North Bend Bike Lane Suitability Analysis

Brian Van Abbema, Jace Riley, and Nathanial Story

University of Washington
GEOG 569 GIS Workshop

8/17/2018

For the City of North Bend, WA
Community and Economic Development

Executive Summary

Jesse Reynolds, a Long Range Planner from the City of North Bend, reached out to the MGIS program for GIS related assistance regarding bike lanes. North Bend is a growing community and is seeking ways to expand the trafficability of the city in a manner that coincides with its brand statement; “the highly-livable small town that is creating the premiere outdoor adventure destination in the Puget Sound region”. Part of this effort involves considering modes of transportation beyond automobile traffic. Bicycling provides a manner of transportation for the city that is sustainable and recreational. The biggest roadblock to this expansion is the lack of facilities- namely bike lanes. The bike lane network in the city is very small, and Jesse desired a way to more efficiently direct efforts in expanding the bike lane network.

As part of the project proposal, North Bend is seeking a way to rate roads and road segments regarding their suitability for hosting a bike lane. The proposal involved a right-of-way dataset, proximity to certain existing structures, and existing infrastructure. The North Bend Bike Lane Suitability team was formed to work on this project. Initially, the plan as devised, was to create a geodatabase of polygon shapes within a topology derived from available overhead imagery. This dataset would be combined with data on slope and speed limit data for each road to form a suitability dataset, which would then be compared to sensitive locations like bridges, waterways, vegetation, etc.

The first major hurdle in this project was a matter of data acquisition. The initial plan was to leverage available King County Orthoimagery to determine road widths and to digitize the right-of-way dataset. Two group members were able to use a King County webservice to access the imagery, however, one group member was unable to. The reason for this is unknown, and after extended troubleshooting, the third group member shifted to using Google Earth Pro. While the final effects of this setback were minimal, the time spent troubleshooting could have been used in a more productive manner.

The second major hurdle in this project was realizing that this sort of dataset was time intensive, without providing enough value to warrant the time sunk into it. This approach was quickly abandoned, but not before approximately five miles of road was completed. Given the time constraints for this project, the team contacted Jesse Reynolds to discuss a shifting of priorities. Together, the team and Jesse explored different avenues of approach for the project, and eventually settled on a modified plan of action. The complicated right-of-way dataset was to assist in determining where the city could construct additional space for bicycle lanes. Jesse mentioned that ideally, the city of North Bend would only have to repaint existing roads, due to the cost of breaking ground and modifying existing road surfaces. This shift in focus allowed the team to modify the workflow for determining road suitability. Instead of polygon shapes, the team could use available imagery instead to identify major changes in road width. This also allowed the team to eschew certain suitability factors that were involved with construction, but

not involved in road repainting, namely the possible environmental effects of new construction.

The third major hurdle in the project occurred after all the relevant data was gathered. With the shift in focus, data collection was significantly faster, which allowed the team more time to explore the initial suitability model. This model quickly proved to be insufficiently weighted, with roads that were unacceptably narrow being rated as far more suitable than they truly were. By engaging in a sensitivity analysis to determine how minimum and maximum values were affecting the suitability scores the team was able to modify the weight values to better capture the desires of the stakeholders.

With all this in mind, the team was able to develop a workflow for determining the suitability of a road segment by considering the speed limit, the slope of the road, and the width of the road surface. This workflow was developed with the use of North Bend geospatial data, and resulted in a dataset ranking the roads within the city. Initially, the team was only going to cover the roads identified in a North Bend aspirational map, but the team was able to expand this workflow to cover every road within the city. Final products deliverable to the community partners include the workflow process included in this report, a shapefile showing the roads within North Bend with suitability scores, and a series of 'hard copy' electronic maps suitable for printing.

Table of Contents

1. Background and Problem Statement

The City of North Bend Washington is a growing city in the larger Puget Sound community and as they meet the needs of a growing population, the city wishes to expand the transportation network in a sustainable manner that helps them preserve the natural beauty of the area. As stated by the city, North Bend wishes to “provide multiple modes of transportation beyond vehicle use and to boost the city’s reputation as a highly-livable small town that is creating the premiere outdoor adventure destination in the Puget Sound region.” Bike lanes provide commuters with a safe and welcoming place to travel using a mode that reduces pollution and encourages a lifestyle more grounded in local community.

The City of North Bend is well situated to build out a bicycle lane network that can help to meet the goals for a sustainable transportation network that maintains the small town atmosphere of the town as it grows. As the map below in Figure 1.1 shows, most of the city is within a one to five minute bike ride to the aspirational bike lane network. The slopes within the city are also mostly flat and using an assumption that most riders can maintain a speed of six mile per hour, most riders can reach downtown within 20 minutes.

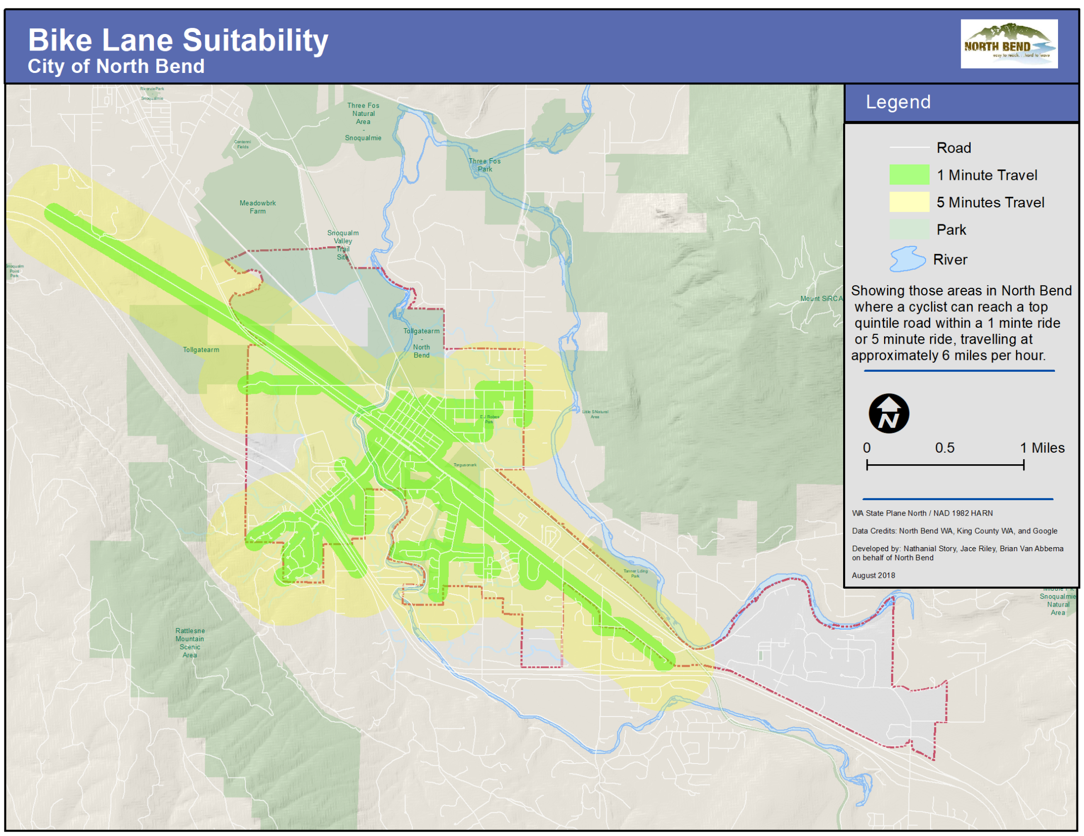


Figure 1.1

In the planning of a bicycle network, regional planner and project sponsor Jesse Reynolds reached out to the project team to develop a bike lane suitability analysis for the City of Bend, using a GIS. The desire was to use a multi-criteria analysis of the existing transportation network to determine which roads in the City of Bend were best suited for bike lanes, and what streets could immediately accommodate them. The multi-criteria analysis was to determine suitability by considering factors of the roadway such as slope, existing traffic conditions such as speed limits, and the available space on the street and publicly owned right-of-way to expand bike lanes onto. This project provided the data and materials to support such a study.

By focusing suitability of factors of existing roadway width, speed limits, slope, and characteristics of the right-of-way, the suitability model was able to answer questions of bike lane suitability in a holistic manner. Of interest is the following list of questions:

1. "Which road's Right of Way can support the expansion of the bike lane network?"
2. "Which roads or road segments can safely support bicycle traffic?"
3. "Which roads or road segments are suitable for the general population to use for recreation and transportation?"
4. "Which roads or road segments are *not* suitable or are too dangerous to warrant expanding a bike lane into?"

Background

An important consideration in bicycle route planning includes current and potential bicycle commuters and users of the infrastructure. In a survey, Su Et. Al. developed a survey for cyclists in Vancouver, B.C to help cyclists determine their own ideal cycling routes based on criteria that they could optimize according to their own preferences. Their literature review indicates several high priority factors that cyclists use when determining an ideal route and found that top considerations in order of preference were: "routes away from traffic noise and air pollution," "route has beautiful scenery," "paths separated from traffic," "route is flat," and a distance of "less than 5km." This review of cycle surveys indicates that cyclists prefer routes that are peaceful in nature and easy to use. Ease of use is a common element of choosing routes away from traffic, as traffic complicates decisions of the user and compromises safety, and distance and slope components show that cyclists prefer a path of least resistance.

Research by cycling blogs such as *The Climbing Cyclist* also show the relationship between slope and biker preferences. This study showed that a slope of 10% provides an upper limit for biking suitability. And finally, a review of GIS software used to measure bike suitability found that indicators of the street condition and characteristics could be used in a GIS to provide a comprehensive score and ranking of total suitability for bike lanes. Studies such as *A Model for Planning a Bicycle Network with Multi-Criteria Suitability Evaluation Using GIS* by Lin and Hsu used indicators of traffic by volume, curb lane width, sidewalk width, speed limit, pavement quality, and curb activity disturbance. To measure total suitability of a roadway for bike lanes.

Bringing together this review of literature, the project sponsor's goals, and the available data sources the project team built an independent bike lane suitability analysis that considered primarily the existing width and expandability of the transportation network, and secondarily the slopes and nature of adjacent traffic.

Project Overview

To meet the needs of the City of North Bend for a bike lane suitability analysis, the project team developed the appropriate datasets and suitability model that could answer the question of both holistic bike lane suitability, and overall constructability. Accomplishing this included the development of a dataset that described the existing roadway, derived from an imagery analysis, and synthesizing those results into a single shapefile of roads data that could be used for further analysis. This report describes that effort in terms of the data, the workflow, an analysis of the results and a discussion for the further use of this data.

The following sections consist of *System Resource Requirements* in which the software and hardware required to undertake the collection of data, processing of imagery data, storage of geodatabases, and geoprocessing is described. This is followed by a *Business Case Evaluation* outlining the costs and benefits of developing these datasets and performing the analysis. The conclusion of the business case section provides a cost-benefit analysis and shows how the continuation of the project team's effort is a worthwhile venture for the City of North Bend. A description of the data is provided in *Data Development*, delineating how the information used to develop the workflow was acquired. In *Workflow Implementation* the developed data is processed according to the workflow plan and synthesized into the final dataset. This section includes detailed instruction on how the process was executed and provides guidance for replicating this workflow. The *Results* of this analysis are provided, described, and interpreted, forming a basis to assist North Bend in their own interpretation and to explain the output of the workflow process. Finally, in *Conclusions and Recommendations* an overall description of the results and a second tier interpretation of the data is provided, alongside possible recommendations for North Bend to execute in the future, using the workflow dataset as a reference.

2. System Resource Requirements

The bike lane suitability analysis for North Bend required a network of systems to analyze and create data for the benefit of the city to determine which areas may be best for bike lanes. This network included data, software, hardware, people, personal and external resources. This network also allowed the city to allocate their resources to their current projects and needs without having to divert too many of their resources towards a project that will help their growth. Much of the system resource requirements are covered in more detail within the business case and data development according to their respective content.

2.1 Data

Data is a major aspect to a project of this size and scope. There are requirements for both raster and vector data. The vector data requirements include city limit boundaries as well as the areas of projected growth, rivers and bodies of water, parcels and right of way, road centerlines containing speed limit, traffic volume, and road quality per road segment. Raster dataset requirements include a digital elevation model to calculate slope, and imagery relevant to the scale and project area.

2.2 Software/Hardware

The main software requirement for this project was the Advanced Single Use License for ArcGIS Desktop with the Spatial Analyst extension. If the city were to do the project themselves it could ultimately have been done with one ArcGIS license, the single extension and any required maintenance for the licenses. To handle the data an enterprise data management system would be ideal especially with multiple editors, and this need rises as the project area and data volume inflates. With this project, however the resources available were three single use licenses of ArcMap, the Spatial Analyst extension, Google Drive and email. For communication purposes between the analysts and the stakeholder, Skype was used. This helped to organize what data was needed and how to tackle some of the issues that came up.

The hardware required for this project is ultimately just a computer system powerful enough to have ArcMap operated on it. The minimum requirements as per ESRI are 2.2 GHz CPU speed, 4 GB RAM, 4GB disk space and a 64 MB RAM video/graphics adapter. These are the minimum requirements, but generally more power is recommended. There is a tradeoff between money invested in faster hardware and the time savings in personnel costs based around waiting for analytical processes to complete.

2.3 People

This project required a network of people to include the analysts, as well as multiple people that may be considered to stakeholders. The stakeholders included people in the planning department as well as public works. A bike lane suitability analysis requires direct communication between each of these people as well as many more individuals to actually implement the project to include the planning and zoning committee, elected officials, and citizens of the city.

2.4 Institutional Resources

One requirement for this study was to be able to gather information from sources that could be implemented into the study. A core component for this research was from research based search engines like EBSCO Host and Google Scholar. These research search engines are essentially online libraries that maintain research and peer reviewed articles based on a variety of topics. They allowed the group to search countless other projects in relation to bike lane suitability analysis. These were key in determining what types of factors should be considered in the suitability analysis for a city the size of North Bend. An example of this would be that it would be better to search articles that gave the research steps for a bike lane in cities close in size to that of North Bend, rather than all of the factors that might be incorporated into a plan for a city the size of Boston, Massachusetts or Dallas, Texas, where the traffic volume plays a major part into the decision of bike lanes, where this is less so with smaller cities.

The group did not have access to an enterprise data management system and as a result did not have an effective way to share data and have multiple editors. The most effective way that was discussed was to have a SharePoint web account made specifically for the University of Washington, by the city of North Bend. This allowed North Bend to maintain their data integrity as well as not allow access to data that was not necessary for analysis. The data that was needed was placed into this SharePoint for easy access as well as to be another option for posting data between through group members and the city.

3. Business Case Evaluation

Building bicycle lanes in any city begins first with exercising of conceptual and long-term planning of a network, which is followed by subsequent programming of improvements and finally design and construction of the infrastructure. Creating a long-term vision for a bicycle network is an endeavor which costs a city resources in terms of staff time and meeting spaces that are used to discuss and build out a plan for the expansion or creation of such a network. Such an activity is by nature rooted in a GIS, as planners and residents will inevitably pore over network and city maps to sketch out and envision the implementation of their goals. The depth and robustness of the GIS used by a city in such a planning effort can vary however and that determination of a GIS in planning will impact the costs in time and resources that are expended in a planning effort. A simple street network planning effort will result in several iterations of plans and lost time and resources, while a robust GIS that leverages available imagery and other data sets can avoid such iteration in planning and save a city both time and resources. This report aims to enumerate that benefit and show the efficacy of using a robust GIS and multi-criteria-analysis for planning the bicycle lanes of North Bend.

This Capstone group's effort to create a GIS and suitability multi-criteria-analysis for bike lanes in the City of North Bend provides the city with two primary benefits: a workflow and streamlined process that uses existing data products and services to build out a robust roads dataset that supports a suitability model and an analysis model that allows planners to assess the feasibility of bicycle lanes without the expense of survey and engineering studies that may lead to multiple iterations of the planning process. As a baseline product, the report and GIS platform provided by the group provides the city with a developed workflow for a GIS technician that will allow the city to quickly roll out a roads data set that serves as a backbone for suitability analysis. And a suitability model allows planners to question their assumptions on the existing transportation infrastructure and plan future bike lanes based on the existing capacity to support these lanes.

In the following section, Benefits, an enumeration of project benefits from increased efficiency, avoided costs, expanded planning capabilities, and other advantages of the group's bike suitability GIS is provided. This is followed by a breakdown of the estimated costs to providing
The GIS service and expanding the work of roadway imagery analysis of the group to the entire city. The breakdown of costs is found in Costs. Finally, it shown in Benefit-Cost Analysis that the total value provided to the City of North Bend by a bike suitability analysis GIS provides a net benefit to their planning efforts and should be strongly considered for continuation in their bicycle planning efforts.

3.1 Benefits

Producing a robust GIS analysis workflow, roadway centerline dataset, and bike lane suitability model provides several benefits to the process of planning bicycle infrastructure. In this Benefits section of the report it is illustrated that there is monetary value in this workflow and in investing resources to build a robust spatial roads data set. Benefits to a bike lane planning effort are: a streamlined and less iterative planning process, a workflow product provided to the city, ancillary uses of the GIS data derived from this effort, and finally, the communicative role that maps provide in developing and communicating a bike plan.

3.1.1 Streamlined Planning Process

Using the Seattle Bike Master Plan (SBMP) as a template for planning a bicycle network, it can be inferred that the city resources needed to bring together a bicycle lane network plan is extensive, costing a great deal of city resources and time. As described in the SBMP, the planning process is both technical and a public process that includes: community input, briefings with advisory boards, coordination among city staff and regional agencies, and intensive data review. The process outlined in the SBMP indicates that the city would meet often both internally and with stakeholder groups as they develop a desired network for their bicycle commuters. Each iteration of a plan, for any street or bike lane corridor would cost many hours of staff resources and supplies for community outreach and communication. Without data, errors made in this effort that may arise from assign a bike lane to a street not physically suitable to bike lanes may result in the need to revisit planning activities and incur undue costs.

