Constructed Wetland Suitability Analysis in Oregon

AN AUTOMATED GIS STANDARD & PROJECT FEASIBILITY APPROACHES

Terminal Project at the University of Oregon

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Executive Summary

Communities across Oregon have begun to take an interest in non-traditional approaches to stormwater management. Of these approaches, those designated as "Green Infrastructure" have begun taking a major role. Green Infrastructure is a blanket term to denote natural or semi-natural systems which perform a valuable service for human communities. Stormwater Green Infrastructure aims to capture, store, infiltrate, or slow down precipitation and runoff at the site level. Green Infrastructure has a number of benefits, including lower capital and operational costs versus traditional systems[1], flexibility in terms of scale, carbon sequestration dividends[2], and resilience to natural hazard events[3].

Of particular note, constructed wetlands or extended wet ponds are a Green Infrastructure strategy successful in treating large volumes of stormwater and providing natural habitat for wildlife communities. According to the Environmental Protection Agency, these projects are defined as "treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality."[4]

Many successful examples of constructed wetlands lie within small and mid-sized communities in places such as Arcata, California, Houghton Lake, Michigan, and Cannon Beach, Oregon[5]. However, despite their realization in many places, constructed wetlands have yet to see widespread application across Oregon. Along with institutional resistance to change and maintenance concerns, a primary reason for this lack of investment is missing information on areas suitable for constructed wetland projects. Smaller communities in particular often lack the time, formal knowledge, and appropriate tools to perform a rigorous assessment of which locations in their community may be suitable.

To address this shortfall, this report presents an automated Geographic Information System (GIS) suitability analysis tool for constructed wetland projects in Oregon. Rather than serving as a detailed "site selection" tool, this program is intended as a "site search" tool to identify the boundaries of suitable project areas and associated characteristics. The analysis itself is performed using a range of geographic data sets related to a variety of accepted constructed wetland practices and design techniques. To maintain the largest possible assortment of potential users, all datasets and the tool programming language within this program were gathered from open source locations such as the State of Oregon's *Spatial Data Library*. To illustrate the applicability of this tool, a sample suitability analysis was performed in Cottage Grove, Oregon. This analysis was evaluated along with relevant local planning documents and case studies of successful constructed wetlands projects in various land use situations. These results have been presented to give greater direction in how this analysis tool might be utilized and applied by other Oregon communities.

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[2] Foster, J., Lowe, A., & Winkelman, S. (2011). The value of green infrastructure for urban climate adaptation. *Center for Clean Air Policy*, *750*.

[3] Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., ... & Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of environmental management*, *146*, 107-115.

[4] Constructed Wetlands. (2016, October 06). Retrieved from https://www.epa.gov/wetlands/constructed-wetlands

[5] Constructed Wetlands for Wastewater Treatment and Wildlife Habitat: 17 Case Studies. (2016, October 06). Retrieved from https://www.epa.gov/wetlands/constructed-wetlands-wastewater-treatment-and-wildlife-habitat-17-case-studies

Introduction

Over the past several decades, urban planning, landscape architecture, and emergency management professionals have begun to explore the role of Green Infrastructure (or "GI") as it relates to the built environment. Green Infrastructure can be defined both as a set of landscape or design principles, but also as an inventory of existing natural landscapes which perform relevant and needed services for human communities. Most broadly, Green Infrastructure comprises all natural, semi-natural and artificial networks of multifunctional ecological systems within, around, and between urban areas, at all spatial scales[6].

One particularly fast growing area of interest related to Green Infrastructure is stormwater and wastewater management using constructed wetlands. Growing urban development, and the accompanying rise in impervious surface area, has increased both the frequency and intensity of stormwater runoff events in urban areas[7]. These runoff episodes are strongly correlated with higher levels of nitrate and phosphate loading, sedimentation and waterway erosion, and fecal coliform pollution related to over loaded capacity in traditional stormwater treatment systems[8]. Furthermore, these impacts are likely to increase over time as climate change influences on precipitation patterns continue to manifest. In the Pacific Northwest region of the United States, including the Willamette River basin, climate change is likely to increase the intensity of autumn and winter precipitation events, leading to greater levels of projected stormwater runoff in these areas[9]. Additionally, increasing conventional infrastructure services such as wastewater treatment in fast growing communities is becoming progressively more challenging due to the high capital and maintenance costs associated with these projects.

To mitigate against these effects, many municipalities across the country have begun to integrate constructed wetland practices as part of their urban infrastructure. Large metropolitan areas such as Chattanooga, TN have developed extensive constructed wetland projects and stormwater parks to help solve challenging water quality impediments, flooding impacts, and demand for natural spaces[10]. Mid-sized Oregon cities, such as Forest Grove, have also begun to include constructed wetland projects into their comprehensive wastewater treatment systems[11]. As Oregon's population continues to grow in the coming years, constructed wetland practices will become an increasingly crucial component of the state's stormwater and wastewater management policies as cities struggle to balance urbanization, flood hazard mitigation, and water quality targets.

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[6] Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., & James, P. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape and urban planning*, *81*(3), 167-178.

[7] Mansell, M. G. (2003). *Rural and urban hydrology*. Thomas Telford.

[8] Mallin, M. A., Johnson, V. L., & Ensign, S. H. (2009). Comparative impacts of stormwater runoff on water quality of an urban, a suburban, and a rural stream. *Environmental Monitoring and Assessment*, *159*(1), 475-491.

[9] Chang, H., & Jung, I. W. (2010). Spatial and temporal changes in runoff caused by climate change in a complex large river basin in Oregon. *Journal of Hydrology*, *388*(3), 186-207.

[10] https://landscapeperformance.org/case-study-briefs/renaissance-park

[11] Fernhill Wetlands: Clean Water Naturally. (n.d.). Retrieved from http://www.fernhillnts.org/

Research Context

Constructed wetlands offer a range of benefits both ecologically and financially for host communities, including wastewater treatment[12], flood water storage[13], and wildlife habitat[14]. These findings are bolstered by a report from the EPA which suggests that constructed wetlands can serve as a cost effective, technically feasible approach to treating wastewater and runoff for the following reasons[15]:

- Wetlands can be less expensive to build than other treatment options
- Operation and maintenance expenses (energy and supplies) are low
- Operation and maintenance require only periodic, rather than continuous, on-site labor
- Wetlands are able to tolerate fluctuations in flow
- They facilitate water reuse and recycling
- They provide habitat for wetland organisms
- They can be built to fit harmoniously into the landscape and provide aesthetic enhancement of open spaces

Additionally, due to unique siting requirements, constructed wetlands can also overcome institutionally perceived suitability issues surrounding characteristics such as soil drainage patterns.

Barriers to Implementation

In a review of three large US cities, one of the major identified barriers to implementing GI practices was general site suitability. Along with resistance to change, public awareness and motivation, and maintenance concerns, cities were continually seen as placing or seeking to place GI in locations that are environmentally or logistically unfit[16]. Legitimate site constraints, such as steep and unstable slopes, must be considered ahead of time and can potentially limit the feasibility of large-scale green infrastructure implementation. However, certain site suitability constraints appear to produce barriers which are not entirely accurate. For example, sites containing clay soils were frequently cited as a constraint due to their poor drainage characteristics[17]. However, these sites may be quite suitable for specific designs such as constructed wetlands which actually perform best in standing water conditions.

