – Normalized Infestation Area Statistics, and are illustrated graphically in Figure 2.1 – Normalized Infestation Area versus Time.

There are tens of animation considerations that could be addressed in this paper. We will focus on the design considerations that were most pertinent to satisfying the needs of our project sponsor and our group's project goals. These considerations comprise the design consideration discussions that follow.

2.1.1 Animation Platform

There are many animation platforms available. Initially, we evaluated Adobe Flash and Autodesk's Maya as possible alternative platforms for animating the County's giant hogweed and garlic mustard data but the frustration of learning how to efficiently use a new software platform and the expense of purchasing a new software package solely for the purpose of completing this project steered us in the direction of ArcGIS. Additionally, we were concerned that we could get hampered by the data incompatibilities that would plague us if we tried to transform the geodatabase and shapefile data provided to us by the County into some other non-ESRI software platform. We were aware from our International Case Studies Class (Geography 568) that animations were possible within the ArcGIS framework. However, nobody within our group had developed animations within ArcGIS or any other software prior to taking on this project. After some poking around in ArcGIS help files and after watching several YouTube videos that explained some of ArcGIS's animation capabilities, we elected to use the ArcMap and ArcScene platforms to develop our animations for the County because we reasoned that our familiarity with these interfaces would make learning how to animate somewhat easier than it would be to start trying to animate data with a completely foreign software platform. Later on in the course of our project, we also decided to use GE to present our time-enabled noxious weed infestation data. The ability to use very current, high-resolution background imagery as well as terrain and building models in the GE platform saved us time because it obviated our need to scour the internet in search of comparable digital elevation models and high-resolution imagery that we would have to import into ArcScene. Another clear advantage to using GE was the huge reduction in file size that it afforded us relative to exporting animation files from ArcScene. By leveraging the GE platform, the user does not need to store the background imagery data locally within an animation file for playback. Instead, the imagery is streamed via the internet from Google servers during animation playback. The only thing needed for an end user to view an animation sequence is a time-enabled KML or .kmz file. It is expected that the majority of the intended audience for these animations, which will likely consist of stakeholder groups, County representatives, engaged members of the public, and government officials, will have internet access and the ability to install GE on their computers. Thus, we felt that relying on the GE platform was not restricting access to the animations to a limited audience.

2.1.2 ArcGIS Animation Methods

ArcGIS 10.0 provides the user with two methods of building and controlling animations: the *Time Slider* window and the *Animation Toolbar*. The *Time Slider* window provides the user with the ability to quickly animate a layer that contains an attribute field that captures or reflects time. For example, if a data set contains an attribute field that captures the date that a river's stage is measured over several months, this data can be animated by selecting the measurement date field as "time enabled" and setting up a few parameters that control the range of dates shown, length of the animation, and so forth. After the user selects appropriate parameter settings, the animation can be played via a set of on-screen radio buttons that resemble cassette deck controls. Figure 2.2 – Time Slider Window Options presents a representative screen capture showing some of the options available within the *Playback* tab of the time slider interface. From ArcGIS, animations can be exported either to audio video interleave format (.avi extension) for playback on various media players or as sequential animation frames in either bitmap format (.bmp extension) or Joint Photographic Experts Group (JPG) format (.jpg extension) to enable combination of the frames in a 3rd party animation software package or via using the ArcGIS tool *Raster to Video,* available in the *Conversion Tools* toolbox. The *Time Slider* approach is attractive because it is simple to set up and does an ample job animating based solely on a time-enabled attribute field. However, it does not offer the user the ability to zoom around to different parts of a map while animating to show different regions or to follow the path of a moving object across a map – a feature that can be used to impressive effect in a 3-dimensional map created in ArcScene.

(Using the Time Slider Tool, ArcGIS 10.0 Help)

The second animation method offered up by ESRI is the *Animation Toolbar*. With this method, the user is granted many more options than is the case with the *Time Slider* approach. For instance, the user has the ability to move the map extent between reference positions called "key frames" during the animation sequence. After the user establishes several key frames, the software interpolates frames between them to create stepped transitions between these different map regions during animation playback – thereby simulating movement. Additional flexibility is offered by this approach through the use of time tracks. One or more animated layers can be assigned to a specific time track that governs when these layers appear during the animation sequence. Multiple tracks can be included within a single animation sequence as well giving the user the ability to transition between time tracks to control visibility of various layers during the course of the animation sequence. For example, a camera track can be used to zoom into a map region so that when a layer that is contained within a separate time track becomes active it can be seen in greater detail. Figure 2.3 – Animation Toolbar and Options presents a representative screen capture showing some of the options available within the animation toolbar. Like the *Time* Slider, the *Animation Toolbar* gives the user the options of exporting the animation to either AVI format or as sequential images. Lastly, the *Animation Toolbar* allows the user to animate data that is not time-enabled. For example, layers can be turned on and off during an animation sequence according to their order of appearance in the ArcMap table of contents, bypassing the need to have a time attribute included in their attribute tables. It's beyond the scope of this paper to fully describe all of the features offered by the *Animation Toolbar*.

(The Animation Toolbar, ArcGIS 10.0 Help)

The main disadvantage we found with using the *Animation Toolbar* method to set up an animation sequence was that it was somewhat complicated to understand and was not intuitive. However, after some research and trial and error, we managed to get things working satisfactorily. We used this approach to create a flyby animation sequence that used a moving camera track and noxious weeds data on separate time tracks to illustrate giant hogweed infestations throughout the City of Seattle in the ArcScene module. After showing our preliminary ArcScene animation results to the County, the decision was made to focus on 2-dimensional animations created in ArcMap because this allowed us more options for using aesthetically pleasing background data and produced crisper details in the final animation product. However, some weeks after this decision was made, we discovered that GE could serve as a viable animation alternative to ArcScene so we reactivated our efforts in developing 3-dimensional animations using GE.

2.1.3 Google Earth Animation Methods

We explored two distinct types of animation afforded by GE: animation via movement across space and animation via movement across time. We use the phrase *movement across space* to refer to translational movement within GE along either vertical or horizontal axes from one geographic location to another, while we use the phrase *movement across time* to refer to the presentation of various snapshots of noxious weed infestation areas in GE in sequential chronological order. Until this project, I was not aware of the fact that GE enables the playback of time-enabled data using a time slider toolbar much like that in ArcGIS. However, when reading about the *Export to KML* (Version 2.5.5) extension on ArcGIS.com, we realized that one of the features that was included with this extension was the ability to encode time stamps and attributes within the exported KML files; a feature lacking in the KML export tools included within the standard ArcGIS 10.0/ArcINFO license-level installation (Martin, K. 2013). As it turned out, this extension, although a little tricky to install, worked beautifully for creating time-enabled KML files that could be played in GE using the time slider toolbar. Additionally, the extension allows the user to select an attribute field that can be used to vertically extrude features relative to either ground surface or a user-specified elevation reference. For more information regarding the use of this extension, please refer to Appendix 8.2 – Export to KML Extension Highlights. The GE time slider toolbar is automatically added to the GE graphic user interface (GUI) when a time-enabled KML file is selected in the "Places" tab. Options for controlling animation playback are limited but include the ability to control animation speed, establish the time zone that the animation time fields correspond to, play the animation as a continuous loop if desired, and establish a timespan over which the animation will play if the user wishes to only display a subset of the timespan encompassed by the data set. Figure 2.4 – Google Earth Animation Interface presents a representative screen shot that details some of the animation options available within this platform.

Animation across space is accomplished in GE by creating a tour, whereby the viewer is “flown” from one location to the next in the GE landscape. Tours can be created by linking together place marks – saved locations analogous to a spatial bookmark in ArcGIS that, in addition to storing horizontal coordinates, also store altitude, tilt, heading, range, and other parameters that relate the place mark to the surface of the Earth. Thus, variable focal scales can be used in a single tour by zooming in to show detail at specific infestation locations and zooming out to show neighborhood trends in weed infestations at smaller scales across a broad landscape. To create the translational component of our GE animations, we created several place marks and imported GIS data from ArcGIS to supplement these place mark locations. Then we created tours by linking these place marks together into predetermined sequences while recording the output using the tour radio buttons in the GE GUI, effectively creating a flyby animation sequence. GE also allows the user to organize place marks into folders from which tours can be automatically created, obviating the need for the user to use the radio buttons.

As one would expect, animating across time in GE is slightly different than in ArcGIS. For example, two time fields must exist in the attribute table of the KML files to enable animation to occur in GE: a “start” time and an “end” time (Martin, K. 2013). This information is used to inform the animation engine in GE at what point in time to begin animating the feature and for what duration the feature should be displayed during animation playback. In ArcGIS, only a single time field needs to exist in the time-enabled layer’s attribute table to enable animation of the layer. The data that we received from the County at the onset of the project contained two time fields (“survey date” and “date”) but these fields did not reflect “start” and “end” times. The field “survey date” in the noxious weed infestation shapefile presents the date that the particular data record was surveyed in the field and essentially provides a snapshot date of the infestation magnitude at that particular site. The field “date” presents the date of the surveyed infestation generalized to one calendar year. For example, a “survey date” with a value of “March 3, 2003” would equate to a “date” of “2003”. Thus, to enable encoding of time fields into the KML files that we created, we had to add “start” and “end” time attribute fields into the source shapefiles from which the KML files would be derived and populate these fields. The existing “date” field included in the data supplied by the County served as our “start” date field because it represented the generalized date of the survey date that exists for each of the records in the attribute table. To populate the “end” date field that we added to the attribute table, we used ArcGIS’s field calculator and created an expression that added one year to the value of the “date” field. This approach enabled us to export

KML files that would display each of their data records beginning at the time of their “start” date and continuing until the onset of their end date was reached during playback.

2.1.4 Animation Objectives

In reading the project description and in the course of meeting in-person with County representatives, some clear objectives were identified for our animation efforts. First, the animations should focus on key noxious weeds species. There are 41 Class A noxious weeds species listed on the King County website – an overwhelming number to deal with in the limited time we have for this project. Fortunately, the County had anticipated this problem and in the course of our discussions with them they identified two Class A noxious weeds of particular interest to them that they preferred we focus our efforts on: giant hogweed and garlic mustard.

> Garlic mustard is an invasive non-native biennial herb that spreads by seed. Although edible for people, it is not eaten by local wildlife or insects. It is difficult to control once it has reached a site; it can cross-pollinate or self-pollinate, it has a high seed production rate, it out competes native vegetation and it can establish in a relatively stable forest understory. Giant hogweed is originally from Asia and was introduced as an ornamental. Spreading by seed, giant hogweed has escaped into numerous backyards, ravines, parks, abandoned lots, streams, woods, and roadsides. It can crowd out other plants and take over natural areas, especially in moist areas such as stream sides. (Garlic Mustard and Giant Hogweed, King County Website)

Thus, these two species became the focus of our project efforts for animation as well as for geospatial and multi-criteria analyses.

The second animation objective that was determined was to illustrate the changes in noxious weeds distribution over time – ideally across all years of data coverage within the County’s Microsoft Access database. Included within this broad objective is to identify the success of the Noxious Weed Control Program’s (NWCP) efforts, and to identify spatial trends in noxious weed distribution. The County hopes that by visualizing the distributions of these weeds across time through the use of dynamic animated sequences, eradication patterns will emerge that can possibly be attributed to program efforts and problem areas may be identified where future efforts might be concentrated. Although we are providing the County with the animations to help them fulfill this objective, we were not provided with information detailing specific noxious weed eradication efforts or the dates on which they were carried out. Thus, it is not within the scope of our report to discuss the success or failure of such efforts.

However, the trends in noxious weed distribution and magnitude that are displayed by our animations will help the County representatives with the expertise and data to make these determinations assess the efficacy of their eradication efforts over time. Additionally, we referenced Table 2.1 and Figure 2.1 extensively to identify the peaks in infestation magnitudes that occurred across the temporal range that we established for our animated sequences to ensure that some of the extreme infestation values were included as stops along our animation tours.

A third animation objective is to provide a visual tool that the County can use in meeting situations with stakeholders, property owners, and the general public to help convey visually the magnitude and extent of the noxious weed infestation problem that exists in King County to supplement the public noxious weeds information that is already available through their website and other media. Animations tend to be a more lively and eye-catching media than static printed brochures for conveying statistical summary information having a geospatial component. Additionally, animations can succeed in communicating complex spatial trends where other media are not as effective or prove too complex to understand for non-scientific audiences.

2.1.5 Normalization of Infestation Area by Cover Class

The data set that the County provided to us contains garlic mustard infestation area data from June of 1998 through August of 2012 and giant hogweed infestation area data from May of 1996 through September of 2012. The infestation area reported in the attribute table of the noxious weed data provided to us represents the total area of plants found in square feet for a given site, where each site refers roughly to an individual tax parcel. This total area is the sum of patches of plants where each "patch" is the smallest perimeter that can be established around plants that are within 50 feet of one another within the same tax parcel. During survey events, the County also estimates the percentage of ground cover occupied by a specific noxious weed species' within the footprint of its infestation area and refers to this parameter as "cover class". Because tax parcel boundaries have changed over the multiple years of data collection that have occurred, the county has switched to using parcel centroids as the mechanism of attaching noxious weed data to geographic locations. The parcel centroids do not change as drastically as the parcel boundaries over time and this approach makes it easier to continue to present legacy data relative to new survey data based on newer parcel centroids.

In our initial meeting the County suggested that we explore an approach to presenting the data that included normalizing the infestation areas reported for the various sites by their cover class values. This normalization would be accomplished through multiplying each reported infestation area value recorded in the noxious weeds attribute table by its corresponding cover class value where cover class values are available. We are in agreement with this approach because it enables us to proportion the magnitudes of the observed infestation areal footprints for each year by the percentage of weed cover observed within them, allowing for ratio-scale comparisons among the infestation sites. Normalizing the infestation area effectively removes the void space from the "area" measurement by factoring in plant density to give a more comparable metric by which to compare infestation magnitudes of various sites. Unfortunately, the cover class data available for these two species does not mirror the data coverage of their infestation areas and is more limited.

Cover class data is consistently available for garlic mustard from April 2001 and onward, and is consistently available for giant hogweed from March 2001 and onward. Although it is available for early year data for both weeds, the collection of cover class information was very sporadic. It was not until around the year 2001 that cover class information was collected at roughly the same temporal spacing as the infestation areas. Although this reduces the potential number of records we may use in our animations, we feel that have a reasonable number of infestation area-normalized records to use to create a compelling animation sequence. However, in the interest of completeness, we will still investigate the full extent of the non-normalized data set in addition to providing animations that draw upon the normalized data set if time permits. The total number of infestation site records available for garlic mustard from 1998 through 2012 is 1,559, while the total number of giant hogweed records from 1996 through 2012 is 12,270, suggesting that the giant hogweed data set may offer greater depth of coverage. When the data is normalized and records for which cover class values are not available are omitted from the data set, however, the total number of garlic mustard records is reduced to 1,038 and the total number of giant hogweed records is reduced to 2,477. Hence, the disparity between record numbers between the two species is reduced by normalizing the data.

2.1.6 Establishing Temporal Bounds for Animations

We decided to postpone our decision regarding using the complete, non-normalized data set or the more limited, normalized data set until we examined the results of both approaches, submitted these alternative animations to the County for review and comment, and had time for sufficient team deliberation following receipt of County comments. Temporal boundaries for the animations would then be determined by this decision. If we elected to use the normalized data, the starting year for both garlic mustard and giant hogweed animations would be 2001, the year marking the consistent collection of cover class data, and the ending year would be 2012, the most-recent year for which complete data is available. If we instead elected to use the non-normalized data, the starting year for garlic mustard would be 1998 and the starting year for giant hogweed would be 1996, and the ending year for both weeds would be 2012. Ideally, we would include as many years of data as possible while cautiously considering the quality of the data used. Ultimately, we decided to use the normalized data because the County preferred that approach and it is a stronger, better metric for presenting the infestation data because it accounts for weed density where the *infestation area* metric does not.

2.2 Animation Testing

In order to test our animation designs, animations were created using the *Time Slider* and *Animation Toolbar* ArcGIS animation methods as well as the *Time-enabled KML file in GE* method discussed earlier in this report. The *Animation Toolbar* and *Time-enabled KML* approaches were employed to animate the areal extent and magnitude of giant hogweed infestations in ArcScene and GE flyby-style animation sequences, respectively. ArcScene is one of two 3-dimensional viewing platforms offered by ESRI ArcGIS software. This platform enables geospatial data to be draped onto a 3-dimensional surface and viewed in oblique angles to simulate perspective viewing of an area – allowing the viewer to perceive data 3-dimensionally. During our draft ArcScene flyby sequence, the animation begins with a plan view extent of the City of Seattle and then begins zooming into the City while simultaneously moving into increasingly oblique viewing angles. After a stable oblique view has been established, the giant hogweed infestations are presented as proportional lines where line height is proportional to infestation area. Each year of infestation area coverage persists in the view for approximately 2 seconds before the animation advances to the next year of coverage, affording the viewer ample time to digest each coverage year before the next year is presented. The resulting animation sequence was visually engaging but, due to the oblique viewing angles, it was difficult to associate a given infestation with a distinct geographic area. We have included a sample of this animation as ArcScene Giant Hogweed Flyby Sequence.avi in Appendix 8.1 for reference. County was appreciative of our research and preliminary efforts along the 3-D ArcScene animation front but after some discussion, we reached agreement with them that the 2-D ArcMap-based animations would provide more meaningful information because they could be presented with a variety of background data and the spatial relationships between infestation sites and other map features and reference points could be maintained with more clarity using the 2-D approach. Based on these discussions, we chose to limit our development of the ArcScene 3-D animations and focus our efforts on the development of the 2-D *Time Slider* animation approach that both we and the County found superior in satisfying the project objectives.

During week six of the project, we learned that GE was a capable alternative to ArcScene for animating in 3-D. We began exploring this approach and were so impressed with the preliminary results that we decided to invest time and effort into developing 3-D animations with this platform despite the limited time remaining in the project. GE is a sophisticated software product that allows for visualization of the entire surface of the Earth using a range of imagery and background layers. Its greatest advantages over the ArcGIS platforms are that it is free software and that it does not require the end user to host the data that is being displayed in its GUI. There is one drawback we discovered with using GE for our 3-D animations, however, and this is the fact that King County employees are not allowed to install GE on their work computers because of permissions issues and/or copyright constraints. We learned about this limitation when we enthusiastically informed the County representatives about the great quality of our preliminary animations using GE in comparison to ArcScene. After some discussion, the County encouraged us to continue developing animations with GE because it would give the animation products the potential to reach a large audience over the internet by eliminating the need for the end user to download enormous animation files or be redirected to an animation server such as Vimeo or You Tube. Hence, we proceeded with development.

Through a combination of research, development, testing, draft animation creation, feedback from project sponsors, and revision and refinement, we arrived at our final animation products. Figure 2.5 – ArcGIS & Google Earth Animation Development presents a process diagram that details the events, decisions, and deliverables comprising our animation work.

2.2.1 Time Slider Animations

The *Time Slider* approach was used to create a series of 2-dimensional, plan view style animations, where each map in the series encompasses a fraction of the entire extent of the City of Seattle. One hurdle in making the animations we have encountered using the time slider approach is that ArcGIS prefers to base the "start" time of the animation on real data values that exist within the time-enabled attribute field in the data set. The consequence of this is that if you want to present the data in step increments of 1-year, the beginning of the time step boundary will be set to the earliest date value in the attribute table and the end of the time step boundary will be set to one year from that date. For example, if your first data point has a date stamp of March 2, 2010, your annual time steps will run from March 2, 2010-March 2, 2011; March 2, 2011-March 2, 2013… etcetera. To present the data in snapshots that show infestations that are recorded for a complete calendar year in clean, one-year time steps like Jan 1, 2010-Jan1, 2011, we had to add some 'artificial' records into the attribute table to give us this ability. We accomplished this by adding records into the attribute tables of the noxious weed feature classes dated January 1, 2001, to enable starting our time steps at the beginning of the first year where cover class information was recorded consistently for the noxious weeds. No noxious weed infestation area data was included in these supplemental records so the resulting animations did not reveal any spurious or false data – the records merely enabled the time increments of the animation sequence to start and end cleanly at the beginning of a calendar year.

2.2.2 Animation Toolbar Animations

We also created animations in ArcMap suing the animation toolbar approach. This method offers more flexibility than the time slider and includes a range of additional options, including the creation of key frames, which are basically spatial bookmarks between which additional animation frames can be interpolated automatically by the software, and animation tracks, which allow the user to explicitly control the time during which specific animation layers are displayed during animation playback. One of the greatest advantages to the animation toolbar method is its capacity to animate feature data that does not even include temporal information. With the animation toolbar, a group layer in the ArcMap table of contents can be animated – sidestepping the need for a time field altogether. Using the group animation approach, animation layers are played in the order that they are arranged within the ArcMap table of contents. We used this method to good effect in our ArcScene animations early on in animation development. However, we later abandoned animation development in ArcScene in favor of animation development in GE because the latter proved to be a better animation platform for reasons that we will discuss in subsequent sections of this report.

(The Animation Toolbar, ArcGIS 10.0 Help)

2.2.3 Google Earth Animations

To create our finished GE animation sequences, we combined the place marks tour with playback of the time-enabled KML data showing noxious weed infestation areal magnitudes over time. In this manner, the viewer is *toured* across the City of Seattle to specific destinations while the noxious weed infestation magnitudes are looped continuously across the temporal extent of the weed data. At any time during playback, the user can pause either the tour, the loop of weed infestation data, or both to focus their attention on key areas of the city or to pan and zoom to an area of their choosing. The user can resume either the tour or the loop of weed infestation at any time from any location, or elect to create their own custom tour that emphasizes key areas of weed infestation that are of particular interest to them. This affords the end user immense flexibility in how they choose to interact with the data. The tour length was deliberately kept reasonably short (~1.5 minutes) because we realize that the County needs to use these animations in meeting and outreach forums where information delivery must occur within rigid timeframes. Additionally, we used GE Pro's *Movie Maker* tool to export our tours to Microsoft Windows Media Format (WMF) file format. Although quite large, these movie files will allow interested parties a means of watching these noxious weeds animations if they do not have internet access or GE installed on their computers.

In our tests with creating animations in GE, we experimented with several parameters in an attempt to produce high-quality animation exports that captured snapshots as well as trends in noxious weed infestations across time and space. I performed much of the work after hours at my workplace because the internet connection speed available there is much faster than through my home digital subscriber line (DSL). High-bandwidth internet access is paramount when you are attempting to render and export an animation from GE because the high quality imagery needs to be sampled at very high frame rates (~60 frames per second) in order to produce smooth animations, so faster data transfer reduces the export time. Additionally, selecting a high-definition resolution of 1,280 by 720 pixels or higher for the export file will increase export rendering time but increase the image quality of the resulting animation file. We tested different navigation speeds between place marks and discovered that slower speeds produced smoother movement in the tour sequence. However, using slower movement speeds during the tour added length to the tour sequence and subsequently, file size to the resulting animation export file. In light of this, we were careful to balance fluidity and time to keep the animation file sizes reasonable and keep the motion lively.

(Steps for Recording Movies, Google Earth Pro Help)

2.2.4 Presentation Scale/Map Extent Testing

In our early phases of animation testing, we attempted to find the best compromise between enabling the map viewer to discriminate between closely spaced infestation sites and minimizing the number of map frames needed to provide coverage for the entire extent of the City of Seattle. Through visual analysis of the more densely-spaced infestation locations, we determined that a map scale of 1:24,000 appeared to be the lower boundary where the discrimination of individual infestation sites could be maintained. In order to illustrate the magnitude of the noxious weed infestation areas at the sites, we used point symbols that were graduated in size as well as in color (a form of redundant coding), growing in size and evolving to red hues of color as magnitudes increased. At this scale using a standard 8.5” by 11” page size, roughly 15 map frames were required to provide coverage of the entire geographic extent of the City of Seattle. Animations for both garlic mustard and giant hogweed were created over these 15 map extents at 1:24,000 scale. In the case of garlic mustard, the temporal bounds of the animation sequence range from 1998 to 2012, and for giant hogweed, the temporal bounds of the animation sequence range from 1996 to 2012 – in both cases the maximum ranges of date values for which infestation areas were available in the attribute table for the non-normalized infestation area data. For our draft animations, we felt it was important to present infestation area information over as broad a temporal range as possible because this approach utilized the maximum possible extent of the available data and the greatest possible number of data locations.

In setting up our map templates for the animation sequences, we utilized ArcGIS data-driven pages. This feature allows the user to create multiple map layouts from a single ArcMap document (.mxd drawing) and to dynamically change values for layout properties such as page number, map scale, data frame angle, and map name based on values captured in a polygon attribute table. By automating our map production, we were able to propagate edits made to a single .mxd document across multiple maps. This approach both saved us time and improved consistency and accuracy across maps.

After we created preliminary drafts of these animations at the 1:24,000 scale, we submitted them to the County for review and comment via sharing a Dropbox folder with them. The animation files are enormous, averaging roughly 250 megabytes (mb) in size apiece, so the Dropbox approach, whereby multiple users can synchronize the same shared folder across an internet connection and store their copy of the folder locally on their computer’s hard drive, proved invaluable in exchanging large files with multiple users that don’t share a common intranet infrastructure.

The County responded with several comments to our draft animations. To begin with, they requested that we create the animations over a maximum of 6 individual map frames, despite the loss in site detail brought on by this decrease in map scale. Thus, we re-divided the City of Seattle into 6 approximately equal map extents, ranging in scale from 1:48,000 to 1:50,000, to satisfy the County’s request. We did assert our concerns that this would result in a loss of fidelity in the data but after additional discussion with the County, we realized that a reduction in the number of total map extents of animation coverage would make the animations better suited for public consumption because it would help limit the number of animation options that the County would need to provide and explain. It also became clearer in our ongoing discussions with the County that it was more important that the animations clearly emphasize the general trends in noxious weed infestation magnitudes over time rather than the finer details of site-by-site infestation magnitudes. Through this feedback loop that we established with our County sponsors we defined focal scales that struck the best compromise in terms of illustrating both detail and general infestation trends. This allayed our fears that obscuring some data points might detract from the quality of our animation product because by taking a more general approach, we were actually better meeting the needs of the client.

The GE framework utilizes many dynamic, oblique viewing angles, causing scale to vary throughout the extent of the viewer window. Thus, we did not adhere to a common scale when presenting various place marks in the course of our animation tours because it was not possible. In creating our place marks that were used to drive our animation tours, we initially establish viewing extents that captured roughly the same six extents that were used in our 2-D ArcGIS animations. However, these six original extents were designed to work in plan-view format and they did not translate well to the oblique viewing angles we wanted to use in GE. Thus, we developed new viewing extents for the GE animations that better served the unique characteristics of each data set. For example, the giant hogweed data is distributed generally throughout the entire City of Seattle while the garlic mustard data occurs in limited data clusters throughout the City. We chose to use place marks that encompass broad geographic areas for the giant hogweed animation sequence while for the garlic mustard, we elected to use place marks that were zoomed in on infestation clusters over limited geographic areas.

2.2.5 Animation Symbology

After reviewing some of our preliminary ArcGIS-based 2D animations, the County commented that they would prefer we change our symbology for the noxious weed sites from our initial use of square-shaped symbols, graduated in both size and color to reflect infestation magnitude, to something simpler. After some discussion and exploration of alternative approaches to symbology, we provided the County with an animation that relied on proportional symbology, utilizing graduated blue circles that increase in size to reflect increasing noxious weed infestation magnitudes, and they liked this approach much more than the initial, square-symbol-driven approach. Figure 2.6 presents an example of the use of this symbology approach to illustrate giant hogweed infestations in Seattle. In consulting our Cartography textbook by

Borden Dent from an earlier course in the program, it became clear that this new approach embodied better cartographic best practice than our prior approach as well because we were presenting a quantitative metric of interest (normalized noxious weed infestation area) using symbols of the same shape and hue but using symbol size to convey infestation magnitudes rather than hue. Using different hues is generally considered an effective way to convey qualitative differences between categories but is not necessarily recommended for conveying magnitudes (Dent et al., 2009, p. 261).

The County indicated at the onset of the project that in the animation sequences that we produced, it was important to present the sites that had been monitored but for which no infestation area had been recorded as well as the sites that did register measurable noxious weed infestation areas. Normally when data that expresses a range of magnitudes is symbolized, classes are established over specific value ranges in the data. Using this traditional approach, a value of zero would exist as the minimum bounding value for a class that may encompass much larger values, making it impossible to differentiate between the zero-value locations and the locations having values near the upper end of the class range. We used definition queries to create two separate data layers in the ArcMap table of contents – one layer containing only the zero values and the other containing all values other than zero. Proportional symbology was applied to the layer containing the non-zero values and a fixed symbol consisting of a light blue circle was used to represent the sites having values of zero. This enabled us to separately control and present the sites having zero infestation magnitudes while still applying proportional symbology to the sites having magnitudes greater than zero.