A GIS that describes physical features can quickly eliminate unsuitable pathways or make planners aware of the higher costs associated with building bicycle lanes on streets or corridors that may require a development exaction or other expansion of the right-of-way (ROW). Educated assumptions will be used to quantify the benefits, or cost savings, of not executing an iteration of a bicycle planning process. That is, determining the approximate cost of planning a bicycle lane without this project developed workflow, so that the benefit of not needing to execute that planning can be classified as a cost savings

For the purposes of this exercise it's assumed that a Senior Transportation Planner is assisted by a Junior member and that these two planners work for half of their full-time schedules, over the course of the month to plan and assign a simple layout of a bicycle network for future build out. Assisting these planners is a Communications Specialist that coordinates meetings with stakeholder groups that have expressed interest in influencing the bike network. The Communications Specialist is needed for a total of 50 hours and in their role they: set up community meetings, respond to concerns, and coordinate agency responses to the public. And finally, a GIS Analyst is included on the team in a limited role, providing maps that convey plans and the existing infrastructure. This role does not provide a more advanced analysis as is provided by this capstone project, but rather simple cartography that provides maps as a conversation piece. The GIS work for this effort is a total of 20 hours.

Using King County salary averages, the assumed effort that is put into a simple bike network construction, including overhead of benefits, is used to calculate the estimated cost of choosing a bike lane on a single corridor or roadway. The total cost here is what will be assumed to be lost if a roadway is found in subsequent studies to be unsuitable for a bike lane expansion and the planning effort must be repeated. The total cost for such a repeated effort, for a single stretch of roadway, is estimated to be $30,860. This cost breakdown is summarized in Table 3.1.

Project Position	Est. Hours	Hourly Rate	Overhead Rate	Total Cost ($)
Senior Transportation Planner	180	$ 50.00	$ 30.00	$ 14,400.00
Junior Planner	180	$ 36.00	$ 30.00	$ 11,880.00
Communications Specialist	50	$ 36.00	$ 30.00	$ 3,300.00
GIS Analyst	20	$ 34.00	$ 30.00	$ 1,280.00
				$ 30,860.00

Table 3.1

3.1.2 Workflow Development Value

When discussing monetary benefits and costs, two figures will be used. The first will use the salary of GIS Specialists employed by King County. The second will be the hourly rate Nathanial earned while working as a GIS intern during his undergraduate studies. According to King County, in 2017 the two lowest paid GIS Specialists each earned $34.33 per hour. This can be rounded to $35 dollars per hour. While interning, Nathanial earned $16 per hour. These two values will be used when calculating the monetary effects this project will have.

Quantifiable efficiencies in workflow are the primary drivers in the cost-benefit analysis. Of immediate benefit to North Bend is the free work being given to them and leveraged for the creation of the products detailed in the scope of work. These products are the workflow designed to be used in the future to rank possible bike lane expansions, and the dataset developed using North Bend data. Exact time investment into this project is unfortunately unavailable, but in approximate terms, the three group members have been putting in hours equivalent to one full time analyst. This means that each member is putting approximately two to three hours, five days a week into this project. As an example, Nathanial works from between 5:00 PM and 5:30PM to between 8:00 PM and 9:00 PM each night on this project, with an additional two to twelve hours on the weekends. As mentioned above, the combined efforts of all three group members can be conservatively approximated as representing the efforts of one full time employee working 40 hours per week.

40 hours per week, over eight weeks, comes out to 320 hours. So, the range of money saved in labor to develop the workflow is between $5,120 and $11,200. This cost in labor can be considered added value to the city. These figures can also be leveraged when calculating costs for manually re-creating the results of the workflow within individual road segments. This is explored within the following section regarding imagery.

3.1.3 Imagery Analysis Benefit over a Survey

Regardless of any previous work done in the area, before work can be taken to expand a road or bike lane, a survey must be done. According to the City of North Bend Suitability Analysis Project Sponsor, the current workflow used to determine which areas might or might not support a new bike lane is primarily based around 'intuition' and 'gut feelings'. An area or road segment is chosen using the judgments of city planners and may then be professionally surveyed by an engineering consultant following a full planning effort, determining whether the area can support the proposed changes.

With the use of imagery, the need for surveying does not decrease, but the amount of surveys needed for a given proposal shrinks from greater than or equal to one, to just one. Imagery analysis allows for rough estimations of road and parcel width to within approximately one foot. This further allows roads to be classified and preselected for development interest. According to the 2017 USDA *Cost Estimating Guide for Road Construction* approximate costs for road survey are more than $1000 a mile, sometimes ranging as high as $10,000 per mile, with hourly costs for land surveyors alone exceeding $100 an hour. This means that for each road the workflow developed during this project determines to be a poor location for a new bike lane or new construction, thousands of dollars and hours of highly paid personnel costs have been avoided.

For the purpose of a benefit-cost analysis, assume that a one-mile stretch of roadway will has been planned by the city and must be redone, and resurveyed after the initial engineering study showed that the existing facilities could not accommodate a bike lane. It is also assumed that costs for a survey are somewhere in the middle of the range of estimated cost. These assumptions show that a mile of roadway, planned correctly with the aid of a robust GIS suitability analysis has a survey value of $5,500.

3.1.4 Quantifiable, Unexpected Events

While the nature of unpredicted or unexpected events makes it difficult to pin down how exactly this workflow and project can be taken advantage of in the future, the geographic data associated with the project can be leveraged for future decision making and emergency planning. What follows is a short list detailing some of the ways the data gathered or created with this workflow can assist in unrelated future projects.

- Slope Data:
    - Direction and possible severity of future flood events
    - Degree of effort required for wheelchair use

- Road Width:
    - Route analysis and primary/secondary route synthesis for emergency evacuation

- ROW Width:
    - Road exaction determination for future development

While the items on this list of unexpected benefits of an imagery analysis of the ROW do not have a readily available monetary value, it can be assumed that building out these information products would be similar to the costs of survey per mile used previously. At $5,500 each, the value of the total unexpected benefit of a ROW imagery analysis comes to $16,500.

3.1.5 Intangible Benefits

In addition to quantifiable benefits relating to data use and financial information, there is also a host of unmeasurable or intangible benefits to this workflow and the information surrounding it. The primary benefit is that familiarity with a product or tool increased the frequency with which it is used. Problems that previously seemed overly daunting or even impossible shift into the realm of possibility.

In more specific language, the largest intangible benefit to this workflow is that it opens up the way to increasing the familiarity the city planners of North Bend have with ArcMap, and GIS as a whole. This familiarity can then be leveraged in other projects- possibly reducing or eliminating the need for contract GIS work. A municipal planner with skills as a novice in geographical analysis will personally benefit from the efficiencies that come with those skills.

Other intangible benefits related to this workflow and map products are a possible increase in public engagement. A picture is worth a thousand words, and a good map is worth even more. By being able to visualize the current conditions of the town and provide maps detailing possible changes, the general public has greater access to the governmental decision making process. For the purpose of this report, these benefits will remain unmonetized.

3.1.6 Total Benefit

This benefits section has explored and given monetary value to the benefits provided to the City of North Bend or other small municipalities from a GIS dataset that leverages imagery to make roadway measurements, as well as a bike lane suitability model. By streamlining the planning process, a city could save at the very least $30,860 in labor costs by avoiding errors in assumptions that a non-GIS-centered effort could develop. The workflow developed by the Bike

Lane Suitability Analysis team, valued as a product delivered to the city and calculated from labor costs, is valued at $11,200. By avoiding repeated surveying efforts, a city can avoid at least $5,500 in unnecessary costs per mile from imagery derived GIS data. Some ancillary benefits to the project's results were identified and quantified in a general manner to a total benefit of $16,500. Last were the intangible benefits of a GIS analysis in bicycle lane planning. While these benefits were not classified monetarily, they can still be beneficial and should be considered when a city expands its planning toolset. In total, the monetary benefit of adding a GIS imagery analysis and suitability model to a bike planning effort is $64,060.

Benefit Type	Monertary Value
Streamlined Planning Process	$ 30,860.00
Workflow Document	$ 11,200.00
Avoided Survey (Per Mile)	$ 5,500.00
Ancillary Project Benefits	$ 16,500.00
	$ 64,060.00

Table 3.2

3.2 Costs

This next section aims to quantify the labor, software, and hardware costs of implementing both the ROW imagery analysis and bike lane suitability model. Examining the costs of GIS professional wages as well as the costs of ESRI software provides a project cost estimate for use in a final benefit-cost scenario.

Costs fall into two general categories: Those that can be quantified on a per mile basis, and those that cannot. While all costs can eventually be amortized on a per mile basis, there are costs that are truly incurred by the mile, and those that are not. An example of those that are not truly determined on a per mile basis are equipment costs, software costs, and electricity. While those three can be amortized over the course of a technicians work, the per mile cost must be calculated after the fact, and cannot be accurately predicted before the work is at least planned.

Truly mile based costs are those that are pegged directly to their use by the mile. This includes a technician's salary while he is working on a mile based project, or perhaps a credit cost in a Software as a Service platform like ArcGIS Online, or the material costs in repainting a road surface. In other words, there will be a cost breakdown in absolute terms, and in mileage terms. The current assumption is one technician, with one PC and one license package from ESRI. For simplicity's sake, this technician is a contractor, self-employed, and thus ineligible for benefits. Additionally, there is the personnel cost of an organic asset to the city acting as the manager/point of contact for the city.

The majority of the cost for this project comes from licensing and personnel. ESRI licenses cost a significant amount of money, which are listed as:
ArcGIS Desktop Advanced Single Use License - $8,541.00
Primary Maintenance for ArcGIS Desktop Advanced Single Use License - $3,045.00
ArcGIS Desktop All Extensions Bundled Single Use License - $6,471.00
Primary Maintenance for ArcGIS Desktop All Extensions Bundle Single Use License - $1,523.00
Total - $19,580. (State of Washington DES MPA Price List, 2017)

In order to provide a legitimate estimation of costs, numbers will need to be attached to the general categories of cost for this project. The below table reflects that information.

Type	Hour Budget	Per Hour	Per Instance	Instance per Hour	Total over Contract
Contractor	320	$ 35.00			$ 11,200.00
Electricity	320	$ 0.05			$ 16.64
Workstation			$ 2,510.00		$ 2,510.00
Licenses			$ 19,580.00	$ 9.41	$ 3,012.30
Management	40	80			$ 3,200.00
					$ 19,938.94

Table 3.3

The costs for labor are also high, and comprise the largest slice of the cost calculation. The above table represents a sort of worst case scenario where the city of North Bend must accept almost all costs associated with the project, from hiring a contractor, to supplying a workstation, as well as licensing. If the work required is tweaked so that the contractor can use their own equipment, and either use an Esri license the city already owns and is paying for, or supplies his own, thousands of dollars in costs have been reduced. This does not include miscellaneous costs that are inherent to office type working environments already borne by North Bend, such as cleaning supplies, paper, general electronics, etc. Because the project is relatively small in scope and can make use of many resources already bought and paid for, the true cost of the project can be hard to pin down. For the sake of simplicity, assume office costs of approximately $70 and that rounds the total costs to $20,000.

3.3 Benefit Cost Analysis

With approximate costs of an imagery analysis and bike suitability model in-hand, as well as a monetary valuation of the benefits of such an analysis, The worthiness of the work proposed by this Capstone project can be evaluated. By performing a benefit over cost ratio (benefits divided by costs) a determination whether the costs are truly worth the effort can be determined. A value less than one indicates that costs of the project are greater than the benefits, and values greater than one indicate a higher value than cost.

Total Benefit = $64,060
Total Cost = $20,000
Benefit/Cost = $64,060/$20,000 = 3.2

The benefit to cost ratio indicates that for a small scale planning effort of a bicycle lane, investing in GIS data that describes the roadway dimensions and attributes is worth at least 3.2 times the effort required to develop the data. Many benefits calculated by this effort were done only on a single mile basis in an effort to make conservative estimates, while the costs were calculated for the entire City of North Bend. It is therefore likely that the true benefits will outnumber the costs up to or exceeding 3 times.

Investing in an imagery analysis and suitability model before planning a bicycle network has been demonstrated to have significant value to a municipality, with efficiencies gained beyond bike planning. With this knowledge, it is recommended that the City of North Bend continue developing the imagery analysis started by this Capstone project and refine the suitability model provided by the group as best fits the city.

4. Data Development

The data development is an extremely important step to the suitability analysis. Without the preparation of this data, no analysis could be done unless it was already developed by an outside source. This section explains what datasets were available and briefly what steps were taken to develop them for use in analysis. Section five, *Workflow Implementation*, goes more into depth about how the developed data was used through the workflow.

4.1 *Available Data*

Available data came from either the datashare provided by the city of North Bend, King Counties Data Repository, or USGS. Below are these datasets, with their source and short description.

Name	Source	Description
City_Limits	City of North Bend	Represents project area and city limits
UGA	City of North Bend	Represents the Urban Growth Area of the North Bend area
Stream_Buffers	City of North Bend	Represents the streams and rivers, to aid in analysis as areas not able to expand roadways for bike lanes.
NBend_Parcels	City of North Bend	Represents the property areas that generally cannot be considered in analysis.
Roads	King County	Represents the road centerline and contains important data to include speed limit and road class.
Aerial Photos 2017	King County	Overhead imagery to be used to measure widths of Right of Way and roads.
DEM	USGS	Represents the slope of North Bend with 10 meter pixels

Table 4.1

4.2 Data Preparation

The main data that required the most preparation was the road centerline feature which was derived from the Roads feature to include speed limit and road class. To gather the data for the road and right of way widths, a measurement was calculated through imagery analysis. The process was to measure per road segment from one side of the road surface to the other, as well as one side of a parcel to the other to calculate the right of way width. This is signified below in figure 4.1. For longer road segments, two or three measurements would be made taking the average as the width. A calculation was done to determine the required width of the right of way from the road class aspect of the roads, where the particular numbers are listed in the workflow implementation section. The slope of the given road segments was also to be added from the DEM. The data was also to be calculated in a way to determine the suitability ranking of each road segment. The workflow implementation section goes more in depth as to how the imagery analysis was conducted.

Figure 4.1

5. Workflow Implementation

With the data gathered and distilled from imagery, the team was able to move on to running the data through the workflow process previously developed. Mentioned earlier, a roadblock developed in the creation of the right-of-way dataset. This roadblock involved the time commitment required for a polygon dataset. The team shifted to a point measurement based method to make the collection of data possible within the nine week quarter.

Initially, the data to be collected was focused on a very robust, however cumbersome and time intensive imagery analysis. An initial scope of work document called out data points to be drawn from the imagery analysis that could provide a more complete analysis of suitability. The first iteration focus points were:

- Total width from parcel to parcel
- Existence of, and width of sidewalk features
- Existence and size of landscaping or vegetation features
- Number and nature of existing lanes
- Width from curb to curb
- Slope of street segment
- Speed limit for traffic of the street segment

In order to focus efforts on the development of a suitability model a simplified set of data points were drawn from imagery analysis. The team was able to condense and shift priority to fewer factors. These factors were:

- Width from parcel to parcel
- Width from curb to curb
- Slope of the segment
- Speed limit for traffic of the street segment

These factors acceptably cover three facets of bike lane suitability. Width of the road surface and the right-of-way speak to the space available for bicycle lanes. With the ability to create a bike lane through road painting instead of construction, costs are lowered, allowing for a greater expansion, or a lower barrier to begin bike lane creation. Slope takes the comfort of the rider into consideration. Lower slope as pointed out in the literature review provides a more comfortable riding environment and lowers overall speeds for riders traveling downhill. Safety is the focus of speed limit information, as danger in bicycle lanes rises with speed and the differential between traffic and bicycle speed. (Conrad et. al 2016, 5)

5.1 Width

The team decided early on to normalize the width data to the original road segment provided by King County, using the minimum width common to the segment. For example, a road through downtown that was 25 feet wide with an additional 5 feet on each side in parts for parking would be recorded as 25 feet. A road segment that widens out significantly to incorporate several turning lanes would not reflect the width of those lanes in its width value. The same is true for the right-of-way the road segment occupies. As an example, if the right-of-way for 2/3rds of the segment was 25 feet wide, and the last third was only 15 feet wide, the width of the right-of-way recorded in the final data set would only be 15 feet. This was done to provide a conservative estimate.

The team used road standards data from the city of North Bend to assign minimum roadway widths to classifications provided for each roadway segment. (CAD drawings from which roadway standards were drawn are provided in the Appendix). This road standard data contained two key pieces of information: the minimum roadway width and the minimum right-of-way width. The road surface consists of the area that vehicles may use to drive on, such as traffic lanes, turning lanes, bike lanes, and shoulders. The road feature includes all the previous items, with the addition of curb width, sidewalks, vegetation features, and anything else that together makes up the entire road width. By adding 10 feet to the minimum road standard requirements, a minimum width required for a bicycle lane can be subtracted from the measured width to create a value for the excess width available for construction of a road segment. This provides the excess width of the road surface and the right-of-way, two of the four factors required.

Code	Class	Driving Width	ROW Width	Bike Lane Addition	Min Road Width
A	Service Alley	18	20	10	28
C	Collector	22	68	10	32
L	Local	18	58	10	28
M	Minor Arterial	34	76	10	44
P	Major Arterial	34	76	10	44

Table 5.1

5.2 Slope

Slope data, created from 10 meter USGS DEM data and the ArcMap's *Spatial Analyst*, was reclassified according to grade descriptions for bicyclist comfort (de Neef 2013). These classifications are listed below:

- 1: 0-1% slope. “A flat or nearly flat road.”