As a possible solution, it has been suggested that cities "simplify uncertainties about site suitability with simple mapping applications. Using GIS, city departments can map a variety of layers related to green infrastructure: slope, soil type, prior land uses and contamination, and proximity to water sources. The

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[12] Vymazal, J. (2010). Constructed wetlands for wastewater treatment: five decades of experience. *Environmental science & technology*, *45*(1), 61-69.

[13] Guo, J. C. (2017). *Urban Flood Mitigation and Stormwater Management*. CRC Press.

[14] Worrall, P., Peberdy, K. J., & Millett, M. C. (1997). Constructed wetlands and nature conservation. *Water Science and Technology*, *35*(5), 205-213.

[15] Luise, J. D., Robert, E., Lamonte, G., Barry, I., Jeffrey, L., Timonthy, B., ... & Harold, W. (1993). A Handbook of Constructed Wetlands.

[16] Hammitt, S. A. (2010). *Toward sustainable stormwater management: overcoming barriers to green infrastructure* (Doctoral dissertation, Massachusetts Institute of Technology).

[17] Hammitt, S. A. (2010). *Toward sustainable stormwater management: overcoming barriers to green infrastructure* (Doctoral dissertation, Massachusetts Institute of Technology).

combination of these layers could produce citywide suitability maps by which residents could look up their properties and find site-specific menus of appropriate green infrastructure options."[18]

Unfortunately, despite the relatively straight forward task associated with this mapping approach, determining suitable sites for appropriate GI projects often requires large time and capacity commitments from city public works or planning departments. For example, in another review of six green infrastructure projects, the capital costs of "identifying, mapping, and planning" were recognized as three of the five major costs associated with green infrastructure initiatives.[19] Additionally, these resource constraints associated with initial identification and mapping phases are likely to be amplified in smaller municipalities with tighter budgets and competing agendas.

Research Questions

Despite possible advantages, there is currently no Oregon specific framework or strategy for analyzing potential constructed wetland project sites. As in many areas, Oregon cities must address local "site search[20]" suitability problems to effectively pursue constructed wetland plans in their communities. Larger cities often have both the time and money to dedicate adequate resources to pursue site feasibility studies. However, even cities such as Portland, OR have struggled with mapping and siting GI projects[21]. These issues can be compounded by a city's lack of technical information on effectively locating projects and low capacity on the part of municipal employees to identify applicable geographic areas. While not unique to smaller communities, these problems are likely to be amplified when considering small town constructed wetland suitability analysis. Providing Oregon communities with adequate information to pursue future constructed wetland projects must consider issues of cost, speed of implementation, return on investment, and availability of existing data.

With this context in mind, this report seeks to answer the following questions:

- ***Can an initial, Oregon-specific constructed wetlands suitability analysis tool be created using open source data?***
- ***What are the results of this analysis tool across a range of small to mid-sized Oregon communities?***
- ***How can these results be used by communities to pursue constructed wetland projects within their Urban Growth Boundaries?***

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[18] Hammitt, S. A. (2010). *Toward sustainable stormwater management: overcoming barriers to green infrastructure* (Doctoral dissertation, Massachusetts Institute of Technology).

[19] Naumann, S., Davis, M., Kaphengst, T., Pieterse, M., & Rayment, M. (2011). Design, implementation and cost elements of Green Infrastructure projects. *Final report, European Commission, Brussels*, 138.

[20] Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview. *Progress in planning*, *62*(1), 3-65.

[21] Hammitt, S. A. (2010). *Toward sustainable stormwater management: overcoming barriers to green infrastructure* (Doctoral dissertation, Massachusetts Institute of Technology).

Existing Literature

Green Infrastructure Planning

Green Infrastructure can be defined as existing or modified natural landscapes which perform needed services, such as water storage and treatment, for human populations. Green Infrastructure comprises all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales[22].

One particularly fast growing area of interest related to Green Infrastructure is stormwater management. In this arena, the United States Environmental Protection Agency (EPA), states GI is "a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits. While single-purpose gray stormwater infrastructure—conventional piped drainage and water treatment systems—is designed to move urban stormwater away from the built environment, green infrastructure reduces and treats stormwater at its source while delivering environmental, social, and economic benefits."[23] The EPA identifies the following variety of Green Infrastructure projects:

- Downspout Disconnection
- Rainwater Harvesting
- Rain Gardens
- Planter Boxes
- Bioswales
- Permeable Pavements
- Green Streets and Alleys
- Green Parking
- Green Roofs
- Urban Tree Canopy
- Land Conservation

Over the past several years, GI approaches to dealing with urban stormwater concerns has developed an extensive and rapidly expanding literature[24][25]. Increasing development and impervious surface area has increased both the frequency and intensity of stormwater runoff events in urban areas[26]. These runoff episodes are strongly correlated with water resource pollution and over loaded capacity in stormwater

[22] Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., & James, P. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape and urban planning*, *81*(3), 167-178.

[23] What is Green Infrastructure? (2016, September 23). Retrieved from https://www.epa.gov/green-infrastructure/what-green-infrastructure

[24] Rouse, D. C., & Bunster-Ossa, I. F. (2013). *Green infrastructure: a landscape approach* (No. 571).

[25] Miles, B., & Band, L. E. (2015). Green infrastructure stormwater management at the watershed scale: urban variable source area and watershed capacitance. *Hydrological Processes*, *29*(9), 2268-2274.

[26] Mansell, M. G. (2003). *Rural and urban hydrology*. Thomas Telford.

treatment systems[27]. These negative impacts are likely to increase over time as climate change alters existing weather patterns and precipitation levels.

To mitigate against these effects, many municipalities across the state of Oregon have begun to integrate GI approaches into their stormwater management plans. Large metropolitan areas such as Portland, OR have developed extensive tool books to guide Green Instructure development within their respective service areas[28]. Mid-sized Oregon cities, such as Eugene, have also begun to include GI projects into their comprehensive stormwater management plans with detailed design manuals and the predicted effects on stormwater output[29].

Constructed Wetlands

Constructed stormwater wetlands are a particular type of GI project that attempts to mimic the natural environments associated with hydric soils. Much like natural wetlands, these projects treat wastewater loads through a combination of aerobic microbial degradation, anaerobic microbial degradation, vegetation uptake and nitrification. Unlike other allotment or site specific GI approaches, constructed wetlands often perform best at a streetscape, precinct, or regional scale[30]. Constructed wetlands are efficient treatment systems for a variety of stormwater contaminants and have proven to be especially effective at treating or removing stormwater pollutants such as suspended solids, nutrients and toxic agricultural substances[31]. According to the EPA, constructed wetlands can effectively remove approximately 45% of total nitrogen and approximately 60% of total suspended solids from wastewater loads[32]. Constructed wetlands are incredibly flexible in their applicability and have been used successfully to provide treatment to several types of wastewater including agricultural runoff, landfill leachate, industrial waste, and urban stormwater[33].