After reviewing our initial animations, in which we created a separate class to represent sites having zero values to enable them to be distinguished from sites having values greater than zero, the County suggested that we create additional versions using conventional classes that included the zero values. We followed this recommendation and the resulting animations were better received by the County than the initial animations, despite the loss of the ability to discriminate the individual sites. We realized after this particular test phase that our initial approach of keeping the zero values identifiable provided good information in the sense that the viewer could easily track sites across time that expressed zero values. This was useful because it provided a metric of success of eradication efforts. For example, if a site that expressed an infestation area of 4,000 square feet in 2001 was reduced to zero infestation area by 2005 and remained zero for the duration of the remaining years monitored in the data set, the eradication efforts could be deemed a success. However, presenting these zero areas across time during an animation sequence came with a price: clutter. In working with a relatively small map scale in which to present closely spaced data points, leaving the zero values in the map as separate symbols effectively diluted the clarity of the figure-ground balance in the map. By combining the zero values into classes along with the measured infestation areas, visualization of the magnitudes of infestation became clearer in the resulting animations.

Recalling the work of Wang, Yu, and Ma, one means of tailoring an animation sequence to improve cognition of the portions of the animations that depict large or rapid changes in the temporal phenomena being depicted is to allocate more animation time for these portions and less animation time for portions of the sequence where less change occurs (Wang et. al., 2008, p. 4). We experimented with this approach by allocating more time for years where larger numbers of sites either spiked or decreased in infestation area and less time for years where the infestation magnitudes appeared to remain relatively constant across two or more time steps. The results of this test were entirely subjective but in terms of the aesthetic quality of the resulting animation sequences, we felt that the sequences that allocated the same amount of time per coverage year in the animation – typically 2-3 seconds – appeared to be the most desirable and fluid. Sequences with more time devoted to periods of rapid or widespread change appeared less fluid and perhaps more importantly, less rhythmic. In our testing we realized that it was important to maintain a steady rhythm with this style of temporal animation, despite the spikes in information delivery that may occur, because the user begins to anticipate the next frame in the sequence. Breaking up the timing appears to disturb the clarity of the information delivery and appears to detract from the quality of the animation product.

We found we were more limited in regard to symbol selection, color, and labeling of the features displayed within the GE realm than in ArcGIS. We elected to develop two symbology alternatives to present to the county: point symbols graduated in color and in height to represent the magnitude of weed infestations at their locations (redundant coding), and cylinders of a single color extruded in height proportional to the magnitude of weed infestations. We found through trial and error that extruding the points and cylinders to an elevation in meters that was equal to 10 times the square root of a point's infestation area yielded an aesthetically pleasing result when viewed in GE at the scale ranges encompassed by our animations sequences. Additionally, through visual experimentation, we determined that a cylinder radius equal to 25 feet achieved a good balance between making features visible at great distances while minimizing feature overlap when zoomed in on an area of interest. After a GIS feature class is exported to KML using the *Export to KML* extension, the radius of the cylinders is fixed and cannot be adjusted by the user. Hence, it was important for us to find a cylinder radius size and color that would provide good visibility across a range of scales and viewing angles to give the end users maximum flexibility in using this data. We are providing cylinders in red and green hues that provide strong contrast with the GE backgrounds, enabling the cylinders to remain visible across distances of several miles. Each symbology approach appeared to offer merit for different reasons so we thought it was worthwhile to offer the County a few methods of visualization of the noxious weed infestation areas within the GE environment. In the case of the point symbols, the combination of extrusion by attribute and color-coding provided a form of redundant coding that enabled the comparison of weed infestations for even distant locations. In the case of the cylinders, the larger screen area occupied by the cylinders made them visible across long oblique sight lines. Figures 2.7 and 2.8 present screenshots of the point symbology and extruded cylinder symbology, respectively, as used for the GE animations.

2.2.6 Temporal Bounds for Animations

After deliberation among ourselves, experimentation with both the non-normalized and normalized data sets, and obtaining County feedback, we elected to use the infestation area data normalized by cover class. In doing so, the temporal bounds for our animations were effectively set. The beginning point for animation sequences for both garlic mustard and giant hogweed was determined to be January of 2001, the time at which the County began to collect cover class information consistently for both of these weeds. The end point for animation sequences for both weeds was determined to be December of 2012; the end of the most recent year for which infestation area and cover class data is available for both weeds. Although this approach only allows for 12 separate animation frames to be presented, it satisfies the requests of the County, adheres to best statistical practices, and actually enhances the figure-ground qualities of the resulting maps by reducing the amount of overlapping data points – particularly in the 2-D ArcGIS-based animations.

As we mentioned previously, using the normalized data sets reduced the number of available records for use in our animation sequences. However, this actually ended up being beneficial for our ArcGIS-based animations. In our initial experiments in animating the data, we used the entire non-normalized data sets for both weeds. Additionally, our initial animation extents were presented at 1:24,000 scale in ArcMap because this was the minimum scale at which symbol overlap among adjacent sites occurred but was not excessive. In response to County comments, we reduced the number of extents required to provide complete geographic coverage across the City of Seattle for the animations from 14 extents at 1:24,000 scale to 6 extents at 1:50,000 scale. Reducing the scale necessarily increases the amount of symbol overlap among adjacent sites if the same map symbol sizes are used to represent the infestation magnitudes. However, because the number of records were reduced significantly by using the normalized data set, the amount of overlap was still acceptable. Had we changed the scale but continued to use the non-normalized data, overlap would have increased significantly. Fortunately, the tour-based approach to animation in GE that we adopted, where oblique viewing angles persist throughout the majority of the animation sequence, is not prone to the same overlapping symbol problems that are encountered when creating animations in a plan-view format.

2.2.7 Export Quality and Format

ArcGIS provides the user with two options for exporting animations: AVI format and sequential images. We explored both approaches as each approach has advantages. The AVI format is uncompressed and captures maximum quality. The sequential images approach allows the user to export individual animation frames as JPG files that can be recombined using the *Raster to Video* tool in ArcTools, which offers the advantage of reduced animation file size. Through testing we determined that the sequential images approach followed by recombination with the *Raster to Video* tool was the best compromise between quality and file size with the ArcGIS animations.

At the Pro License level, GE gives the user the capability to export tours as animation files in either WMV or AVI format. In our testing, AVI exports were superior to WMV but were enormous in size due to their uncompressed nature. Additionally, the 64 bit Windows 7 operating system that is commonly installed on contemporary computers allows a maximum file size of 2 gigabytes (GB) for exported AVI files, which is reached relatively quickly when using high-definition export settings in GE. Through testing we determined that exporting to WMV format at 60 frames per second (fps), and 15,991 kilobits per second (kbps) bitrate produced smooth results in a common high-definition (HD) format of 720x1280 resolution, and resulted in reasonably sized files relative to their quality (~100 megabytes (MB) per minute of video).

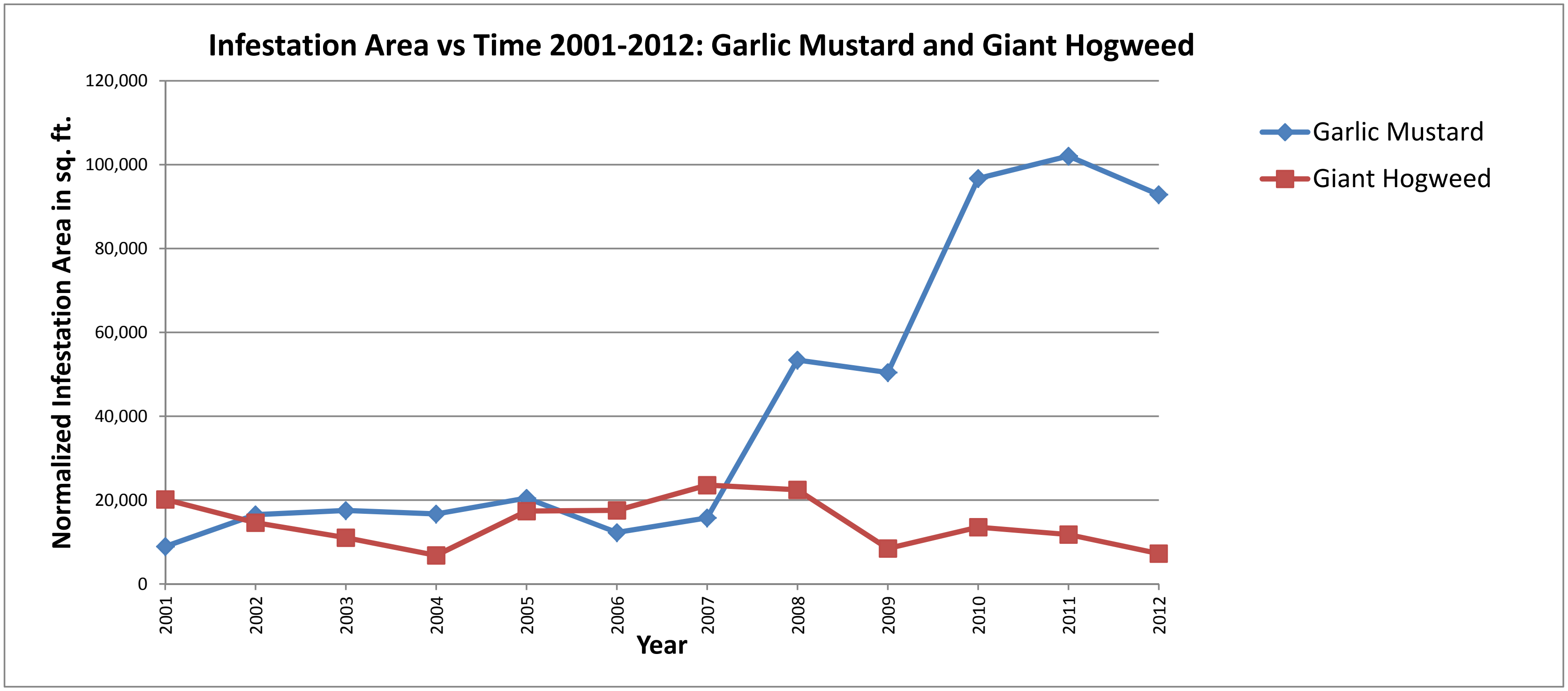
It is our hope that many persons who visit the County’s Noxious Weed Control Program web page will elect to download KML files from the site and will reproduce the GE-based animations on their own personal computers and interact with them. However, we do acknowledge that in addition to the KML files, animation video files are a necessary deliverable for the County for several reasons. For example, if playback of one of our animations is desired where internet is not available, live GE animations using KML files will not be possible. Secondly, the County has mentioned that due to permissions and copyright issues, they are not allowed to install GE on their work computers so our video files will be the only means by which they can view our GE-based animations while at work. The ArcGIS-based animations will be delivered to the County both as both animation video files in AVI format and as live mixed document format (MXD) ArcGIS documents that the County can edit, update, and modify to suit their interests over time. The GE animations will be delivered to the County in Google KML/KMZ formats as well as in WMV formats. All animation deliverables are detailed in Appendix 8.1 – Animation Deliverables, and will be included in our report on an attached DVD supplement.

2.2.8 Patterns Observed in Animations

One of the County's objectives in having us create animations for them was to watch the animations and try to assess whether or not observed patterns in noxious weed decline could be correlated with the Noxious Weed Control Program's eradication and mitigation efforts. In the course of animation testing, we determined that both ArcGIS 2-dimentional animations and GE 3-dimensional animations are effective in conveying relative infestation magnitude trends across time to the viewer but that each approach has unique strengths and weaknesses associated with it. Recall that Table 2.1 presents a simple statistical summary of the giant hogweed and garlic mustard data for the time span 2001 to 2012. We focused on this timeframe because cover class data was consistently collected for both weed species over this interval. Table 2.1 indicates that the peak value for the normalized areal sum (infestation area multiplied by cover class percentage) of all surveyed giant hogweed infestations was 23,650 sq. ft. and occurred in 2007, with the second highest value of 22,483 sq. ft. occurring the following year. Subsequent years showed a general decline in infestation magnitude for this metric. When comparing this information against the 2-dimensional ArcGIS animations, it is visibly apparent that the frequency of higher infestation magnitudes is higher for the years 2007 and 2008 than in other years included within the animation sequence. This lends credence to using ArcGIS animations to help identify patterns in infestation magnitudes across time. However, it is important to use data class ranges and symbol sizes that communicate the range of magnitudes across to the viewer in a manner that makes these differences discernible to the eye. If the symbols had been too close in size, it would not have been as easy to identify the larger infestations from the smaller ones.

When comparing the tabular infestation summary data against the GE animations, it is not as easy to identify the years over which the peak infestation magnitudes occur across a large extent of the animation frame. This is largely the result of the oblique viewing angles utilized for the GE animations. In oblique map views, distant objects appear smaller due to the use of perspective and scaling, reducing the map viewer's ability to discriminate between the infestation magnitudes of locations that are in different positions relative to the foreground and background encompassed within the field of view of a given animation frame. The plan view animations that we created in ArcGIS do not suffer from this problem because the size ranges of the symbology used to illustrate the infestation magnitudes remain constant throughout the map, enabling the viewer to easily compare sizes to visually gage magnitudes. When a GE animation sequence is designed to hover near a specific infestation colony over a number of time steps, the scaled cylinder approach that we developed for symbolizing the normalized infestation areas was very effective in communicating even small-scale variations among the values expressed by sites relatively near one another, providing a close-up view of the infestation trends across time for a limited area. We used this approach to good effect in our GE animation sequence "Garlic Mustard Greatest Hits", included in Appendix 8.1. So to reiterate, both ArcGIS and GE are effective tools for visualizing the fluctuating magnitudes of noxious weed infestation magnitudes across time but each has its niche. This realization made us appreciate our decision to provide the County with two separate animation alternatives because it demonstrates that both ArcGIS and GE animations have merit and act to complement rather compete with one another. To reiterate a point made in our *Animation Objectives* section, although we are providing the County with animations to help them correlate observed declines in noxious weed infestation at specific sites across time, we were not provided with information detailing specific noxious weed eradication efforts or the dates on which they were carried out. Thus, it is not within the scope of our report to discuss the success or failure of such efforts. However, the trends in noxious weed distribution and magnitude that are depicted visually by our animations will complement the County's knowledge of intervention and eradication activities to help them identify sites where their countermeasures have been effective or not.

Figure 2.1 - Normalized Infestation Area vs Time



Notes: 1 Infestation area represents the total area of plants found in square feet for a given site. It is the sum of patches of plants where each "patch"is the smallest perimeter you can draw around plants that are within 50 feet of one another. An area of "0" means no plants were found at a given site on the given year and these values have been excluded from our analysis.

2 Cover class represents the percentage of ground cover occupied by a noxious weed species within the footprint of its infestation area.

3 Normalized infestation area is given by the product of (infestation area) X (cover class).

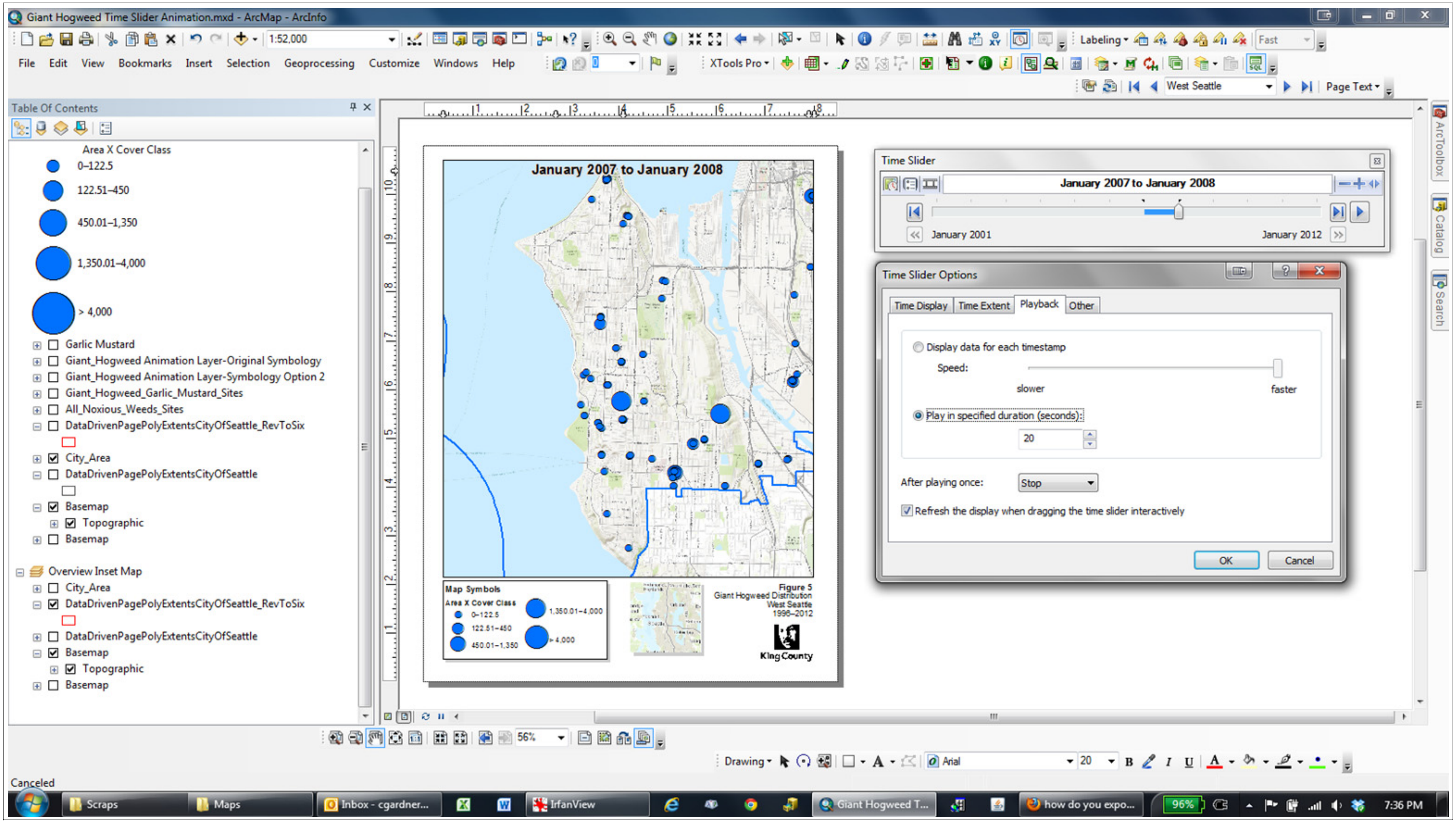


Figure 2.2

Time Slider Window and Options

King County
Noxious Weed Control Program

Notes:

·Noxious weed data provided by King County.

·Imagery provided by ESRI Basemaps Layer.

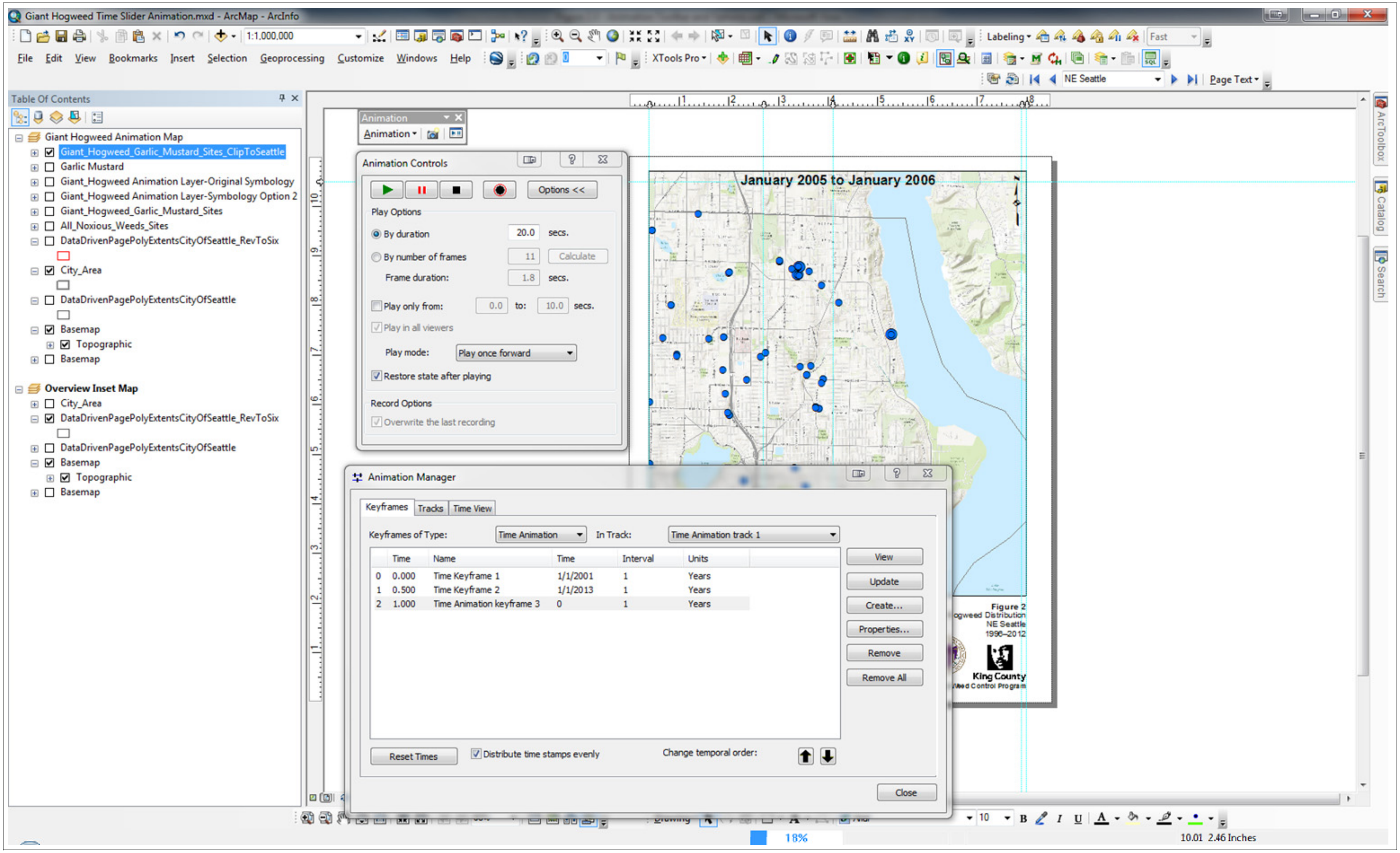


Figure 2.3

Animation Toolbar and Options

King County

Noxious Weed Control Program

Notes:

- Noxious weed data provided by King County.
- Imagery provided by ESRI Basemaps Layer.

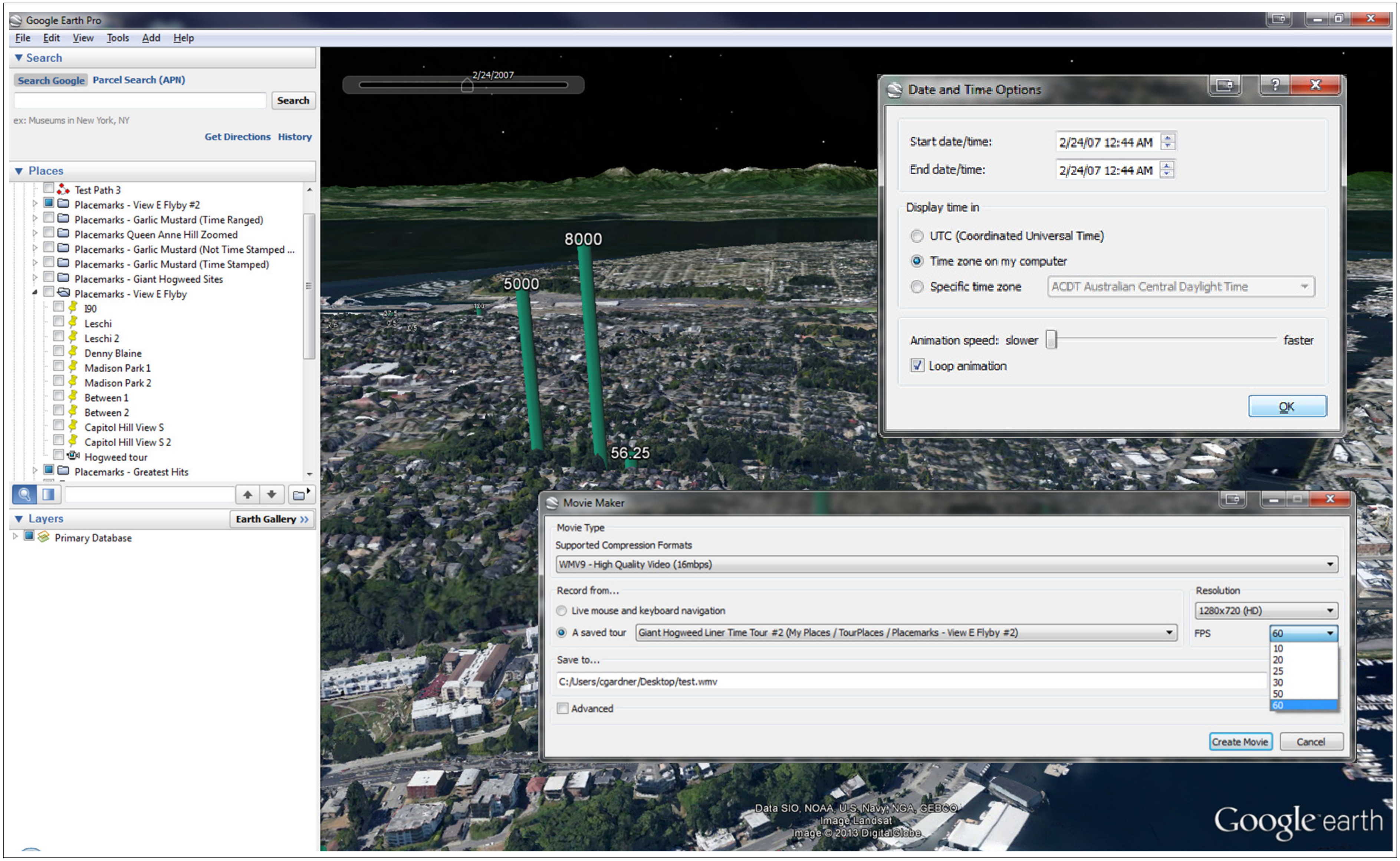


Figure 2.4

Google Earth Animation and Video Interface

King County

Noxious Weed Control Program

Notes:

·Noxious weed data provided by King County.

·Imagery provided Google and its imagery partners.