- 2: 1-3.5% slope. "Slightly uphill but not particularly challenging. A bit like riding into the wind."
- 3: 3.5-6.5% slope. "A manageable gradient that can cause fatigue over long periods."
- 4: 6.5-9.5% slope. "Starting to become uncomfortable for seasoned riders, and very challenging for new climbers."
- 5: 9.5-15.5% slope. "A painful gradient, especially if maintained for any length of time"
- 6: 15.5% slope and higher. "Very challenging for riders of all abilities. Maintaining this sort of incline for any length of time is very painful."

In order to lessen processing time, the road centerlines that formed the basis of the analysis were buffered to 1000 feet and used to *Clip* out a subset of the elevation raster. This raster was run through *Slope (Spatial Analyst)* to find the percent slope. Because the DEM data was in a coordinate system that used feet as its linear unit, and the vertical unit was meters, a Z-factor was used to convert the 'meter' elevation to fit the 'feet' coordinate system. This produced a slope raster dataset showing the slope in terms of percent rise.

This slope dataset was then reclassified with *Reclassify (Spatial Analyst)* to convert the individual slope values into the above grade values, ranging from 1 to 6. This converted the slope from a continuous dataset into a discrete dataset, making it suitable for the next processing step. With every cell within the dataset now holding an integer value between 1 and 6, the raster was transformed into a polygon shapefile. By using *Raster to Polygon (Conversion)* without simplifying polygons, the raster dataset could be intersected properly with the road data.

The penultimate step with the slope dataset was to inspect it for possible errors. While most road surfaces within North Bend cling to the Earth's surface, bridges do not. This means that in areas where there are bridges, the data will more closely match that of the ground beneath the surface. Three locations within North Bend feature areas where the slope does not match reality. To rectify this, those three areas were merged with the correct slope shape next to it.

The final step was to *Intersect* the road shape with the slope shape. This sliced the road shape into several hundred smaller shapes, and appended the slope category data to each fragment. This works to convert the slope data into a line shape and allow for a single table calculation solution. This created the third factor of four required.

5.3 Speed

The King County roads dataset came with posted speed limit data from the source. It is in Miles Per Hour and was able to be plugged into the suitability calculation as is. As part of the initial suitability exploration, the team pegged the speed at which a road becomes unsuitable at the same speed mentioned in the University of Maryland report, or 45 miles per hour (Conrad et. al 2016, 2). This was because North Bend does not place a premium on road speed, due to the current traffic patterns within the city. This threshold was later expanded after the team re-tooled how weighting and suitability was calculated in relation to assigned point values. This created the last factor of four required for the analysis.

5.4 Assigning Point Values

With each factor calculated and populated with raw values, each had to be assigned a universal point value in order to allow each factor to be used in a multi-criteria analysis. Each factor is in a unique data form. Distance is not slope, slope is not speed, and speed is not distance. In their raw form neither can be compared to each other. In the first iteration of the suitability model, each factor was assigned a single value that was to represent the suitability of each factor within a road segment. These values ranged from 2 to -2 within each factor, and from 6 to -6 in the final calculation. These initial suitability categories are featured below.

Suitability Factor	Value Range	Factor Score
Speed Limits	Less than 40 mph	2
	40 to 49 mph	0
	Greater than 50 mph	-2
Excess Roadway	6 feet or greater	2
	2 to 4 feet	1
	0 to 1 ft 11 inches	0
	No excess	-2
Slope	0 - 2 percent slope	2
	3-5 percent slope	0
	6 percent and above slope	-2

Table 5.2

Bicycle Suitability Score Range	Interpretation
4 to 6	All three suitability factors have greater than minimum desirable values. The characteristics of the roadway are most likely desirable by the average bicyclist.
0 to 3	At least two of the three suitability factors have minimum desirable or greater than minimum desirable values. One may be less than desirable. The characteristics of the roadway could be desirable by the average bicyclist.
-3 to -1	At least two of the suitability factors have less than minimum desirable values. One may have the minimum desirable values. The characteristics of the roadway may not be desirable by the average bicyclists.
-4 to -6	All three suitability factors have less than the minimum desirable values. The characteristics of the roadway are most likely not desirable by the average bicyclists.

Table 5.3

It was eventually discovered that not only was the suitability matrix too simplistic, but it also placed too much value on road speed and slope. Roads that were far too narrow to support a new bike lane were being scored between 0 and 4, far higher than they should have been logically. The core idea was sound, but the team had failed to take into consideration the priorities of North Bend. The first half of rectifying this miscalculation was to revamp how scored were assigned.

Road widths shifted to include space for two bike lanes per road. The new logic assigned to this calculation aligned more closely with North Bend's priorities. Each entry for excess width was assigned the following percentile classification values:

- 0 or more feet. This is space for two bicycle lanes, one in each direction of traffic. These numbers represent the road standards width plus the 10 feet for two lanes: **100**
- -5 to 0 feet. This is space for at least one full bicycle lane: **50**
- -10 to -5 feet. This is space for one partial bicycle lane: **25**
- -10 or fewer feet. This represents areas with no available width for a bike lane: **0**

Slope remains largely the same, only shifting to incorporate the percentile change and the reclassification values. It was done this way to allow the 6 classification values to be preserved in case North Bend shifts its own priorities regarding rider comfort.

- 1 or 2. This represents an unchallenging slope for beginners and more experienced riders, suitable for recreation or transportation: **100**
- 3. This represents a more challenging slope, still suitable for transportation: **50**
- 4 to 6. This represents road slopes too challenging for regular transportation use, and uncomfortably steep for recreational use by any but the most dedicated cyclists: **0**

Speed values were the most affected, shifting to incorporate more changes in road speed while still taking North Bend's priorities into consideration. Despite the higher danger that road speeds in excess of 45 miles per hour pose to bicyclists, these speeds are still considered acceptable. Unlike slope and road width above, there is no speed at which a road segment can be disqualified.

- 25 mph or slower: **100**
- 25 mph to 45 mph: **75**
- 45 mph or higher: **50**

Shifting the value ranges for each factor into a percentile based assignment helps connect the inherent value for each factor to how North Bend prioritizes these three factors. The mistake made was that there was no separation between inherent value within a factor and how North Bend placed its own value on that factor. The second half of rectifying this mistake is to transform gross priorities from North Bend into finer determinations of value mathematically.

5.5 Assigning Weights and Sensitivity Analysis

There is a rough hierarchy in place for the three factors used in this part of the analysis. Road width is highest, by a large margin. Followed by slope, and finally speed. As mentioned earlier, this hierarchy exists because North Bend is primarily interested in cheaply adding bicycle lanes. The other two factors are far less important, but cannot be eschewed entirely because they still represent vital considerations, and also allow the ranking and prioritization of roads that have otherwise identical excess width to work with. In other words, given two road segments with the same amount of available road width, slope and speed limits considerations can be used to give one road an edge over the other, allowing the same amount of money to create a comparatively superior bicycle lane. Each factor must be assigned a weight according to its rank in the hierarchy that results in few falsely acceptable roads and maximizes the effect road width has on the final score without reducing the effect of the other two factors to the point where they are not used. Weights must be assigned so that perfect scores in slope and speed cannot bring an overly narrow road into an acceptable category, and that the contribution of slope and speed is high enough to allow the ranking of otherwise identical roads. Weighting is executed by multiplying the raw score by the factor's weight percentile and all three are added together, providing a score from 0-100. By testing different weighting methods, the strength of each factor can be compared to the desired output data, and used to determine how the process is sensitive to influence from each factor. Five weighting methods were developed and compared against each other and the method most aligned with North Bends priorities was selected.

	Unweighted		Positive Ranking | 3-<rank>+1	
	Weight Value	Percentile	Weight Value	Percentile
Width	1	33.3%	3	50%
Slope	1	33.3%	2	33.3%
Speed	1	33.3%	1	16.7%

Table 5.4

	Fractional Ranking | 1/<rank>		Exponential Ranking 1 | (3-<rank>+1)^2	
	Weight Value	Percentile	Weight Value	Percentile
Width	1	54%	9	64%
Slope	1/2	28%	4	29%
Speed	1/3	18%	1	7%

Table 5.5

	Exponential Ranking 2 | (3-<rank>+1)^(3-<rank>+1)	
	Weight Value	Percentile
Width	27	84%
Slope	4	13%
Speed	1	3%

Table 5.6

The first four weighting strategies placed too much power within the speed and slope factors. This leads to false positives, as roads widths scoring 0 can still be classified rather high if the slope and speed scores are perfect. Comparing the Unweighted strategy to the second Exponential Ranking strategy, a perfect slope and speed score with a road score of 0 gives a final score of 66 and 16 respectively. This wide gulf highlights the unsuitability of the initial suitability model. The weighting method chosen was Exponential Ranking 2 because of the five available strategies, it most captured the desires of the City of North Bend. This method was used to calculate the final suitability scores for the roads within North Bend.

6. Results

An assessment of the bike lane suitability analysis is divided into two major components in this section. Beginning with the overall suitability scores of each road segment, map graphics explore where a the bike network would be *best* suited for expansion, including a closer look at the neighborhoods that make up the City of North Bend. Next, a determination is made of immediate constructability, and where developer exactions may be possible where immediate construction is not possible.

6.1 Suitability Results

To derive the final suitability scores for the roads in North Bend, each factor score was multiplied by its decimal weight and added together. This resulted in a polyline shapefile with entries for each roadway segment, a total of 1152 entries. Each of these entries had a suitability score of 1 to 100, a higher score being more desirable in this case. These scores were further divided into quartiles. Each quartile can be thought of as representing one type of road width suitability, with differing scores within that quartile providing a means to prioritize among equally suitable roads. An explanation of scores is below:

- 81-100: These roads feature space for two bike lanes. Higher scores indicate more favorable speed and slope conditions. A 100 score road should be favored over a 90 score road.
- 42-61: These roads feature space for at least one bicycle lane.
- 23-41: These roads do not have enough space to fit even one bicycle lane, but still possess some excess width.
- 2-22: These roads have no available width for bicycle lanes, but may still be suitable for lane sharing or provide other recreational opportunities.

Interestingly, within the North Bend suitability dataset, approximately 14 of 39 miles have a score over 85. Approximately 7 more miles are capable of supporting a single bike lane. This means that with only a repainting of the road surface, the bike lane network could expand to over 50% of the surveyed road segments within North Bend. It also provides a rich environment for selecting those road segments, having a powerful impact on the expandability of a bike network in the City of North Bend.

Please note that while the following maps symbolize a quintile distribution of scores, this is for illustrative purposes only, as weighting priorities exclude the possibility of a road segment scoring between 60 and 80. As future priorities shift this quintile may become available for use. Maps will be presented in-line, with further explanation and analysis following.

Figure 6.2 features an overview of the North Bend Bike Lane Suitability dataset. Generally speaking, the most suitable roads are located in the downtown area and the south/south-western portion of the city. Note that the roads to the south-east, in Tanner, are generally less suitable than the roads within North Bend proper.

Key areas of focus include downtown North Bend and three residential areas. Residential Area A is in the southernmost portion of North Bend, slightly south-west of the North Bend Outlet Mall and separated from the rest of the city by Interstate 90. Residential Area B is located due south of downtown North Bend. Residential Area C is located north-east of downtown North Bend.

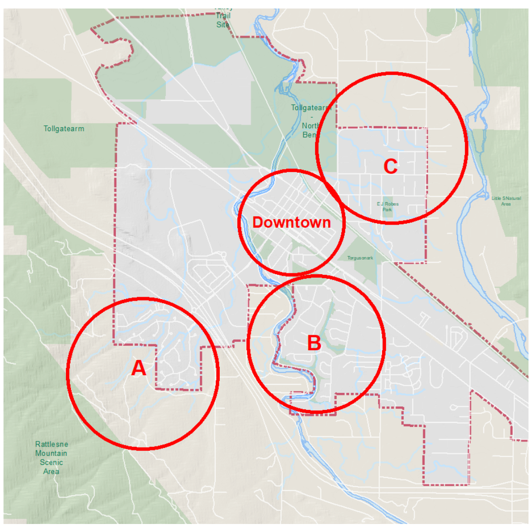


Figure 6.1

North Bend is geographically a rather small city. From downtown, most places within the city can be reached by walking in less than an hour and bicycle lanes could cut this time in half. Because the downtown area is centrally located and forms the focal point of the region it can be considered a key part of the bike lane suitability analysis.

Looking at the suitability results with the Downtown area, Figure 6.3 looks closer at this central location. Most roads within downtown are fully suitable for the addition of bicycle lanes. While most of the downtown area is suitable for bike lane expansion, North Bend currently plans to integrate bicycle traffic through the use of 'sharrows', or road indications that combine bicycle and low speed traffic in the same traffic lanes. The key takeaway from this map is that the two southern Residential Areas both have uninterrupted access to downtown via Main Ave S. Ballarat Ave N links the northern Residential Area C to downtown through a non-ideal road segment, but if North Bend continues forward with plans for the use of sharrows on this street, then the non-ideal status of Ballarat Ave N should not be an issue in the expansion of the bicycle network.

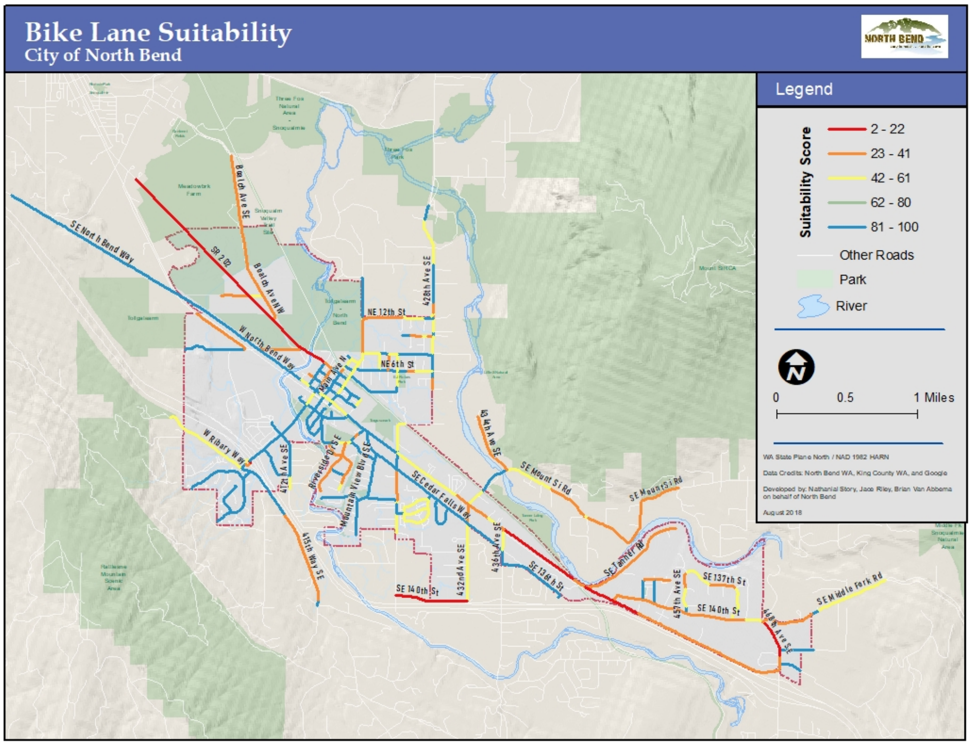


Figure 6.2

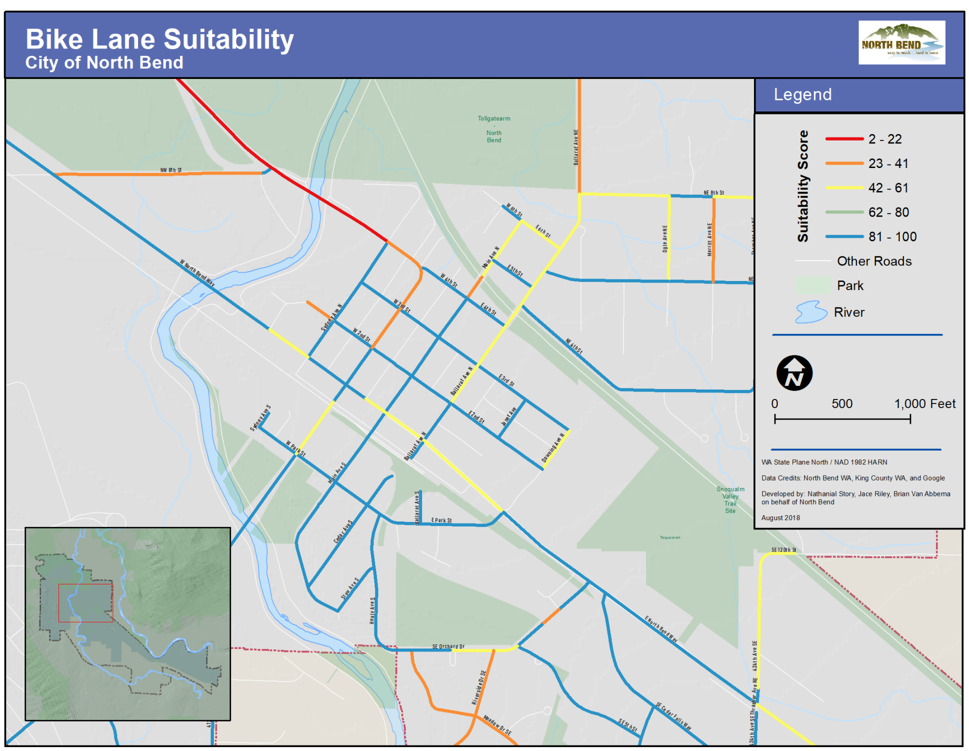


Figure 6.3

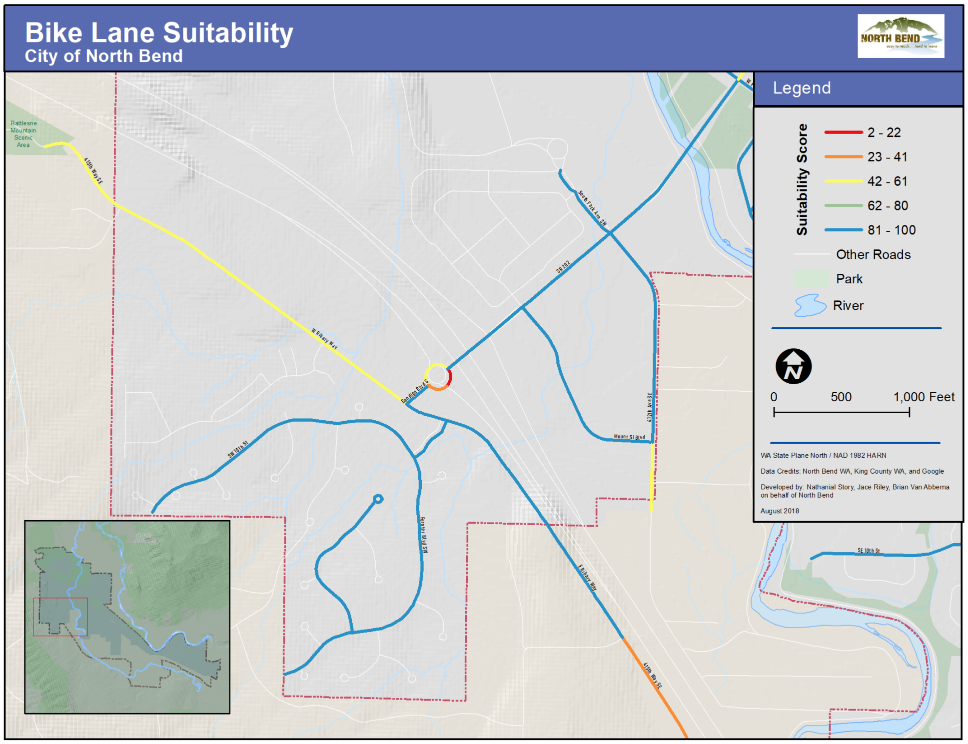


Figure 6.4

Residential Area A is shown in Figure 6.4, across I-90 from the North Bend Outlet Mall. Most of the streets in this region are fully suitable for bicycle lane expansion except for W Ribary Way and 415th Way SE. The roundabout that links North Bend to the interstate is a tricky situation. The road surface itself is not suitable for bike lane expansion, but there is considerable real estate in the form of raised concrete dividers.