Additionally, constructed wetlands have been shown to provide wide variety of additional ecosystem services such as carbon sequestration, flood mitigation, wildlife habitat, and cultural amenities[34]. Capitalizing on these attributes, constructed wetlands have increasingly become the centerpieces of larger "stormwater parks."[35] These projects and associated landscapes have often been called upon to perform multiple roles in the urban environment, such as flood water management and wastewater treatment, largely due to the lower cost associated with constructed wetlands technology and the resulting stress reduction on existing stormwater facilities.

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[27] Mallin, M. A., Johnson, V. L., & Ensign, S. H. (2009). Comparative impacts of stormwater runoff on water quality of an urban, a suburban, and a rural stream. *Environmental Monitoring and Assessment*, *159*(1), 475-491.

[28] City of Portland. (n.d.). *Green Street Construction Guide* [Brochure]. Author. Retrieved from https://www.portlandoregon.gov/bes/article/228860

[29] *Stormwater Management Plan* [PDF]. (n.d.). Eugene, Oregon: City of Eugene.

[30] Lloyd, S. D., Wong, T. H., & Chesterfield, C. J. (2002). Water sensitive urban design: a stormwater management perspective.

[31] Tony, H. F. W., CRC Cooperative Research Centre for Catchment Hydrology, & Wong, T. H. F. (1999). *Managing urban stormwater using constructed wetlands*. Cooperative Research Centre for Catchment Hydrology.

[32] THE CASE FOR GREEN INFRASTRUCTURE: JOINT-INDUSTRY WHITE PAPER. (2013, June). Retrieved from https://www.nature.org/about-us/the-case-for-green-infrastructure.pdf

[33] Vymazal, J. (2010). Constructed wetlands for wastewater treatment. *Water*, *2*(3), 530-549.

[34] Moore, T. L., & Hunt, W. F. (2012). Ecosystem service provision by stormwater wetlands and ponds–A means for evaluation?. *Water Research*, *46*(20), 6811-6823.

[35] A Green Sponge for a Water-Resilient City: Qunli Stormwater ParkHaerbin City, Heilongjiang Province, China. (n.d.). Retrieved from https://www.asla.org/2012awards/026.html

Constructed wetlands entail some noteworthy maintenance and upkeep costs which cannot be overlooked. Additionally, due to a reliance on vegetative growth, constructed wetlands and similar systems "may take longer to function as storm-water controls, which may increase the possibility of disparities between the recipients of their costs and benefits."[36] The primary costs associated with constructed wetlands are pumping energy, compliance monitoring, maintenance of access roads and berms, pretreatment maintenance, vegetation harvesting, and equipment replacement and repairs.[37] However, even these costs are often much lower than those associated with traditional "gray" infrastructure, by anywhere from a factor of 2 to 10[38]. In one specific example from Staten Island, New York, the Bluebelt Drainage Basins use purposefully placed wetlands to temporarily store and filter 350,000 gallons of stormwater during storm events. This project drains over 14,000 acres and saves over $80 million in conventional sewer costs[39]. Beyond these direct cost savings, constructed wetlands can also add indirect value to surrounding properties, particularly in a residential setting. A number of constructed wetland projects have "indicated that the value of residential land immediately adjacent to linear open space wetland/lakes, will sell at two to three times the average value received for residential lots within standard sectors of the estate."[40] The increased value of adjacent lots also appears to have a ripple effect on surrounding properties. Studies suggest that "although land values progressively decline with distance from the open space/water elements, there is a substantial added value that accrues to the whole of the estate, rather than only to those lots that line the perimeter of linear open space/wetlands."[41]

Suitability Analysis

Land use suitability analyses are one of the most useful applications for Geographic Information System (GIS) tools. According to Jacek Malczewski, suitability analysis "aims at identifying the most appropriate spatial pattern for future land uses according to specify requirements, preferences, or predictors of some activity."[42] Suitability analysis can be applied at many different scales and locations, but are typically associated with a known spatial boundary in which the analysis is performed. Within this larger area, Malczewski states that "The land suitability analysis problem involves classification of the units of observations according to their suitability for a particular activity. The analysis defines an area in which a good site might exist."[43]When pursuing a suitability analysis, the existing literature makes a distinction between "site selection problems" and "site search problems."[44] Site selection problems are approached by evaluating all relevant land use attributes, such as size or location, and then ranking

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[36] Jaffe, M. (2010). Environmental reviews & case studies: reflections on Green Infrastructure economics. *Environmental Practice*, *12*(4), 357-365.

[37] Vymazal, J. (2010). Constructed wetlands for wastewater treatment. *Water*, *2*(3), 530-549.

[38] Kadlec, R. H., & Wallace, S. (2008). *Treatment wetlands*. CRC press.

[39] Economides, C. (2014). Green Infrastructure: Sustainable Solutions in 11 Cities across the United States. Retrieved from http://water.columbia.edu/files/2014/04/Green_Infrastructure_FINAL.pdf

[40] Tony, H. F. W., CRC Cooperative Research Centre for Catchment Hydrology, & Wong, T. H. F. (1999). *Managing urban stormwater using constructed wetlands*. Cooperative Research Centre for Catchment Hydrology.

[41] Tony, H. F. W., CRC Cooperative Research Centre for Catchment Hydrology, & Wong, T. H. F. (1999). *Managing urban stormwater using constructed wetlands*. Cooperative Research Centre for Catchment Hydrology.

[42] Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview. *Progress in planning*, *62*(1), 3-65.

[43] Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview. *Progress in planning*, *62*(1), 3-65.

[44] Cova, T. J., & Church, R. L. (2000). Exploratory spatial optimization in site search: a neighborhood operator approach. *Computers, Environment and Urban Systems*, *24*(5), 401-419.

evaluated sites based on these characteristics to determine a best possible site. In contrast, site search problems apply to situations in which there is not a pre-determined list of candidate sites and the boundaries of all appropriate sites must be determined. Site search problems must inherently be resolved before more nuanced and detailed site selection problems can be approached. With this in mind, site search analyses give a general idea of suitability for a particular land use, but they also provide additional information such as land shape, connectedness to other suitable landscapes, and aggregations of similar land uses[45]. This approach is consistently recognized as a best management practice when considering water sensitive stormwater management schemes. Specifically, a site analysis will generally include an "audit of regional land-use zoning, climate and landscape characteristics. Important regional land-use zones may include green corridors and conservation areas. Identifying these regional land-use zones provides the opportunity to enhance, protect and/or create links between areas of regional significance."[46] More specific site analysis references can include geology and soils, drainage patterns, climate, significant natural features and existing infrastructure.[47]

GIS analysis procedures, including suitability analyses, also face a number of criticisms. Specifically, it is argued that GIS tools reinforce the idea of the planner as a "rational scientist," rather than a public servant who must address the concerns of elected representatives, local citizens, and marginalized communities[48]. Unintended consequences from technical development analyses and the continuing exclusion of major areas of the public from the planning process has created a sizeable skepticism of the role that GIS approaches should play in land use decisions[49]. Malczewski summarizes this tension by stating "It is argued that the advancement of the high-powered microcomputing hardware and the lowering of the costs of desktop GIS software have popularized GIS but achieved limited success in improving the general public's participation in community-based GIS projects. Participation, in this view, is a political rather than a technological issue."[50] As much as possible, GIS techniques, including suitability analyses, should remain cognizant of the social implications and political impacts inherent in all land use evaluations.