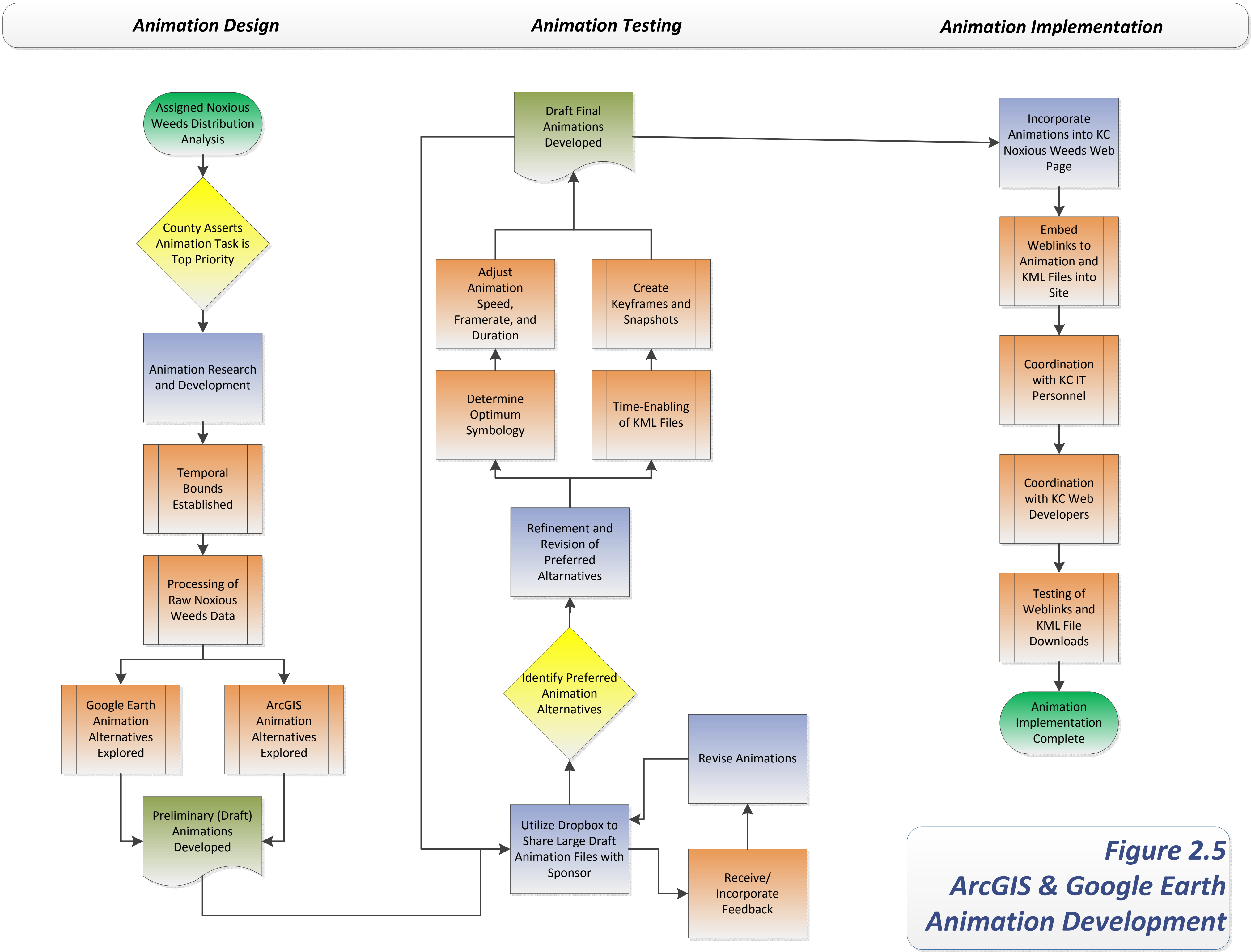
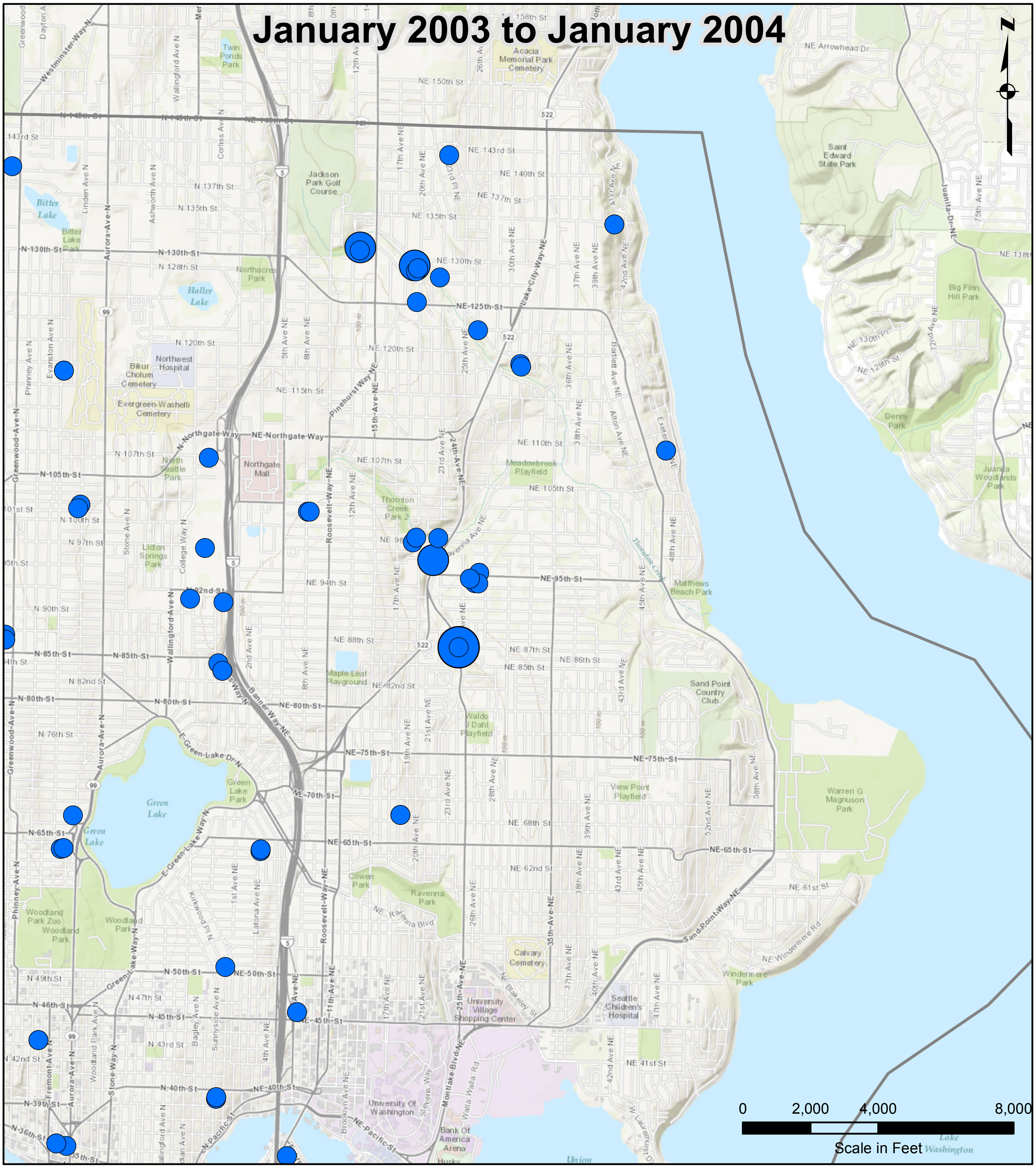


Figure 2.5
ArcGIS & Google Earth Animation Development



Map Symbols

Area X Cover Class

- 0–122.5
- 122.51–450
- 450.01–1,350
- 1,350.01–4,000
- > 4,000

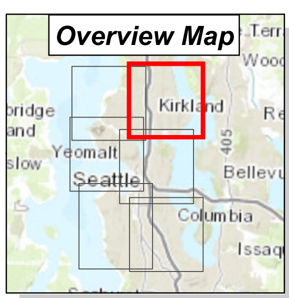


Figure 2.6
Giant Hogweed Distribution
NE Seattle
2001–2012

King County
Noxious Weed Control Program

Notes:
· Noxious weed data provided by King County.
· Background data provided by ESRI Basemap Layers.

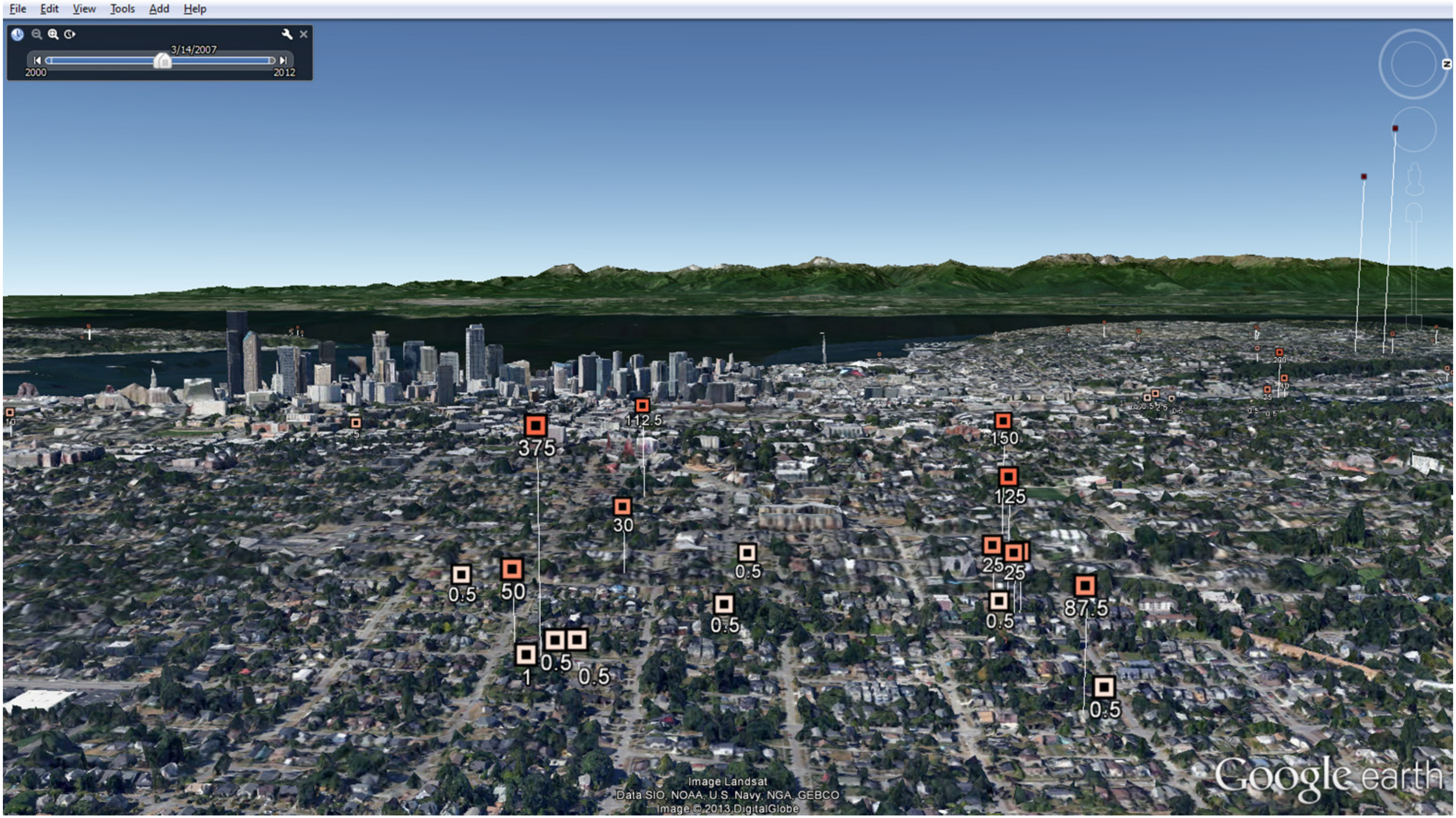


Figure 2.7

Graduated Point Symbology – Google Earth

King County

Noxious Weed Control Program

Notes:

·Noxious weed data provided by King County.

·Imagery provided by Google and its imagery partners.

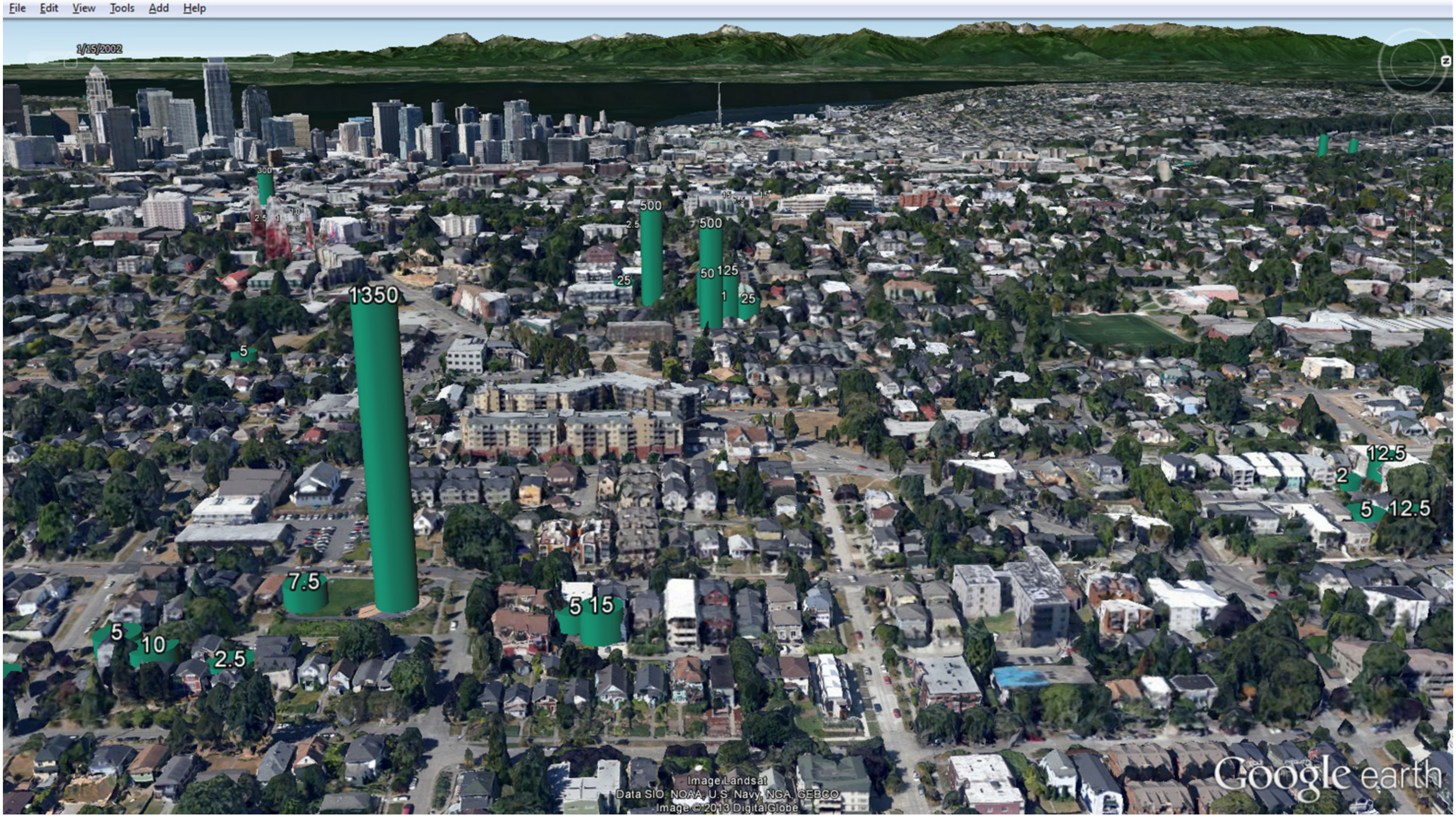


Figure 2.8

Green Cylinder Symbology – Google Earth

King County
Noxious Weed Control Program

Notes:

·Noxious weed data provided by King County.

·Imagery provided by Google and its imagery partners.

Table 2.1 - Normalized Infestation Area Statistics

Giant Hogweed - Area Normalized by Cover Class

Year	Count	Minimum	Maximum	Sum	Mean	Std. Deviation
1/31/2001	**334**	0.10	5,625	20,173.1	60.4	334.0
1/31/2002	320	0.10	1,875	14,634.8	45.7	161.2
1/31/2003	290	0.10	3,750	11,055.6	38.1	229.9
1/31/2004	167	0.10	625	6,832.2	40.9	93.1
1/31/2005	240	0.10	2,500	17,390.3	72.5	208.4
1/31/2006	230	0.10	3,750	17,555.0	76.3	293.3
1/31/2007	226	0.10	**8,000**	**23,565.0**	104.3	**631.1**
1/31/2008	184	0.10	4,000	22,483.5	**122.2**	453.7
1/31/2009	127	0.10	2,900	8,479.5	66.8	278.1
1/31/2010	120	0.10	5,250	13,554.5	113.0	548.5
1/31/2011	146	0.01	2,900	11,811.5	80.9	280.2
1/31/2012	85	0.05	2,175	7,262.5	85.4	267.3

Garlic Mustard - Area Normalized by Cover Class

Year	Count	Minimum	Maximum	Sum	Mean	Std. Deviation
1/31/2001	16	0.10	5,000	8,953.8	559.6	1188.4
1/31/2002	37	0.10	10,000	16,545.4	447.2	1647.9
1/31/2003	47	0.10	7,997	17,533.6	373.1	1263.7
1/31/2004	56	0.10	6,819	16,698.4	298.2	977.8
1/31/2005	65	0.10	7,500	20,486.3	315.2	1073.2
1/31/2006	66	0.10	2,392	12,293.1	186.3	473.9
1/31/2007	78	0.10	3,175	15,789.0	202.4	574.2
1/31/2008	86	0.10	30,000	53,429.6	621.3	3377.7
1/31/2009	116	0.10	25,000	50,457.2	435.0	2344.1
1/31/2010	150	0.10	67,500	96,737.6	644.9	5494.7
1/31/2011	153	0.01	**70,000**	**102,082.8**	**667.2**	**5657.5**
1/31/2012	**168**	0.05	49,000	92,882.0	552.9	3937.9

Notes:
1. Infestation area represents the total area of plants found in square feet for a given site. It is the sum of patches of plants where each "patch"is the smallest perimeter you can draw around plants that are within 50 feet of one another. An area of "0" means no plants were found at a given site on the given year and these values have been excluded from our analysis.
2. Cover class represents the percentage of ground cover occupied by a noxious weed species within the footprint of its infestation area.
3. Normalized infestation area is given by the product of infestation area times cover class.
4. Values presented in **bold** represent categorical maximums.

3 MULTI-CRITERIA ANALYSIS

In order to assist the County Noxious Weed Program staff in their goals of eradicating noxious weeds and in their education and outreach efforts, we also have decided to do a multi-criteria analysis to seek out areas of King County that can be considered "Moderate to High" or "High" risk areas for garlic mustard invasion. From this analysis, we then created an 'invasion risk' map to visualize the risks. We chose to focus our MCA efforts on garlic mustard for two reasons: the first being that garlic mustard is one of the two key Class A noxious weeds for which they have an abundance of and the second being that during our literature review we found a previous study that proved to be a useful model. Multi-criteria modeling is "run in a GIS that allows for the combination and weighting of multiple factors" (Krist et.al., 2007, p. 94). By ranking and weighting multiple variables and then combining them in a raster-based weighted sum, we are able to see an area's susceptibility for garlic mustard outbreak. Eradicating noxious weeds once they have invaded an area is a difficult task because outbreaks are difficult to spot and removal is a labor intensive affair. By creating an 'invasion risk' map through a MCA, the County can take some preventive measures towards stopping garlic mustard outbreaks before they happen. By knowing where to look, staff can concentrate their prevention efforts with those land owners areas deemed "Moderate to High" and "High" risk. Additionally, an 'invasion risk' map can assist County staff in their education and outreach efforts by being able to effectively visualize the risk of noxious weeds. The resulting map from this analysis can assist in giving the public a sense of urgency regarding noxious weeds outbreaks.

3.1 *Multi-Criteria Analysis Design*

In order to effectively design a multi-criteria analysis model, it is important to understand exactly what an MCA is. An MCA could certainly be done in a number of ways, but we have chosen to use a process we utilized for mapping forest insect and disease risks. A summarized list of the process includes the following steps for determining forests' risk to insects and disease (Krist et. al., 2007, p. 7-10):

1. Identify a list of risk agents,
2. Identify, rank and weight criteria that determine susceptibility and vulnerability to each risk agent,
3. Re-scale risk agent criteria values and combine the resultant maps in a model of risk potential using a weighted overlay,
4. Compile the resultant values from previous step and identify areas on a base map that are at risk.

As mentioned in the four steps above, it is highly important to design the MCA to include variables (risk agents) that are known to contribute to garlic mustard outbreaks. Equally important is to then determine the rankings of these risk agents and the particular weight to give each of them. Garlic mustard, like most noxious weeds, is adept at moving in to many different types of landscapes. For this reason, when designing our MCA, we leaned heavily on the work of a previous MCA done in the Upper Peninsula of Michigan. Basing our model on a peer-reviewed model gives our MCA a certain credibility from the outset and allowed us to move forward quickly with our data gathering. The following sections will detail how our group moved through each of the four steps.

3.1.1 Multi-Criteria Analysis Datasets (Risk Agents)

The first step in the process is identifying the risk agents and gathering the various GIS datasets of those risk agents. Based off our discussion with King County staff and our literature review, we collected the following risk agents: known garlic mustard observations, dispersal pathways (roads, rivers, trails, and railway lines), land cover, soil pH, and soil drainage class. We drew upon multiple existing datasets to bring together the data requirements for these risk agents. These datasets included both raster and vector datasets. Additionally, we derived several new datasets to complete our analysis utilizing the source data we gathered. For example, we created a raster of soil pH for King County from data that originated as a table in Microsoft Access. Our data layers were sourced from King County Noxious Weed Program staff, the United States Geological Survey (USGS), the United States Department of Agriculture's National Cooperative Soil Survey, and the King County GIS Data Portal. All datasets were incorporated and arranged appropriately into the capstone project file geodatabase before any data analysis was conducted. Importation of all vector data into feature datasets and all rasters within this file geodatabase provided us a means of grouping together related datasets and ensured that all data conformed to the same spatial reference, improving drawing performance and spatial consistency. All of these rasters and vector files are listed in Appendix 8.5: Dataset List. This appendix contains information regarding the layer name, definition, important attribute fields, and data source reference.

Garlic mustard cannot spread if it has not already taken hold somewhere. Because wind dispersal is virtually non-existent (Cavers et. al., 2003, p. 225), seeds fall close to the mother plant. Thus it is safe to assume that areas that are close to known sites are more likely to have new garlic mustard outbreaks. Therefore it is important to have known garlic mustard observations as part of the MCA. As mentioned earlier, King County staff asked us to focus our efforts on garlic mustard and giant hogweed because they were two Class A noxious weeds for which they had an abundance of data. Therefore it was a simple process of communicating with Edward McFarlin of King County's Noxious Weeds Program in order to obtain the data. Edward was able to email our group pre-existing point shapefiles of garlic mustard sites (as well as giant hogweed) that we imported as a feature class into the "Noxious Weeds" feature dataset within our geodatabase. With these point locations, we then used the Spatial Analyst tool 'Euclidean Distance' tool to determine how close to garlic mustard sites all areas of King County are. The result of running this tool is a raster containing distance from garlic mustard sites for each cell. The cell size for all pixels is 30 meters to be consistent with our land cover data. It is this raster that serves as the GIS layer for the weighted sum analysis.

Additionally, garlic mustard does not have the ability to spread without certain pathways on which to do so. Most garlic mustard seeds remain dormant for at least a year before they germinate (Cavers et. al., 2003, p. 226). Therefore, human, animal and water disturbances to the soil in which the seeds are dormant can result in the seeds attaching to humans and animals and being dispersed over long-distance (Shartell et.al., 2011, p. 117). To model human dispersal we needed their primary land-based methods of traveling: roads, trails, and rail lines. We downloaded vector line files for all three from the King County GIS Data Portal and imported them into a 'Roads' feature dataset in our geodatabase. Also from the King County GIS Data Portal, we downloaded the streams shapefile and imported it into the 'Hydrology' feature dataset. This file has all streams for King County from levels 1 to 6. The first step in being able to create a dispersal path risk agent was to narrow down the amount of streams. We chose to utilize stream levels 1 and 2 because they cover the primary waterways (i.e. Cedar River, Duwamish River, Skykomish River, etc.) and not the very small, short tributaries. We did this because we are concerned with garlic mustard's ability to disperse to far reaching areas and this will mostly occur in these primary waterways. The second step in being able to use this data was to merge the four files (roads, trails, railways, and streams) into one file. After doing so, we ran another Euclidean distance function to determine how far each area of King County was away from one of these four dispersal risk agents.

Garlic mustard most frequently invades areas of deciduous forest and urbanized areas, but can also be found in many other types of land cover (Shartell et. al., 2011, p. 120). This data was obtained from the 2006 National Land Cover Dataset (NLCD) from the USGS in a raster format. The original downloaded NLCD is for the entire continental United States and is a 1.1 Gb file. Because of this size, we clipped file to King County in order to reduce the memory space needed in the geodatabase and to make processing times faster when using it in analysis.

The final risk agents to consider were both soil characteristics: pH and drainage class. Both of these characteristics are found in the Soil Survey Geographic Database (SSURGO) format from the USDA's Natural Resources Conservation Service. Soil pH data was in compiled soil horizon level datasets and soil drainage class was stored at the component level of soil geography. Both of these datasets were in Microsoft Access table format. SSURGO data is mapped at the soil map unit level, for which all horizon and component data can be joined, therefore we also downloaded a map unit polygon shapefile. Each soil component consists of multiple horizons of varying depths. Each horizon has a unique ID that is linked to its corresponding component. For each horizon, the varying depths can have the same or different pH data. In order to determine one pH number for the component, we first had to do a weighted depth average. To do this we determine the percentage each horizon depth had versus all other horizon depths in that component. Those percentages were then multiplied against each horizon's pH value. Those sums were totaled to get the weighted depth average for that soil component. Once a final pH value was determined this table was joined to a component table. At this point, a similar process was necessary to then move the component level soil pH data to the map unit level. However, instead of a weighted depth average we needed to perform a weighted area average. Each component had a unique ID that correlated to a particular map unit. The percentage of area for each component within the map unit was calculated and then multiplied by its soil pH value. These new values were then totaled to determine a final map unit level soil pH value. This table was then joined to the map unit polygon geography in ArcGIS. At this point the data was ready to use in an MCA. Soil drainage class did not need any data processing as all components that shared a map unit unique ID also shared the same drainage class. As we did with the soil pH data, we simply needed to join the table to the map unit polygon feature class in order to use in a GIS-based MCA. Because we were performing a raster based MCA, the final step in processing soil data was to convert both drainage and pH vector polygons to rasters. This was done with the 'Polygon to Raster' tool in the 'To Raster' sub-toolbox inside the 'Conversion Tools' toolbox.

3.1.2 Ranking and Weighting Risk Agents

Now that all necessary data was obtained and processed it was necessary for us to rank and weight each variable. Again, we leaned heavily on a previous MCA for garlic mustard invasion risk and our discussions with County staff in determining the ranks and weights. Shartell uses three different multi-criteria models, one for introduction risk, another for establishment risk, and finally one for spread risk (Shartell et. al., 2011, p. 120). For our purposes we felt one model was a more appropriate choice as it would be easier to accomplish and would still be quite capable of showing an invasion risk. In the introduction model, Shartell utilized dispersal, vegetation, soil drainage, soil pH and 'other' features. 'Other' features were locations like campgrounds and structures. Their analysis was done in the mostly rural and isolated Upper Peninsula of Michigan. These features also were only weighted as 7% of the model. Due to the low weighting and since our analysis was for a county with a large amount of development, we decided this portion of the model was unnecessary. During a meeting with Edward McFarlin from King County, he felt it was essential to include known garlic mustard sites in the analysis and should be the most heavily weighted. With this in mind we settled on the four remaining risk agents from Shartell's introduction risk model with the addition of known garlic mustard sites.

Having decided on these risk agents, we then proceeded to rank each variable on a scale of 1 to 5 depending on the particular characteristic's susceptibility to garlic mustard invasion, with 5 being the most susceptible. The first risk agent we scored was proximity to known garlic mustard sites (Table 3.1). For known sites, we scored areas within 200 meters as a '5', areas between 200 meters and 400 meters a '4', and 400 to 600 meters a '3'. All areas beyond 600 meters were given a score of '0'. It is important to give all areas a score regardless if they are at risk or not because if an area has no score it will not be considered in the final weighted sum analysis. This holds true for all risk agents considered.

For proximity to dispersal pathways, we used the four methods of dispersal (roads, trails, rail, and waterways) Shartell utilized, but with Ed McFarlin's suggestion, we shortened the distance bands in half. Areas within 100 meters were scored '5', areas 100 to 200 meters were scored '4' and areas between 200 and 300 meters were scored '3'. All areas beyond 300 meters were given a score of '0' (Table 3.2).

For the land cover risk agent, we ranked 16 different land covers from 1 to 5 (Table 3.3). Deciduous forest was given the highest ranking of '5' due to it being the land cover where garlic mustard is most often found (Meekins et. al., 1999, p. 743). We ranked developed areas and mixed forests a '4' because Garlic mustard is often found in urban areas and mixed forests also are composed of deciduous trees, although not necessarily the most dominant (Shartell et. al., 2011, p. 116). For evergreen forests and shrub/scrub we mostly used our judgment to give them a ranking of '3', while only assigning a '1' to these remaining land covers: grassland/herbaceous, pasture/hay, cultivated/crops, woody wetlands, and emergent herbaceous wetlands. And open water, perennial ice/snow and barren land (rock/sand/clay) were given scores of '0'.

Because garlic mustard is most often found in mesic shaded areas as well as well-drained sunny sites and forested areas (Meekins, et. al., 2002, p. 258), a ranking of '5' was given to moderately well drained and somewhat poorly drained. Decreasing susceptibility resulted in a decreasing risk score. Well drained and poorly drained soils scored '4'. Very poorly drained and somewhat excessively drained were given a score of '3'. Finally, excessively drained and water were given a score of '1' (Table 3.4).

Soil pH scores were also ranked according to their suitability (Table 3.5). Whereas Shartell rounded to the nearest whole number, we chose to use the actual pH value. This allowed us to have a more graduated scoring system than Shartell. According to Shartell, "garlic mustard prefers neutral to basic soils" so pH of 6 to 7 was designated '5'. We then scored pH values of 5.5 to 5.99 a '4'. Values of 5.0 to 5.49 were scored '3' and the range of 4.5 to 4.99 was scored '2'. 4.0 to 4.5 were to be scored '1', although no areas of King County had pH values this low. If an area did not have a pH value it was given a score of '0' (Shartell et. al., 2011, p. 120).

The final task in this second step of our process is to decide on weighting scheme to be used in our overlay weighted sum MCA (Table 3.6). Originally we had planned on using Shartell's introduction model as our base model. However, after discussing the MCA with Edward McFarlin of King County, we decided add in known garlic mustard sites as the most heavily weighted on top of the four primary risk agents from Shartell. We used our judgment to assign a weight of 33% of the final score to proximity to known garlic mustard sites. Shartell gave weights of 43% to proximity to dispersal pathways, 22% to land cover, and 14% to both soil drainage class and pH values (Shartell et. al., 2011, p. 121). Again, using our judgment, we decided to maintain the relative weights of the four risk agents to each other. These four risks combined for 93% of the original introduction risk model weights. "Other features" were not used in our analysis, but they accounted for 7% of Shartell's model. Using proximity to dispersal pathways as an example, we divided the 43% weight by the total weight of 93% to get its percentage of the total weight, resulting in 46.2% of the total weight. We then applied this percentage to the remaining 67% weight after assigning 33% to proximity to known garlic mustard sites. After multiplying 46.2% by 67 the result is a weight of 31% for proximity to dispersal pathways. After doing this for the remainder of the risk agents, we ended up with weights of 16% for land cover, 10% for soil drainage class and 10% for soil pH value. This methodology allowed us to have weights equal the desirable 100% without randomly assigning values.