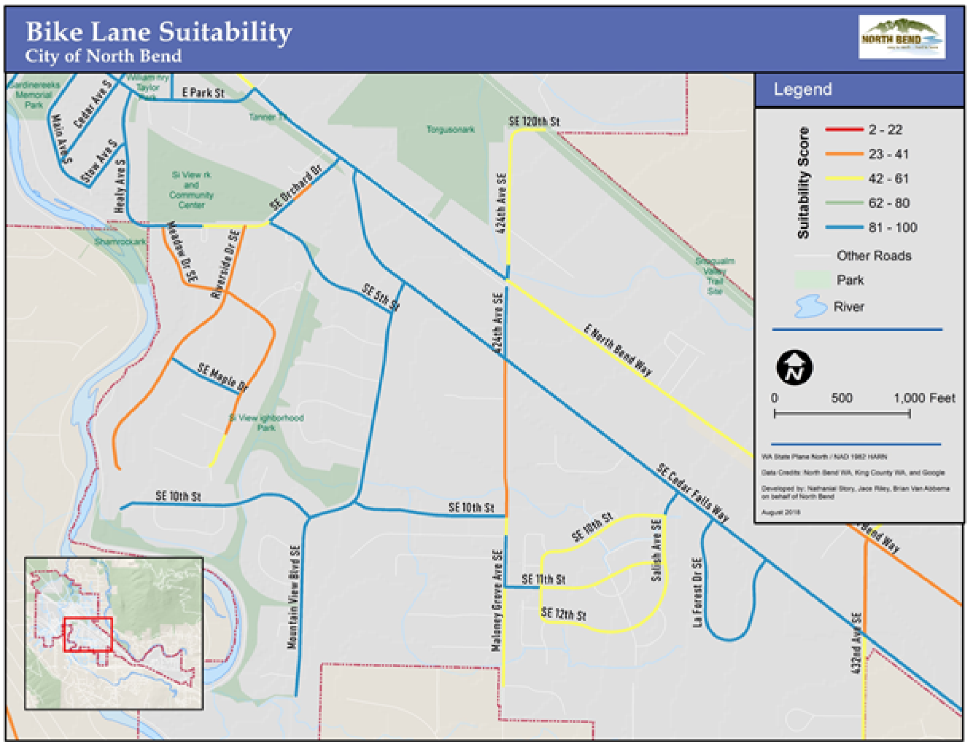


Figure 6.5

In Figure 6.5 is Residential Area B, due south of the North Bend downtown area. Mountain View Blvd SE, SE 10th St, and SE 5th St provide good coverage of this residential area. Remaining roads within this region are less than suitable, but because they are in low speed residential neighborhoods, the danger to cyclists is lower than on main roads, so bike lane expansion in these areas can be eschewed in favor of lane sharing. Additionally, most of this neighborhood has direct access through suitable roads to the downtown area via E Park St.

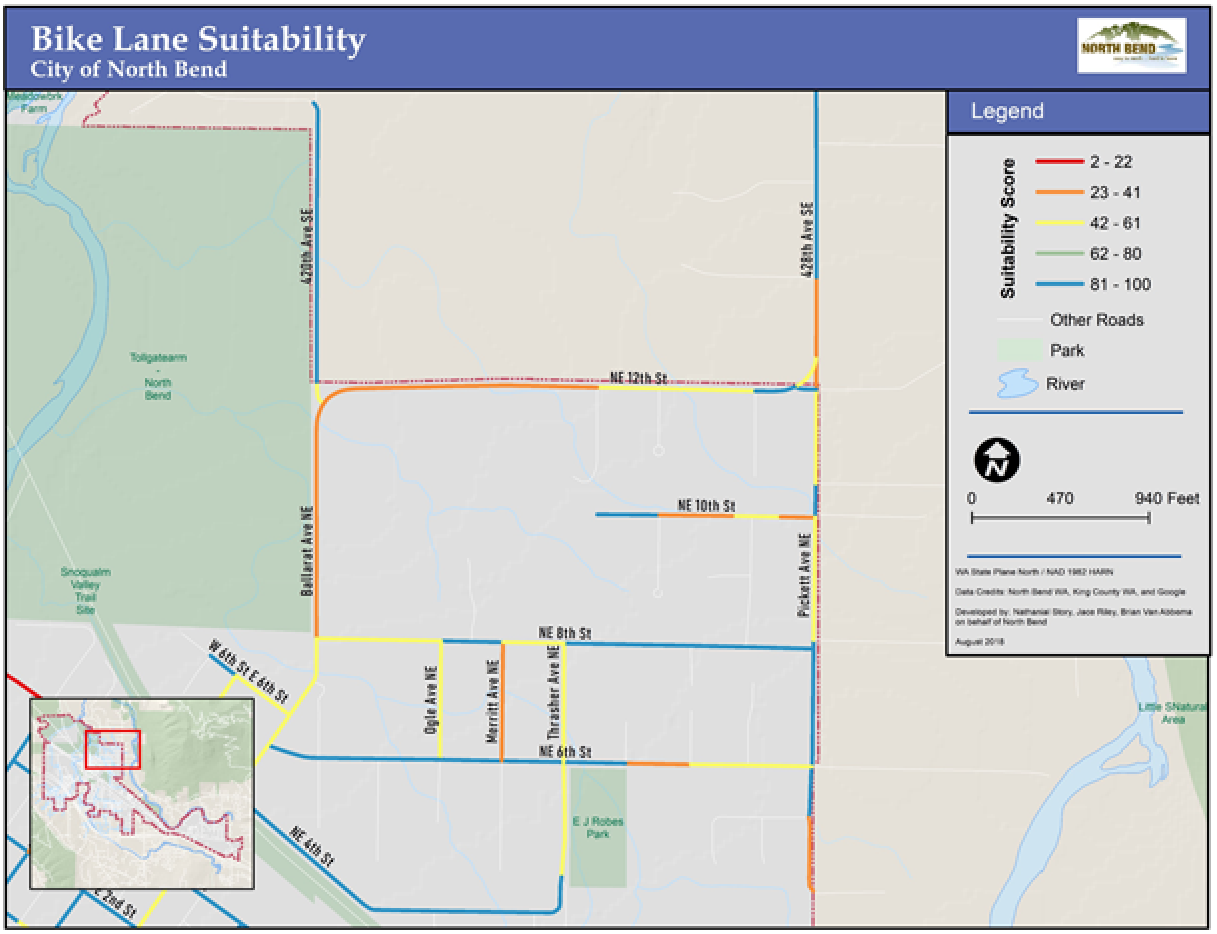


Figure 6.6

Residential Area C, in Figure 6.6 is the least ideal of the three Residential Areas, showing the lowest suitability score per road segment. Due to the narrowing of the road surface through certain key junctions, there is no path from the area to the downtown through suitable road segments. Like with Residential Area B, there is still the possibility of providing sharrows for sharing lanes with general purpose traffic to open up bicycle access from this region to the downtown area.

6.2 Available Roadway and Developer Exactions

In addition to a comprehensive look at suitability of each roadway segment for bicycle lane expansion, of interest to the City of North Bend is the ability to fit their desired bike network into the existing roads or within the existing right-of-way (ROW) by way of developer exactions. An exaction is a tool by which the city can compel developers to reconstruct parts of the existing ROW during construction of a new development. Exactions provide an opportunity to construct infrastructure and expand the roadway to accommodate bicycle lanes. It is of keen interest to a planning effort, whether a prospective bike lane network both can be constructed and if that effort will require a collaborative effort with adjacent landowners and developers.

The level of constructive effort needed to implement a bicycle lane on a given road will be impacted by the existing available roadway width. If for example, an arterial roadway currently consists fifteen feet of width not needed to carry the car traffic on an arterial, it can be said that there exists enough space to install two 5-foot bike lanes on that road, without making concessions to the existing travel demands or by expanding the roadway. This option limits construction costs to paint and other treatments in the roadway. And alternatively, if an appropriate excess roadway width does not exist for constructing a bike lane, there still exists the possibility to expand the road into the existing ROW. If the city owns extra space adjacent to the roadway, they may compel developers to expand the roadway for bike lanes during the development of new plans in the city. While this second option adds expense to the construction of bike lanes, it does expand the potential bike lane network.

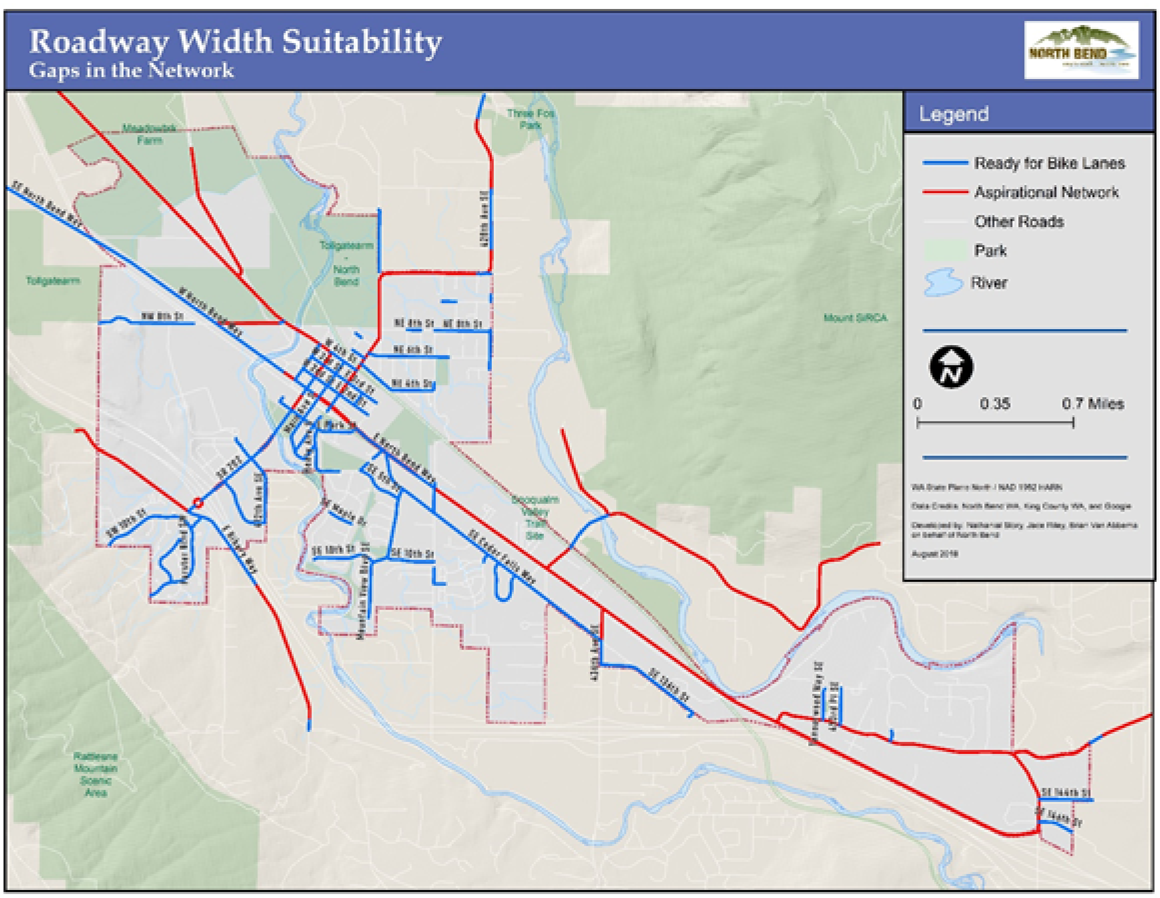


Figure 6.7

To look not only at the overall suitability of a roadway to bike lanes but also expandability, the analysis was extended to compare the City of North Bend's aspirational bike lane network to the narrow analysis of available roadway and ROW. Utilizing the results of the imagery analysis and road centerline data set analysis was able to show where the city's aspirations could immediately be realized in the existing roadway, and in locations where this was not possible, whether a developer exaction could be requested within the ROW available. Overlaying the set of roads with at least ten feet of excess roadway width over the City of North Bend's aspirational network can illustrate if roads will require an expansion before completing the bike network. The maps in Figure 6.7 and Figure 6.8 show the results of this analysis for the entire city and downtown North Bend respectively.

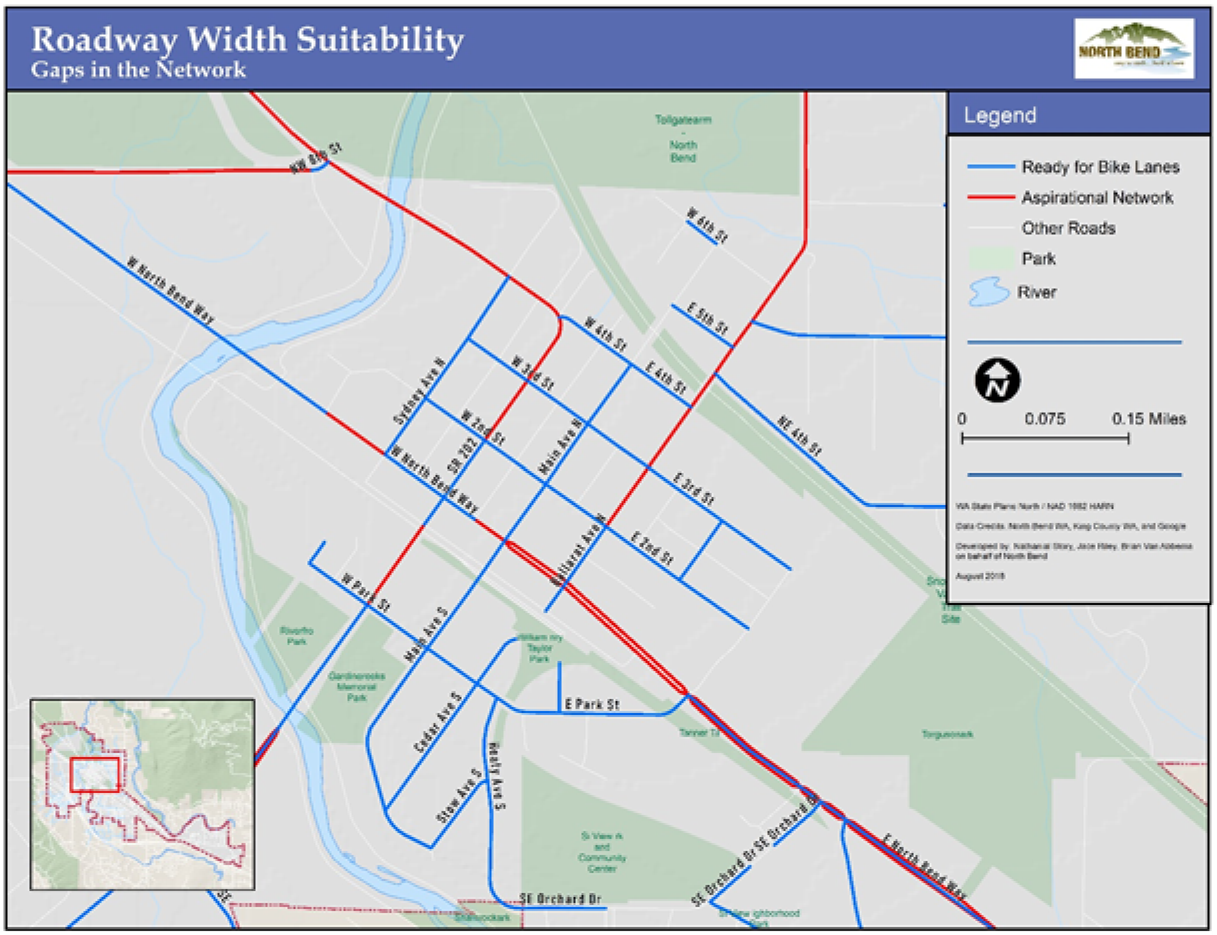


Figure 6.8

With the knowledge of where developer exactions may be necessary to expand the bike lane network, the next step of this analysis was to determine where the ROW width existed to make such a request. Adding together the excess roadway and excess ROW (fields developed in the centerline dataset) the amount of ROW width available for road expansion by road classification type can be determined. If the sum of these two values is greater than 10 feet, there exists room to expand the road within the city's jurisdiction. This information will further help determine where the aspirational bike network can be built out. Figures 6.9 and 6.10 illustrate where exactions are necessary and possible.