Identifying Appropriate Approaches

Given the wide variety of possible scales and attributes associated with GI projects, an essential characteristic of planning consists of carefully defining what types of projects should be pursued or evaluated. The work of Karen Firehock and her book *Strategic green infrastructure planning: a multi-scale approach*[51] identifies several types of Green Infrastructure patterns and projects. The general methodology presented in Firehock's book is most applicable for relatively large areas such as cities, counties, or ecoregions. In particular, chapter seven of her book, titled *Using Models and Spatial Data to Create Natural Asset Maps*, compiles relevant data and analysis tools for identifying areas with suitable

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[45] Aerts, J. C. J. H. (2002). *Spatial decision support for resource allocation. Integration of optimization, uncertainty analysis and visualization*. UvA.

[46] Lloyd, S. D., Wong, T. H., & Chesterfield, C. J. (2002). Water sensitive urban design: a stormwater management perspective.

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[50] Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview. *Progress in planning*, *62*(1), 3-65

[51] Firehock, K. (2015). *Strategic green infrastructure planning: a multi-scale approach*. Island Press.

Green Infrastructure characteristics. While Firehock's book presents a broad range of Green Infrastructure projects which fall outside the specific boundaries of stormwater management, such as wildlife dispersal routes and habitat connectivity, several data sets dealing with stormwater or water quality are presented. The following table highlights these specific data sets from Firehock's methodology and their corresponding purpose:

Dataset	Purpose
Roads (interstate/primary)	Reference for locations.
Parcel Information	Parcel size and ownership are helpful for evaluating long-term conservation potentials (e.g. are they large enough to manage for habitat or working lands?). For urban areas, knowing where vacant parcels are located can help identify opportunities for restoration and creating new green space.
Land Cover	Shows types of land coverage.
Digital Elevation Models (DEM)	Stitch downloaded 'tiles' together to show elevation. Slopes may be important in thinking about runoff potential or lands that are more or less attractive for others (development, farming, grazing). Can also help with map graphic quality by using 'hillshade.'
Zoning	To evaluate allowed land uses and potential risk or compatibility with priority habitat cores.
Watershed Boundaries and major streams	To manage by watershed and also to determine boundaries for land cover types and potential runoff issues.
Floodplains and Floodway Fringe	To determine areas of risk that may be best left undeveloped for public safety while also providing wildlife corridors. Overlay with forest cover to determine buffer capacity
Wetlands	Provides sensitive landscape and key hydrology

Decentralized Stormwater Utilities & Resilience

Stormwater utilities and their associated infrastructure are often one of the most costly and complex pieces of investment in the urban arena. Throughout the 19th and 20th centuries, urban stormwater and wastewater systems underwent a process of intense monopolization and combined construction methods[52]. Water treatment was increasingly viewed as a job for the public sector, with most treatment

[52] Karvonen, A. (2011). *Politics of urban runoff: nature, technology, and the sustainable city*. MIT Press.

processes occurring at large central facilities. Emphasis was placed on moving unwanted water quickly and efficiently through the urban environment. This was done to maximize the efficiency of large public investments in water treatment facilities, which often needed to remain viable over the course of several decades with increasing levels of population pressure[53]. Additionally, allowing utilities to be managed under a less centralized, site-specific approach often had negative public health impacts due to low levels of regulation on how urban water supplies should be handled[54]

While these policy and engineering choices made significant improvements in terms of reducing disease vectors and improving clean water access to city residents, modern analyses have revealed significant complications associated with centralized "grey" water infrastructure systems[55][56]. The most noteworthy issues are degradations to natural water systems, acute water pollution impacts during high rainfall events, and high capital costs for increasing the capacity of existing treatment systems. Additionally, the lack of redundancy inherent in centralized utility systems drastically increases their risk to outside disturbances, including natural hazards.

In Oregon, natural hazards are increasingly recognized as a crucial element in public utility and land use planning decisions[57]. Using the framework of "urban resilience," more cities are beginning to understand the value of having multiple utility systems in the event of large scale disasters. Redundant systems reduce the risk associated with total utility collapse during disaster events[58], promote less energy intensive and costly water treatment strategies, and reduce many negative environmental externalities associated with modern urban water systems[59]. Despite these advantages, decentralized systems have not become widely adopted in the United States.

Political & Financial Constraints

A major barrier to decentralizing stormwater utilities in the US appears in the form of institutional bureaucracy and pre-existing policies concerning the provision of water treatment. As the paper *Paradoxes of decentralization: Water reform and social implications in Mexico* illustrates, even when policies are adopted which promote decentralization, there may be unintended consequences surrounding water resource contamination or water use efficiency[60]. From a historical perspective, the principal reasons for transitioning towards a centralized provision and treatment model were improving local water quality, reducing parochial conflicts concerning water use, and reducing public health crises associated with wastewater. From a different perspective, Andrew Karvonen's book *The Politics of Urban Runoff* demonstrates the ways in which simplified regulatory mechanisms concerning urban

[53] Karvonen, A. (2011). *Politics of urban runoff: nature, technology, and the sustainable city*. MIT Press.

[54] Howe, C., & Mitchell, C. (Eds.). (2012). *Water sensitive cities*. IWA Publishing.

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[60] Wilder, M., & Lankao, P. R. (2006). Paradoxes of decentralization: Water reform and social implications in Mexico. *World Development*, *34*(11), 1977-1995.

stormwater have been detrimental to sustainable or resilient water systems. Karvonen argues that blanket policies reduce technological innovation, incentivize wasteful water use, and create systems which are not capable of handling peak events associated with natural hazards such as floods[61].

Finally, one form of resistance to decentralized stormwater systems comes from public inertia and expectations surrounding who should supply water services. Private citizens in the US have come to rely almost exclusively on centralized water services over the course of the last century. The paper *Increasing urban water self-sufficiency: New era, new challenges*, identifies fifteen case studies showing the challenges of increasing the role that decentralized water systems should play in the urban landscape[62]. In particular, the authors note that the subsidized nature of urban water resources has undermined the concept of stormwater treatment as an expensive resource to provide. Public expectations have drifted towards the idea that stormwater services are cheap, limitless, and require low levels of maintenance. The authors note that decentralizing water systems will inherently raise the energy and financial costs associated with water treatment in certain situations. Looking forward, increasing stormwater utility resilience will necessarily involve some increase in cost. This point is especially relevant when considering that portions of a successful decentralized stormwater network will likely involve dealing with much more expensive and complicated private citizens[63]. It must be noted however, that many distributed water utilities, particularly stormwater treatment, have much lower levels of associated capital cost[64]. Additionally, they recover from natural hazard impacts more quickly than traditional systems and typically result in less overall financial damage[65].