3.1.3 Re-scale Risk Agent Criteria Values

The Weighted Sum tool (found in the Overlay sub-toolbox inside the Spatial Analyst Toolbox in ArcGIS' ArcToolbox) requires raster layers with integers to function. This made it necessary then to use the previously decided upon rankings to re-scale the risk agents into the proper format. In order to do this, we utilized the Reclassify tool (found in the Reclass sub-toolbox inside the Spatial Analyst Toolbox). This tool makes it a simple process. Double-clicking the Reclassify tool opens an interface that has four requirements. The first is to choose the input raster. Second, the user must choose which attribute field from the input raster is to be reclassified. Both of these first choices are easy as there are drop down menus that give the user the available choices. Once the attribute field is chosen, all the 'Old' values are populated. An adjacent column for 'New' values can be edited and this is where we 'plug-in' our designated rankings. The final requirement for the tool is to simply name the output raster and designated where it is to be stored. We simply added "_reclass" to the end of our input rasters to make them easy to find and sent the output rasters to our geodatabase. This tool was used to re-scale three of our risk agents: proximity to known garlic mustard sites, proximity to dispersal pathways, and land cover. These three risk agents' original format was a raster therefore the Reclassify tool was the most appropriate method. We created individual maps (Figures 3.1, 3.2, and 3.3) of these three reclassified rasters in order to help us better understand our final results. By being able to visualize input risk agents and their geographic spread, it is easier to gain a grasp of the geographic distribution of invasion risk countywide. However, for our soil drainage class and soil pH values, we manually re-scaled them while they were still in vector polygon format. This was necessary because, as mentioned previously, we needed to convert these polygons to rasters. If an attribute is to be brought along in the conversion process, it must be in an integer format. Thus, we needed to re-scale the soil characteristics first before we converted. This was done by adding a new field in each polygons attribute table that would contain the ranking. We selected the particular characteristic we wanted to re-scale, then opened the attribute table, clicked on the 'Show selected features' button, and used the Field Calculator to change the selected features to the associated ranking. As an example, for soil drainage that needed to be ranked '5', we first 'Selected by Attribute' those polygons that had a drainage class equal to Moderately Well Drained or Somewhat Poorly Drained. Then after opening the attribute table and showing just those selected features, we used the Field Calculator for our newly created field ('drain_rating') to equal '5'. We then proceeded to change the selection for those classes that were ranked a '4' and repeated the process. This process was repeated for the soil pH values as well. Once this was done for all of the different rankings for drainage and pH, we then used the Convert to Raster tool to create a raster for each risk agent based on the 'drain_rating' and 'pH_rating' fields. Again, we created individual maps (Figures 3.4 and 3.5) of these risk agents to give us a more in-depth comprehension of the final MCA results. Having done this for these two risk agents, and reclassified the other three agents, we then brought all five rasters into one ArcGIS map document in order to analyze them.

3.1.4 Creation of Invasion Risk Map

Having done all of the "hard" work of data gathering, processing, reclassifying and overlaying for weighted sum, we then created a final invasion risk map (Figure 3.6). To accomplish this task, we utilized the 'Weighted Sum' tool in the 'Overlay' sub-toolbox in the 'Spatial Analyst Tools' toolbox. This tool allowed us to consolidate the different variables into one unique raster with risk scores for each cell. For each re-scaled variable, the weight chosen was multiplied to each cell's risk score. The five scores were then totaled to produce a final invasion risk score for each of the 1.2 million cells in the analysis area. These scores ranged from zero to 4.9, meaning no cell scored a '5' for each of the five variables. The next step was to reclassify the raster into invasion risk scores of integers from '1' to '5' based on the level of risk in order to more easily use unique values in the symbology. Scores of 2.0 or lower reclassified to a '1' and called "Low Risk". Scores from 2.0 to 3.0 were reclassified to a score of '2' and labeled "Low to Moderate Risk". Scores from 3.0 to 4.0 were reclassified as a '3' and called "Moderate Risk". And scores from 4.0 to 4.5 were reclassified as a '4' and labeled a "Moderate to High Risk". And lastly any score greater than 4.5 was reclassified as a '5' and labeled "High Risk".

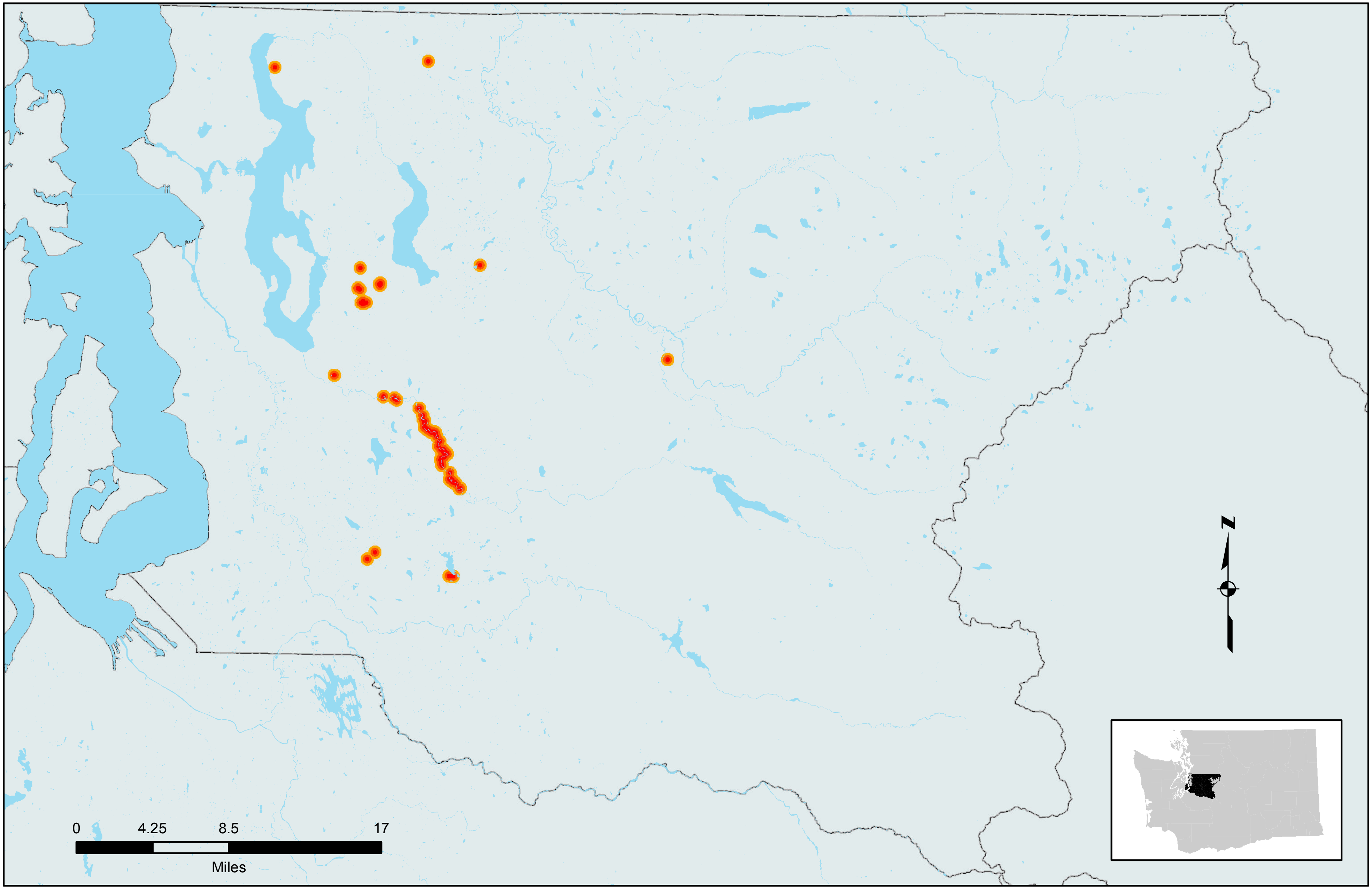
3.2 *Results*

The final invasion risk map symbology was done in the same color scheme as the five different variable maps in order to maintain consistency. Having analyzed the individual variable maps, looking at the distribution of the scores in the final invasion risk is both understandable and surprising at the same time. What we see is understandable because each variable had that westerly slant as far as high risk scores. In the invasion risk map, the western half of the county is predominantly orange to red, which clearly reflects the high risk nature for each of the variables. However, initially I would have expected to see more areas in the "Moderate to High Risk" and "High Risk" areas. The individual variable maps all paint a picture of susceptibility in the western half of the county, but the weighted sum analysis only results in 1.7% of analyzed cells with a score of 4.0 or higher. This can be explained by the weighting scheme however. For example, 42.2 percent of the cells analyzed score '4' or '5' for soil pH, but soil pH is only given a weight of 10% in the analysis. Due to the known garlic mustard sites being given at 33% of the total weighted scheme, they have a much larger effect on the final analysis. As a result, only those areas that are within 600 meters of a known garlic mustard location even have the possibility of scoring more 4.0 or higher. Because of the weighting scheme, the highest possible score an area could have outside of the 600 meters is 3.35. When examining the final distribution of risk scores, it is obvious how much of King County scores at least 3.0 in areas outside of those areas immediately next to known garlic mustard sites. Fully 8.8% of the scored areas are classified a '3' or "Moderate Risk". This suggests that these areas, although not in immediate risk of garlic mustard, will be at a much higher risk if garlic mustard continues to spread into these areas.

3.3 *Lessons Learned*

With all projects, there are aspects that we wish could have been better. While the MCA is entirely credible and defensible, we do believe it could perhaps be better. The first thing that jumps out when examining the invasion risk map is the lack of data for the City of Seattle. Because we used soil pH values in our analysis, we were unable to incorporate the city into our work. Currently, the Soil Survey Geography (SSURGO) data only has full data tables for the western and eastern portions of King County, but only has map geography for the city. Although the city only accounts for approximately 4% of the land area of the county, it contains approximately 79% of the known garlic mustard observations. Part of this high number is due to more easily being able to monitor and respond to sites in the city. But it is also a reflection of the amount of disturbance that occurs in urban areas and the resulting invasions of non-indigenous species. Clearly though, with such a large representation of observations being in the city it would have been quite useful to be able run the MCA including the city. There is a flip side to this idea though. Because the city already has the majority of garlic mustard observations, County staff is already well aware of where the risks are, which in effect, is the entire city. By only doing analysis for the County outside of the city, the map is better able to suggest new areas for surveying, monitoring, and engagement efforts.

Additionally, we might have been better able to localize our model. Our MCA was based on a model done in the Upper Peninsula in Michigan, not one done anywhere in the Pacific Northwest. Garlic mustard is a highly adaptable plant and, although literature certainly generalizes variables of susceptibility, it is possible that different conditions exist in King County than they do in the Upper Peninsula of Michigan. To that end, perhaps the results of a geographic weighted regression could have been useful in informing a more localized model. Other independent variables like slope, aspect, elevation, demographics, etc. might have an effect in garlic mustard sites. Using a geographic weighted regression analysis might suggest certain variables be included in an MCA, but also could possibly eliminate some of our existing variables.



Proximity to Garlic Mustard

- 3 - Between 400 and 600 meters
- 4 - Between 200 and 400 meters
- 5 - Within 200 meters

Figure 3.1

Garlic Mustard Multi-Criteria Analysis
Ranking for Proximity to Known Garlic Mustard Sites

Known garlic mustard locations were obtained from King County Noxious Weeds Program staff. A Euclidean distance measurement was run to obtain proximity to locations for areas in King County. Only those areas within 600 meters were given a ranking.

King County

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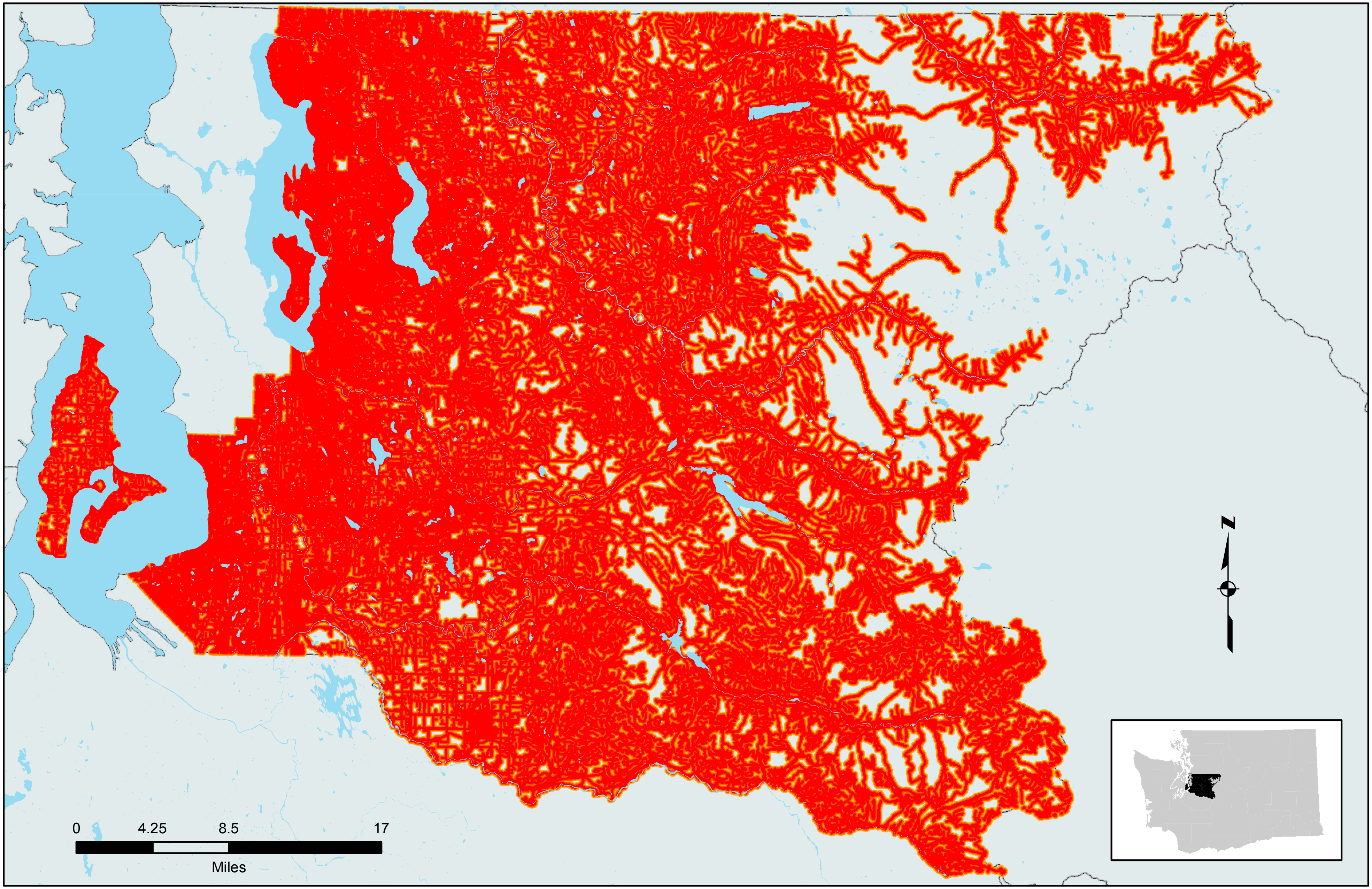

Proximity to Dispersal Pathways

- 3 - Between 200 and 300 meters
- 4 - Between 100 and 200 meters
- 5 - Within 100 meters

Figure 3.2

Garlic Mustard Multi-Criteria Analysis
Ranking for Proximity to Dispersal Paths

Roads, rails, and waterways are the primary methods of seed dispersal for garlic mustard. A merged shapefile of these four was used as the base for a Euclidean distance measurement. Cells within 100m are assigned a risk of '5'. Those areas between 100m and 200m are assigned a risk of '4'. Between 200m and 300m are assigned a risk of '3'. All areas beyond 600m are assigned a risk of '0'.

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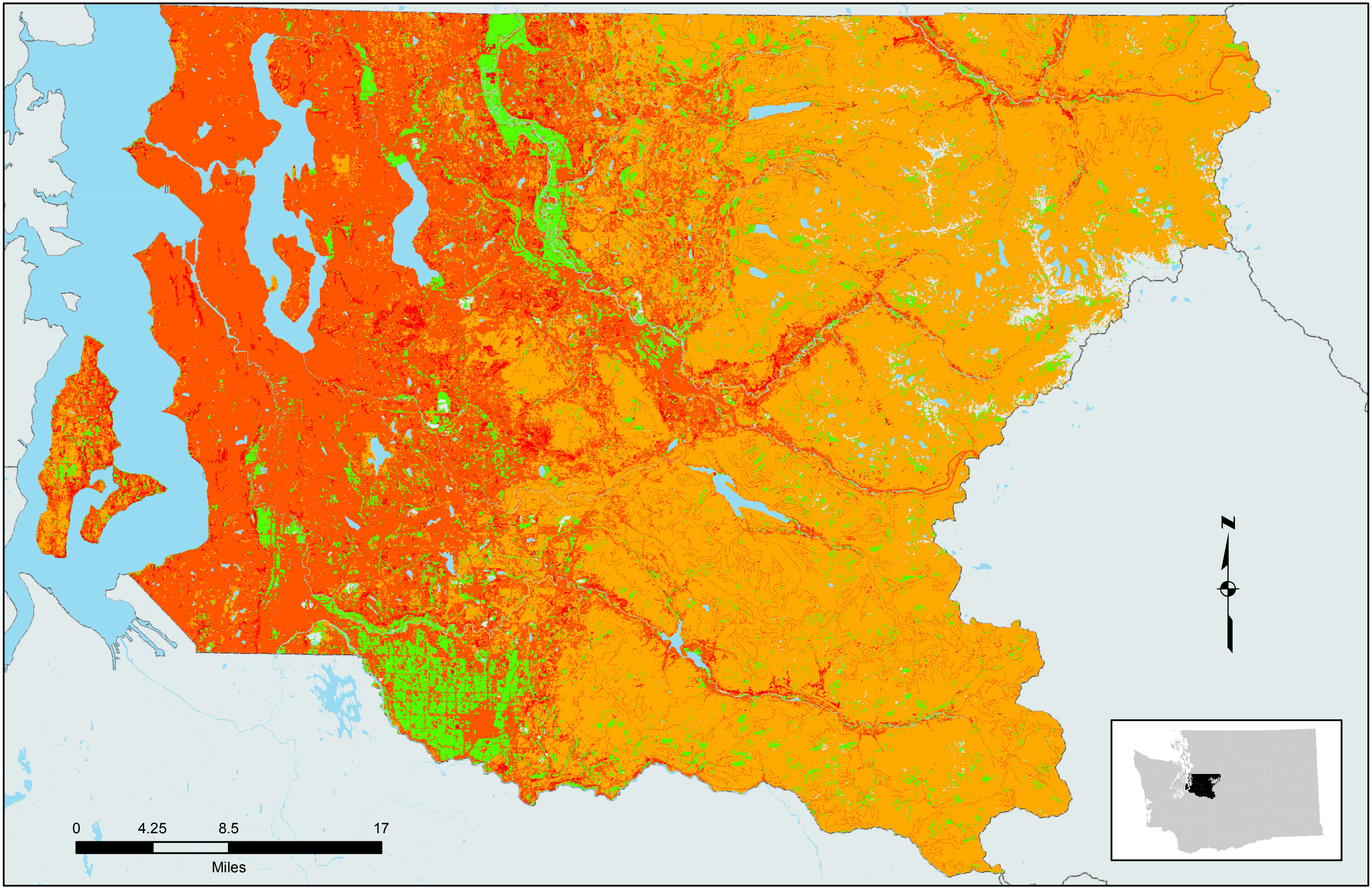

Land Cover Category and Ranking

- 1 - Wetlands, Grass, Pasture, Crops
- 3 - Evergreen Forest, Shrubs
- 4 - Urban Areas, Mixed Forest
- 5 - Deciduous Forest

Figure 3.3
Garlic Mustard Multi-Criteria Analysis Ranking for Land Cover

Land cover data was obtained from the United States Geologic Survey's National Land Cover Dataset from 2006. In total, 13 different land cover classes were given a ranking of at least a '1'. Water, perennial snow, and barren land were given a score of '0'. Urban areas consists of codes 21-24, which correlate to different levels of development.

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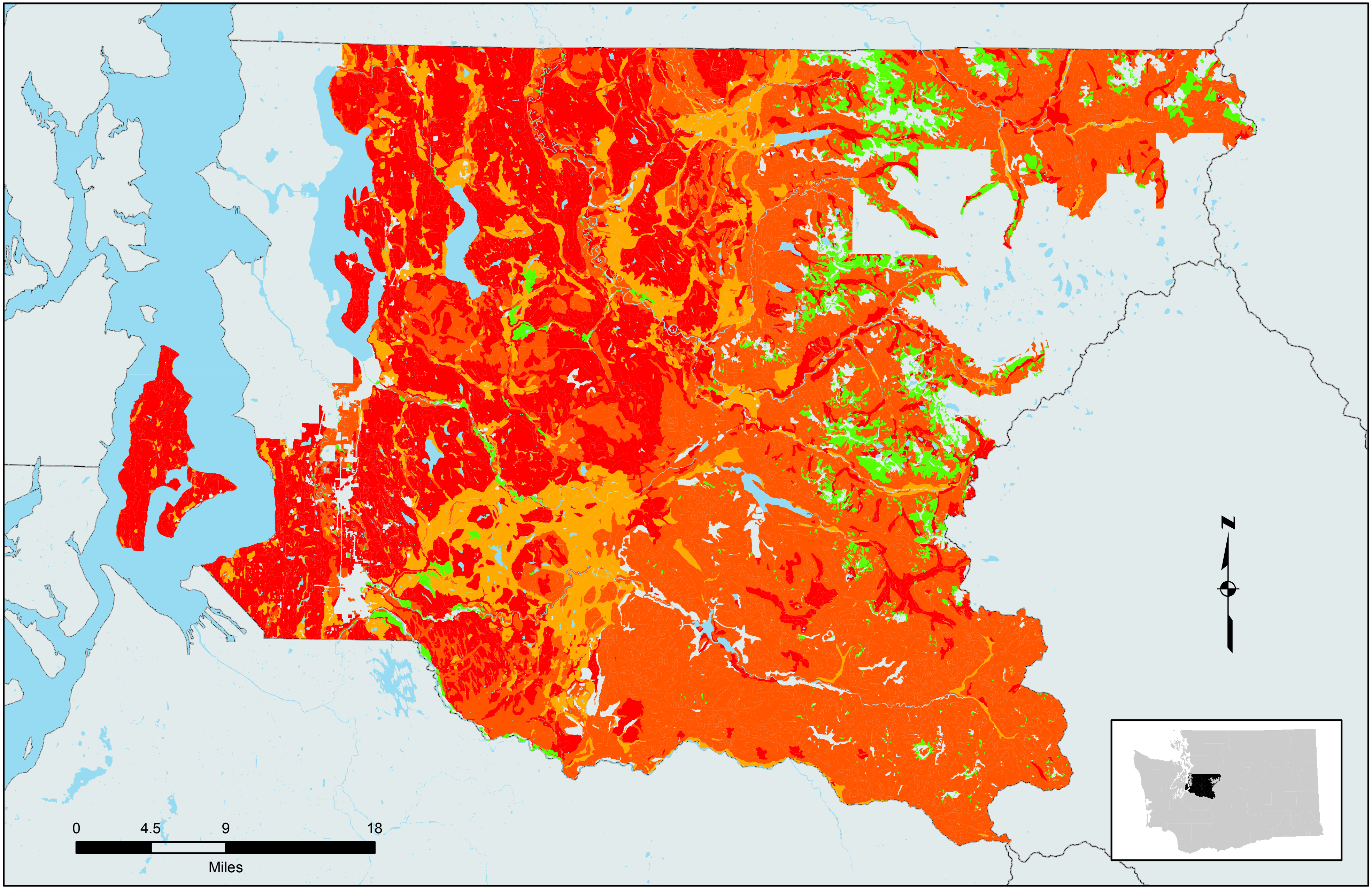

Soil Drainage Rankings

- 1 - Excessively Drained or Water
- 3 - Somewhat Excessively or Very Poorly Drained
- 4 - Well or Poorly Drained
- 5 - Moderately Well or Somewhat Poorly Drained

Figure 3.4

Garlic Mustard Multi-Criteria Analysis Ranking for Soil Drainage Class

Soil drainage classifications obtained from the United States Department of Agriculture's Soil Survey Geography Dataset. Soil drainage ranking scheme derived from Shartell et. al. (2011).

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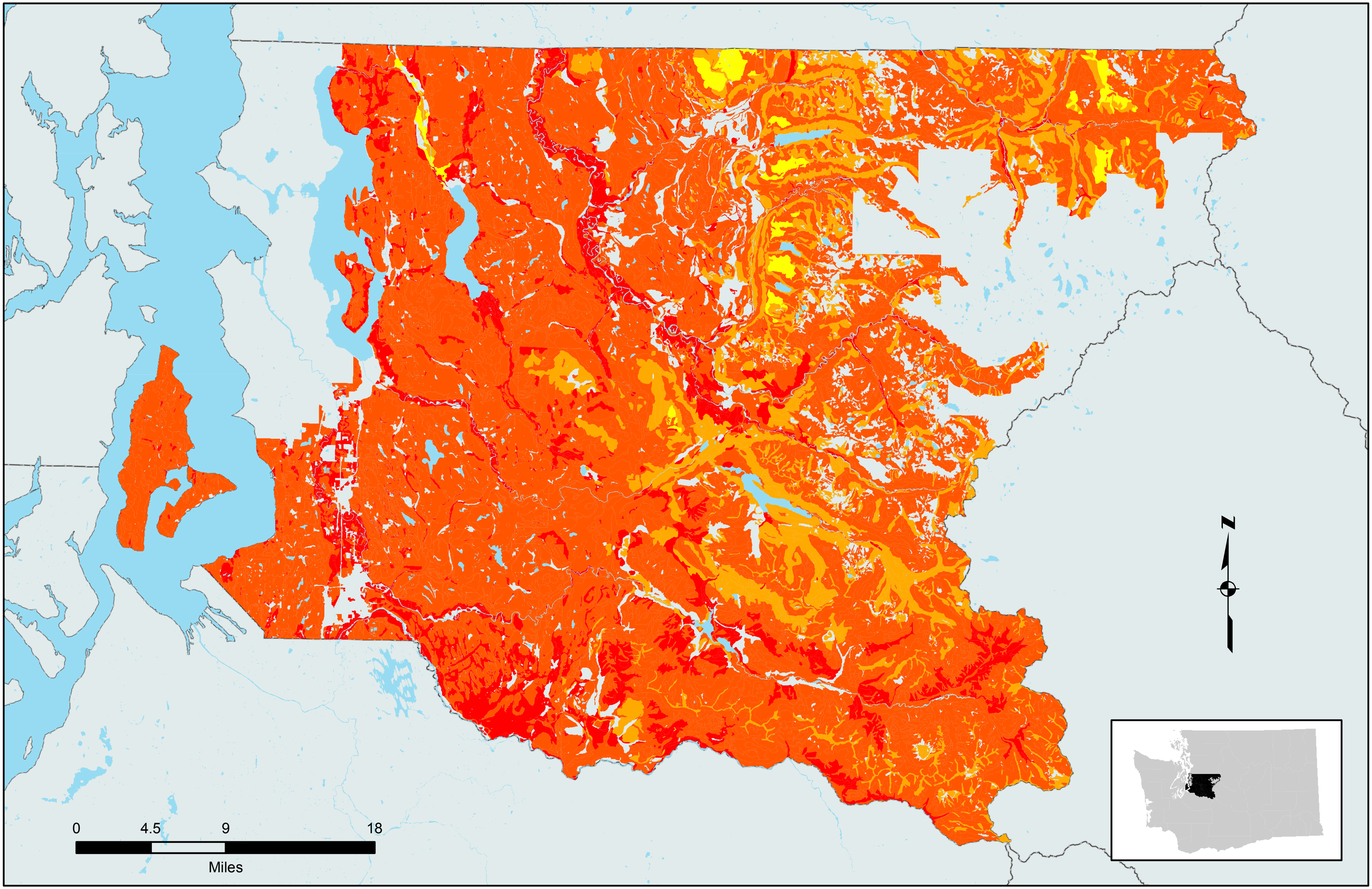


Soil pH Rankings

- 2 - pH of 4.5 to 4.99
- 3 - pH of 5.0 to 5.49
- 4 - pH of 5.5 to 5,99
- 5 - pH of 6.0 or higher

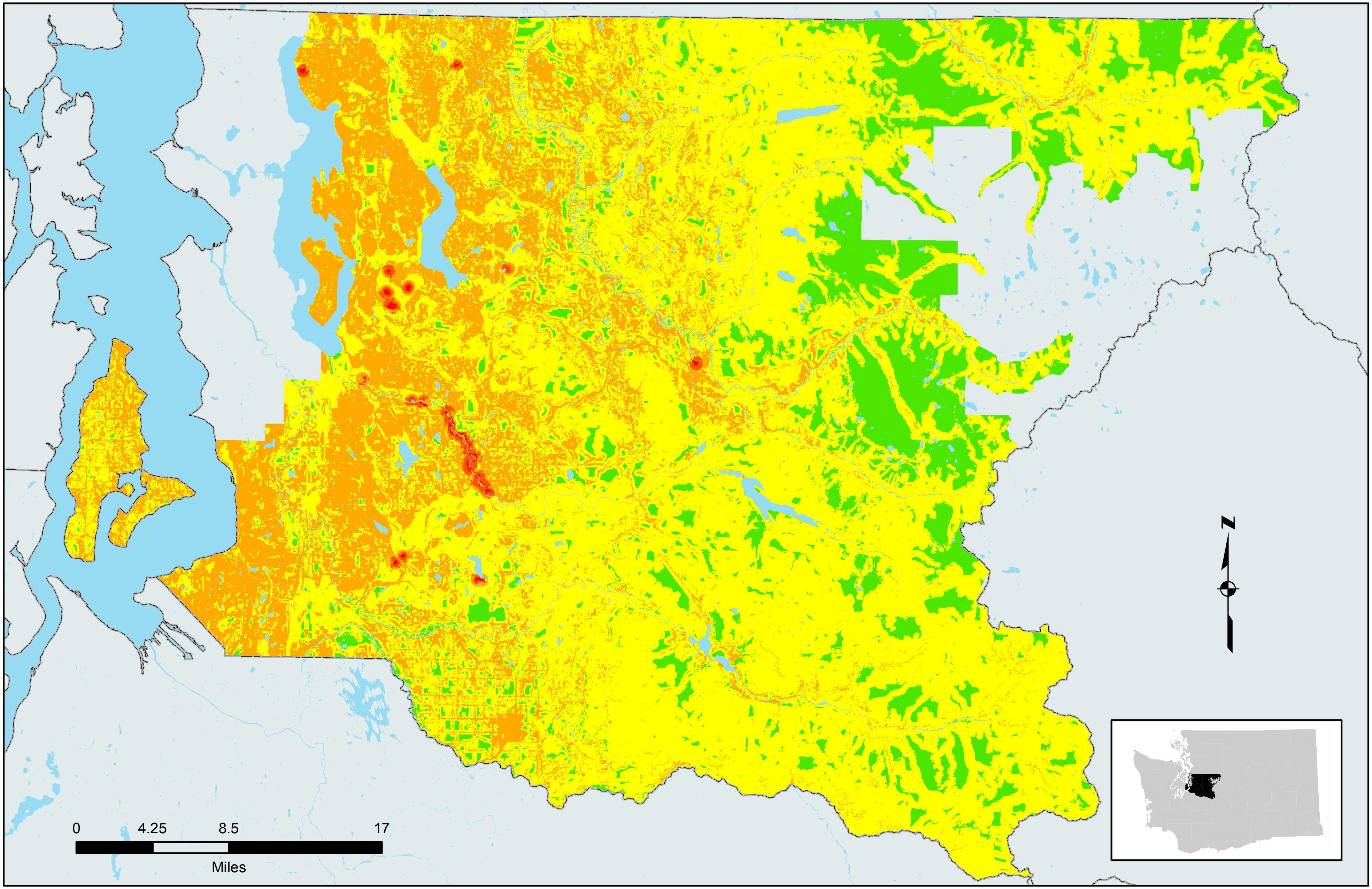
Figure 3.5

Garlic Mustard Multi-Criteria Analysis
Ranking for Soil pH

Soil pH values obtained from United States Department of Agriculture's Soil Survey Geographic (SSURGO) Dataset. Soil pH rankings derived from Shartell et. al. (2011). A ranking of '5' is the most susceptible to garlic mustard invasion, while a ranking of '1' is the least. In King County, no soil units have a pH below 4.5, therefore no areas receive a ranking of '1'.