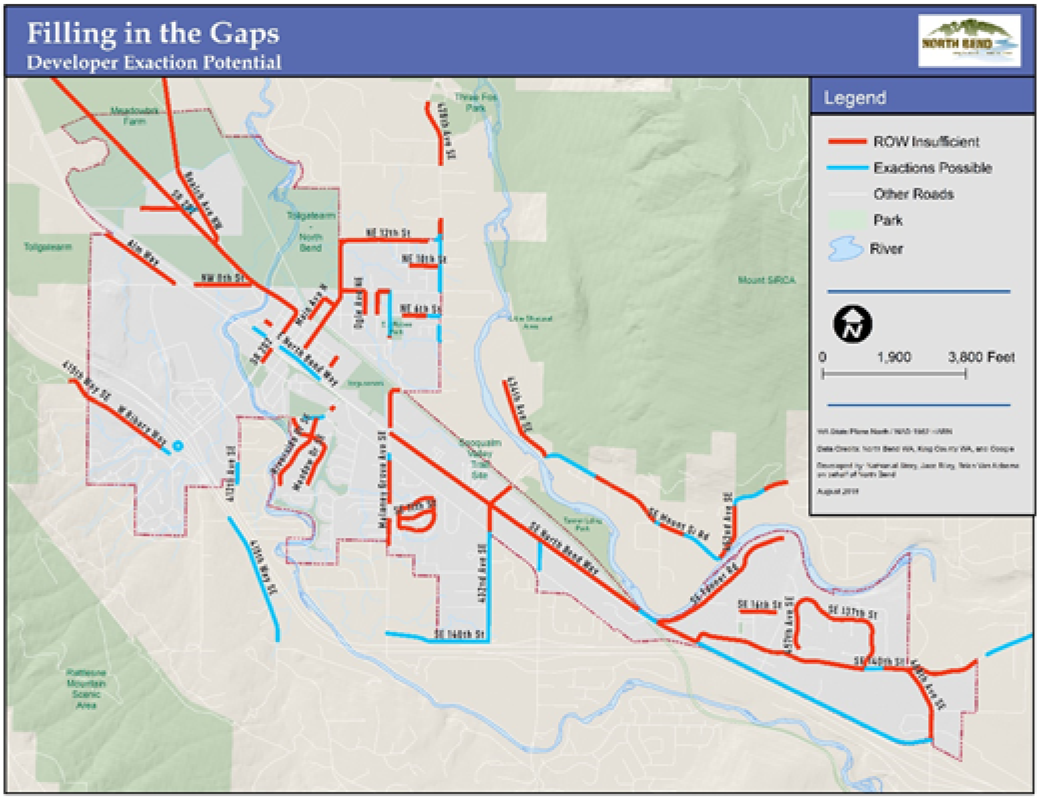


Figure 6.9

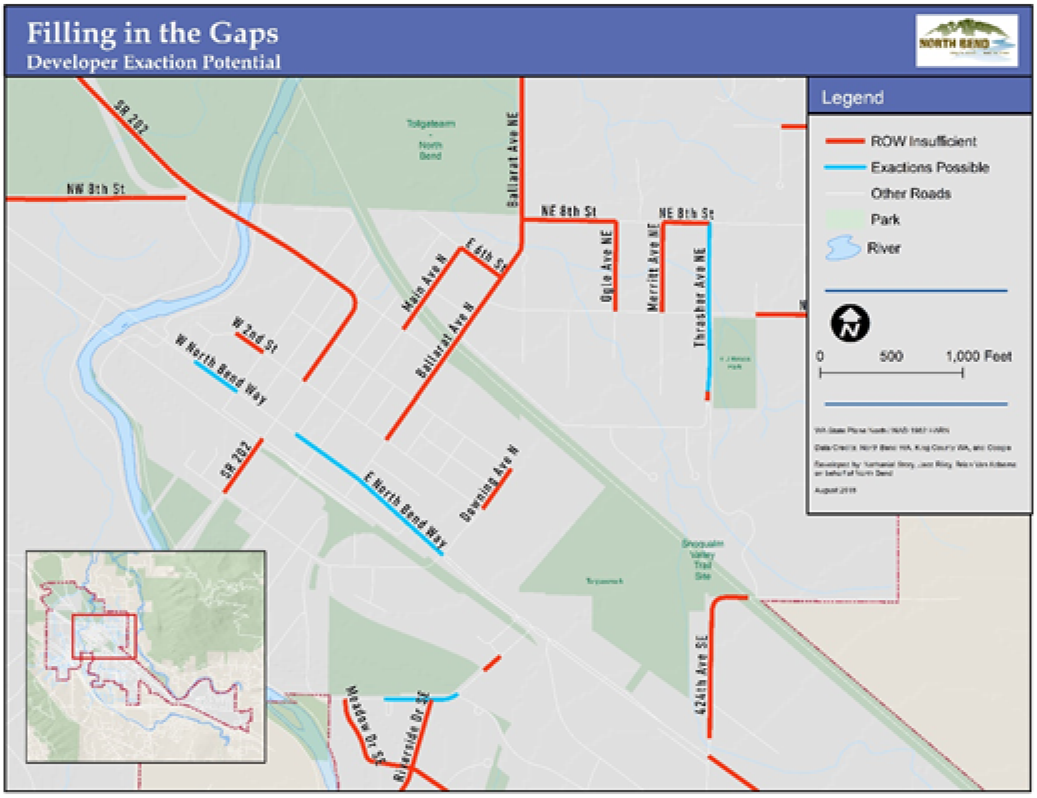

Filling in the Gaps
Developer Exaction Potential
Legend
ROW Insufficient
Exactions Possible
Other Roads
Park
River
0
500
1,000 Feet
SR 202
NW 8th St
Ballarat Ave NE
NE 8th St
Ogle Ave NE
Merritt Ave NE
Thrasher Ave NE
E 6th St
Main Ave N
Ballarat Ave N
W 2nd St
W North Bend Way
E North Bend Way
Downing Ave N
424th Ave SE
Meadow Dr SE
Riverside Dr SE

Figure 6.10

7. Conclusions and Recommendations

The development of a Bike Lane Suitability dataset, workflow, and suitability model presented the group with several insights to not only the nature of the City of North Bend's transportation infrastructure, but also into the work behind a suitability analysis. This section explores the conclusions that can be drawn from that analysis, as well as recommendations the group would have for further development of such a GIS.

In the first section, *Conclusions,* the results of analysis discussed in the previous *Results* section is explored and attempts to provide some answers to the questions that drove this effort. Such as where can the City expand its roadway network, and where will expansion require the least amount of investment. Next, in *Recommendations* the project team provides advice for extending the work into the future and expanding analysis to the entire city. In other words, if this project were be redone, or extended to other cities, how should things be done differently? And finally, *Lessons Learned* highlights and explains different issues or opportunities that cropped up during the execution of this project. Separate for *Recommendations* this sections audience is of future students undertaking similar projects, rather than the City of North Bend. It includes problems with data acquisition, how this methodology compares with the previous method North Bend was using to determine where to prioritize possible bike lane expansions, and how this workflow can be modified to match different levels of GIS knowledge and available technology

7.1 Conclusions

As is shown in the *Business Case* section of this report, the City of North Bend could gain significant financial benefit through an improved and more informed planning process when considering a bike lane network. By identifying not only the most suitable roads for bike lanes, but also where more constructive effort would be required, a complete GIS dataset centered on a suitability analysis will allow the city to make informed decisions and anticipate large capital costs when applicable to building out the network. The results of our suitability analysis show that the City of North Bend is well situated to expand its bike network within the existing transportation network and these results can also inform further discussion of the current aspirational network.

Most of the City of North Bend and the aspirational network is ready for bike lane expansion with the existing roadway widths. The suitability analysis found that in the residential areas and Downtown of North Bend, most roads can accommodate a bike lane if changes to parking designation are made where necessary. This information will help the city move forward with the confidence that when their planning efforts are turned over to engineering design, survey efforts will not uncover roads that are far too narrow for bikes, bringing the planning efforts back to their early stages.

An analysis of the excess right-of-way shows that where roads do not provide adequate space for bike lanes, there are not many streets where an expansion of the road is possible. Within the downtown, only North Bend Way and Thrasher Avenue show potential for using developer exactions to expand the roads for bike lanes. The eastern half of the region has the largest deficit in needed roadway widths and this fact combined with its distance from the city center, may support the conclusion that bike lane expansion efforts should be concentrated to downtown and the residential areas surrounding it. Focusing efforts in this area would offer a bicycle path not just from downtown to the surrounding homes, but also connect these areas with the outlet mall. Further investigation is required, but there may be a way to leverage the malls parking lot infrastructure, combined with new bike lanes, to reduce traffic congestion downtown.

Where gaps do exist in the aspirational network the city may consider sharrows or reclassifying streets. Sharrows will allow for a designation of a bike network, while maintaining the existing service for other travel modes. A shared lane, while indicating that bikes *may* travel in the lane, does degrade the overall safety of the rider. And so, the city can consider a reprioritization of their street network as they expand bike lanes and move towards sustainable modes by reclassifying streets in a manner that will fit bike lanes.

7.2 Recommendations

As the City of North Bend considers future use of the Bike Lane Suitability data set and implementation of the process workflow some key points should be considered and in this section is provided recommendations for continuing the project.

It is recommended that the City of Bend test out the workflow of imagery analysis, converting values into road-centerline values and then performing calculations to ensure that the standards assumed or interpreted by the project group, do indeed meet the standards of the City. Additionally, the City should review the weights and points provided to the factors of bike lane suitability to insure that they match the desires and priorities of the City.

This project leads to several potential future paths. The first is to select a top ranking road and begin to survey in earnest for expansion. Secondly, North Bend may decide to analyze the data again to develop a planning project to create a cohesive network plan. Lastly, North Bend may want to release the results of this project to the public and seek comments.

Option 1 involves North Bend planners choosing a high ranking road to continue development on as a way to test out the workflow, not just for accuracy, but also gather planning data on further bicycle lane expansions. This could possibly involve getting a survey team involved and going through the entire process to paint one particular road or road segment into a new bike lane. This would provide valuable data on the time and cost requirements for turning this projects aspirations into reality. It also forms the foundation for the two other potential paths.

Option 2 involves creating a planning project to not just transform a single road or road segment, but to run the data derived from this project through the city's own planning process to develop a new aspirational network of bicycle lanes to link key areas of the city in need of non-automobile transportation. This could form the core of North Bend's efforts to support their brand statement.

Option 3 is a blend of options 1 and 2, where North Bend creates materials to present to the residents of North Bend, with a breakdown of possible costs, in order to gather public opinion on further development. The city could seek opinions on where to develop, based on the ranking of road segments, combined with where the citizens of North Bend would or could see themselves making use of the lanes.

7.3 Lessons Learned

The first item is data acquisition and organization. Some data was easy to acquire and painless to use. The project sponsor had access to GIS data for North Bend and shared this data on a SharePoint platform. While North Bend features many maps on its website that could have been digitized, Jesse was able to save the team time by providing enterprise GIS data and limiting the number of paper-only maps to a single map, the "Aspirational Bike Lanes" map. The central location for initial data collection and information sharing by the project sponsor was an important foundation for building out the project GIS and following geospatial analysis.

Arguably the most important data for this project was not as painless as getting digital files from Jesse. King County hosts an Orthoimagery Data Layer on its GIS portal that one of the three group members could not gain access to. An email was sent to the county office asking for assistance with this matter, but no response was received. As a result, one team member conducted imagery analysis using Google Earth Pro. As imagery analysis was drawn from multiple sources, the consistency of measurements made by the team cannot be guaranteed and therefore the group would recommend that the City of North Bend or other project groups begin their own analysis with consistent imagery services when building out a road-centerline dataset.

To organize the group's data, a Google Team Drive was created. The initial idea was to use this drive for sharing data and reports among the group members, however this format was not always held as the group did email files to one another rather than using the central depository. This fact led to variance in data schema that had to be rectified later in the project. This could be avoided in future projects by creating not just a central data repository but also a method for making updates. When adding new data to a drive or enterprise database, there should exist a method for communicating the new data and any changes in schema. For a group project this could be accomplished by requiring emails at the addition of any new data.

8. References

Conrad, David, Elise Miller-Hooks, Paul Schonfeld, and Kai Zhao. 2016. "SAFE ACCOMMODATION OF BICYCLISTS ON HIGH-SPEED ROADWAYS IN MARYLAND." University of Maryland. Project Number SP509B4H: 2-6 http://www.roads.maryland.gov/OPR_Research/MD-16-SHA-UM-4-06_Bicycles-on-High-Speed-Roadways_report.pdf

de Neef, Matt. 2013. "Gradients and cycling: an introduction." Accessed August 10, 2018. http://theclimbingcyclist.com/gradients-and-cycling-an-introduction/

Del Beato Et. Al. *Gradients and Cycling: An Introduction*. The Climbing Cyclist. Link

Electricity Local. *North Bend Electricity Rates*. Accessed July 2018. https://www.electricitylocal.com/states/washington/north-bend/

Hsu, T. P., and Y. T. Lin. "*A Model for Planning a Bicycle Network with Multi-Criteria Suitability Evaluation Using GIS*." WIT Transactions on Ecology and the Environment 148 (2011): 243-252. Link

The News Tribune.Salaries: *King County Employees for 2017*. Staff Report. April 02, 2018. Accessed July 2018. https://www.thenewstribune.com/news/databases/article25861870.html?appSession=5BRD37Z27F9S24Q4A4X152T7YC6AOI5Q5Y5Y53524TPYBNA6Y902GK6X0A5OPPT1560S0WS2JO6YHV8741FG3Q2X0064HHJZ435H3C2QX8VY189V248X7Z6GW1J5FKG0

City of North Bend. 2016. *City of North Bend, Washington 2017-2018 Biennial Budget*. https://northbendwa.gov/Archive/ViewFile/Item/3317

Peterson, George Et. Al. *Unlocking Land Values to Finance Urban Infrastructure.* World Bank; Public-Private Infrastructure Advisory Committee. 2009 https://ebookcentral-proquest-com.offcampus.lib.washington.edu/lib/washington/detail.action?docID=459647

Reynolds, Hyde. *North Bend Bike Lane Suitability Analysis.* City of North Bend, WA. Link

Seattle Department of Transportation. *Seattle Bicycle Master Plan: 2017-2021 Implementation Plan.* Accessed July 2018. https://www.seattle.gov/Documents/Departments/SDOT/About/DocumentLibrary/BicycleMasterPlan/BMP_Imp_Plan_2017_vr32.pdf

State of Washington. *State of Washington DES MPA Price List E418M-3Q2017*. https://fortress.wa.gov/ga/apps/contracting/DES%20Price%20List%20Update%209-27-2017.pdf

Su. Et. Al. *Designing a Route Planner to Facilitate and Promote Cycling in Metro Vancouver, Canada.* Transportation Research Part A. Volume 44, Issue 7, August 2010, Pages 495-505.