[61] Karvonen, A. (2011). *Politics of urban runoff: nature, technology, and the sustainable city*. MIT Press.

[62] Rygaard, M., Binning, P. J., & Albrechtsen, H. J. (2011). Increasing urban water self-sufficiency: New era, new challenges. *Journal of Environmental Management*, *92*(1), 185-194.

[63] Schäffler, A., & Swilling, M. (2013). Valuing green infrastructure in an urban environment under pressure—The Johannesburg case. *Ecological Economics*, *86*, 246-257.

[64] Foster, J., Lowe, A., & Winkelman, S. (2011). The value of green infrastructure for urban climate adaptation. *Center for Clean Air Policy*, *750*.

[65] Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning*, *100*(4), 341-343.

Methodology

This report will focus on two major investigation methods:

- A quantitative, GIS based analysis for evaluating the suitability of constructed wetlands projects across Oregon.
- Case study reports of successful constructed wetlands based on a range of land use characteristics and project objectives.

GIS Analysis

To ensure this analysis framework or "tool" is useful for the widest range of possible interest groups, a focus has been placed on the following parameters:

- *Utilization of open source data files and programming language.* Python[66] is a freely available programming language widely used in GIS analysis approaches. Additionally, all original data files have been sourced from the State of Oregon's *Geospatial Data Clearinghouse*[67] and the *Multi-Resolution Land Characteristics Consortium*. Both sources maintain publicly accessible websites providing geospatial data files for any interested parties. The following data files were specifically chosen for the suitability analysis:
    - **Oregon Digital Elevation Model (DEM) - 10 Meter Resolution**[68]
    - **Oregon Statewide Flood Hazard Database - FEMA Flood Insurance Studies**[69]
    - **Oregon National Land Cover Database- Percent Developed Imperviousness 2011**[70]
    - **Oregon Urban Growth Boundaries - 2015**[71]
    - **Oregon Soil Survey Geographic Database (SSURGO) from State Soil Geographic Database (STATSGO) Soils Compilation**[72]
    - **Oregon Rivers- River Reach**[73]
    - **Oregon Transportation Network - 2015**[74]
    - **Oregon Mapped Wetlands and Hydric Soils**[75]

A final data file, "Lane County Tax Lot Information," was included to narrow the suitability results into a meaningful framework and provide a final level of analysis. This final data set is critically important for

[66] Welcome to Python.org. (n.d.). Retrieved from https://www.python.org/

[67] Oregon Geospatial Enterprise Office. (n.d.). Retrieved from http://www.oregon.gov/geo/Pages/sdlibrary.aspx

[68] (n.d.). Retrieved from http://spatialdata.oregonexplorer.info/geoportal/details;id=387c8e50d4174c5689c0e8a313d87fb2

[69] (n.d.). Retrieved from http://spatialdata.oregonexplorer.info/geoportal/details;id=f2cc36de1f0a42d29b8dfdd71721a7d3

[70] National Land Cover Database- Percent Developed Imperviousness 2011. (n.d.). Retrieved from http://www.landfire.gov/bulk/downloadfile.php?TYPE=nlcd2011&FNAME=nlcd_2011_impervious_2011_edition_2014_10_10.zip

[71] (n.d.). Retrieved from http://spatialdata.oregonexplorer.info/geoportal/details;id=394740b8fffc44a78b3747ca03acb34a

[72] (n.d.). Retrieved from http://spatialdata.oregonexplorer.info/geoportal/details;id=6dcf40d86b894d69bdd1edec941c4d72

[73] (n.d.). Retrieved from http://spatialdata.oregonexplorer.info/geoportal/details;id=161b8e74e7ef457180fba6429c9ee1ee

[74] (n.d.). Retrieved from http://spatialdata.oregonexplorer.info/geoportal/details;id=a3f15e64538a43ad9fea7f14dce4075b

[75] (n.d.). Retrieved from http://spatialdata.oregonexplorer.info/geoportal/details;id=3a36a0db86d141f196940d903e440e2d

relevant results, but must generally be included by parties performing future analysis as tax lot data is typically held by municipalities or county institutions as proprietary information.

This tool and its base code is intended to provide a first-order approach to identifying suitable constructed wetland sites and thus is not intended as a final site analysis or specific project suitability determination. Certain developments will have notably different site requirements than others, depending on treatment goals and local conditions. As with all tools, the code applied in this report will function best when changes are applied by local practitioners looking to evaluate specific projects based on requirements such as maximum size, budgetary restrictions, land ownership patterns, or water treatment thresholds.

Defining Constructed Wetland Suitability

The following section outlines the parameters utilized in determining geographic areas that are suitable for constructed wetlands projects. These parameters were taken from a compilation of professional and municipal guidance documents, with specific emphasis on the following:

- *New Jersey Stormwater Best Management Practices Manual: Standard for Constructed Stormwater Wetlands*[76]
- *Minnesota Stormwater Manual: Design criteria for stormwater wetlands*[77]
- *Eugene Stormwater Manual: Constructed Treatment Wetland*[78]

The following list of constraints were pulled from the previous management documents and best practice manuals. They span a range of geologic restrictions, hydrologic restrictions, financial restrictions, and legal restrictions. Each represents a specific attribute unique to constructed wetland projects:

- **Located on slopes no greater than 20%**
- **Located in areas with less than 49% impervious surface cover**
- **Located outside FEMA designated Special Flood Hazard Areas**
- **Located outside mapped and designated wetlands**
- **Located on Natural Resource Conservation Service Class 'C' or 'D' soils**
- **Located on lots at least one acre in size**
- **Located on vacant parcels or areas with low improvement values**
- **Located 75 feet from major waterways**
- **Located 5 feet from property line boundaries**

The following table is a breakdown of spatial analysis performed on datasets as they relate to constructed wetland suitability. Each section is categorized based on the analyzed dataset, the specific

[76] New Jersey Stormwater Best Management Practices Manual: Standard for Constructed Stormwater Wetlands. (2004, February). Retrieved from http://www.njstormwater.org/bmp_manual/NJ_SWBMP_9.2%20print.pdf
[77] Minnesota Stormwater Manual: Design criteria for stormwater wetlands. (2016, January). Retrieved from https://stormwater.pca.state.mn.us/index.php/Design_criteria_for_stormwater_wetlands
[78] Eugene Stormwater Manual: Constructed Treatment Wetland. (2008). Retrieved from https://www.eugene-or.gov/DocumentCenter/View/4560

analysis performed, and the associated justification based on existing scholarly and professional literature.