King County

Noxious Weed Control Program



Invasion Risk Ranking

- Low Risk - <= 2.0
- Low to Moderate Risk - 2.0 to 3.0
- Moderate Risk - 3.0 to 4.0
- Moderate to High Risk - 4.0 to 4.5
- High Risk - 4.5 to 5.0

Figure 3.6

Garlic Mustard Multi-Criteria Analysis: Ranking for Invasion Risk

Rankings based on weighted sum analysis of risks associated with five variables. The variables chosen were based on Shartell et. al. (2011) and discussion with King Co. Noxious Weeds Control Program staff. The variables used were known garlic mustard locations (weighted 33%), dispersal pathways (weighted 31%), primary land cover class (weighted 16%), soil pH (weighted 10%) and soil drainage characteristics (weighted 10%). Depending on specific characteristics, each variable was ranked from 1 to 5 depending on susceptibility to garlic mustard invasion.

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Table 3.1 - Proximity to Known Garlic Mustard Sites Rankings

Within 200 meters	5
Between 200 to 400 meters	4
Between 400 to 600 meters	3
More than 600 meters	0

Table 3.2 - Proximity to Dispersal Pathways Rankings

Within 100 meters	5
Between 100 to 200 meters	4
Between 200 to 300 meters	3
More than 300 meters	0

Table 3.3 - Land Cover Classifications Rankings

41 - Deciduous Forest	5
21 - Developed, Open Space 22 - Developed, Low Intensity 23 - Developed, Medium Intensity 24 - Developed, High Intensity 43 - Mixed Forest	4
42 - Evergreen Forest 52 - Shrub / Scrub	3
71 - Grassland / Herbaceous 81 - Pasture / Hay 82 - Cultivated / Crop 90 - Woody Wetlands 95 - Emergent Herbaceous Wetlands	1
11 - Open Water 12 - Perennial Ice / Snow 31 - Barren Land (Rock / Sand / Clay)	0

Table 3.4 - Soil Drainage Class Rankings

Moderately Well Drained Somewhat Poorly Drained	5
Well Drained Poorly Drained	4
Somewhat Excessively Drained Very Poorly Drained	3
Excessively Drained Water	0

Table 3.5 - Soil pH Values Rankings

6.0 to 7.0	5
5.5 to 5.99	4
5.0 to 5.49	3
4.5 to 4.99	2
Less than 4.5	0

Table 3.6 - Risk Agent Weighting Scheme

Proximity to Known Garlic Mustard Sites	33%
Proximity to Dispersal Pathways	31%
Land Cover	16%
Soil Drainage Class	10%
Soil pH Value	10%

4 GEOSPATIAL ANALYSES/SPATIAL STATISTICS

4.1 Analyses Tests Performed

As part of our entire analysis process we conducted a variety of spatial statistics test and operations in order to determine if there are any discernible spatial patterns for the Garlic Mustard within the City of Seattle. This information was used to further enhance our understanding of the Multi-Criteria Analysis (MCA). This was also done in order to verify and modify our methodology and results from the MCA. We were also curious to see if there were any interesting results that would occur or if we would find something unexpected.

Several different tests were run in order to determine any discernible spatial patterns among the data point locations. IBM SPSS Statistics software and the ArcGIS Spatial Statistics Tools extension were utilized. These software packages offered tools and tests which satisfied our requirements. The first tool in SPSS used was the Kolmogorov–Smirnov test. According to the IBM SPSS Statistics Information Center,

> The One-Sample Kolmogorov-Smirnov Test procedure compares the observed cumulative distribution function for a variable with a specified theoretical distribution, which may be normal, uniform, Poisson, or exponential. The Kolmogorov-Smirnov Z is computed from the largest difference (in absolute value) between the observed and theoretical cumulative distribution functions. This goodness-of-fit test tests whether the observations could reasonably have come from the specified distribution. (IBM SPSS, 2012)

This test was used to determine if the distribution of the Garlic mustard data was normal. If the distribution was normal then we would be able to conduct different types of regression analyses.

There were several different tools from the ArcGIS Spatial Statistics Tools extension which were used. These used include: Spatial Autocorrelation (Global Moran's I), Multi-Distance Spatial Cluster Analysis (Ripley's K Function), Cluster and Outlier Analysis (Anselin Local Moran's I), and Geographically Weighted Regression (GWR). These tools were used to determine if any apparent clustering or discernible patterns of the data points and/or values occurred. These tools were run within the ArcMap environment and were used to determine spatial statistics.

4.1.1 One-Sample Kolmogorov-Smirnov Test (K-S Test)

The first test which was conducted was the One-Sample Kolmogorov-Smirnov Test, also known as the K-S test. This test, as stated previously, is a goodness-of-fit test which tests if the observations could have come from the specified distribution. This test is used to determine if there is a “normal” distribution to the data so that other tests, such as linear regression, can be performed. The K-S test was performed on the Garlic Mustard data. We examined the distribution of data of both the Cover Class and the Area Normalized by Cover Class. The Cover Class attribute is a measure of cover density if looking at the total area of the infestation’s footprint from a bird’s eye view. While the Area Normalized by Cover Class is a combination of the cover class times the area and normalized in order to produce a better representation of the data. However in both cases the results of these tests showed that the attribute data did not have a normal data distribution. In both cases the Asymp. Sig (2-tailed) parameter results were 0.000. The p-value is smaller than the level of significance and therefore we have to reject the null hypothesis. This indicates that the data is not normally distributed. This information can be seen in Figures 4.1 - Cover Class Attribute and 4.2 - Area Normalized by Cover Class Attribute, which depict the results of the One-Sample Kolmogorov-Smirnov Test. Since our data is not normally distributed, it is not possible to conducted linear regression on the data using SPSS. We were unable to further use SPSS in our analyses.

4.1.2 Spatial Autocorrelation (Global Moran's I)

The next spatial statistics test performed was the Spatial Autocorrelation (Global Moran's I) test from the ArcGIS Spatial Statistics Tool. This test measures spatial autocorrelation based on feature location and attribute values using the Global Moran's I statistic (ArcGIS Resource Center, 2012). According to the Spatial Autocorrelation (Global Moran's I)(Spatial Statistics) webpage, on the ArcGIS Resource Center website,

> This test measures spatial autocorrelation based on feature locations and attribute values using the Global Moran's I statistic. Given a set of features and an associated attribute, the Spatial Autocorrelation tool evaluates whether the pattern expressed is clustered, dispersed, or random. When the z-score or p-value indicates statistical significance, a positive Moran's I index value indicates tendency toward clustering while a negative Moran's I index value indicates tendency toward dispersion. (ArcGIS Resource Center, 2012)

This test was done on garlic mustard and giant hogweed. This test was performed because of interest in determining if there was a clustering tendency for the data within the City of Seattle boundary. If there is a clustering tendency for the data, there may be other factors that could be looked at which explain this clustering. It may help to further model the spread of these noxious weeds.

The spatial distribution of garlic mustard had a high z-score, 32.44, which indicates that there is a less than 1% likelihood that this clustered pattern was the result of random chance. The Significance Level (p-value) represents a probability for which it represents the chance that the observed spatial pattern was created by some random process. Garlic mustard had a p-value of 0.000 indicating that it is very unlikely the observed pattern happened by chance. These results give a strong indication that the spatial pattern of Garlic mustard is not randomly distributed and that there is a tendency toward clustering for this data. This information is depicted in Table 4.1 which summaries the results of the Global Moran's I test. Similar results were obtained for giant hogweed. It had a z-score of 27.65 and a p-value of 0.000, both of which are indicators for a strong tendency of clustering. Once again the spatial pattern for this noxious weed shows it is not a result of random chance. The test shows that it is also unlikely to be randomly spaced. This information can be found in Table 4.1.

4.1.3 Multi-Distance Spatial Cluster Analysis (Ripley's K Function)

The next test performed was the Multi-Distance Spatial Cluster Analysis (Ripley's K Function). The ArcGIS Resource Center website, Multi-Distance Spatial Cluster Analysis (Ripley's K Function) (Spatial Statistics) webpage states, "This function determines whether features, or the values associated with features, exhibit statistically significant clustering or dispersion over a range of distances" (ArcGIS Resource Center, 2012). The tool is able to summarize spatial dependence (feature clustering or feature dispersion) over a range of distances that can be selected by the user. In our analysis, this tool ran several different times using varying parameters to see if there were any differences in the outcome. We used Area and Area Normalized by Cover Class as the Weight Field. This field was used to represent the data that was analyzed for clustering or dispersion.

A distance band or threshold distance is used in the analysis in order to explore patterns at multiple distances and spatial scales. Each analysis run used fixed distance bands of 1,000 feet and were run ten times so that there would be ten 1,000-foot distance bands at which the K function was evaluated and the rate of clustering or dispersion analyzed. In the analysis, the number of permutations selected for the Compute Confidence Envelope was 99. This translates to a confidence level of 99%. There is an undercount bias for features located near the boundary of the study area. To compensate for such bias two different Boundary Correction Methods were utilized and the differences compared. The first method used was No Boundary Method correction in which all points were used in the neighbor counts. The next method was the Simulate Outer Boundary Values Method, which creates points outside the study area boundary that mirror those found inside the boundary in order to correct for underestimates near the edges. It was found that there were slight differences in the results. The overall final outcome for this analysis was the same. At all distances our data had a strong tendency toward being clustered, which is further corroborated by the Cluster and Outlier Analysis (Anselin Local Moran's I) that were also conducted.

The results of the Multi-Distance Spatial Cluster Analysis are graphs and tables which depict various attributes that are used to determine if a feature exhibits statistically significant clustering or dispersion over a range of distances. The graph produced for each test run has several attributes contained within it. There is a red line signifying the Observed K value, a blue line signifying the Expected K value, and grey lines signifying the confidence envelope. Figure 4.3 is an example of the graphical output for the data. The data represented is the Area Normalized by Cover Class attribute with a Compute Confidence Envelope of 99 and Boundary Correction Method set at Simulate Outer Boundary Values. Figure 4.4 is another example of the graphical output for the data. The data represented in this graphic is the Area attribute with a Compute Confidence Envelope of 99 and Boundary Correction Method set as None. As can be seen the results are similar to the other graphic in many ways. There are some slight differences which most likely can be attributed to the different options selected in running the test. The output graphics are representative of all the other test runs as well. The lines were slightly different but the overall shape of the lines and results were similar. As can be seen from the graph, the Observed K is larger than the Expected K value at any particular distance indicating the distribution is more clustered than a random distribution at that distance (scale of analysis). The Multi-Distance Spatial Cluster Analysis (Ripley's K Function)(Spatial Statistics) webpage, which is part of the ArcGIS Resource Center website states that:

> The expected results will be represented by a blue line while the observed results will be a red line. Deviation of the observed line above the expected line indicates that the dataset is exhibiting clustering at that distance. Deviation of the observed line below the expected line indicates that the dataset is exhibiting dispersion at that distance. (ArcGIS Resource Center, 2012)

For both of the graph examples the red line was above the blue line for all of the different distances. As a result it has been determined that the datasets are exhibiting clustering at all of the distances measured.

Four different test runs were performed; two for the Area attribute and two for the Area Normalized by Cover Class attribute. Each test run used a Compute Confidence Envelope of 99 corresponding to a confidence level of 99%. Each attribute had one run using the Boundary Correction Method set to None and one using Simulate Outer Boundary Values. The following four tables (Tables 4.2, 4.3, 4.4, 4.5) are the results of these test runs. Each table has the following attributes listed: Expected K, Observed K, Diff K, LwConfEnv, and HiConfEnv. The Multi-Distance Spatial Cluster Analysis (Ripley's K Function)(Spatial Statistics) webpage, which is part of the ArcGIS Resource Center website states that:

> Expected K and Observed K fields containing the expected and observed K values, respectively. A field named Diff K contains the Observed K values minus the Expected K values. If a confidence interval option is specified, two additional fields named LwConfEnv and HiConfEnv will be included in the Output Table as well. These fields contain confidence interval information for each iteration of the tool, as specified by the Number of Distance Bands parameter. (ArcGIS Resource Center, 2012)

When interpreting the results of the tables according to the Multi-Distance Spatial Cluster Analysis (Ripley's K Function)(Spatial Statistics) webpage part of the ArcGIS Resource Center website states that:

> When the observed K value is larger than the expected K value for a particular distance, the distribution is more clustered than a random distribution at that distance (scale of analysis). When the observed K value is smaller than the expected K value, the distribution is more dispersed than a random distribution at that distance. When the observed K value is larger than the HiConfEnv value, spatial clustering for that distance is statistically significant. When the observed K value is smaller than the LwConfEnv value, spatial dispersion for that distance is statistically significant.

When reviewing the tables based on the interpretation instructions from the above paragraph, one can see that for all of the tables the Observed K values for all ten distance bands is higher than the Expected K values. According to the interpretation instructions this shows that the distribution is more clustered than a random distribution for all of the distances evaluated. Tables 4.3 and 4.5 also have an Observed K value that is higher than the HiConfEnv value, which also signifies that spatial clustering for that distance is statistically significant. The opposite is true for Tables 4.2 and 4.4 which have lower Observed K values than the HiConfEnv value. Both of these tables did not use any Boundary Correction Methods. It is suspected that as a result this is what caused the Observed K to be lower than the HiConfEnv value. The

Boundary Correction Method was able to correct for the bias which occurs normally at the boundary. Not having a method applied has caused the Observed K to be skewed in Tables 4.3 and 4.5. However, since these tables also had an Observed K that was higher than the Expected K there is still clustering occurring. Therefore we are confident in our results of the Ripley's K Function that there is clustering occurring for both the Area and Area Normalized by Cover Class. This view is further reinforced in the results of the Cluster and Outlier Analysis (Anselin Local Moran's I) analyses which we also performed on the selected attributes.

4.1.4 Cluster and Outlier Analysis (Anselin Local Moran's I)

After conducting the Multi-Distance Spatial Cluster Analysis (Ripley's K Function) test, the next test conducted was Cluster and Outlier Analysis (Anselin Local Moran's I). According to the Cluster and Outlier Analysis (Anselin Local Moran's I) webpage, on the ArcGIS Resource Center website, "given a set of weighted features this test identifies statistically significant hot spots, cold spots, and spatial outliers using the Anselin Local Moran's I statistic" (ArcGIS Resource Center, 2012). The webpage, How Cluster and Outlier Analysis (Anselin Local Moran's I) works, on the ArcGIS Resource Center website states,

> This test is especially good to perform as interesting spatial patterns based on attributes can be identified. The tool identifies spatial outliers as well. It calculates a local Moran's I value, a z-score, a p-value, and a code representing the cluster type. There are several different cluster types: cluster of high values (HH), cluster of low values (LL), outlier in which a high value is surrounded primarily by low values (HL), and outlier in which a low value is surrounded primarily by high values (LH). (ArcGIS Resource Center, 2012)

This information is especially useful in determining interesting spatial patterns. This test was performed multiple times on the Area and Area Normalized by Cover Class attributes. In order to conduct these tests we had to specify a conceptualization of spatial relationship method. This method specifies how spatial relationships among features are conceptualized. Our analyses used the Fixed Distance Band conceptualization which from the Cluster and Outlier Analysis (Anselin Local Moran's I) (Spatial Statistics) webpage on the ArcGIS Resource Center website is a method,

> In which each feature is analyzed within the context of neighboring features. Neighboring features inside the specified critical distance receive a weight of 1, and exert influence on computations for the target feature. Neighboring features outside the critical distance receive a

weight of zero and have no influence on a target feature's computations. (ArcGIS Resource Center, 2012)

This seemed to be the most appropriate method as visually there appeared to be some clustering and using a distance band to limit the influence of neighbors outside of a critical distance was deemed appropriate. We also had to choose a distance method which specifies how distances are calculated from each feature to neighboring features. The Euclidean Distance or the straight-line distance between two points (as the crow flies) option was utilized for all of the test runs. This was chosen over Manhattan Distance as a straight line was more appropriate to use than measurements using a block grid system.

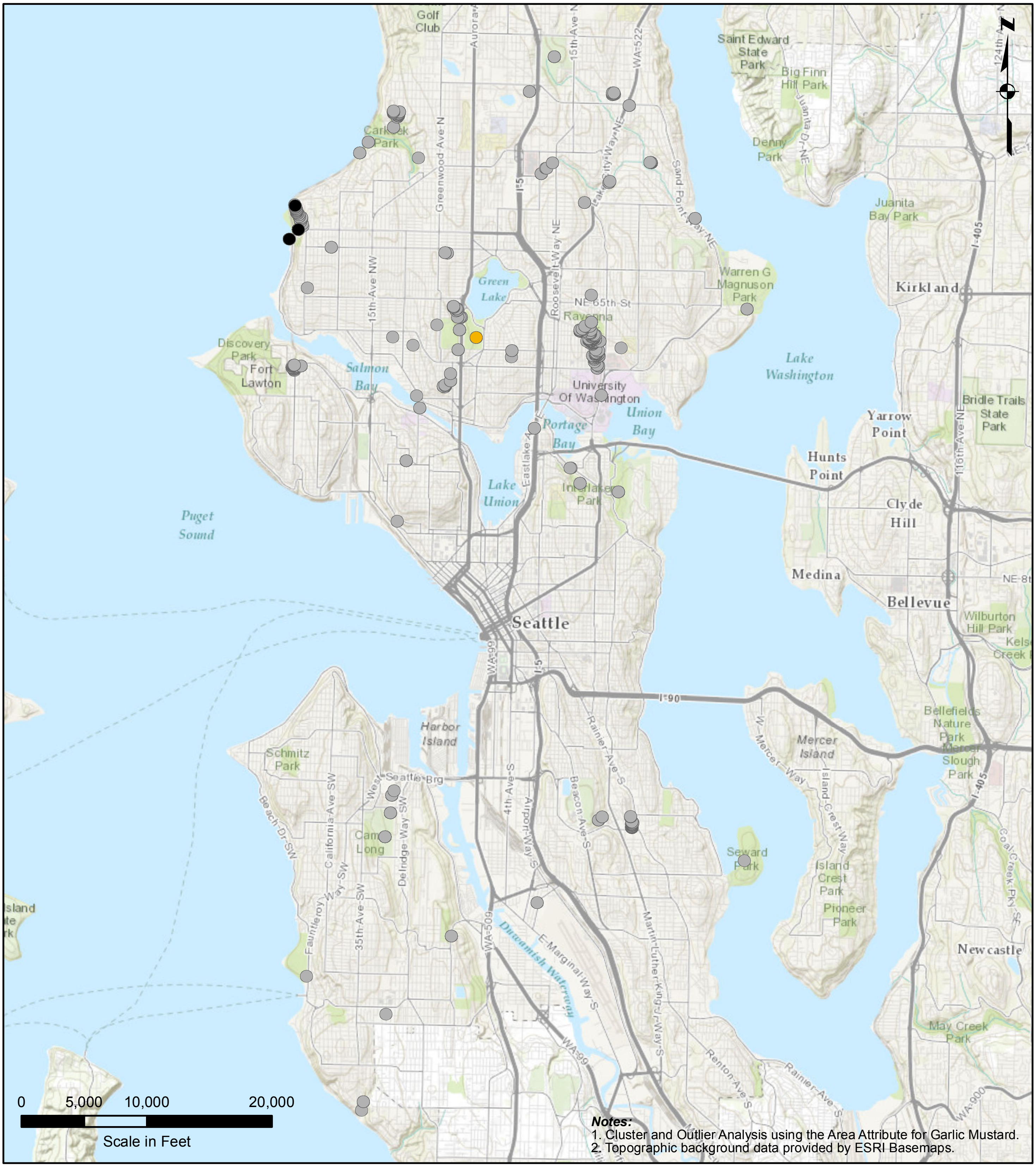
The next parameter to set was a Distance Band or Threshold Distance, which specifies a cut off distance for the Fixed Distance Band. Features outside the specified cutoff for a target feature are ignored in analysis for that feature. Various widths of distance bands were tried starting with 1000ft and going up to 10,000ft. At each interval, up to 10,000ft, Warning 000846 occurred. This warning states features had no neighbors which generally invalidates the statistical properties of a test as discussed in the "000846 : <value> features had no neighbors which generally invalidates the statistical properties of a test" webpage within the ArcGIS Resource Center website (ArcGIS Resource Center, 2012). The solution to this error is to increase the distance band threshold until the error no longer occurs. A distance band of 10,000ft did not produce this error and therefore was used in the analyses as the statistical properties of the test were not invalidated because all of the points had at least one neighbor.

From the repeated analyses we were able to see some interesting phenomena regarding the clustering and outliers of the attributes: Area and Area Normalized by Cover Class. In both cases there were areas of HH and HL clustering. However, for the majority of the city there was no significant statistical clustering pattern for both of the attributes. These clustering patterns can be seen in Figure 4.5 - Area attribute and Figure 4.6 - Area Normalized by Cover Class attribute. It is surprising to see that there is not more clustering or outliers occurring based on the visual spatial pattern of the data. This is an indication that the values for the attributes are very similar and that there is not much variability between them over a given distance.

For both attributes there were clusters of HH values in the Golden Gardens Park area, located within the northwest section of Seattle. This area consists of a predominantly wooded area, with steep hill slopes, and some disturbance due to human activities. This appears to be an area that is highly susceptible to Garlic Mustard invasion and, as indicated in the figures, has a high rate of it for both of the attributes.

There is also a HH cluster in West Seattle alongside Longfellow creek for the Area Normalized by Cover Class attribute. This area is within the West Seattle Recreation Center, which is a golf course and contains many of the variables which allow for the spread of Garlic Mustard. The Area Normalized by Cover Class and Area attribute also has one HL value located within Woodland Park Zoo. Its location is on a steep hill slope covered by forest just to west of the soccer and baseball playing fields. Once again this is an area in which the parameters are present to help the Garlic Mustard spread. This site is unique as it is surrounded by areas of low values and it is situated by itself. Besides these HH and HL cluster locations there were not many other cluster and outlier locations of the analyzed attributes within the City of Seattle. As can be seen there are outliers and clustering for high values and these areas tend to be located within landscapes that are susceptible to Garlic Mustard invasion. The resulting pattern will help in our identification of areas for management changes.

These are the statistical tests which the group performed to get a better understanding of the data. As determined by the results of the various tests, there is a tendency towards clustering of the selected attributes: Area and Area normalized by Cover Class. This shows that there are some external factors which are influencing this clustering. These statistical tests do show us that the distribution pattern is not random and therefore it is possible to offer an explanation as to why there is clustering. This is accomplished through doing the Multi-Criteria Analysis and modeling the distribution and factors influencing Garlic Mustard.