USDA Forest Service Northern Region Engineering. 2017. *Cost Estimating Guide for Road Construction.* https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5279284.pdf

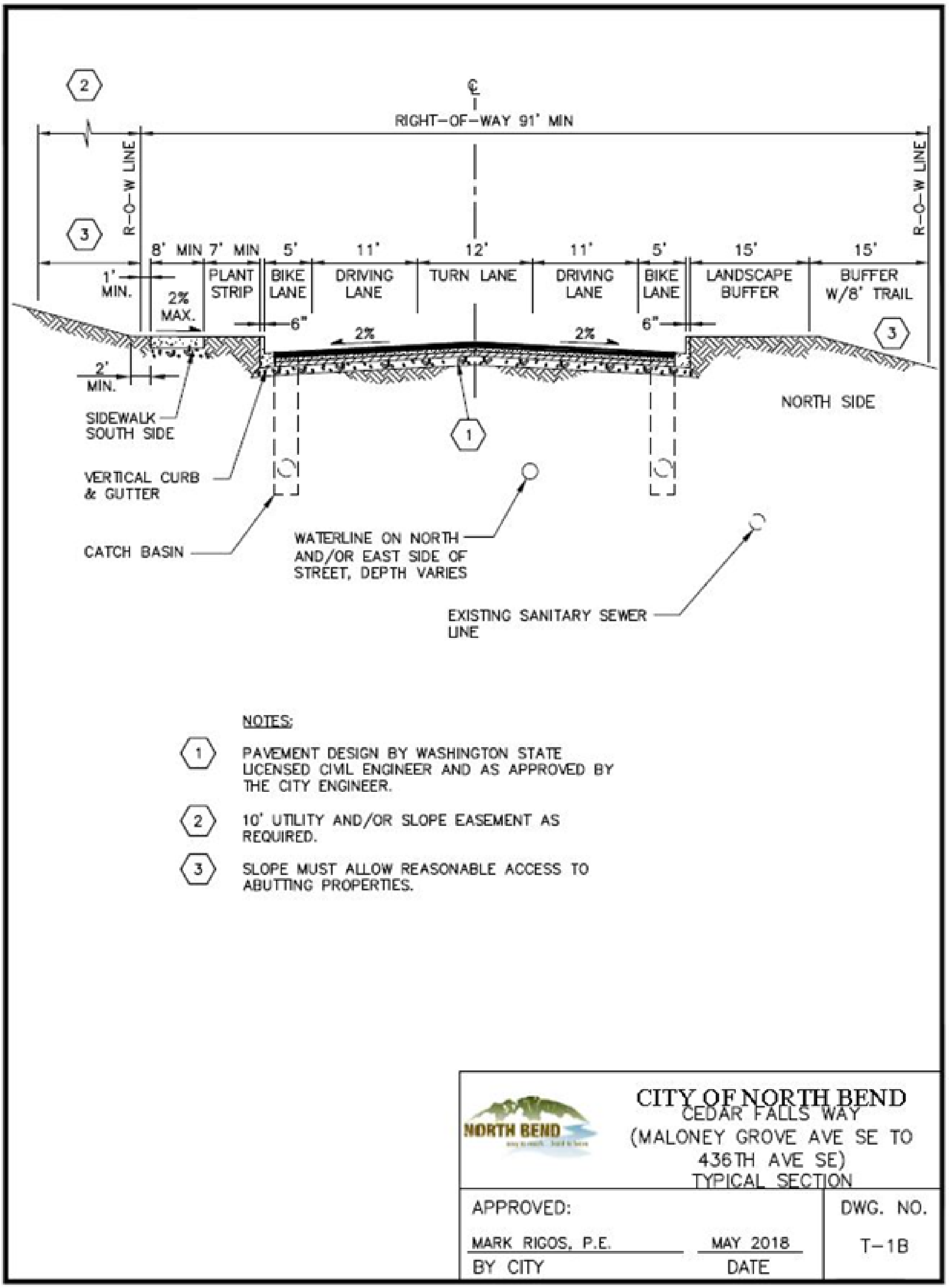
9. Appendix A: Highest Rated Roads Arranged by Length

Street Name	Length (Ft)	Street Name	Length (Ft)
SE North Bend Way	7105	Main Ave N	1034
SE Cedar Falls Way	6913	Sydney Ave N	1034
W North Bend Way	6337	SE Orchard Dr	990
SR 202	3543	453rd Pl SE	887
Mountain View Blvd SE	3360	SE 146th St	845
Forster Blvd	2935	Tannerwood Way SE	760
SE 136th St	2685	W 2nd St	705
SE 10th St	2630	W 3rd St	702
NW 8th St	2404	W Park St	693
E North Bend Way	2348	South Fork Ave SW	611
SW 10th St	2247	SE Maple Dr	583
E Ribary Way	2137	436th Ave SE	554
NE 4th St	2128	424th Ave SE	524
428th Ave SE	1976	Ballarat Ave N	508
NE 6th St	1908	Stow Ave S	425
Main Ave S	1799	W 4th St	415
La Forest Dr SE	1739	Maloney Grove Ave SE	374
NE 8th St	1654	E 4th St	352
412th Ave SE	1653	E 5th St	351

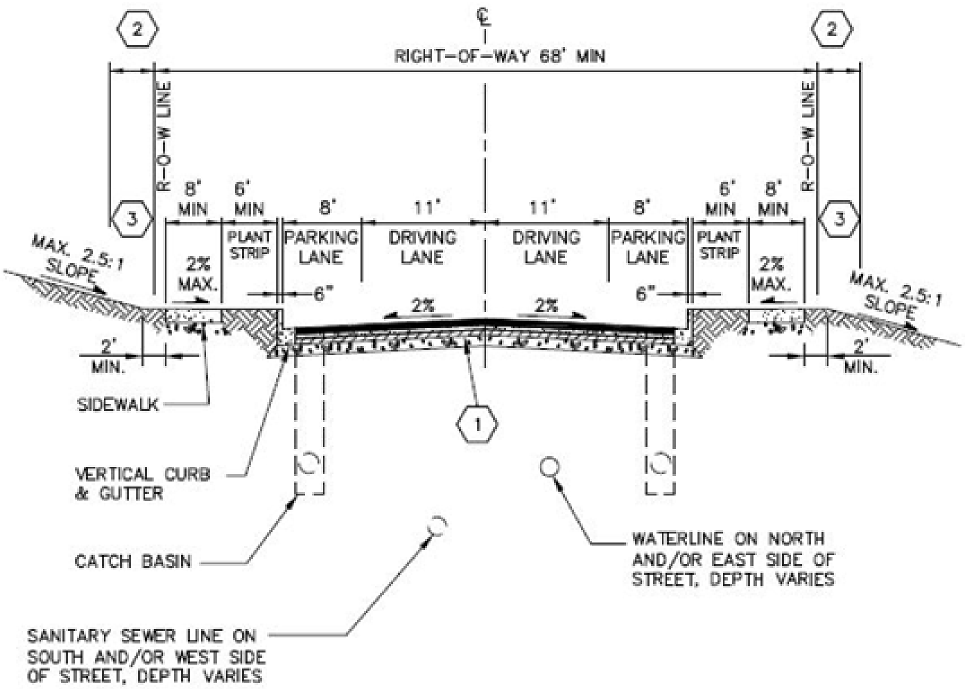
Mount Si Blvd	1540	Janet Ave	349
420th Ave SE	1489	NE 10th St	331
E Park St	1373	NE 12th St	330
SE 144th St	1270	SE Middle Fork Rd	307
SE Mount Si Rd	1223	W Ribary Way	287
E 3rd St	1187	SE 11th St	267
E 2nd St	1185	457th Ave SE	265
SE 5th St	1173	Ballarat Ave S	238
Pickett Ave NE	1108	415th Way SE	231
Forster Blvd SW	1106	Bendigo Blvd S	216
Healy Ave S	1079	Salish Ave SE	209
Cedar Ave S	1034	W 6th St	173
Main Ave N	1034	Sydney Ave S	124
Sydney Ave N	1034	Thrasher Ave NE	121

Appendix B: CAD Drawings Used to Derive Roadway Standards

Arterial Standard



<u>Collector Standard</u>



NOTES:

(1) PAVEMENT DESIGN BY WASHINGTON STATE LICENSED CIVIL ENGINEER AND AS APPROVED BY THE CITY ENGINEER, OR MINIMUM PER SECTION 4.38.

(2) 5' UTILITY EASEMENT (BOTH SIDES)

(3) SLOPE MUST ALLOW REASONABLE ACCESS TO ABUTTING PROPERTIES.

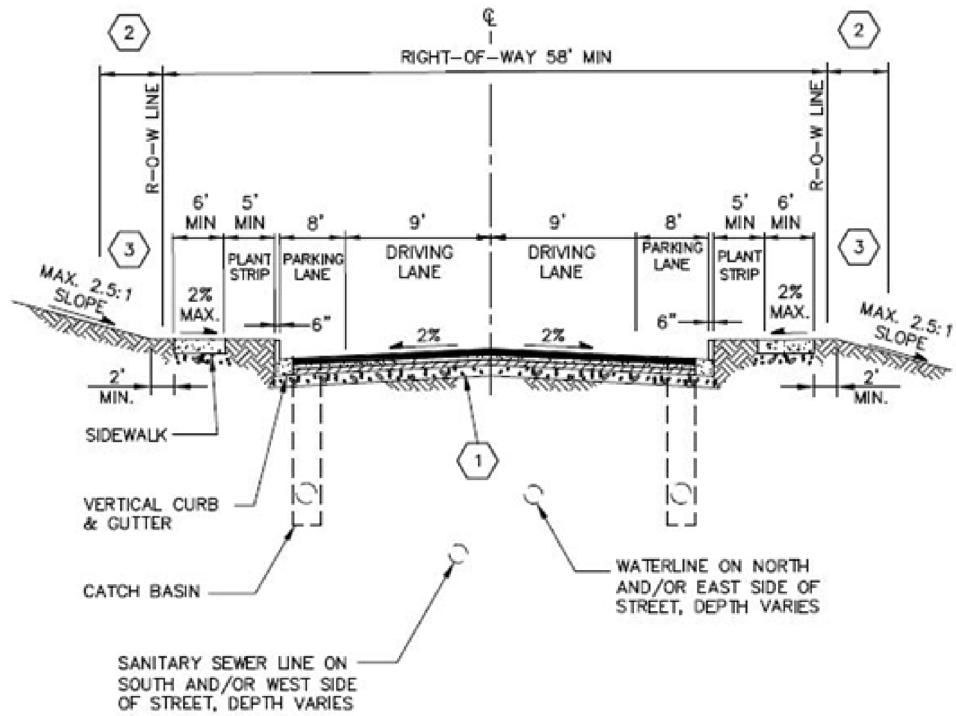
NORTH BEND

CITY OF NORTH BEND

COLLECTOR STREETS TYPICAL SECTION

APPROVED:		DWG. NO.
MARK RIGOS, P.E.	MAY 2018	T-6A
BY CITY	DATE	

Residential Standard



NOTES:

1. PAVEMENT DESIGN BY WASHINGTON STATE LICENSED CIVIL ENGINEER AND AS APPROVED BY THE CITY ENGINEER, OR MINIMUM PER SECTION 4.38.
2. 5' UTILITY EASEMENT (BOTH SIDES)
3. SLOPE MUST ALLOW REASONABLE ACCESS TO ABUTTING PROPERTIES.

NORTH BEND	CITY OF NORTH BEND RESIDENTIAL LOCAL STREETS FOR COTTAGE HOUSING AND MULTIFAMILY TYPICAL SECTION	
APPROVED: MARK RIGOS, P.E. BY CITY	MAY 2018 DATE	DWG. NO. T-7