Dataset	Analysis	Justification
Oregon Digital Elevation Model (DEM)	A slope analysis was performed on the original raster file, with results broken into five categories of slope percentage. These results were converted to vector format for further analysis across data types. Finally, an attribute selection analysis was performed on the slope vector data and all slopes exceeding 20% were excluded from further analysis.	Slope degree is a critical component of properly sited constructed wetland projects. Sites with large slope degrees are likely unsuitable for projects due to concerns of erosion, landslide effects, and poor water storage rates. Existing literature and design manuals state that constructed wetland projects should be placed on sites with no greater than 20% slope. Additionally, constructed wetlands should be located at least 100 feet from surrounding areas exceeding 10% slope.
Oregon National Land Cover Database- Percent Developed Imperviousness	The original raster was converted to vector format for further analysis across data types. Finally, an attribute selection analysis was performed on the land cover vector data and all areas exceeding 49% impervious surface cover were excluded from further analysis.	Impervious surface cover is a defining characteristic of constructed wetlands and water quality impacts. The NLCD's impervious surface database estimates impervious on a 100 point scale from 0 (completely pervious) to 100 (completely impervious). Impervious surface covers greater than 10% can begin to have negative impacts on water quality and surface runoff. However, authors have found that GI practices can have positive effects on streams where catchment areas hold 50% impervious surface cover[79]. Additionally, areas with high impervious surface cover often make constructed wetlands projects unfeasible due to higher financial costs associated with remediation and removal of existing impervious area.
Oregon Statewide Flood Hazard Database	An attribute selection analysis was performed on the original dataset to remove all sites within Federal Emergency Management Agency (FEMA) designated Special Flood Hazard Areas. Special Flood Hazard Areas are defined as those areas	It is considered a best practice among planning professionals to avoid soils with wetland characteristics and those with a high probability of future flooding[81]. While one of the major benefits of constructed wetlands is the ability to mitigate flooding impacts, these projects can be easily damaged in flood prone sites.

[79] Walsh, C. J., Fletcher, T. D., & Ladson, A. R. (2005). Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. *Journal of the North American Benthological Society*, *24*(3), 690-705.

[81] Young, R. F. (2011). Planting the living city: Best practices in planning green infrastructure—Results from major us cities. *Journal of the American Planning Association*, *77*(4), 368-381.

	that will be inundated by the flood event having a 1% chance of being equaled or exceeded in any given year. The 1% annual chance flood is also referred to as the base flood or 100-year flood[80].	
Oregon Soil Survey Geographic Database	An attribute selection analysis was performed on the original dataset to remove all feature classes not identified as either Class 'C' or 'D' soils identified by the Natural Resources Conservation Service.	Class 'C' and 'D' hydric soil groups are identified as the most suitable areas for constructed wetland projects due to their lower overall infiltration rates. Class 'A' or 'B' soils, which typically have higher infiltration rates, can still remain useful as constructed wetland sites with appropriate design treatments[82]. However, the additional cost associated with liners or other project additions in well drained areas was deemed a financial barrier significant enough to warrant exclusion.
Oregon Rivers- River Reach	A buffer analysis was performed on the original dataset to remove all parcels less than 75 feet from an existing waterway.	Oregon's Goal 5 statewide land use policy identifies riparian buffers as the following: "significant riparian corridor area setback is 75 feet from the top of bank of a waterway with a stream flow greater than 1,000 cubic feet per second (the Willamette and McKenzie Rivers), and 50 feet for other fish-bearing streams.[83]. To ensure a conservative assessment of suitable land, the statewide riparian buffer was applied at 75 feet for all waterways.
Oregon Mapped Wetlands and Hydric Soils	An attribute selection and erase analysis was performed on the original dataset to remove all feature classes identified as existing mapped wetlands.	Existing literature finds that close proximity to natural wetlands should be avoided due to the fact that constructed wetlands typically do not have the same full range of ecological functions, as they are designed primarily for pollutant removal and erosion and flood control. Furthermore, Oregon's Goal 5 statewide land use policy requires that any and all changes to existing wetlands must be approved under the Oregon Removal-Fill Law (ORS 196.795-990)[84].

[80] Flood Zones. (n.d.). Retrieved from https://www.fema.gov/flood-zones

[82] Davis, A. P. (2005). Green engineering principles promote low-impact development.

[83] *Lane County Statewide Planning Goal 5 Compliance for Wetland, Riparian Corridor, and Wildlife Habitat* [PDF]. (n.d.). Lane Council of Governments.

[84] Waterways & Wetlands Planning. (n.d.). Retrieved from http://www.oregon.gov/dsl/WW/Pages/WetlandConservation.aspx

Lane County Taxlots	A selection analysis was performed on the original dataset to remove all parcels not identified as “Vacant” or having an improvement value of greater than $1,000.	Due to the relatively high land requirements of constructed wetland projects and the cost of purchasing developed properties, vacant lands were identified as priority areas. Additionally, improvement values less than $1,000 were chosen as an acceptable threshold for which constructed wetlands projects could still potentially be pursued on developed properties due the generally low cost.
Lane County Taxlots	A selection analysis was performed on the original dataset to remove all parcels smaller than one acre in size.	Design manuals identify drainage areas of at least 25 acres as highly recommended to supply appropriate water levels for constructed wetland projects. Additionally, the treatment space required for the wetlands themselves should be at least 2% to 4% of tributary drainage area. To provide a conservative estimate of potential project sites, a 4% treatment area calculation was applied the recommended 25 acre drainage area.
Lane County Taxlots	A buffer analysis was performed on geographically suitable taxlots to remove 5 feet of land area from parcel boundaries.	Design manuals from Oregon identify appropriate property line setbacks from the top of the constructed wetland banks as 5 feet. Projects may be located along property lines, but easements would likely be required for non-buildable areas.

Automation Code

See Appendix*

Case Studies

Two case studies were selected based on spatial information collected through the automated suitability analysis performed in Cottage Grove, Oregon. Cottage Grove was chosen as a model community of users who may seek to perform an automated constructed wetlands suitability analysis for the following attributes:

- A relatively small planning and public works staff
    - One full time planning employee[85]

[85] Cottage Grove Planning. (n.d.). Retrieved from http://www.cottagegrove.org/cd/page/planning

- Nine full time public works employees, with two dedicated to stormwater or wastewater services[86]
- A moderate capital outlay projects budget
  - Occupying 27.27% of all budget expenses ($2,254,520) in 2017-2018[87]
- Notable population growth over the next several years[88]
  - 0.51% population growth in Cottage Grove from 2014-2016
  - 1.95% population growth in Lane County from 2014-2016
- As stated in the Stormwater Management Plan[89], pressure to increase levels of stormwater and wastewater service throughout the community
- As stated in the Stormwater Management Plan[90], commitments to reduce water quality impacts and increase levels of natural and open space.

These characteristics illustrate a community who may be willing to pursue constructed wetland projects for both financial and environmental reasons, and would also benefit from the speed and ease of utilizing an automated suitability analysis tool. While not limited to use by smaller municipalities, this area was chosen to provide a demonstrable test of the tool by those most likely to benefit from its methodology. This tool can allow these smaller areas to quickly and economically evaluate the initial possibility of constructed wetland projects in their community to address water quality commitments, repetitive stormwater flooding impacts, or to provide an increase in high functioning natural areas for local residents.

To achieve a greater level of detail, two individual tax lots identified as suitable within the city were selected and case studies which closely matched their unique geographic and land use characteristics were sought. These case studies evaluate two constructed wetland projects based on zoning designations and desired project results. The case studies are not intended as prescriptive directions for what might occur on particular Cottage Grove tax lots or elsewhere, but rather as possibilities for planning practitioners to consider when utilizing the analysis tool results. Additionally, they are intended to help determine the costs and benefits of pursuing constructed wetland projects within the local community.