Clustering Level

- Not Significant
- HH
- HL
- LH
- LL

Figure 4.5
Garlic Mustard
Cluster and Outlier Analysis
Area Attribute

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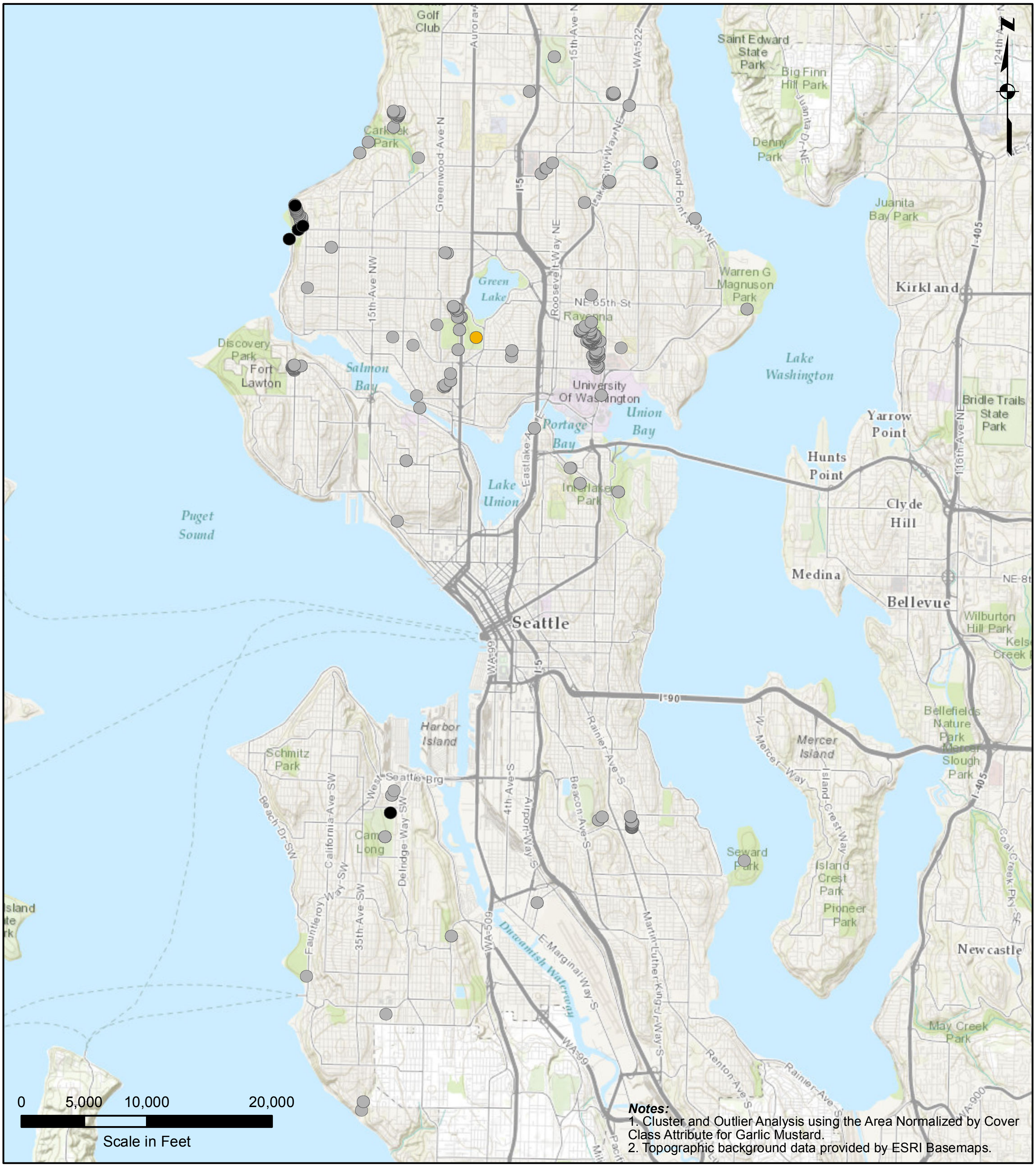


Clustering Level

- Not Significant
- HH
- HL
- LH
- LL

Figure 4.6
Garlic Mustard
Cluster and Outlier Analysis
Area Normalized by Cover Class Attribute

King County
Noxious Weed Control Program

Global Moran's I Summary		
	Garlic Mustard	**Giant Hogweed**
Moran's Index:	0.456239	0.397338
Expected Index:	-0.000964	-0.000404
Variance:	0.000199	0.000207
z-score:	32.440962	27.65321
p-value:	0.000	0.000

Table 4.2

Ripley's K Function: Attribute – Area Normalized by Cover Class; Compute Confidence Envelope – 99; Boundary Correction Method – None

Expected K	Observed K	Diff K	LwConfEnv	HiConfEnv
1000	14106.00	13106.00	6021.89	16065.90
2000	17907.10	15907.10	7700.34	20858.90
3000	18047.30	15047.30	7956.00	21427.50
4000	18102.90	14102.90	8141.86	21489.30
5000	18116.70	13116.70	8264.07	21600.60
6000	18124.30	12124.30	8708.60	21644.90
7000	18127.00	11127.00	9024.80	21991.90
8000	18143.30	10143.30	9258.50	22025.80
9000	18472.20	9472.17	9589.86	22133.30
10000	18652.30	8652.27	9717.43	22778.10

Table 4.3

Ripley's K Function: Attribute – Area Normalized by Cover Class; Compute Confidence Envelope – 99; Boundary Correction Method – Simulate Outer Boundary Values

Expected K	Observed K	Diff K	LwConfEnv	HiConfEnv
1000	10586.40	9586.39	3691.32	11238.90
2000	18755.80	16755.80	5389.70	14811.50
3000	19050.70	16050.70	5853.59	15933.80
4000	19081.10	15081.10	6471.81	16042.80
5000	19099.50	14099.50	7055.13	16086.90
6000	19103.80	13103.80	7165.48	16108.50
7000	19105.40	12105.40	7263.34	16253.00
8000	19113.70	11113.70	8091.43	16282.70
9000	19313.40	10313.40	8550.54	16377.80
10000	19503.60	9503.55	8697.07	16634.80

Table 4.4

Ripley's K Function: Attribute – Area; Compute Confidence Envelope – 99; Boundary Correction Method – None

Expected K	Observed K	Diff K	LwConfEnv	HiConfEnv
1000	19418.10	18418.10	4998.76	19102.80
2000	21085.20	19085.20	6135.41	23703.10
3000	21145.80	18145.80	7042.67	24003.40
4000	21180.50	17180.50	7345.24	24033.90
5000	21188.80	16188.80	7600.90	24070.90
6000	21194.30	15194.30	7672.18	24092.50
7000	21197.00	14197.00	7975.02	24120.10
8000	21211.00	13211.00	8085.89	24130.10
9000	21543.80	12543.80	8372.96	24168.00
10000	21617.60	11617.60	9988.74	24256.10

Table 4.5				
Ripley's K Function: Attribute – Area; Compute Confidence Envelope – 99; Boundary Correction Method – Simulate Outer Boundary Values				
Expected K	Observed K	Diff K	LwConfEnv	HiConfEnv
1000	13977.80	12977.80	3651.58	13583.60
2000	22112.40	20112.40	4930.50	15907.70
3000	22272.40	19272.40	5143.13	17068.00
4000	22290.10	18290.10	5408.53	17106.00
5000	22306.50	17306.50	6503.02	17142.00
6000	22309.70	16309.70	6661.72	17154.30
7000	22311.30	15311.30	6749.82	17190.80
8000	22318.20	14318.20	6911.25	17199.90
9000	22496.60	13496.60	7689.70	17319.00
10000	22618.40	12618.40	8162.68	17497.60

5 PYTHON/ARCPY DATA SUMMARY TOOL

After our first meeting with the County, they expressed their desire that we develop animations to help them visualize the extent of garlic mustard and giant hogweed across time to help them track the success of the program's efforts and to serve as an engaging media by which to convey the noxious weed problem for outreach and meeting purposes. In discussing some preliminary animation ideas with them, we realized that a natural complement to the animations would be to provide the County with a means of generating elegant infestation summary information for specific sites across time. As an animation unfolds, one year of infestation data is presented for a period of time before the animation proceeds to the next year of coverage, until all of the infestation coverage years that were incorporated into the animation sequence have played out. At the conclusion of the sequence, it's difficult for most viewers to recall how specific sites' infestation areas have changed across all time steps. In order to review this information, the animation viewer must replay the animation and pay close attention to key years of coverage where more scrutiny is desired. We proposed that we could write a Python/ArcPy tool that could be ported to an ArcGIS Toolbox and used to generate visual summaries of the infestation values recorded at survey locations across time. This tool would reinforce the information provided via an animated sequence with a hardcopy reference map.

5.1 Tool Design

5.1.1 "Pitching" the Tool

We pitched to the County an ArcToolbox/Python script design idea where each year of infestation area data for a given site is represented as a color-coded polygon. Each additional year of infestation area data that is available is presented as another color coded polygon, and the polygons originate at the surveyed location of the site and stack vertically downward in order of increasing year. In this manner, a concise vertical polygon array presents an elegant temporal summary of a given site's infestation history across time. The County was enthusiastic about this idea, and encouraged us to pursue this approach so long as it didn't detract from our progress with developing animations, which they had already asserted as their top project priority. We thought this approach had merit because not only would it reinforce the content of the animations, it would provide the county with a useful tool for visualizing noxious weed infestation for years to come. Figure 5.1 – Noxious Weed Temporal Visualization Python/ArcPy Tool Development presents a process diagram that illustrates the activities, decisions, and events that brought this tool to fruition.

5.1.2 Packaging the Tool

Over the summer of 2012 we completed a Python programming class as a part of the PMPGIS program that endowed us with the ability to develop scripts in Python that could be executed from within an ArcGIS toolbox dialog. This approach to script implementation makes the script accessible to anybody familiar with using common ArcGIS tools because the script is run from a common ArcGIS toolbox dialog box and doesn't require any knowledge of Python to use. A toolbox script interface also allows for enforcement of data integrity because filters can be established within the dialog box to check that the input data satisfies the data type requirements of the script parameters. Finally, a toolbox allows for documentation to be authored and included within the script, appearing as explanatory text when each parameter is selected in the dialog to inform the user of the purpose of the parameter and how to select appropriate input.

We used our collective programming skills from this class and drew upon my experience implementing tools such as this within the environmental consulting industry to design our infestation area summary tool for the County to be intuitive, simple, and robust.

5.1.3 Tool Parameters

All ArcGIS scripts require parameters in order to execute. Parameters can consist of input and output files, workspaces, file types, and other data and option selections that determine how a tool will run, where the output will be stored, output file types, or other decisions that have a bearing on the script's execution. We carefully considered what essential parameters to include in the tool as well as what additional parameters would add value to it. The County provided us with source data for garlic mustard and giant hogweed. However, in their master geodatabase, they have information for tens of noxious weed species. Thus, we designed our tool to have the flexibility to work with the County's master data set as well as the data subset that they provided to us for this project. We designed our tool around the data types, geometry, and field names that were provided in template format by the County at the onset of the project. In the paragraphs that follow we will discuss in detail each of the parameters that are included in the final iteration of our tool. Figure 5.2 – Python/ArcPy Toolbox Design presents the ArcGIS toolbox interface that appears when the tool is executed within an instance of ArcGIS. All of the parameters discussed below appear within the toolbox interface.

Input Point Feature Class

The first parameter included in our tool design was the input points feature class. This file contains the noxious weed infestation area, horizontal location information, and the survey date corresponding to the year and month that the infestation area was measured, and serves as the information source that supplies subsequent script operations with necessary data.

Output polygon feature class

This parameter determines the name and storage location of the output polygon feature class that is created when the tool executes. This polygon feature class contains the polygons that stack into the infestation summary arrays at each unique location included within the input point feature class.

Unique Location ID field

This parameter enables the user to select the attribute field within the input points feature class that contains unique location identifier information for each site contained in the attrite table of the input feature class. We felt it was important to include this option to capture location information in the event that the user needs to label each infestation area location in a map. Additionally, the script routine uses each unique location as a sorting criterion. The need for sorting is explained explicitly in the discussion regarding the *Survey Date* parameter.

Noxious Weed Species Name

This parameter enables the user to create a query statement using structured query language (SQL) to select a single noxious weed species from the many noxious weeds that appear within the attribute table of the input point feature class.

Infestation Area

This parameter prompts the user to select the field from the attribute table of the input point feature class that contains the infestation area values. In our case, two selection options were available for this parameter: surveyed infestation area and the normalized infestation area that we calculated and added into the attribute table.

Survey Date

This parameter prompts the user to select the field from the attribute table of the input point feature class that contains the date that the infestation area was measured in the field for a particular record in the attribute table. The Python script uses this information to perform a sort operation on the input points feature class using the fields *Unique Location ID Field* and *Survey Date.* The source data is sorted by location in ascending order and then by date in ascending order. In this manner, the records in the attribute table of the input feature class are rearranged and are exported into a new feature class in which all of the unique locations appear as consecutive rows and all of their information is arranged in order of ascending date. This reorganization of the data rows in the attribute table of the input feature class is required to enable writing polygon arrays into the output polygon feature class in order of ascending year so that they stack vertically downward.

Date Range

In response to feedback from the County, this parameter was added to enable a user to select a subset range of dates from the attribute table. Initially, the tool created polygons for the entire range of dates included in the attribute table. This parameter enables the user to create polygons that span a smaller date range if the user is only interested in a limited time interval of the entire data set.

Width of Polys

This parameter enables the user to establish the width of the polygons that are created in the output polygon feature class. By default, the height is set at the same value as the width. The width is expressed in the same units as are defined by the input feature class. This parameter was added after testing determined that the size of the polygons needed to be adjustable in order to create polygons suitable for presentation for various map scales. For example, a polygon created for display in a map of 1:24,000 would be too large for viewing at a scale of 1:2,400. Allowing the user the flexibility to set the width and height of the polygons enables them to create polygons that work for whatever map scale they require of their cartographic products.

Vertical Exaggeration

As in the case of the width parameter discussed in the previous paragraph, this parameter was added after testing to enable the user to vertically exaggerate the height of the polygons relative to their width. In some situations, we found it helpful and aesthetically preferable to create polygons that were rectangular rather than square to express infestation magnitude. By default, the vertical exaggeration is set at 1 (which creates a 1:1 aspect ratio of width to height).

Rotation Angle

As in the case of the vertical exaggeration parameter discussed in the previous paragraph, this parameter was added after testing to enable the user to create infestation area polygons that are rotated to match a user-specified data frame rotation angle. In some situations, it is desirable to rotate a data frame in order to make more efficient use of map area or for aesthetic reasons. We determined through testing that having this flexibility would add flexibility and value to the script. This capability did add significant complexity to the Python code underlying the script.

5.2 Tool Testing

After we established what the tool would do and the parameters needed to make it work, we wrote many lines of Python code and began the task of bringing the infestation area summary polygons script idea to fruition. The following sections will discuss the hardware and software we utilized for tool testing and development, data considerations for the script output, script error handling that was incorporated into the code, additional parameters that were added in response to testing results, and the decision to create an additional output file to provide better labeling control.

5.2.1 Hardware and Software

Coding and debugging were accomplished using Python 2.6.5 and its integrated development environment (IDLE). ArcGIS 10.0 with Service Pack 5 was used to create and edit the toolbox and define its parameters, including detailed parameter documentation, as well as execute the script and create sample output maps. A Lenovo T430s ThinkPad™ laptop computer equipped with a 2.9 gigahertz Intel® Core™ i7-3520M processor and 12 gigabytes of random access memory (RAM) was used to write and execute the code, build the toolbox, and create the summary figures related to script development.

5.2.2 Tool Test Data

We used the noxious weed data that was provided to us by the County for script development and testing to ensure that the script parameters and data types were consistent with King County's GIS standards. We also coded the script to be compatible with both shapefile and geodatabase feature class input and output to give the end users the flexibility to work with both supported ESRI data types as we were informed that the County would be using ESRI software to perform GIS analysis related to the Noxious Weeds Control Program mission. Although our test data was provided in shapefile format, we were informed that the County maintains a Microsoft Access™ database to house all of their noxious weed data. ESRI personal geodatabases are built atop Microsoft Access™ database architecture so making the tool compatible with personal geodatabase feature classes helped align the tool's functionality with existing County business practices and data export formats.

5.2.3 *Script Error Handling*

During testing, we realized the need to check the geometry type of the input feature class to ensure that only point feature classes were allowed as script input. We added some error handling code in the beginning of the script to ensure that the input feature class is of point geometry type and return an error message if it is not. This ensures that the script will execute properly as non-point input will not work with our code.

5.2.4 *Additional Parameters Added*

As we mentioned in our discussion of parameters in Section 5.1, during the script testing phase we identified several parameters that were not included in the initial conceptual version of the script but that would improve the functionality of the script and give the user more explicit control over the script's output if they were implemented. Some of these parameters were developed in response to feedback from the County and some were based on our own experience and intuition gained through the testing phase. After some additional coding, we modified the script to include the *Width of Polys* parameter, the *Rotation Angle* parameter, the *Noxious Weed Species Name* parameter, the *Date Range* parameter, the *Vertical Exaggeration* parameter, and the *Rotation Angle* parameter. The *Rotation Angle* parameter proved challenging to code because it required generating polygons that are rotated based on the user-specified rotation angle. Additionally, the query-based parameters were tricky to work out because they required us to creatively use escape characters in Python in order to feed a text string-based query statement into an existing ArcPy tool. Nonetheless, we were able to successfully implement these parameters after much toil and the tool now works flawlessly.

5.2.5 *Additional Output File*

In the testing phase of script development, it also became evident that it would be beneficial to enable the user a means of labeling the output polygons with full control over label position. It can be difficult to place labels consistently outside of a polygon. To facilitate label placement of the infestation area polygons that are generated, we added syntax into the Python script to generate centroids from the infestation area polygons and export these as a feature class that contains all of the original attribute information from the infestation area polygons feature class. This new point feature class can be used to label the polygons using all of the label placement options available in the Maplex engine with a point feature class.

5.2.6 *Tool Usability*

After designing, testing, debugging, and porting the tool into an ArcToolbox script format, we are very pleased with our effort. The script executes smoothly and is intuitive and easy to use. After the script produces it output files, a minimum of symbolizing is all that remains to produce a very informative map that illustrates the historical magnitudes of noxious weeds infestations for various sites. We are pleased to be providing the County with a useful, easy to use tool to help them better understand the nature and extent of the noxious weed problem as well as facilitate the production of technical and informative graphics for outreach, discussion, and publication purposes. Figure 5.3 - Giant Hogweed Infestation Area Summary presents a representative sample of the script's output files after symbology and labeling have been applied. For the output shown in this figure, the polygons were created with the width parameter set to 20 feet and the vertical exaggeration set at 1.5 to produce polygons suitable for presentation at the 1:3,600 map scale used in this example. Additionally, the range of data shown in this figure was selected using the script's SQL dialog for the year range parameter to include all survey data between the years 2001 and 2010.

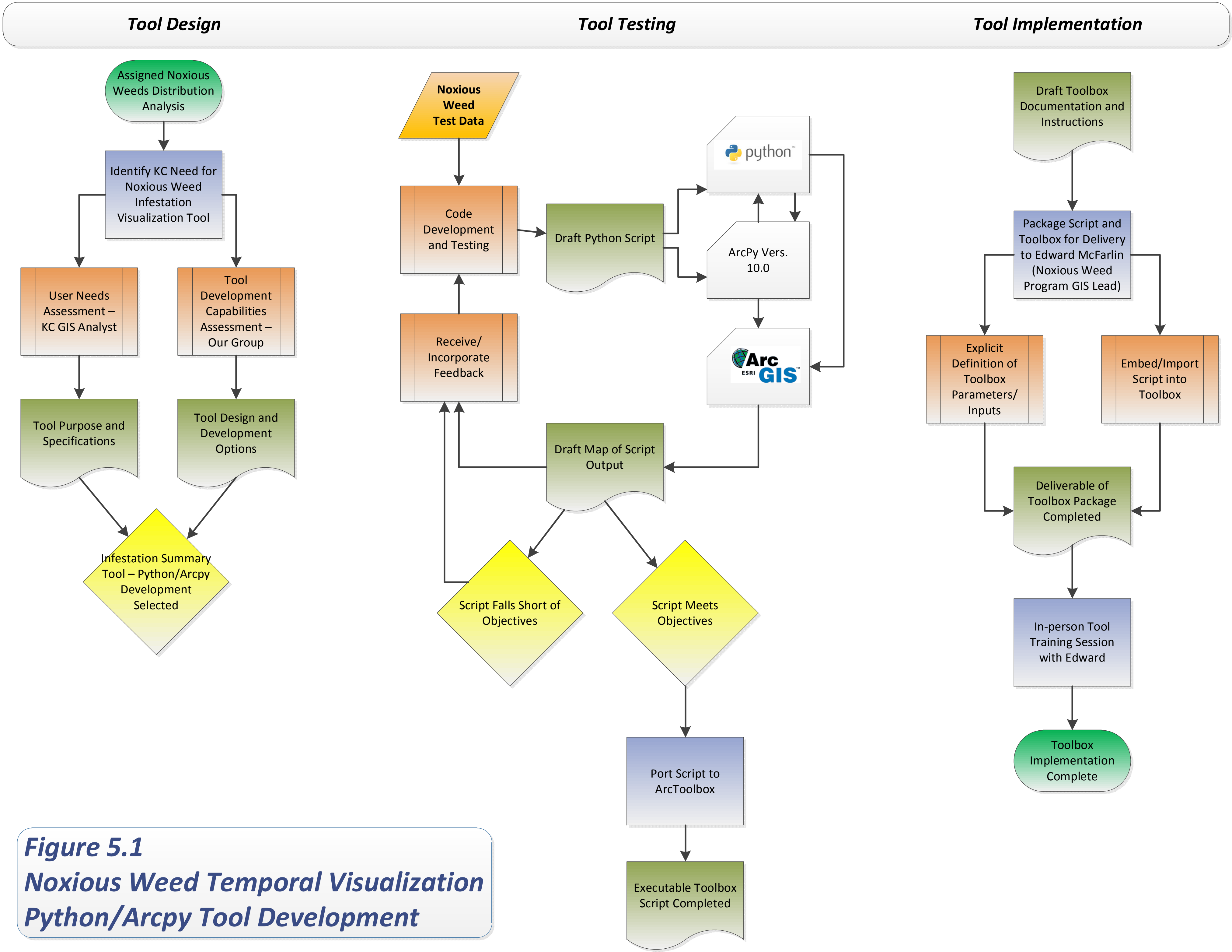


Figure 5.1
Noxious Weed Temporal Visualization Python/Arcpy Tool Development

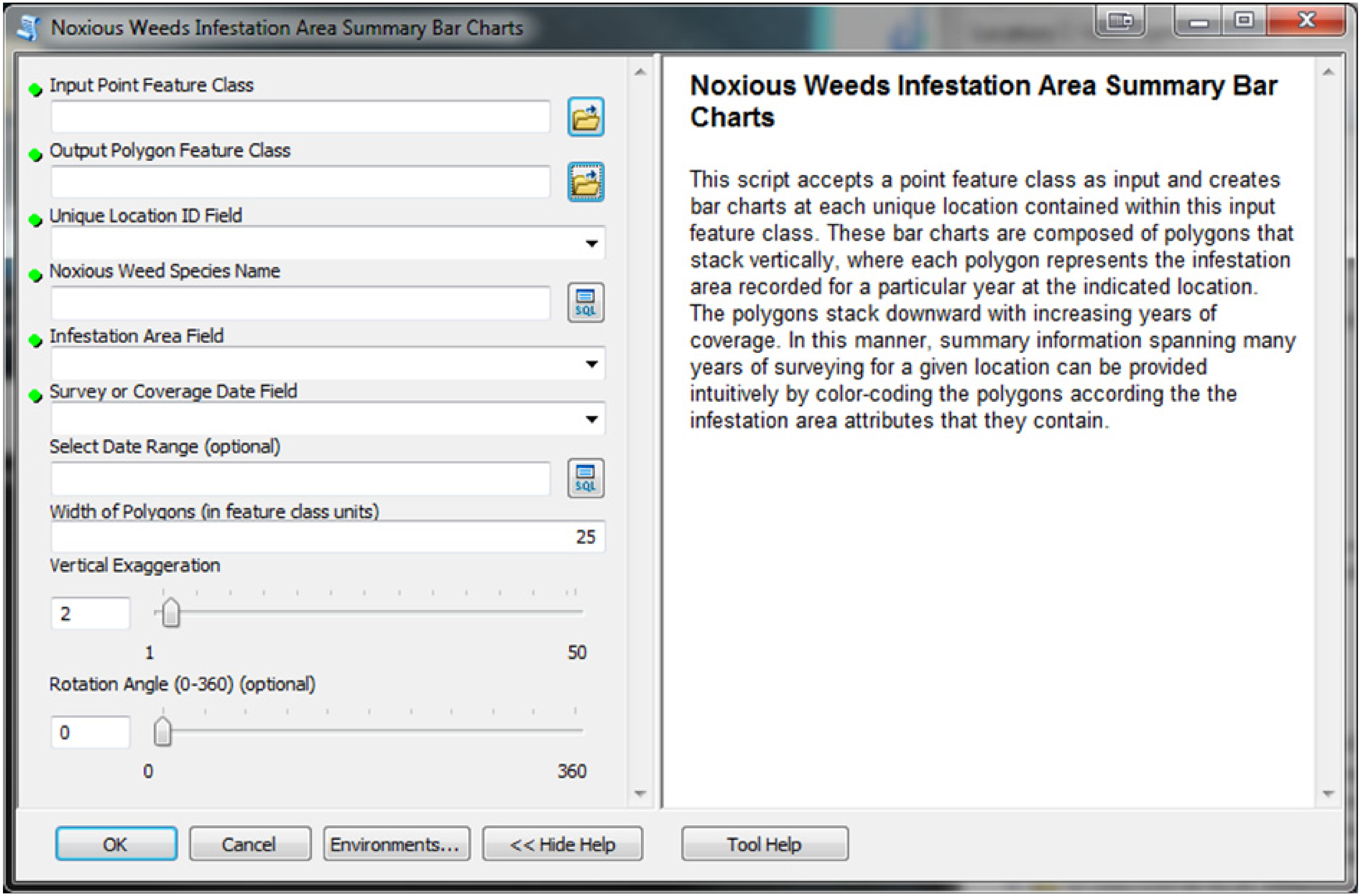


Figure 5.2

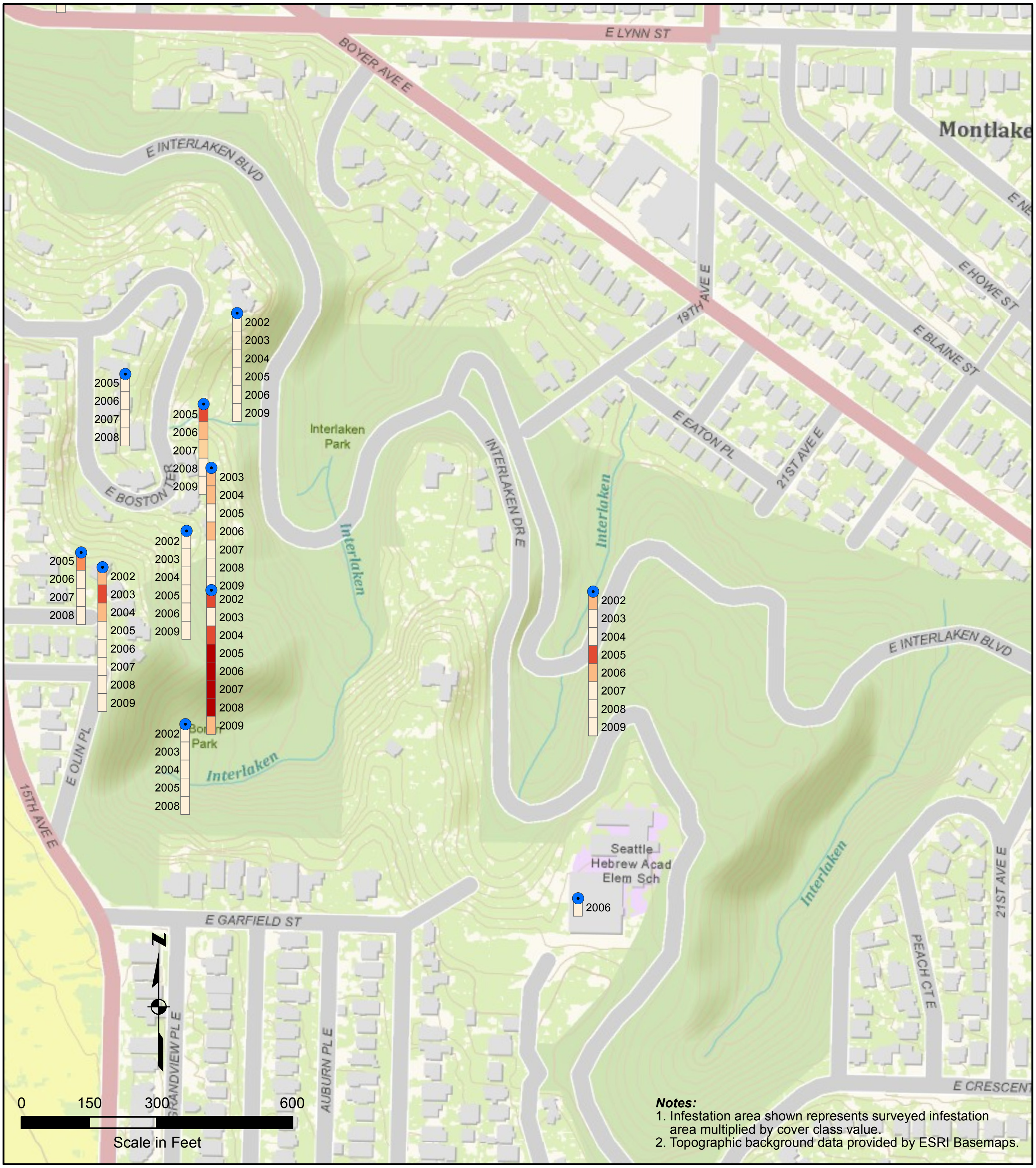
Python/ArcPy Toolbox Design

King County

Noxious Weed Control Program

Notes:

·Toolbox interface design template provided by ESRI, Inc.



Map Symbols
Infestation Area (sq. ft.)[1]

- 0–5
- 5.01–10
- 10.01–50
- 50.01–100
- 100.01–500
- > 500

Surveyed Weed Infestation Location

Figure 5.3
Giant Hogweed Infestation Area Summary
North Capitol Hill Area, Seattle, WA
2001–2010

King County
Noxious Weed Control Program

6 FINANCIAL AND STRATEGIC ANALYSIS FOR SUSTAINABILITY MANAGEMENT

To complete the financial analysis for the project, Nancy Lerner's 'Business Process Analysis/Modeling for Defining GIS Applications and Uses' text was referenced and utilized as the template (Lerner et al., 2007). The type of analysis discussed is an evaluation of proposed future investment. This evaluation considers the future costs and benefits that would occur if this proposed investment is realized and executed. The 'Future 5 Years.xls' template, included with the Lerner reading, was utilized in the analysis. It was felt that this was the most appropriate timespan as with any project involving technology there would most likely be improved software and hardware, which would require additional financial resources within the next five years in order to maintain the viability of the proposed project.

6.1 Financial Parameters

6.1.1 Project Setup Worksheet

Before beginning the analyses there were some parameters and factors that needed to be considered and needed to be entered manually into the Excel workbook. The project will commence in year one (2013) and continue consecutively for five years. This gives the project a timespan between 2013 and 2017. This is the most appropriate timespan as determined on the ever changing technology factor. Inflation was determined to be 2.47%. This was based on data obtained from the United States Department of Labor – Bureau of Labor Statistics website (http://data.bls.gov)(United States, 2013). Average inflation was determined between 2003 and 2013 using the Consumer Price Index – All Urban Consumers Data, applying the 12-Month Percent Change option. The Opportunity Cost of Capital was set to 5.00%, as suggested by the spreadsheet directions, since the group does not have access to and cannot obtain more accurate data from the King County Finance Department. The Opportunity Cost of Capital is the annual return that could be expected from an alternative investment that is forgone in order to fund the project being analyzed (Lerner et al., 2007). The spreadsheet directions suggested utilizing 5.00% if no other information is attainable. The Method for Determining Future Years' Cost of Labor chosen was: Derived by Applying Inflation Rate to Current Costs. This option applies the inflation rate entered earlier to the data on the Labor Rates sheet to estimate what labor costs will be in the future (Lerner et al., 2007). The directions suggested using this option and after reviewing all of the other methodology options it was determined that this was the most appropriate course of action.