Appendix B: Maps

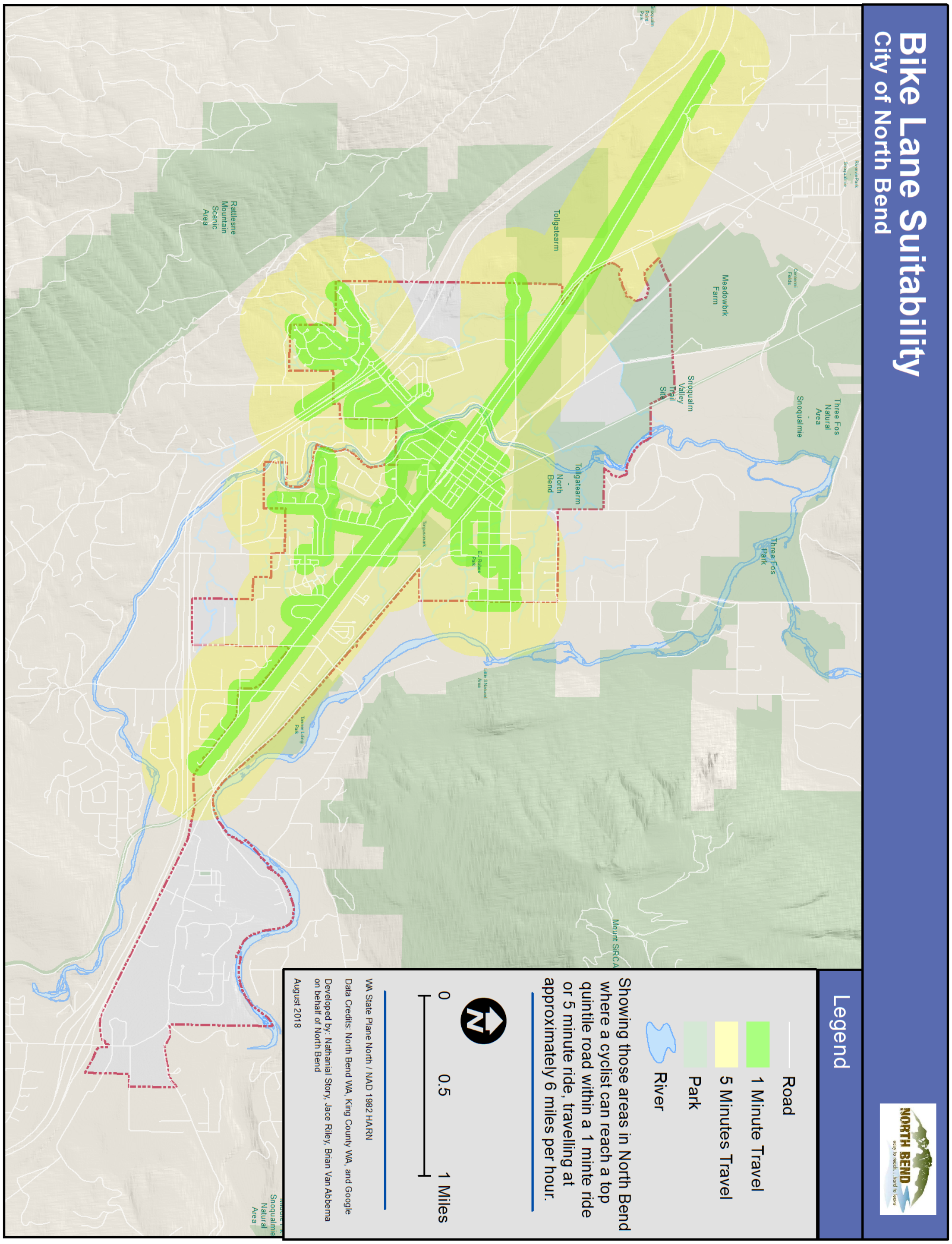


Figure 1.1 : Overview

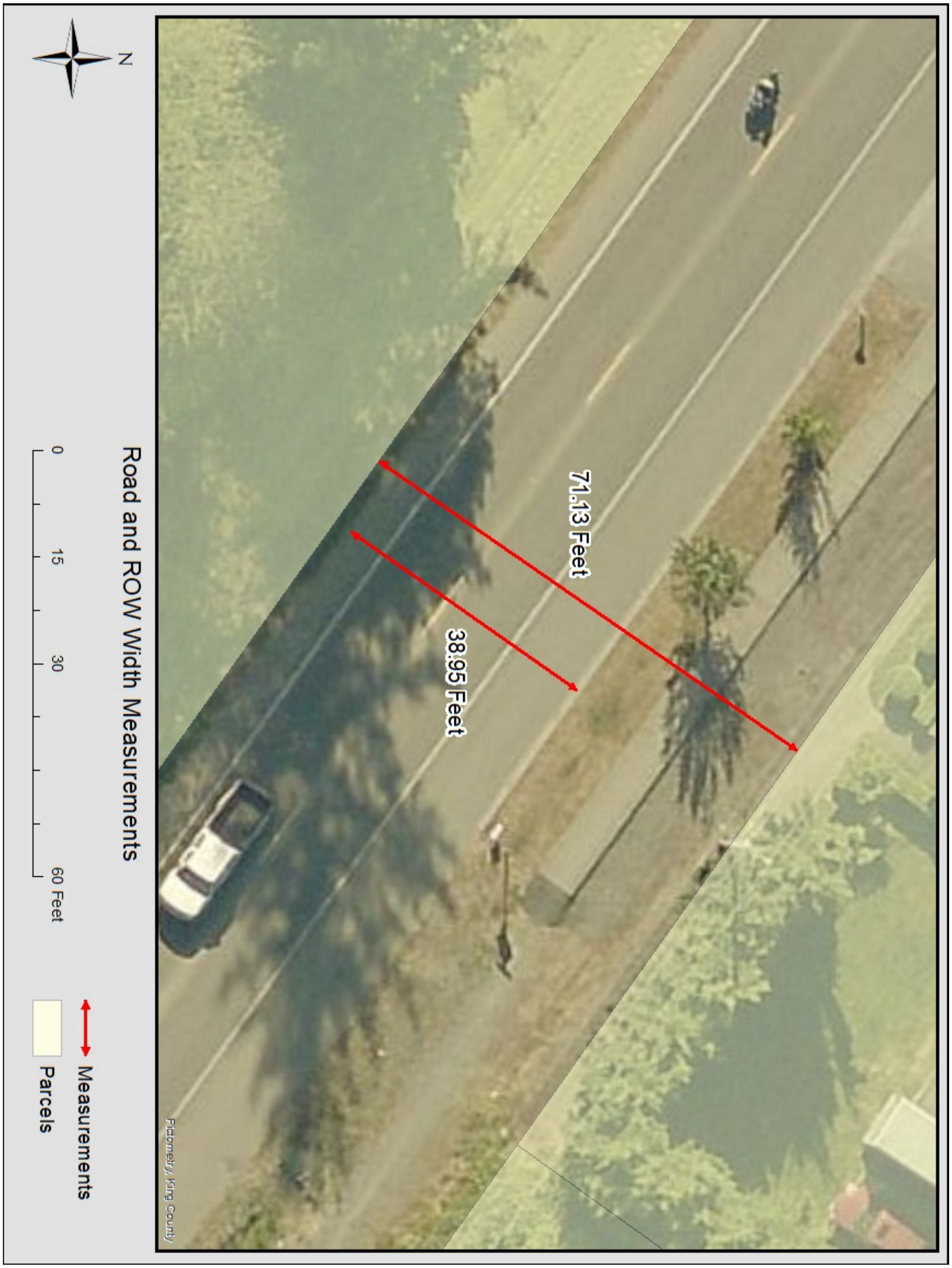


Figure 4.1: ROW Measurements

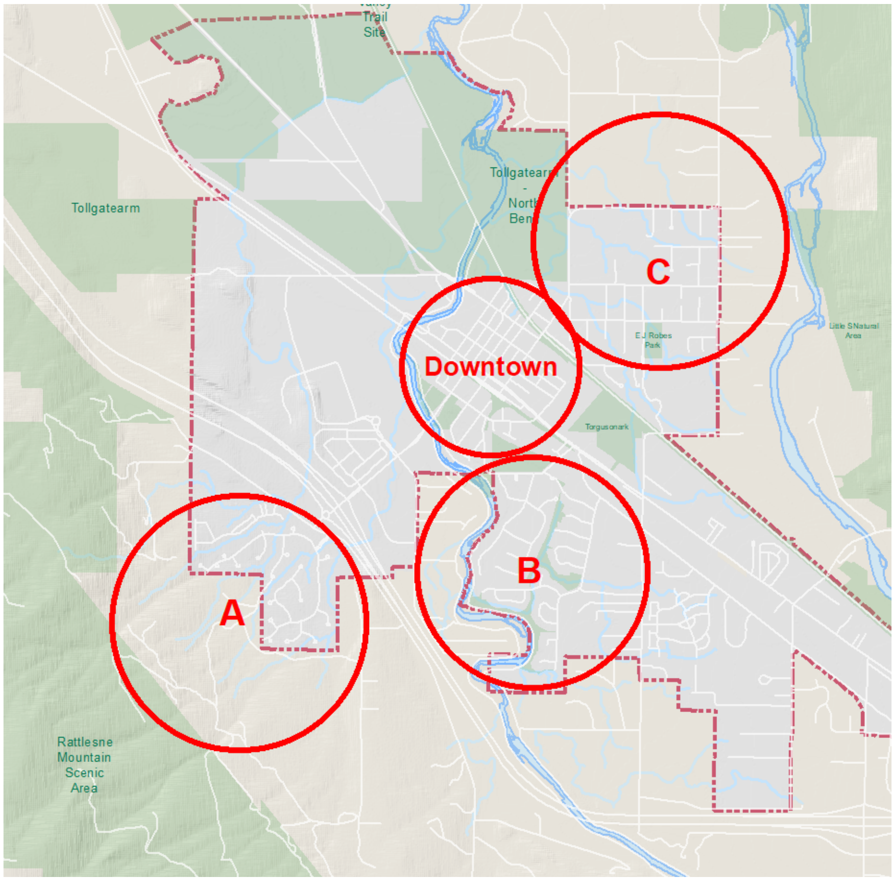


Figure 6.1 : Areas of Interest

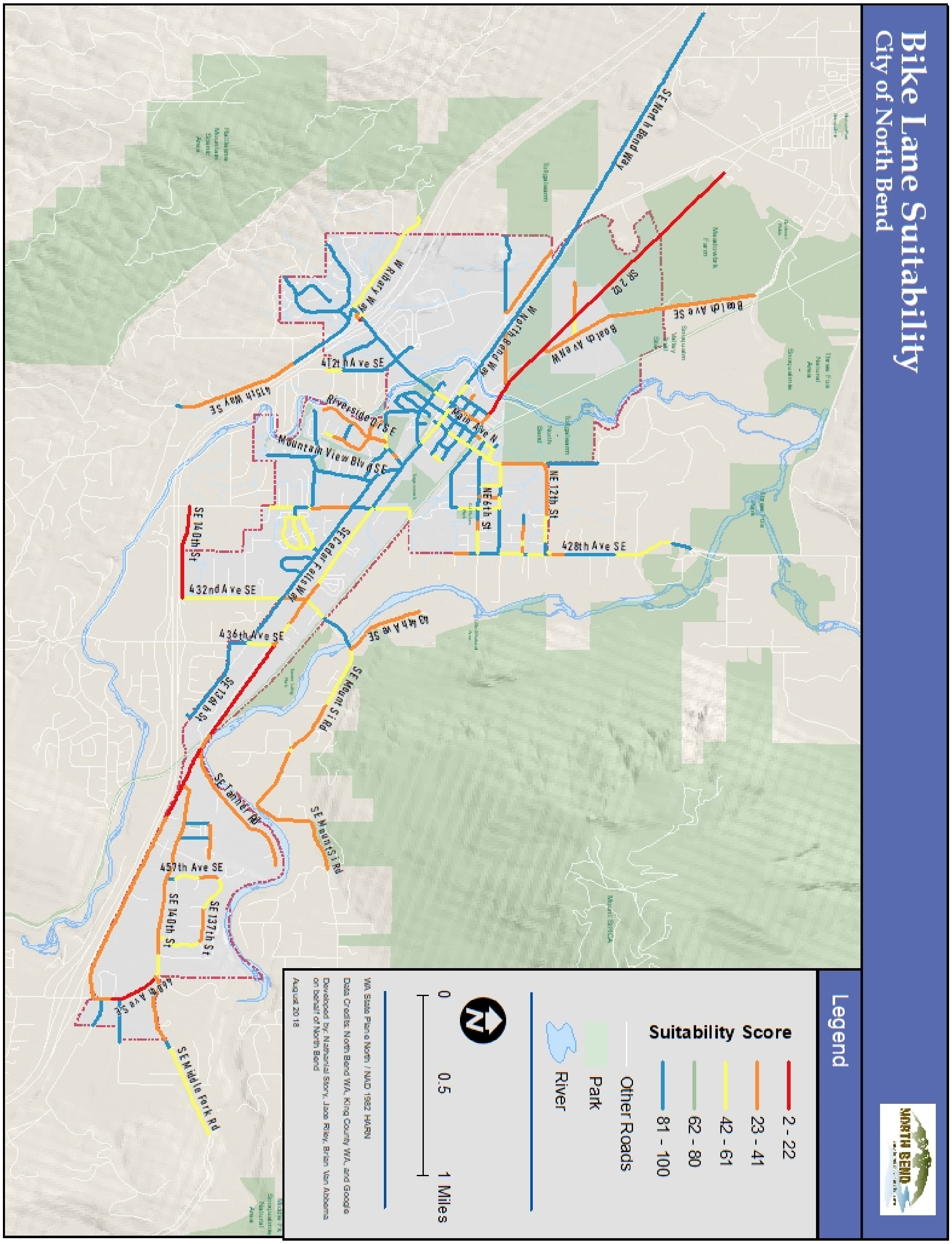


Figure 6.2: Overview of Results

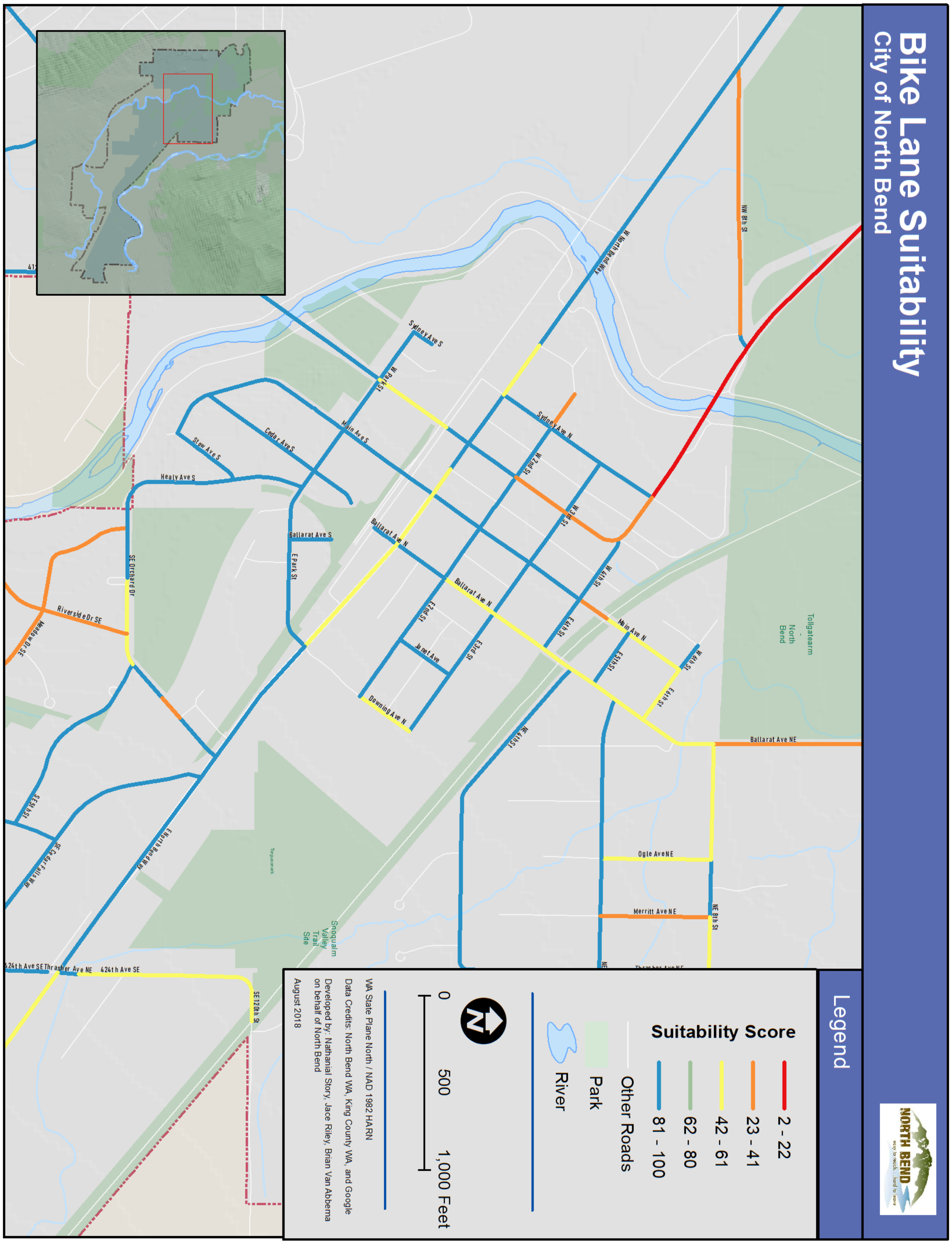


Figure 6.3 : Downtown Results

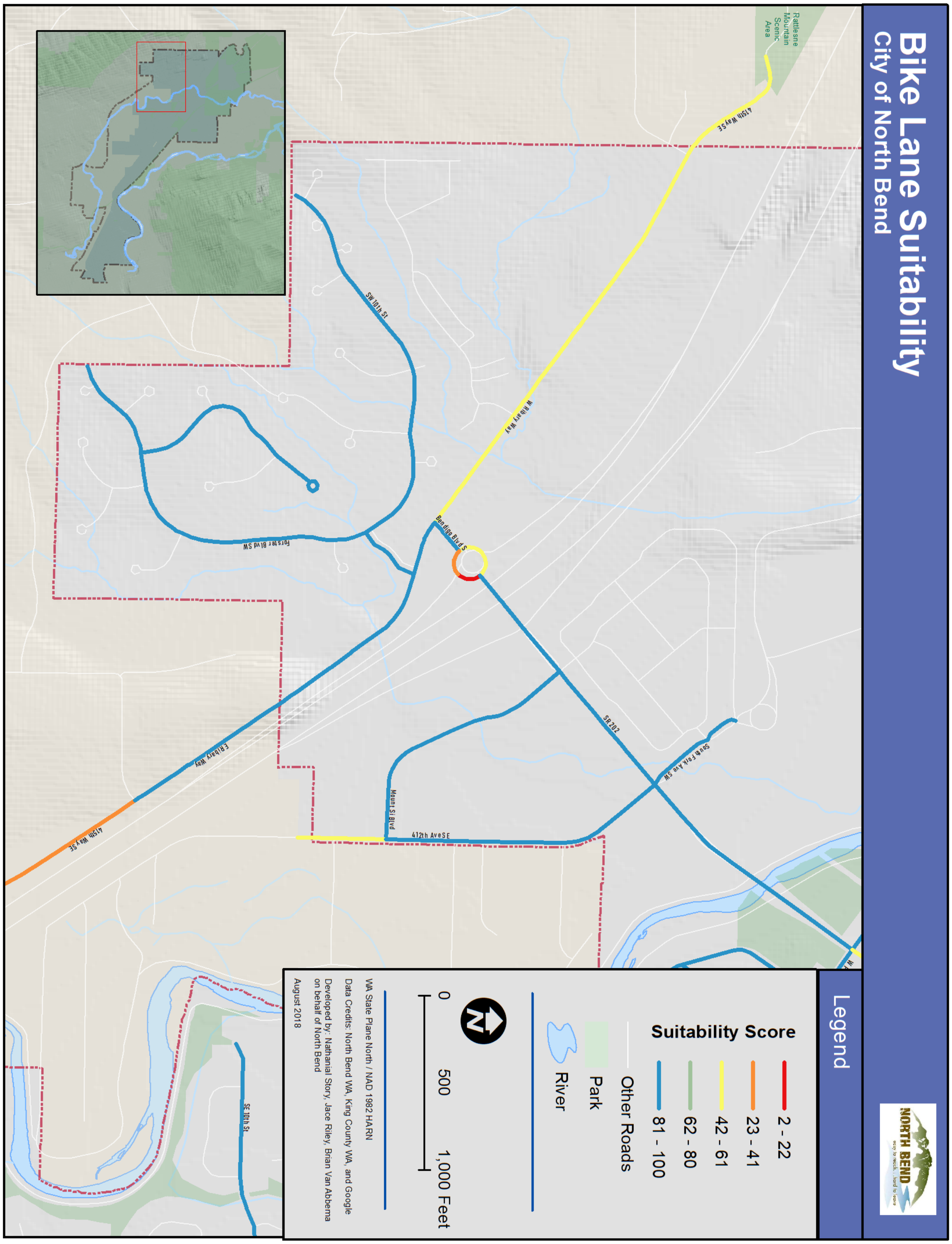


Figure 6.4 : Residential Area A