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[86] Public Works. (n.d.). Retrieved from http://www.cottagegrove.org/publicworks

[87] Cottage Grove-: 2017-2018 Budget. (n.d.). Retrieved from http://www.cottagegrove.org/sites/default/files/fileattachments/finance/page/3471/approved_budget_summaries.pdf

[88] Population Estimates and Reports. (n.d.). Retrieved from https://www.pdx.edu/prc/population-reports-estimates

[89] Cottage Grove- Stormwater Management Plan. (2011). Retrieved from http://www.cottagegrove.org/sites/default/files/fileattachments/community_development/page/418/stormwater_management_plan_2011.pdf

[90] Cottage Grove- Stormwater Management Plan. (2011). Retrieved from http://www.cottagegrove.org/sites/default/files/fileattachments/community_development/page/418/stormwater_management_plan_2011.pdf

Automated Analysis Results

The automated analysis tool has been applied to Cottage Grove, a smaller sized community in Lane County, Oregon. Two additional smaller sized communities in Lane County, Coburg and Veneta, were mapped using the tool to illustrate results across a range of geographic areas. These areas are included in the appendix section of this report.

Cottage Grove

According to the American Community Survey[91], the population of Cottage Grove as of 2015 was 9,819 persons. The median household income was $37,058. Within Cottage Grove's Urban Growth Boundary (UGB), there are 4,636 individual tax lots totaling approximately 4,017 acres.

The results of the constructed wetland suitability analysis show the following:

- **26 lots suitable for constructed wetland projects**
- **Approximately 436 acres of suitable land available**
- **The average size of suitable lots is approximately 17 acres**
- **The largest suitable property is approximately 142 acres and the smallest is approximately 1.2 acres**
- **Zoning characteristics vary considerably, with the majority of suitable acreage (56.2%) currently being zoned as forest and agricultural areas**
- **Five suitable lots are currently owned by the City of Cottage Grove, totaling 62.2 acres**

Values were determined for all tax lots identified as suitable for constructed wetlands by two methods: the Lane County assessor's data as well as the real estate assessment website *Zillow*[92] to determine current market rate values where available. Both of these variable rates were chosen due to the high degree of discrepancy between market property valuations and county tax assessor valuations in Oregon. Having an accurate assessment of property value, whether real market or otherwise, is a crucial piece of data for tool users determining the viability of pursuing projects on a particular property. Without knowing the capital expenses associated with potential land acquisitions, easement purchases, or lost property tax revenue, it is difficult to accurately forecast costs and benefits from any particular constructed wetland project.

Address	Size (Acres)	County Assessed Value	Current Market Value
400 E MAIN ST	47.9	$710,596	N/A
2480 PIONEER PIKE	1.3	$44,672	N/A
PO BOX 1232	1.2	$274	N/A
PO BOX 547	3.3	$51,924	N/A
400 E MAIN ST	3.1	$190,321	N/A
1025 N 19TH ST	2.9	$227,733	$1,148,601

[91] U.S. Census Bureau, 2011-2015 American Community Survey 5-Year Estimates

[92] Zillow, I. (n.d.). Cottage Grove Real Estate - Cottage Grove OR Homes For Sale. Retrieved from https://www.zillow.com/homes/for_sale/Cottage-Grove-OR_rb/?fromHomePage=true&shouldFireSellPageImplicitClaimGA=false&fromHomePageTab=buy

PO BOX 51330	38.2	$112,752	N/A
PO BOX 51330	29.8	$113,766	N/A
PO BOX 65	2.6	$47,727	N/A
400 E MAIN ST	3.6	$41,362	N/A
PO BOX 10545	142.8	$2,191,287	N/A
PO BOX 10545	9.4	$230,000	N/A
31701 RUDOLPH RD	97.0	$22,554	$295,153
375 N Q ST	2.1	$45,118	$550,669
375 N Q ST	3.0	$49,580	$550,669 (*owned with above property)
375 N Q ST	1.5	$41,449	$550,669 (*owned with above property)
400 E MAIN ST	3.0	$114,765	N/A
400 E MAIN ST	4.6	$154,966	N/A
1104 S 2ND ST	16.6	$194,424	N/A
2205 LASATER BLVD	2.6	$30,271	N/A
PO BOX 1611	1.9	$36,830	N/A
707 SHIELDS LN	2.7	$29,964	$205,940
PO BOX 165	3.8	$11,052	N/A
36205 CAMP CREEK RD	3.8	$46,806	N/A
3318 W CECIL CRT	2.0	$42,603	N/A
PO BOX 10666	5.7	$89,040	N/A

Comprehensive Plan

To provide additional legal and planning background information to those areas identified as being suitable for constructed wetland projects, the Cottage Grove Comprehensive Plan was evaluated to determine what uses have been proposed for these areas and how these may or may not conflict with wetland projects. The most recent comprehensive plan[93] (revised, 2012), identifies the following zoning and land use objectives for the areas which have been identified as suitable for constructed wetland projects:

- 14 suitable properties, containing 105.8 acres, are currently zoned as residential classifications, with a majority being identified for low density residential uses.
- 3 suitable properties, containing 24 acres, are currently zoned as industrial classifications, with these uses expected to continue.
- 2 suitable properties, containing 51.5 acres, are currently owned by the city as park and open space resources.

Additionally, the comprehensive plan outlines the several land use and development criteria which may have an effect on the results of the constructed wetland suitability analysis. Each of the following statements are city identified “objectives” and “recommendations” outlined in Cottage Grove’s

[93] Cottage Grove Comprehensive Land Use Plan. (2012). Retrieved from http://www.cottagegrove.org/sites/default/files/fileattachments/community_development/page/393/dm_cg_comprehesive20plan20updated201-17-12.pdf