Net Present Value (NPV) was used in our analysis as the key metric instead of Return on Investment (ROI). The NPV is the sum of the present values of all cash flows (i.e., benefits net of costs) and this is the best overall measure of financial value because a higher NPV always indicates a better financial investment (Lerner et al., 2007). ROI is the ratio of NPV to the absolute present value of all costs and is an inappropriate metric for comparing mutually exclusive investments which is what this analysis did (Lerner et al., 2007). Therefore NPV was used in our analysis and it was decided not to treat any labor costs as a negative productivity benefits (Lerner et al., 2007). This helped to simplify the analysis and made it easier to understand and comprehend. The majority information was entered manually into Table 6.1 – Project Setup Sheet before the beginning of the analysis. Values such as NPV were then automatically calculated as the analysis progressed.

6.1.2 Labor Rates Worksheet

The next step in the analysis was to enter information in Table 6.2 – Labor Rates. On the Labor Rates worksheet there are Job Categories for which the Current Average Hourly Rate ($/Hour) needed to be determined. In order to proceed, salary information for the King County employees who will be utilizing this project needed to be determined. Salary information from 2011 was obtained from the newspaper, The News Tribune, website. They had done a records request and set up a database which allows the reader to search salaries by last name (The News Tribune, 2012). The latest year for which salary information was available is 2011. Salary information was listed as a total for the year. In order to use this information the total salary had to be divided by the number of weeks in a year and then divide by working hours per week to obtain an average hourly rate. There are three types of job categories that were entered into the Labor Rates Worksheet. Program Manager, Education Specialist, and Noxious Weed Specialist and Program GIS Analyst were listed with their average hourly rate. No overtime was entered as it was assumed that these positions were salaried and therefore ineligible for it. Fringe, a wage multiplier which covers the cost of taxes, insurance, and related overhead items that contribute to the cost of employing someone in this category was also included (Lerner et al., 2007). As per the example in the reference text instructions a rate of 33% was utilized. This information is presented in Table 6.2 – Labor Rates.

6.1.3 Labor Cost Multipliers Worksheet

The next worksheet in the financial analysis is the Labor Cost Multipliers worksheet. In this worksheet, for each job category, the labor costs (and productivity benefits) are calculated on a *per hour* or *per FTE* basis (Lerner et al., 2007). In the analysis, the *per hour* option was chosen. This information is presented in Table 6.3 – Labor Cost Multipliers.

6.1.4 Internal Labor Usage Worksheet

The next worksheet to be worked on was the Internal Labor Usage worksheet, which was used to capture all internal labor that was treated as project costs (Lerner et al., 2007). Each job category has a Nature of Work attribute which documents the type of work performed by the job category for the project and the number of hours, per year, of labor associated with it. It was estimated that the Education Specialist will spend 50 hours per year, the Noxious Weed Specialist and Program GIS Analyst 150 hours per year, and the Program Manager 20 hours per year on labor for the project. The only employee who will see a significant increase in labor is the Noxious Weeds Specialist and Program GIS Analyst as he will be performing a lot of new data modeling and analyses as well as producing cartographic material. The expected hours required for the implementation of the recommendations is listed in Table 6.4 – Internal Labor Usage.

6.1.5 Internal Costs Worksheet

Associated with the Internal Labor Usage worksheet is the Internal Labor Costs worksheet. This worksheet automatically calculates internal labor costs based on the usage recorded on the Internal Labor Usage worksheet and labor cost multiplies for each job category (Lerner et al., 2007). No information was added to the table by the users and its purpose was as a summary of the information. This information can be seen in Table 6.5 – Internal Labor Costs.

6.1.6 Contract and Procurement Costs Worksheet

The next table is the Contract and Procurements Costs worksheet and it lists all the one-time and ongoing project costs in the appropriate categories. There have been identified three categories for which there are costs associated. In the Data Conversion and Reconciliation category there is a cost associated with the conversion of shapefile to KML files to be used in Google Earth. It was estimated this cost to be $250 per year for the life of the project. This will be a yearly cost as there will be files that need to be converted every year as new information is added and updated. In the New Software category there will be a cost associated with the purchase of Google Earth Pro software. This is a one-time cost of $400. A pro license is required when using the imagery for external purposes such as in reports, publications, or showing the public the animation (Google Inc., 2013). In addition to the one-time cost of purchasing a Google Earth Pro license there is an annual license renewal fee. This is located in the Software Maintenance Fees category. This fee is $400 and is renewed annually. This information is displayed in Table 6.6 – Contract and Procurements Costs.

6.1.7 Productivity Benefit Worksheet

The Productivity Benefit (Summary) worksheet is for review purposes only. The purpose of this worksheet is to calculate the productivity benefits based on the hours of FTEs recorded on the productivity detail worksheets and the labor cost multipliers for each job category (Lerner et al., 2007). The information is located in Table 6.7 – Productivity Benefits.

6.1.8 Other Benefits Worksheet

The Other Benefits worksheet defines all of the other quantifiable (non-productivity) benefits for the application areas covered by the project (Lerner et al., 2007). There are several different benefits that have been determined and each occurred in all of the years of the project. It was determined that there would be a benefit of $5,000, in the form of reduced map production and distribution costs, by using the created KML files and Google Earth. Being able to efficiently coordinate sites where field crews should visit based on the likelihood of noxious weeds being present would save $10,000 per year. There would also be a $2,000 benefit in the form of reduced costs associated with outreach and education as producing maps and the time spent trying to communicate information would be reduced. Using the MCA to find parcels which are high risk and thus reduce the mailing costs and allocations would produce a $2,500 benefit. The reduction in graphics production costs related to noxious weeds related inquiries by the public would produce a $1,500 benefit. This would be realized through the use of the Python/ArcPy Visualization Tool which would help to decrease the amount of time it takes to create the maps based on the public inquiries. All of this information is displayed in Table 6.8 – Other Benefits.

6.1.9 Productivity Benefits Detail Worksheet

The Productivity Benefits Detail worksheet details and defines all labor productivity benefits for the application areas covered by the project for each of the job categories (Lerner et al., 2007). There were several benefits that were realized by the project and help the individual employees assigned to this project. This would help to make their work be more productive and in the long run save both time and financial resources. The Productivity Benefits for the Education Specialist are listed in Table 6.9 – Productivity Benefit – Education Specialist. The Productivity Benefits for the Program Manager are listed in Table 6.10 – Productivity Benefit – Program Manager. The Productivity Benefits for the Noxious Weeds Specialist and Program GIS Analyst are listed in Table 6.11 – Productivity Benefit – Noxious Weeds Specialist and Program GIS Analyst.

6.1.10 Financial Analysis Worksheet

Table 6.12 – Financial Analysis depicts the results of the financial analysis. As can be seen by the NPV of $116,738 in 2017, this project is financially viable and does make a strong case for being implemented. The break-even point will occur in the first year of the project (2013). The project has a Return on Investment of 58.60%, which great return value given the relatively small amount of cost and investment that is need in order to move the project forward. The Present Value of Cost is listed as $39,843, which is not a large value for cost, given the NPV of this project. The only costs associated with this project are internal labor costs, acquiring software, and software maintenance. There are also potentially ways to reduce some of these costs by sharing the cost of acquiring software and maintaining it with other departments. These may also benefit from the software and the data products produced. Sharing in the cost of purchasing and maintaining the license for Google Earth Pro would be one way to reduce costs.

If such cost sharing were to occur there would be an additional decrease in the costs amounts for the project. Also, as the GIS Analyst becomes more adept at the animation and data modeling workflow process, the amount of time it takes to complete the workflow will decrease and there would be a decrease in the Internal Labor Costs. By becoming more efficient at the workflow process, less time and resources are spent doing the specific tasks. Also increasing the using of automation by creating script tools would also help to decrease costs as this decreases processing time and the need for human intervention. These actions would all help to decrease the project costs and as a result the NPV would increase throughout the project life-cycle. The final output of the Financial Analysis can be seen in Table 6.12 – Financial Analysis.

6.2 Limitations and Caveats

This is the financial analysis that we have conducted for the KCNWDA project. Where ever possible the use of obtained data to fulfill the parameters was utilized. However, in some cases where actual data could not be obtained or was unknown, reasonable assumptions and estimations were made in order to proceed with the analysis. All numbers generated in this fashion were completed conservatively in order to not inflate or skew the results. It is felt that although this may not be a perfect analysis, the results obtained are reasonably accurate and reflect a reasonable outcome for determining the financial viability of the project. Investing a small amount of resources, labor, and money has the potential to pay rather large dividends in the end and allow for a greater understanding of noxious weeds within King County.

6.3 Strategic Analysis

The Strategic Analysis explains how an investment furthers an organization's mission and goals, and it presents intangible (non-quantifiable) benefits as well as addressing project interrelationships (Lerner et al., 2007). In this section the strategic benefits of this project will be discussed. The project does further the King County Noxious Weed program's mission and goals in several different ways and is strategically very important. There is a great deal of potential benefit to this type of analysis being conducted. At the same time a great deal of beneficial information may be lost if the project is not funded. The Intangible Benefits, External Benefits, and the Project Interrelationships will be examined. In addition a Recommended Course of Action is put forward and discussed. These sections will show the strategic benefit to moving forward with this type of project and funding it for the duration of the project life-cycle.

6.4 Intangible Benefits

There would be several intangible benefits that are indirect and not quantifiable. These include the benefit of increased awareness of noxious weed issues through the use of the animations to the population of King County. More people would be able to be aware of the issues but it would be difficult to determine the direct benefits. Another intangible benefit would be the increased outreach potential as a result of the new data deliverables, KML files and animation series. These would help to more effectively communicate the issues, although being able to translate this into a dollar return would not necessarily be possible. These intangible benefits offer great opportunities as any chance to increase the publics' awareness to the issue is a positive action. This can in turn lead to more funding opportunities as people will demand their lawmakers act to stop the spread of noxious weeds. The outcome will lead to a benefit of an improved ecosystem which will ultimately help improve the quality of life for the community.

6.5 External Benefits

There are several external benefits that would be realized if this project was funded and was put into service. Not only would the King County Noxious Weeds Program benefit from using this data and information to make decisions, other County departments and work groups may as well. The Noxious Weeds Program is part of the Department of Natural Resources and Parks. There are other work groups in this department which would benefit from this project and the information generated. Groups working on site restoration or park maintenance would benefit as well. They would be able to know where noxious weeds have a tendency to occur and be able to counteract before the issue becomes a problem. It may be useful in their group's mission and allow them to be more productive as well. In addition to other County departments and work groups other City agencies and city work groups could benefit. For example, our garlic mustard analysis focused on the City of Seattle. The Seattle Department of Planning and Development is in charge of dealing with environmental issues within the City. Sharing the information and modeling process with this department will allow the City to combat the noxious weeds issues within its limits. This is an example of an external benefit to one city within the County. There are many cities within the County and this information could be sent to all of them. The result of this would be better management and control of noxious weeds within all jurisdictions. This would result in a multi-faceted control approach and use the most available resources.

This improves the sustainability management aspect of the noxious weeds issue. As the County and Cities become more aware of the issues and are better suited to manage them it will improve the sustainability of the surrounding ecosystem. The eradication efforts will be more focused and potentially more effective and be able to better combat noxious weed spread. This in turn improves the resilience of the ecosystem and thereby allows it to better withstand shocks and upheavals. Using this project to manage the ecosystem sustainably is possible as it focuses the efforts and resources of the agencies to locations where the most benefits can be realized. By focusing these efforts, it is possible to get the most results out of the limited financial resources currently being felt by the County and other jurisdictions. This in turn will allow the County to use the money saved to further fund the project and potentially further improve ecosystem. The sustainability management benefits of this project far outweigh the costs of doing this project and therefore the project should be incorporated into the King County Noxious Weeds Program operating budget.

6.6 Project Interrelationships

There are some project interrelationships when it comes to this proposed project. Since this project has only dealt with two noxious weed species and according to King County Noxious Weeds there are 41 Class A noxious weeds which need to be managed and eradicated. There is a lot of work left to be done. The project has formed the foundation of doing this type of analysis for all of the Class A noxious weeds. Also the information produced by this project may lead to better collection of noxious weed data, which would help other efforts in controlling their spread. Future projects would be able to use the data created from this project to better manage their time and effort. This would help them decrease their overall costs and increase their benefit outputs. As can be seen, there is much potential project interrelationships that could occur. This is important when considering whether or not to proceed. The benefits of these interrelations are numerous and could possible lead to the development of other projects which would enhance the sustainability management of noxious weeds.

6.7 Recommended Course of Action

As a group we recommend implementation of our project with funding to last for the duration of the project life-cycle. This will ensure that the full benefits depicted in the financial analysis would be realized. As has been discussed, the potential benefits far outweigh the costs of doing the project. The benefits to sustainability management also make it worth proceeding with this project. The benefits of spreading knowledge to other agencies and being able to coordinate and cooperate on the issue is a great tangible benefit and one that could lead to other projects and collaborations. This opens the door to unlimited potential. All of the intangible benefits, external benefits, and project interrelationships show that this project is beneficial and will lead to a better understanding of the noxious weeds issue. It would be prudent in this ever changing world to take advantage of these benefits and knowledge and use them to the fullest potential. Fully funding the project and modeling all of the Class A noxious weeds would be the recommended course of action. However if that is not possible, then a large list of priority Class A noxious weeds should be identified, modeled, and analyzed. Once this is completed it would be possible to view a more accurate cost assessment and determine how to further proceed. This would be the course of action if the project is not fully funded or if there are questions as to how effective the benefits resulting from the project would be. If the outcome is favorable then it would be prudent to move forward with analysis on the rest of the Class A noxious weeds. These are the recommendations for the course of action regarding this project. As has been shown there are many benefits associated with doing this project. It is up to the stakeholders and decision makers to ensure that this project has a future and is implemented. This financial and strategic analysis has given all the necessary tools to make this decision.

Table 6.1 - Project Setup Sheet

Project Name:	King County Noxious Weed Distribution Analysis (KCNWDA)
Date Analyzed:	8/11/2013
Net Present Value (Net Benefits):	$116,738
Annualized Return on Investment:	58.60%
Breakeven Point:	2013
Payback Period (in Years):	0
Inflation Rate:	2.47%
Opportunity Cost of Capital:	5.00%

Project Year Labels:	**2013**	**2014**	**2015**	**2016**	**2017**
Project Life (Number of Years):	5				

Method for Determining Future Years' Cost of Labor:
Derived by Applying Inflation Rate to Current Costs

Notes and Other Assumptions:
Project will commence in year one (2013) and continue consecutively for five years.

Table 6.2 - Labor Rates

Job Category	Current Average Hourly Rate ($/Hour)	Fringe	Burdened Hourly Rate	Average Annual Regular Hours	Average Annual Cost Before Overtime	Average Annual Overtime Hours	Average Overtime Multiplier	Average Annual Cost of Position
Education Specialist	$26.19	33.00%	$34.83	2000	$69,700.23			$69,700.23
Noxious Weed Specialist and Program GIS Analyst	$21.63	33.00%	$28.77	2000	$57,564.57			$57,564.57
Program Manager	$48.58	33.00%	$64.61	2000	$129,287.41			$129,287.41

Table 6.3 - Labor Cost Multipliers

Method for Determining Future Years' Cost of Labor: **Derived by Applying Inflation Rate to Current Costs**

Job Category	**Current Hourly Rate**	**Current Cost/FTE**	**Valuation Method**	**2013 Labor Cost**	**2014 Labor Cost**	**2015 Labor Cost**	**2016 Labor Cost**	**2017 Labor Cost**
Education Specialist	$34.83	$69,700.23	*per Hour*	$34.83	$35.69	$36.57	$37.48	$38.40
Noxious Weed Specialist and Program GIS Analyst	$28.77	$57,564.57	*per Hour*	$28.77	$29.48	$30.21	$30.95	$31.72
Program Manager	$64.61	$129,287.41	*per Hour*	$64.61	$66.21	$67.84	$69.52	$71.24

Valuation Method Options	***Description***
per Hour	*Labor cost reflects average cost per hour worked*
per FTE	*Labor cost reflects average annual cost of one full time position*

Table 6.4 - Internal Labor Usage

Job Category	Valuation Method	Nature of Work	2013.00 Hrs or FTEs	2014.00 Hrs or FTEs	2015.00 Hrs or FTEs	2016.00 Hrs or FTEs	2017.00 Hrs or FTEs
Education Specialist	*per Hour*	Educate public regard noxious weeds and their impacts.	50.00	50.00	50.00	50.00	50.00
Noxious Weed Specialist and Program GIS Analyst	*per Hour*	Conduct data collection and entry, data analysis, map production.	150.00	150.00	150.00	150.00	150.00
Program Manager	*per Hour*	Oversee the program and manage all project decisions and activities.	20.00	20.00	20.00	20.00	20.00

Table 6.5 - Internal Labor Costs

(in future year dollars) **Job Category**	**$2,013 Labor Cost**	**$2,014 Labor Cost**	**$2,015 Labor Cost**	**$2,016 Labor Cost**	**$2,017 Labor Cost**
Education Specialist	$1,742	$1,785	$1,829	$1,874	$1,920
Noxious Weed Specialist and Program GIS Analyst	$4,315	$4,422	$4,531	$4,643	$4,758
Program Manager	$1,292	$1,324	$1,357	$1,390	$1,425
Total Internal Labor Costs	$7,349	$7,531	$7,717	$7,907	$8,102

Total Iternal Labor Investment	**$38,606**

Table 6.6 - Contract & Procurement Costs

(in future year dollars)	**2013**	**2014**	**2015**	**2016**	**2017**
Data conversion and reconciliation					
Convert Shapefiles to KML	$250.00	$250.00	$250.00	$250.00	$250.00
New software					
Google Earth Pro	$400.00				
Software maintenance fees					
Google Earth Pro License Renewal (Annually)		$400.00	$400.00	$400.00	$400.00
Total External Costs	$650	$650	$650	$650	$650

Total External Investment	**$3,250**

Table 6.7 - Productivity Benefits

(in future year dollars) **Job Category**	**Valuation Method**	**2013 Savings**	**2014 Savings**	**2015 Savings**	**2016 Savings**	**2017 Savings**
Education Specialist	*per Hour*	$2,787	$2,855	$2,926	$2,998	$3,072
Noxious Weed Specialist and Program GIS Analyst	*per Hour*	$5,610	$5,748	$5,890	$6,036	$6,185
Program Manager	*per Hour*	$2,908	$2,979	$3,053	$3,128	$3,206
Total Productivity Benefits		$11,304	$11,583	$11,869	$12,162	$12,463

Table 6.8 - Other Benefits

(in future year dollars) **Specific Other Benefits**	**2013 Benefits**	**2014 Benefits**	**2015 Benefits**	**2016 Benefits**	**2017 Benefits**
Reduce map production and distribution costs using created KML files and Google Earth	$5,000.00	$5,000.00	$5,000.00	$5,000.00	$5,000.00
Efficiently coordinate sites where field crews should visit based on the likelihood of noxious weeds being present.	$10,000.00	$10,000.00	$10,000.00	$10,000.00	$10,000.00
Reduce costs associated with outreach and education.	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00
Use MCA to find parcels which are high risk and thus reduce the mailing costs and allocation.	$2,500.00	$2,500.00	$2,500.00	$2,500.00	$2,500.00
Reduce graphics production costs related to noxious weeds related inquires by the public (Python/Arcpy Visualization Tool)	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00
Total Other Benefits	$21,000	$21,000	$21,000	$21,000	$21,000

Table 6.9 - Productivity Benefit Detail - Education Specialist

Job Category: Education Specialist Specific Productivity Benefits	2013 Hours	2014 Hours	2015 Hours	2016 Hours	2017 Hours
Reduce preparatory time needed to obtain static maps showing the distribution of noxious weeds for presentations and outreach events.	10.00	10.00	10.00	10.00	10.00
More effectively communicate with the public regarding noxious weeds and their impacts.	50.00	50.00	50.00	50.00	50.00
Reduction in the length of each outreach event because more information is communicated more effectively.	10.00	10.00	10.00	10.00	10.00
Real-time map making reduces backlog to address public inquiries (Google Earth animations).	10.00	10.00	10.00	10.00	10.00
Total Hours Saved for this Job Category	80.00	80.00	80.00	80.00	80.00

Table 6.10 - Productivity Benefit Detail - Program Manager

Job Category: Program Manager **Specific Productivity Benefits**	**2013 Hours**	**2014 Hours**	**2015 Hours**	**2016 Hours**	**2017 Hours**
More effectively communicate with the public regarding noxious weeds and their impacts	10.00	10.00	10.00	10.00	10.00
Reduced management costs regarding program subordinates.	20.00	20.00	20.00	20.00	20.00
Reduction in the length of each outreach event because more information is communicated more effectively.	10.00	10.00	10.00	10.00	10.00
Reduction in the amount of time spent balancing the program budget.	5.00	5.00	5.00	5.00	5.00
Total Hours Saved for this Job Category	45.00	45.00	45.00	45.00	45.00

Table 6.11 - Productivity Benefit Detail - Noxious Weed Specialist & Program GIS Analyst

Job Category: Noxious Weed Specialist and Program GIS Analyst **Specific Productivity Benefits**	**2013 Hours**	**2014 Hours**	**2015 Hours**	**2016 Hours**	**2017 Hours**
Reduction in the amount of hours necessary to create static maps displaying noxious weed distribution by either using the KML and Google Earth or using the Noxious Weed Infestation Area Temporal Visualization Python/Arcpy Tool.	20.00	20.00	20.00	20.00	20.00
Reduce travel times to survey sites by determining the most likely sites with noxious weeds and being able to group these trips together.	75.00	75.00	75.00	75.00	75.00
Improved understanding about the spread of noxious weeds with King County based on the MCA analysis	50.00	50.00	50.00	50.00	50.00
Focus survey times and trips based on the MCA analysis in order to be able to increase the amount of area surveyed and documented.	50.00	50.00	50.00	50.00	50.00
Total Hours Saved for this Job Category	195.00	195.00	195.00	195.00	195.00

Table 6.12 - Financial Analysis

	2013	2014	2015	2016	2017
Future Cash Flows					
Internal Labor Costs	($7,349)	($7,531)	($7,717)	($7,907)	($8,102)
Contract/Procurement Costs	($650)	($650)	($650)	($650)	($650)
Productivity Benefits	$11,304	$11,583	$11,869	$12,162	$12,463
Other Benefits	$21,000	$21,000	$21,000	$21,000	$21,000
Present Value Multiplier:	*100.0%*	*97.6%*	*95.2%*	*92.9%*	*90.7%*
Present Values					
Internal Labor Costs	($7,349)	($7,349)	($7,349)	($7,349)	($7,349)
Contract/Procurement Costs	($650)	($634)	($619)	($604)	($590)
Total Annual Costs	*($7,999)*	*($7,983)*	*($7,968)*	*($7,953)*	*($7,939)*
Cumulative Costs	*($7,999)*	*($15,983)*	*($23,951)*	*($31,904)*	*($39,843)*
Productivity Benefits	$11,304	$11,304	$11,304	$11,304	$11,304
Other Benefits	$21,000	$20,494	$20,000	$19,518	$19,048
Total Annual Benefits	*$32,304*	*$31,798*	*$31,304*	*$30,822*	*$30,352*
Cumulative Benefits	*$32,304*	*$64,102*	*$95,406*	*$126,229*	*$156,581*
Cumulative Net Benefits	**$24,305**	**$48,119**	**$71,455**	**$94,324**	**$116,738**

Breakeven Year: 2013
Payback Period (in Years): 0
Net Present Value: $116,738
Present Value of Costs: $39,843
Return on Investment: 58.60% *(Annualized)*

7 IMPLEMENTATION

Our report has documented many approaches to augmenting the County's ability to effectively and sustainably manage noxious weeds. The final step in bringing our efforts to fruition involves the successful implementation of the animations, multi-criteria analyses, geospatial data analyses, and python tool within the context of the business case that we have developed. Figure 7.1 – Swimlane Workflow Diagram for Noxious Weed Control Support for Infestation Visualization and Environmental Variable Correlation presents a summary of the activities we have engaged in throughout the course of the project and the time lines over which project phases were carried out. This section will detail the specific implementation activities that will be carried out in Phase 3 of the diagram. Individually, each component represents a meaningful contribution. However, when delivered in concert, the multiple components comprising our deliverable complement each other, adding more value to the final product than the sum of its subcomponents.

As part of the implementation the separate deliverable components will be made ready to be handed over to the County stakeholders. This will involve processing of data for final submittal, creation of metadata for applicable data products, conducting training with County personnel on the use of the MCA, Python Script, and Animation steps, and finalizing print and digital map products for public use. It is felt that with these actions it will be possible for County personnel to quickly acquire the skills to use the tools and methods we have created. This will then help them to have a better understanding of the noxious weeds that they are interested in. It will also enable us to offer further technical support as the County develops the capabilities to use these tools.

7.1 Animation Implementation

Animation implementation will consist of product deliverables, website hosting of animations, and training sessions. Product deliverables will consist of representative animation video files in AVI and WMV formats and ArcGIS MXD documents that contain time-enabled data for garlic mustard and giant hogweed and are configured with time slider settings to enable playback of the entire temporal record that is available for these two Class A noxious weed species. Additionally, we will provide representative GE animation sequences for these two weed species in WMV format as well as the time-enabled KML files that were used to create the exported WMV animations so that the County representatives can recreate these animations on their own computers or make new animations based on new data as it accumulates over time. After the County takes delivery of our animation video files, we will work with the County to determine the best approach to making the animations available via download from their website or via hyperlink to animation files that are hosted by external content providers such as YouTube and Vimeo. Finally, we will schedule a training session of approximately 2 hours duration to enable Chris Gardner to demonstrate the workflows that were used to create these animations to County representatives who are tasked with distributing these animations or creating future animations using our workflow process. In addition to fulfilling the outreach and meeting purposes detailed earlier in this report, the animations can be used in conjunction with multi-criteria analyses maps and maps showing output from the Python tool. For example, the animations can quickly and dynamically illustrate trends that can be investigated in greater detail using the infestation summary maps created with the Python tool, and this information can be combined with results from the multi-criteria analyses to predict at-risk sites for future weed infestations – helping the County direct its eradication efforts where they are most-likely needed.

7.2 Python Tool Implementation

Implementation of the Python tool will consist of electronic delivery of an ArcGIS toolbox that contains our Python/ArcPy script and all of its parameter definitions and documentation. This toolbox is included in Appendix 8.4 and will be provided in a DVD supplement that is included with this report. We will schedule a training session of approximately 1 hour to enable Chris Gardner to demonstrate script execution and follow-up symbology and labeling of the script's output files. We have created extensive documentation that is embedded within this script. For example, each script parameter has explanatory text about its function that appears automatically when the parameter is entered within the script dialog box. We do not anticipate the end users of this script having any issues with its use. However, in the event that help or assistance is needed, we will provide the County with our professional contact information and make ourselves available for customer service-related consultation regarding the script if it is needed in the future. It is possible that script modification will be necessary in the future to keep the script compatible with future versions of both ArcGIS and Python so we are prepared to provide this ongoing service.

7.3 Multi-Criteria Analysis Implementation

Having performed an MCA, we must ask ourselves how exactly this map and data can be utilized. We must examine what internal and external uses the MCA and resulting invasion risk map can serve. Here are some potential implementation strategies we will recommend to our sponsors.