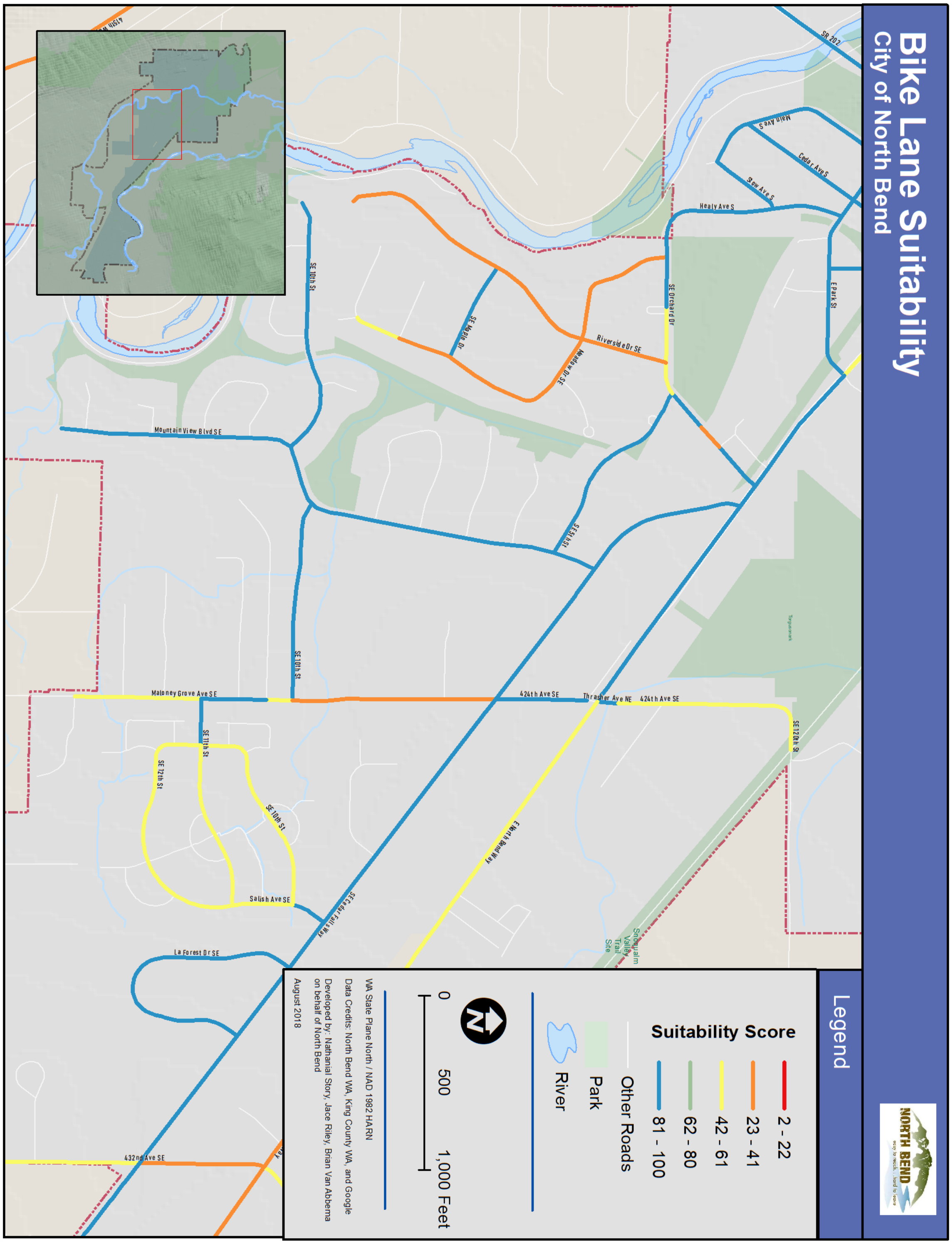


Figure 6.5 : Residential Area B

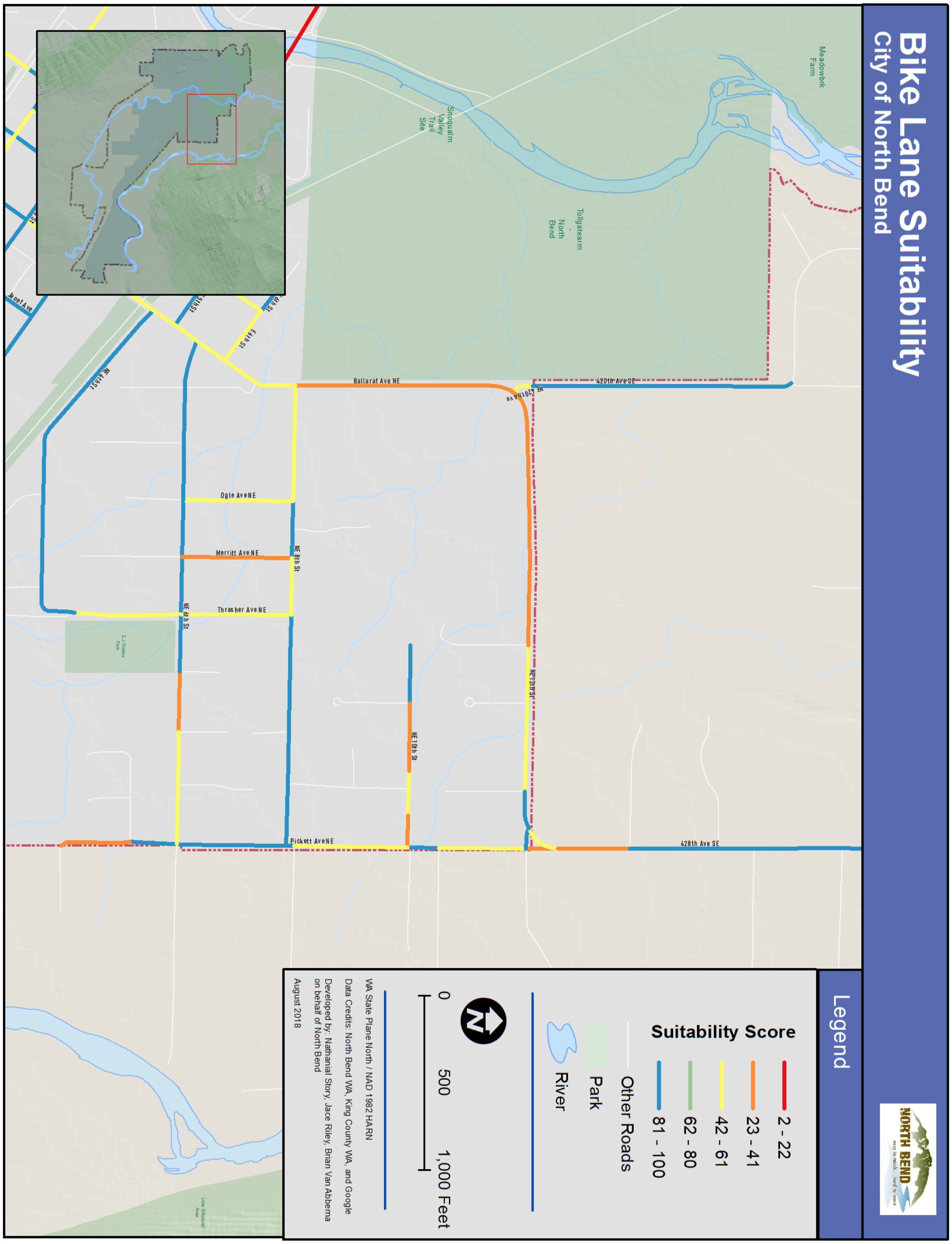


Figure 6.6 : Residential Area C

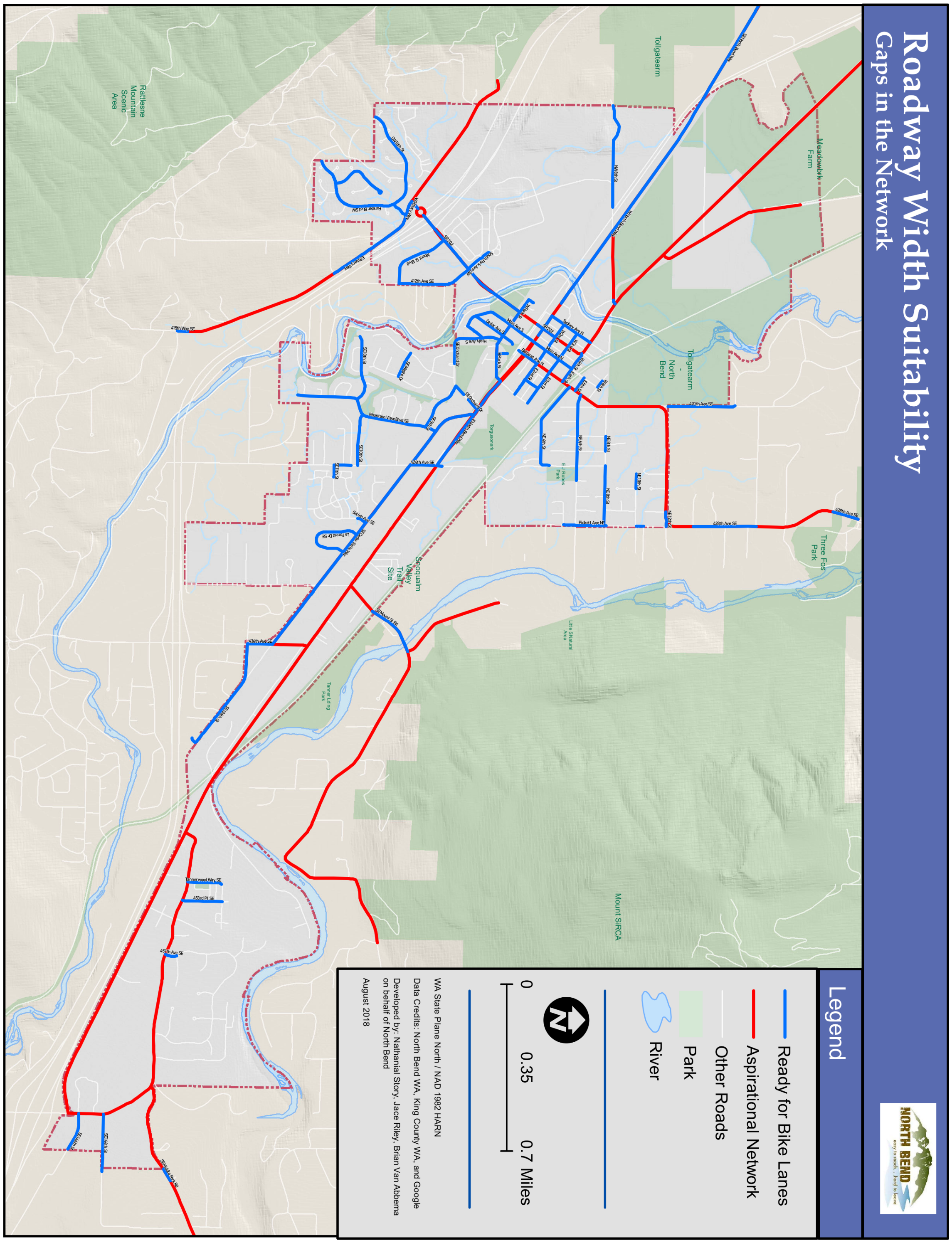


Figure 6.7 : Network Gaps

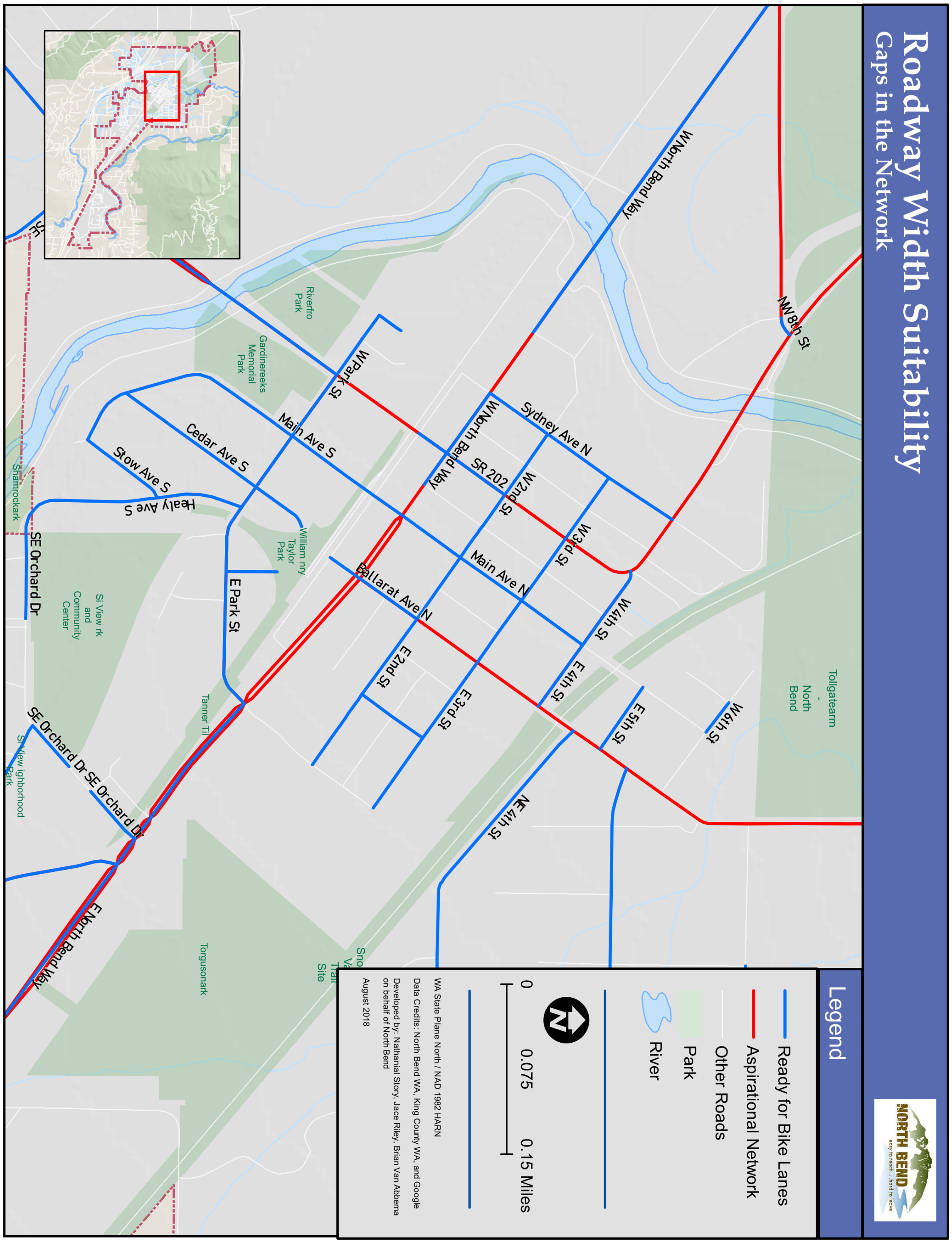


Figure 6.8 : Downtown Network Gaps

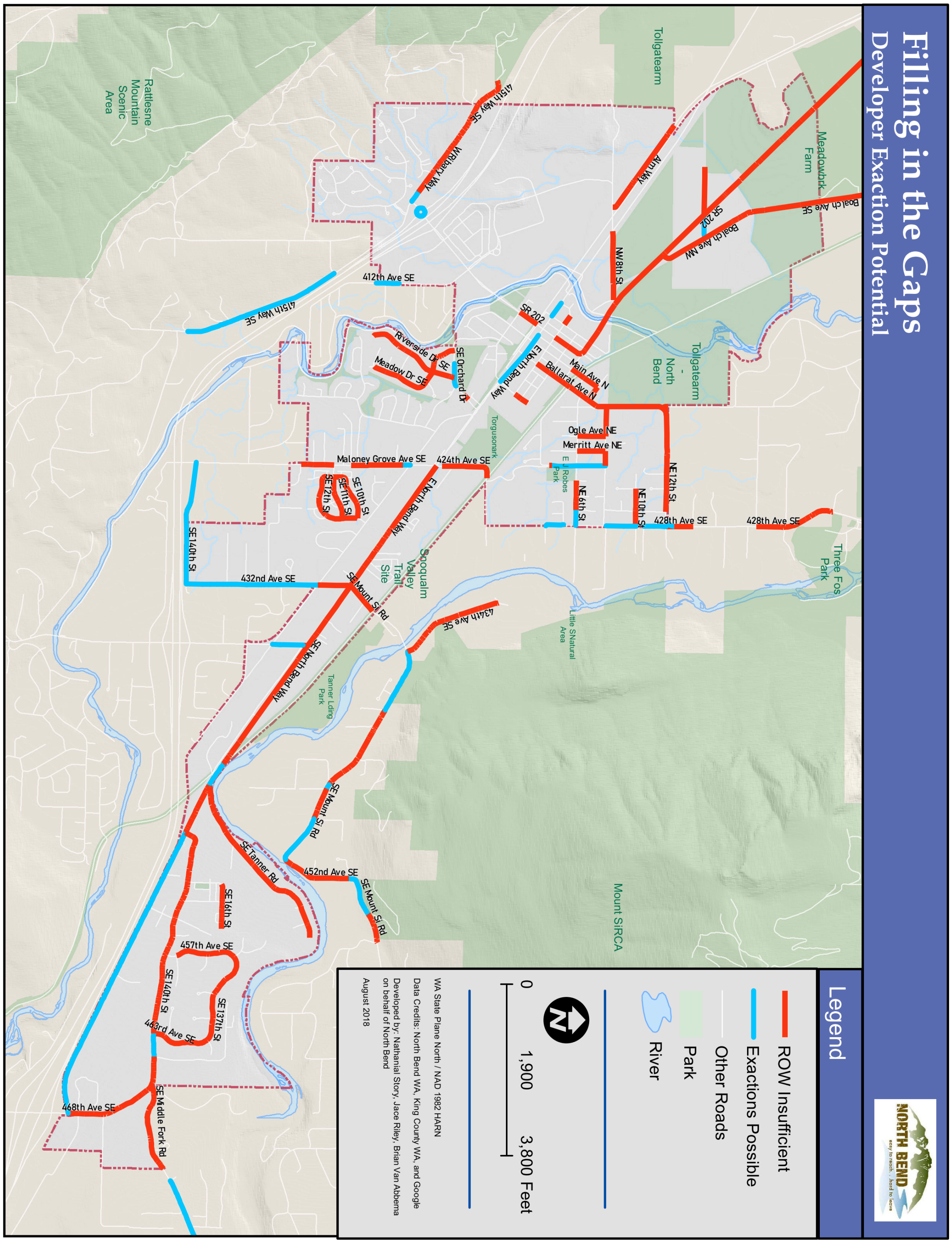


Figure 6.9 : Potential Exactions

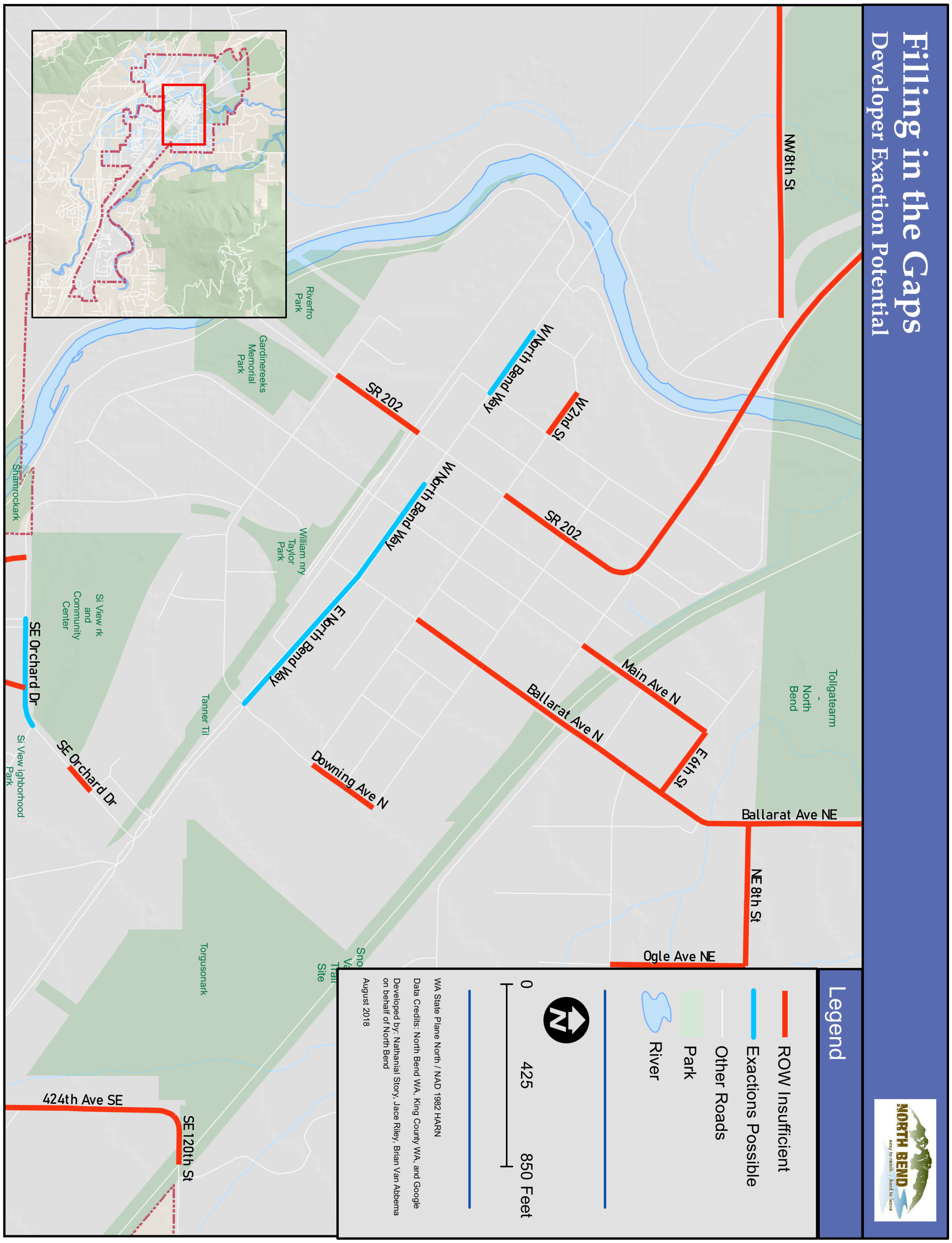


Figure 6.10 : Downtown Potential Exactions