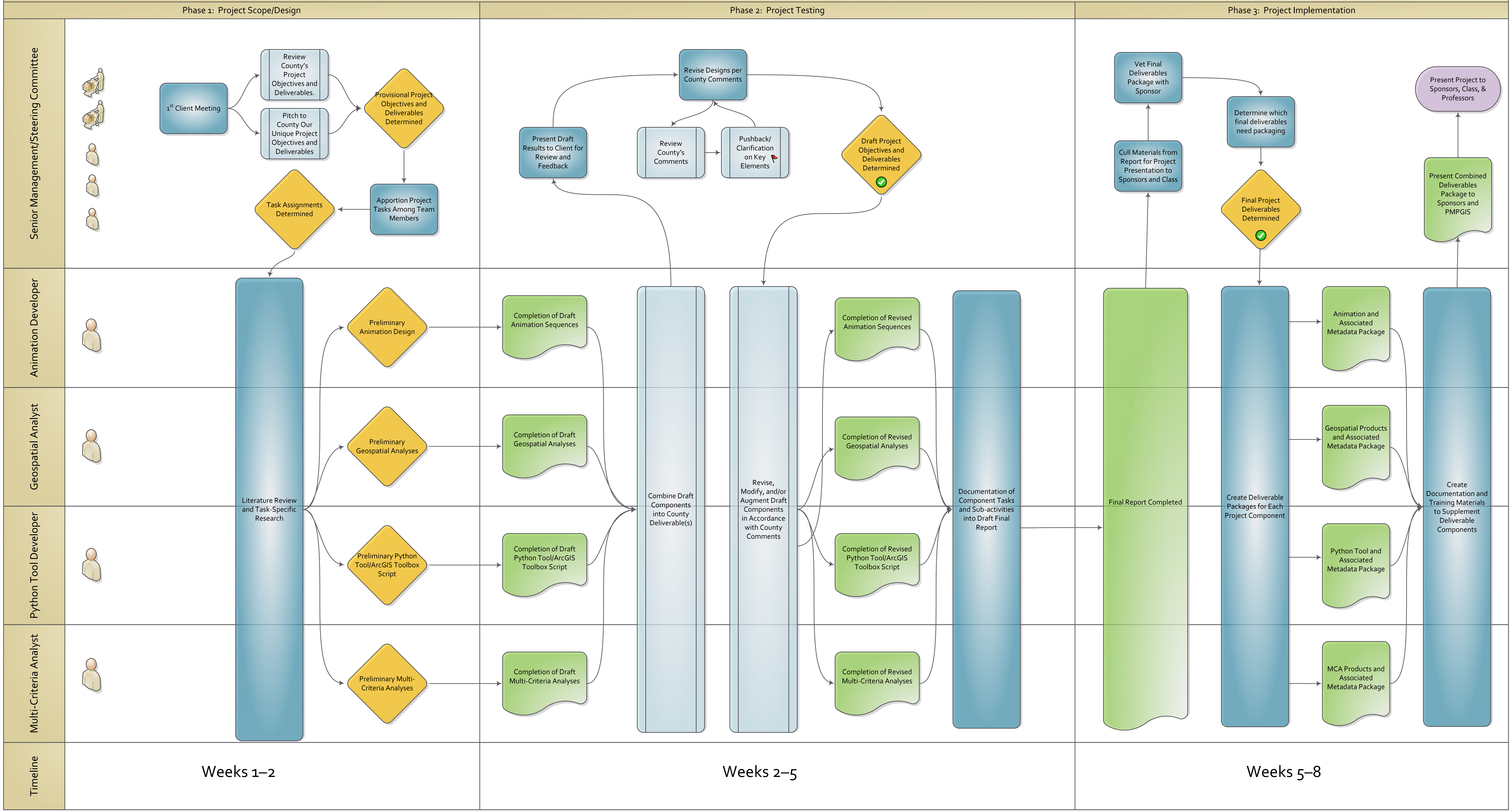
The simplest would be to use the map to further their outreach and education goals. This could be accomplished in a number of ways. Staff could plot a poster sized map that can be laminated to a foam board. King County Noxious Weeds staff attends many fairs and farmers markets throughout the year in order to do community outreach. A large map displayed prominently that details the potential spread of garlic mustard would draw people in and instantly become a talking point. And once people begin asking questions, staff can then have deeper conversations about the nature of noxious weeds and the negative effect they can have. Additionally, when garlic mustard is featured as the "Weed of the Month" in the Noxious Weeds Control Program's monthly newsletter, the map can be used to augment the story being told. Currently, county staff has noxious weed locations displayed on the county iMAP system, an online mapping tool. The iMAP tool is slated to be phased out, so staff has the opportunity to try and use a new system for online maps, either through ArcGIS Online or just a link to a pdf on the Noxious Weeds Control Program's website.

Beyond outreach and education efforts, the garlic mustard invasion risk map can be utilized to better target areas for monitoring. King County staff has limited financial and personnel resources. Therefore, a map detailing where garlic mustard is most likely to spread can enhance the decision-making process that determine where staff can go out to survey. Additionally, the map can be used within the ArcGIS environment to target specific landowners that fall in the "Moderate to High Risk" and "High Risk" areas. Staff can convert the final raster layer for invasion risk into a vector polygon layer. Using a simple "Select by Location" tool, staff can select out any parcel that intersects with those areas most at risk. This selection can be exported into a table that can be linked to a tax assessment table through the unique parcel ID. The tax assessment file has ownership and address that staff can then use to either directly visit sites for monitoring or to send out mailings that ask these owners to be aware of the potential risk. After each year's surveying, new data points can easily be incorporated into the MCA, continually assisting the program's surveying efforts on an annual basis.

And lastly, invasion risk maps can potentially help the Noxious Weeds Control Program with funding requests. Currently, the program's budget comes out of the King County's general fund. By having a defensible visualization of potential spread areas, invasion risk maps can dramatically highlight the necessity for the program's continued work.

These ideas are just the start and are not meant to be exhaustive. But they certainly demonstrate that the MCA is not just an analytical exercise but a valuable tool to help further the outreach and eradication goals for the King County Noxious Weed Control Program.

Figure 7.1: King County Noxious Weeds Program Support for Infestation Visualization and Environmental Variable Correlation



8 APPENDICES

8.1 Animation Deliverables

8.1.1 Exported Animation Files

Exported animation files are attached as a DVD supplement to this report. The DVD includes the following animation sequences that were exported from ArcMap, ArcScene, and Google Earth in AVI and WMV formats:

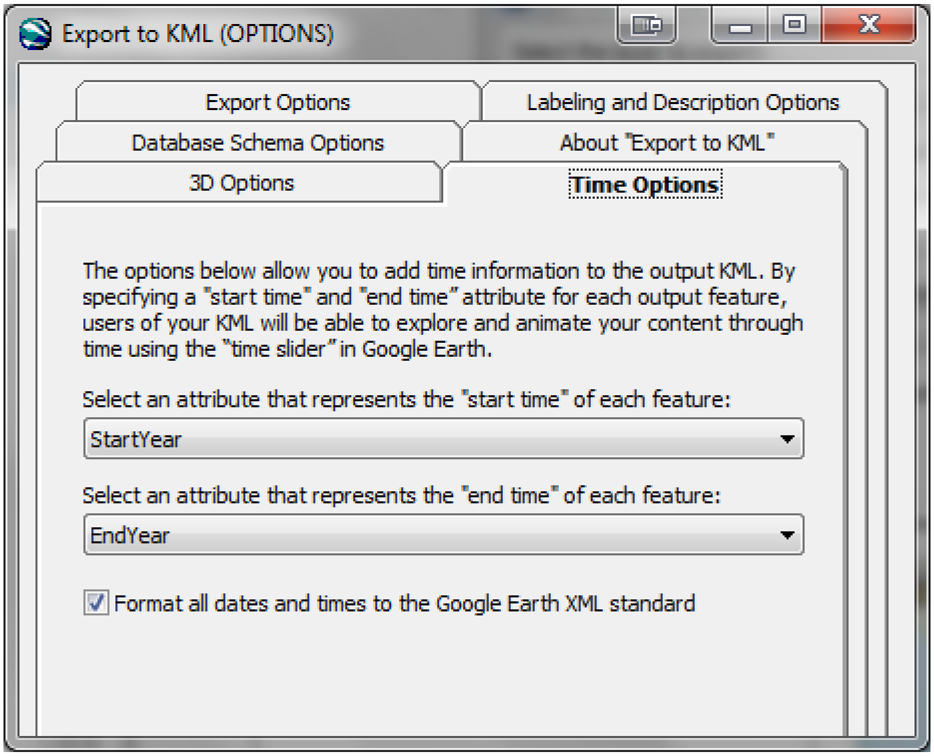
1. Giant Hogweed Flyby ArcScene (AVI);
2. Giant Hogweed Time Slider Fade Away (AVI);
3. Giant Hogweed Tour Linear Time Steps (WMV);
4. Giant Hogweed Tour View to West (WMV);
5. Garlic Mustard Greatest Hits (WMV);
6. Garlic Mustard Seattle Flyby (WMV);

8.1.2 KMZ Files

KML files were created using the *Export to KML* extension in ArcGIS to encode them with time attributes that are recognized by Google Earth and thereby enable playback using GE's time slider controls. KML files were used to store the time-enabled noxious weed infestation data as well as the movement sequences (tours) that together comprise the animation sequences that we produced. When exported from GE, these KML files were compressed into zipped KMZ files. GE can read KMZ files directly so there is no need for the end user to unzip the KMZ file deliverables that we are providing. These KMZ files are provided on the DVD supplement included with this report.

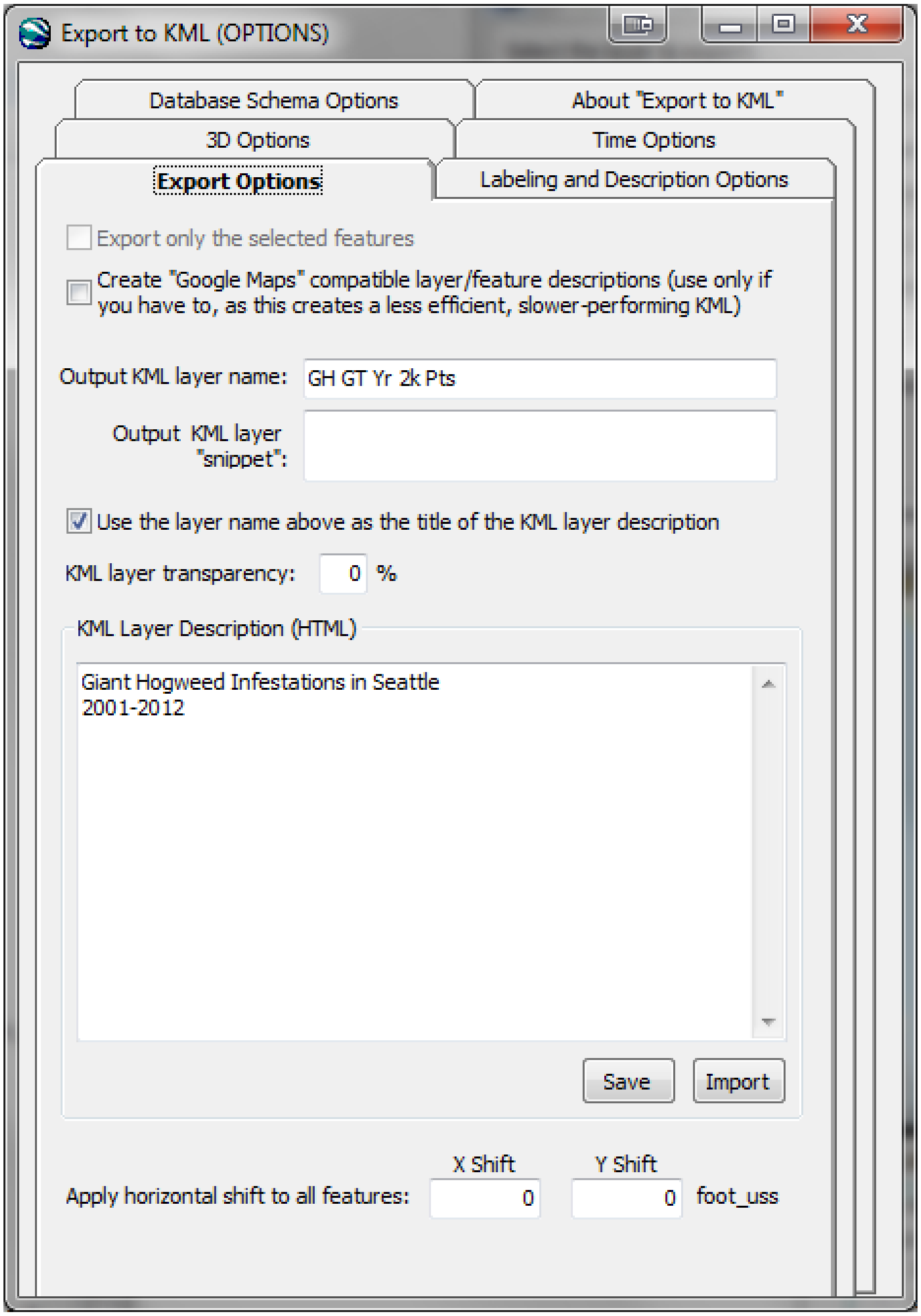
8.2 Export to KML Highlights

8.2.1 Time Options



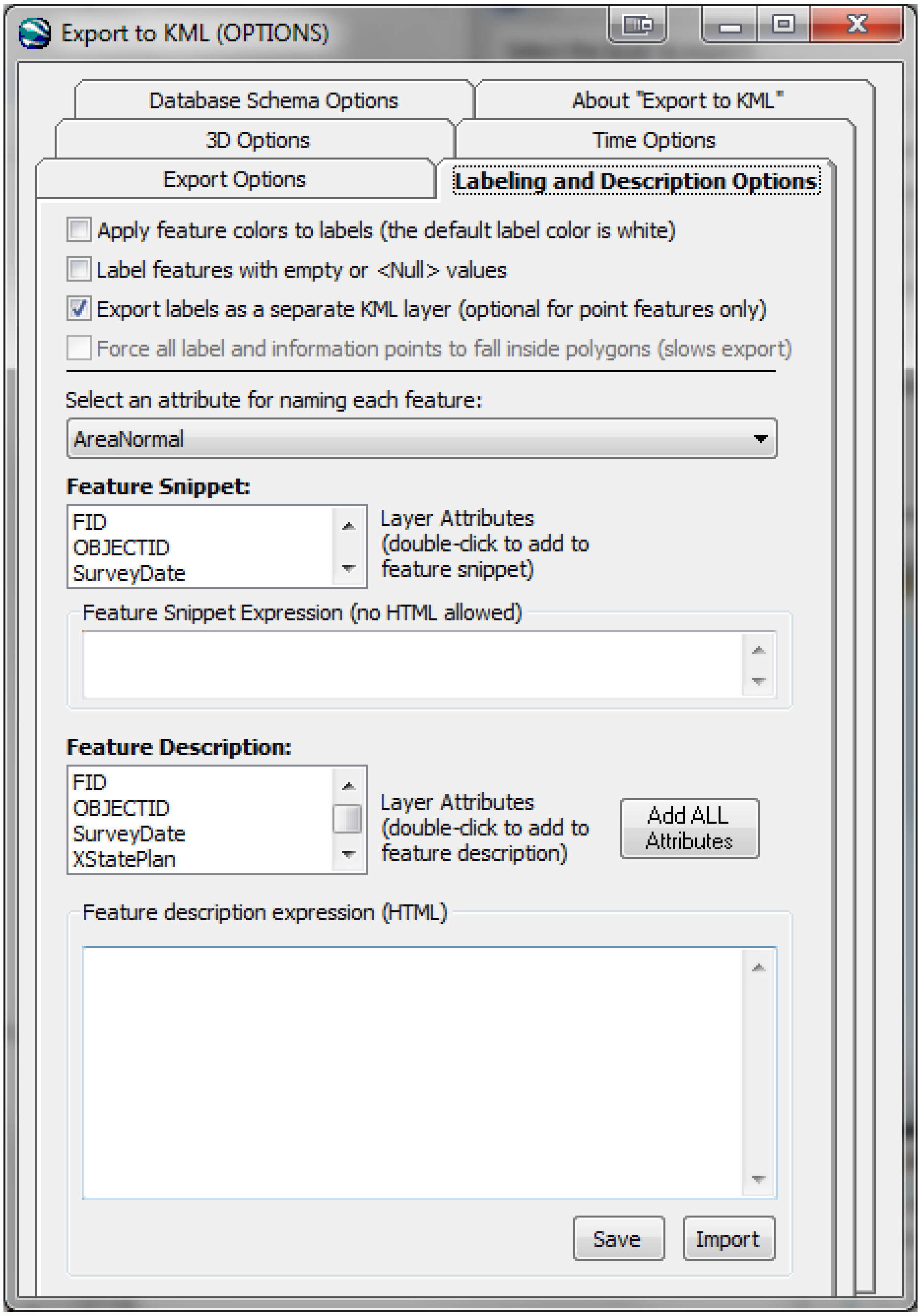
- Added fields "StartYear" and "EndYear" to attribute table of noxious weeds data to enable time. A single time field does not make data *temporal* evidently when attempting to work with time in the Google Earth environment.
- The ability of this extension to temporally-enable data through this dialog box is what allowed us to create animations in Google Earth. The ArcGIS kml tools at ArcGIS 10.0 do not appear to enable this capability. God Bless the City of Portland for this extension!! Additionally, even at the Google Earth Pro level of licensure, I haven't discovered yet how to temporally enable data that is imported as shapefiles.

8.2.2 Export Options



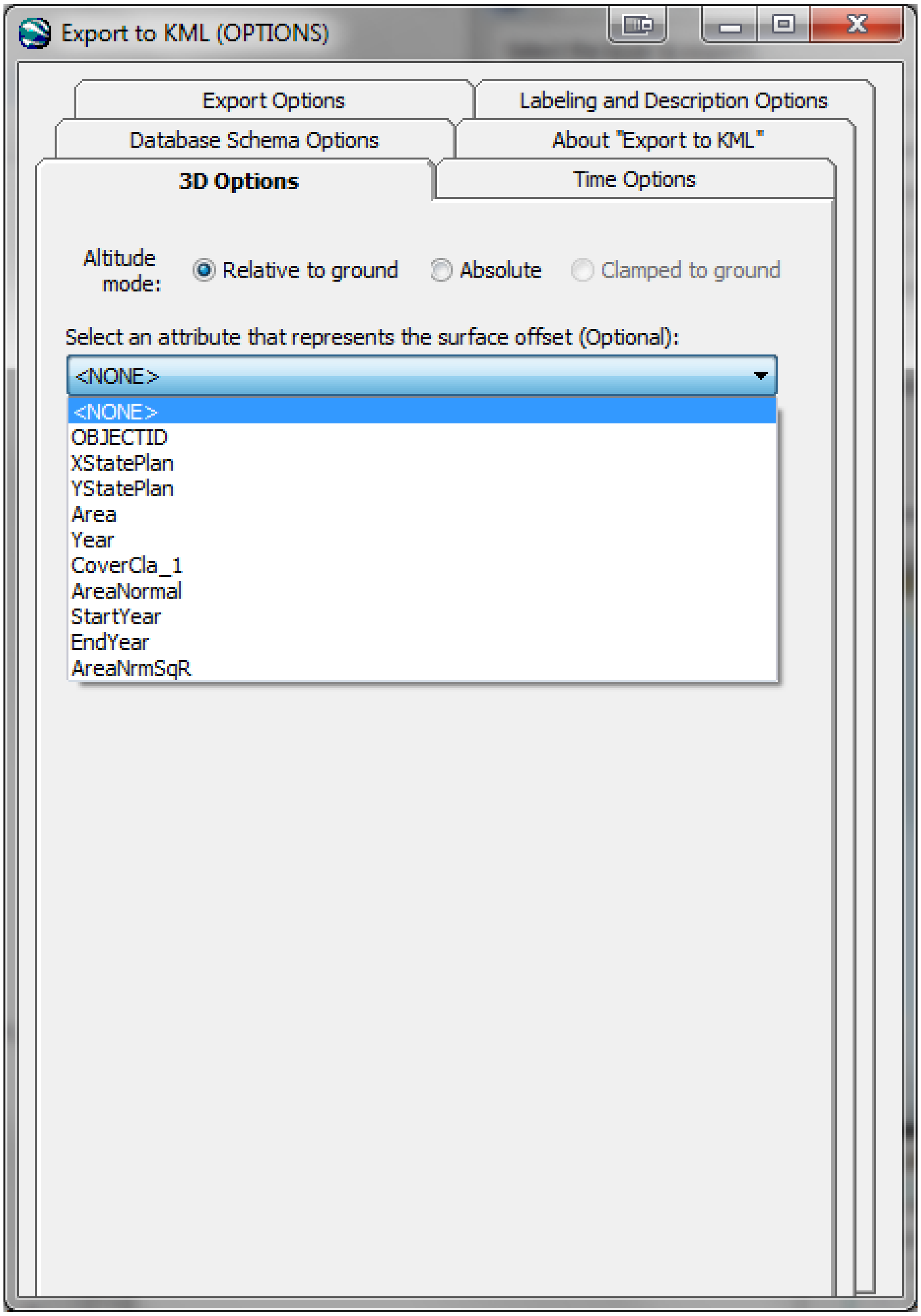
- More export options to consider. It's important to give unique names to your kml layers when you export them. Otherwise they will all inherit the same name from the source shapefile from which they were exported, leading to confusion when you are trying to identify a specific layer in the GE table of contents.

8.2.3 *Labeling and Description Options*



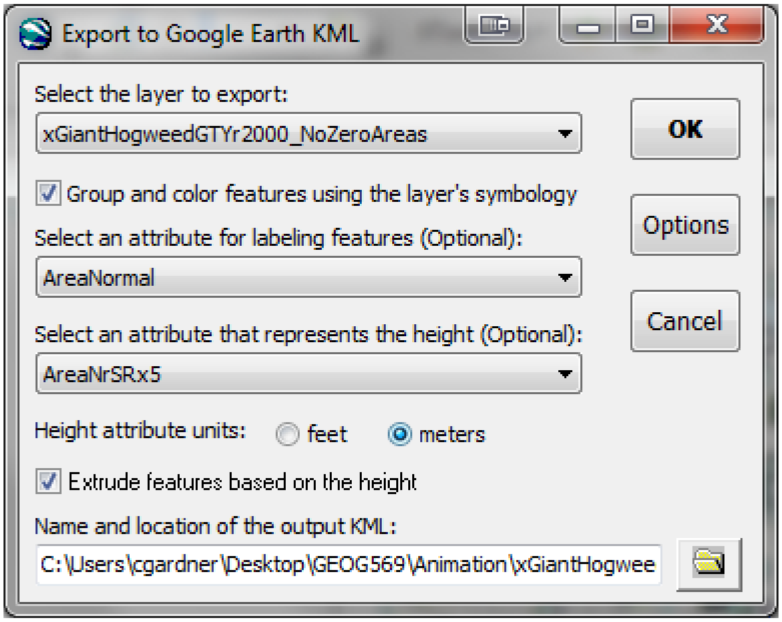
- Very handy option of exporting labels as a separate layer that can be toggled on/off;
- This dialog also enables user to set field to use for unique feature IDs, if that is desired;
- Our points had no unique IDs so this did not apply to us.

8.2.4 3D Options



- If you wanted to have your features hovering over the ground you could specify that here. I elected to use elevation that was proportional to the square root of the infestation area multiplied by a factor of 10. This was done purely based on aesthetic preference. Using the raw normalized infestation area data resulted in some features rendering thousands of feet up in the air so the square root approach acted to compress the dynamic range of the data while still allowing for range-grading across multiple elevations.

8.2.5 Attribute Selection and Extrusion Options



- This dialog box is the most critical:
- Labels fields are established here;
- Extrusion by attribute is established here;
- Administrative things like ‘input file’ and ‘export file’ are also stipulated here.

8.3 ArcGIS Documents and Data

Numerous ArcGIS documents and data products were created as a part of completing our final report. We are providing these documents to our project sponsors to enable them to reproduce our results or modify them to accommodate new data as these become available in the future. These documents and a file geodatabase containing all sourced and derived data used for the project will be provided to our project sponsors on a DVD supplement included with this report. These data were provided to Wilawan Thanatemaneerat on August 22, 2013 during the workshop session.

8.4 Infestation Area Summary Tool and Script

The Python script and ArcGIS toolbox that together comprise the Infestation Area Summary Tool are included in the DVD supplement to this report.

8.5 Dataset List

Feature Class or Raster Name	Definitions	Attribute Fields	Data Source References
Comprehensive Plan Land Use Planning “Comp_Land_Use”	A comprehensive plan is a generalized; coordinated land use policy statement of the governing body of a county or city that is adopted pursuant to the Growth Management Act. The year dated versions are retained for vested permits. This comes from parcels and is related to all		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=complu

	complu layers.		
Noxious Weeds Survey Sitings Noxious_Weeds "All_Noxious_Weeds_Sites"	King County Dept of Natural Resources and Parks, Water and Land Resources Division Noxious Weeds Control Program weed sitings from surveys.		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=noxious_weed
Giant Hogweed Garlic Mustard Sites Noxious_Weeds "Giant_Hogweed_Garlic_Mustard_Sites"	King County Dept of Natural Resources and Parks, Water and Land Resources Division Noxious Weeds Control Program weed		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=noxious_weed

	sitings from surveys. This data has been reduced to only Giant Hogweed and Garlic Mustard Sites.		
King County with Natural Shoreline for Puget Sound and Lake Washington Political “kingsh_area”	County boundaries for King County, with Puget Sound and Lake Washington removed, showing coastal shoreline and Mercer Island. Also as WASHSH for all of Washington State.		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=kingsh

Washington Counties with Natural Shoreline Political “washsh_area”	County boundaries for Washington state, with Puget Sound removed, showing coastal shoreline. Also as KINGSH for King County only.		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=washsh
Incorporated Areas of King County Administrative “City_Area”	Current boundaries for King County incorporated places.		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=city
Cities and Unincorporated King County	Polygons for Cities and Unincorporated King County.		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=city_kc

Administrative “City_KC_Area”			
Soil Survey Geographic (SSURGO) database for King County Area, Washington Soils “soilmu_a_wa663_KC	This data set is a digital soil survey and generally is the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. The information was prepared by digitizing maps, by compiling information onto a planimetric correct base and digitizing,		NRCS Soil Survey Geographic (SSURGO) Database for King County Area, WA http://soildatamart.nrcs.usda.gov/Metadata.aspx?Survey=WA633&UseState=WA

	or by revising digitized maps using remotely sensed and other information.		
Soil Survey Geographic (SSURGO) database for King County Area, Washington including Snoqualmie Pass and Pierce County Soils "soilmu_a_wa664_KC	This data set is a digital soil survey and generally is the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. The information was prepared by digitizing maps, by compiling information onto a planimetric		NRCS Soil Survey Geographic (SSURGO) Database for King County Area, WA http://soildatamart.nrcs.usda.gov/Metadata.aspx?Survey=WA634&UseState=WA

	correct base and digitizing, or by revising digitized maps using remotely sensed and other information.		
Zoning Planning “Seattle_Zoning”	Contains council-adopted City of Seattle zoning and special overlay areas.		WAGDA City of Seattle https://wagda.lib.washington.edu/data/geography/wa_cities/seattle/metadata/cd_2a/Metadata2009/geoguide2.htm
Parcels for King County with Address, Property and Ownership Information	A parcel based layer providing an address based on spatial overlay where available, and a range of other property related		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=parcel_address

	attributes		
Zoning for Unincorporated King County Planning "King_County_Zoning"	Zoning boundaries for unincorporated King County; WA. Created layers using parcels, cities, and legal descriptions. This is the version with the cities clipped out. This is used for GISMO and by KCGIS. We have another version that is presently being maintained as coverage that includes city areas.		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=zoning
City Jurisdiction Code	Lookup table		King County GIS Data Portal

Lookup Table "City_LUT"	for city jurisdiction codes and jurisdicions names.		http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=city_lut
King County Streams Hydrology "Watercourses"	Streams of King County and surrounding area		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=wtrcrs
Open water for King County and portions of adjacent counties Hydrology "Waterbodies"	Open water features, both natural and anthropic, for King County and portions of adjacent counties. Features can be displayed as water or non water to distinguished		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=wtrbdy

	between water and land.		
Sensitive Area Ordinance Wetland Areas Environmental "SAO_Wetlands_KC"	The Sensitive Areas Ordinance (SAO) defines wetlands as those areas of King County that are inundated or saturated by ground or surface water at a frequency and duration sufficient to support, and under normal circumstance do support, a prevalence of vegetation typically adapted for life in saturated		King County GIS Data Portal http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=sao_wetland

	soil conditions.		
Wetlands Environmental “Wetlands_Seattle”	Delineates known wetland areas.		WAGDA City of Seattle https://wagda.lib.washington.edu/data/geography/wa_cities/seattle/metadata/cd_1/Metadata/geoguide2.htm
Surface Geology Soils “Surface_Geology_Seattle”	This data began as a traditional geologic map of the Seattle area published by the U.S. Geological Survey (USGS) in 1962.		WAGDA City of Seattle https://wagda.lib.washington.edu/data/geography/wa_cities/seattle/metadata/cd_1/Metadata/geoguide2.htm
Seattle Streams Hydrology “Seattle_Streams”	Locates existing streams systems and their tributaries.		WAGDA City of Seattle https://wagda.lib.washington.edu/data/geography/wa_cities/seattle/metadata/cd_1/Metadata/geoguide2.htm

	Data based upon previous map documentation, aerial photo examination, GPS data collection and visual field surveys.		
King County Soils Soils “ssurgo_KC_drainage_pH”	Polygon file of soil characteristics, notably drainage class and pH values.		USDA Natural Resources Conservation Service http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx
“wtdsum_garlicmustard_invasionrisk_allNLCD”	Raster of weighted sum score for invasion risk	“Value”	Derived
Reclassified Invasion Risk “wtdsum_garMust_invRisk_reclass4”	Raster of reclassified MCA invasion risk scores	“Value”	Derived

“dispDistance_strlvl1n2_SSURGO_nomaxdist”	Raster of Euclidean distance values to nearest dispersal pathway	“Value”	Derived
“dispDistance_strlvl1n2_SSURGO_nomaxdist”	Raster of Euclidean distance values to nearest known garlic mustard site	“Value”	Derived
“dispDistance_strlvl1n2_SSURGO_nomaxdist_reclass”	Raster of reclassified rankings for proximity to dispersal pathways clipped to SSURGO areas	“Value”	Derived
“distance_garMust_SSURGO_nomaxdist_reclass	Raster of reclassified rankings for proximity to	“Value”	Derived

	known garlic mustard sites		
“NLCD2006KC”	Raster of land cover for King County	“Value”	Derived
“NLCD2006KC_reclass””	Raster of reclassified USGS land cover classifications	“Value”	Derived
SSURGO soils Soils “ssurgo_KC_drainage_pH”	Polygon of soil drainage class and soil pH values	“drain_rating”, “pH_rating”	Derived
“pH_rating”	Raster layer of reclassified SSURGO pH values	“Value”	Derived
“drainage_rating”	Raster layer of reclassified SSURGO drainage class	“Value”	Derived

8.6 References

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