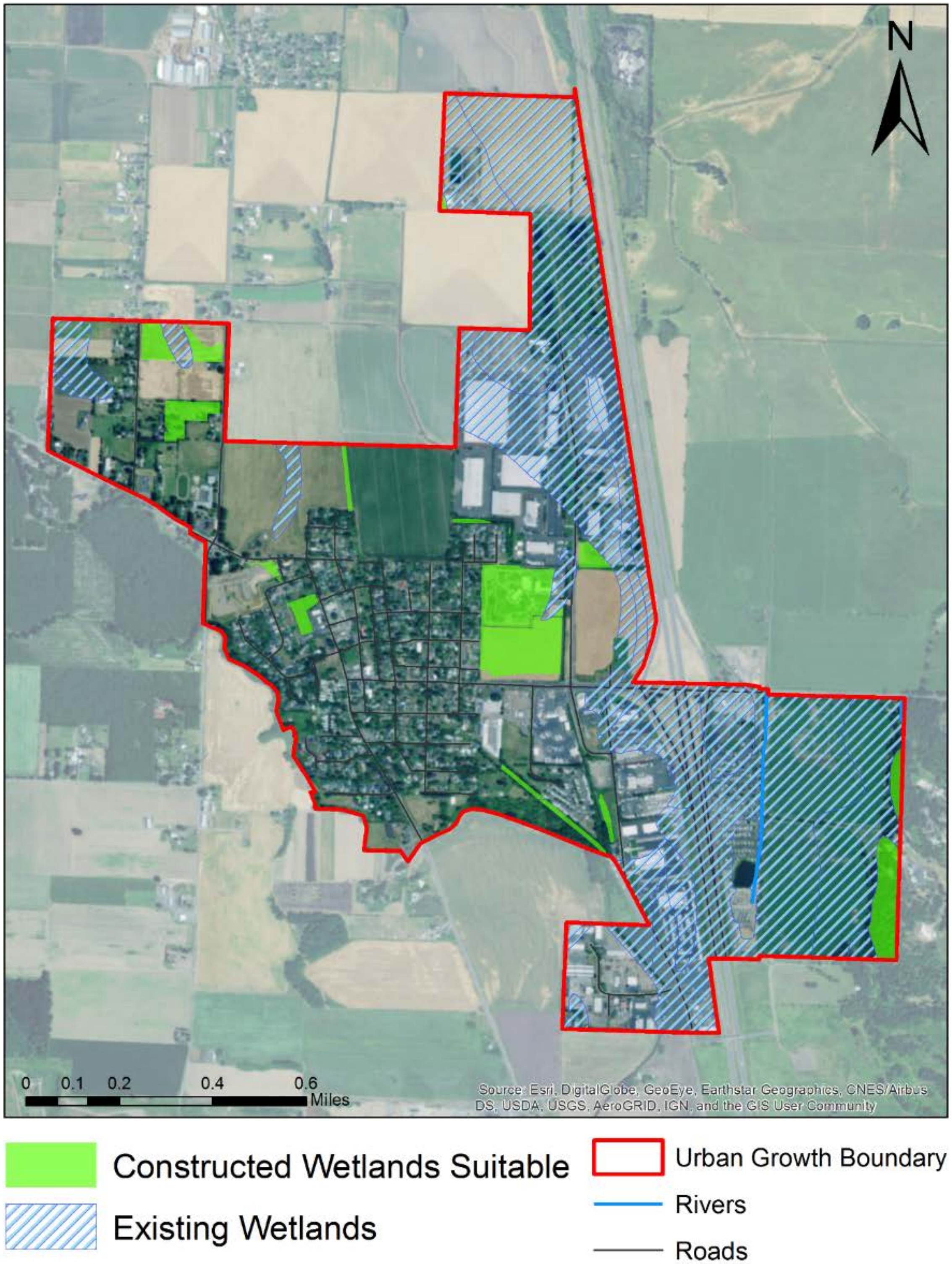
comprehensive plan which would have some effect, both positive and negative, on attempts to pursue constructed wetlands projects within the Urban Growth Boundary. The statements are pulled from the following sections in Cottage Grove's comprehensive plan:

- Public Facilities and Services
- Parks, Recreation, and Open Space
- Urban Design
- Hillside Development
- Air and Water Resources
- Fish and Wildlife Resources

These recommendations range from largely conducive ("Consider a system of river oriented and hill-top parks and open space with interconnected trails linked to residential areas of the community"), moderately conducive ("Money must be allocated for storm and sewer separation work in a Community Block Grant Development proposal for the Northwest Community Neighborhood."), and moderately prohibitive ("Including policies in the new Land Division Ordinance to encourage development of vacant or oversized lots to reduce urban expansion."):

- "The water and sewer distribution centers must be expanded and extended to keep pace with anticipated growth. Currently, developed areas which are contiguous with the city are polluting their own neighborhoods and the city as a whole due to over-development without public sewerage systems." (pg. 22)
- "Money must be allocated for storm and sewer separation work in a Community Block Grant Development proposal for the Northwest Community Neighborhood." (pg. 22)
- "Consider a system of river oriented and hill-top parks and open space with interconnected trails linked to residential areas of the community." (pg. 26)
- "Parks should be acquired and developed on a portion of Mount David and in an area bounded by Sweet Lane, South River Road, West Harrison, and the proposed west side bypass." (pg. 27)
- "Including policies in the new Land Division Ordinance to encourage development of vacant or oversized lots to reduce urban expansion." (pg. 28)
- "To preserve and enhance the beauty of the landscape by encouraging the maximum retention of natural topographic features, such as drainage swales, streams, slopes, ridge lines, rock outcroppings, vistas, natural plant formations and major tree belts." (pg. 32)
- "The concentration of dwellings and other structures by clustering should be encouraged to help save larger areas of open space and preserve the natural terrain." (pg. 32)
- "Encourage development practices which minimize runoff and contribute to groundwater recharge." (pg. 37)
- "The city shall use the proposed site design review ordinance to preserve those natural features and vegetation which tend to mitigate temperature changes, absorbs pollution, and retards runoff." (pg. 37)
- "The city shall protect fish and wildlife resources along the Coast Fork of the Willamette from conflicting uses through the provisions of the Greenway Conditional Use procedures." (pg. 39)
- "Identify areas for possible public acquisition and scenic and use easements." (pg. 40)

Suitability Map



Implications

The following section further evaluates a sample analysis from Cottage Grove to illustrate how this tool and the resulting data generated can be effectively utilized by planning practitioners or public works employees.

Cottage Grove Results

Looking at the combined suitability results a few major takeaways can be gathered:

1) Based on geographic characteristics, it appears that Cottage Grove has a noteworthy amount of vacant land which could potentially be utilized for constructed wetlands projects. A majority of this land is located in the northwest portion of the community along the Coast Fork of the Willamette River.
2) A significant proportion (11.8%) of the constructed wetland suitable land in the community is owned by the City of Cottage Grove as maintained Parks and Open Space.
3) A significant proportion (24.4%) of the constructed wetland suitable land in the community is identified as low density or medium density residential property within the Cottage Grove Comprehensive Plan.
4) A much smaller proportion (5.5%) of the constructed wetland suitable land in the community is identified as industrial property within the Cottage Grove Comprehensive Plan. The three suitable industrial sites are contiguous with one another and are located next to a large developed industrial property.
5) The Cottage Grove Comprehensive Plan is largely conducive to constructed wetlands projects in the analysis area. The plan's objectives and recommendations highlight a number of land use and development guidelines which illustrate how and where constructed wetland projects might be pursued:
    a. *Cluster zoning of residential properties*
        i. Prioritizes undeveloped or vacant land footprints which may be directed towards constructed wetland projects
    b. *Stormwater and sewer separation for the neighborhoods in the Northwest portion of the* city
        i. This area of the city holds a significant portion of the suitable land area for constructed wetland properties. Additionally, providing separated sewer and stormwater service to outlying areas of the city will likely prove expensive, and constructed wetlands could potentially reduce the cost of this endeavor while providing similar levels of service.
    c. *Acquiring areas for public use and scenic enjoyment*
        i. Constructed wetland projects often serve dual purposes, one of which is increasing levels of public park and open natural space
    d. *Urgent need to expand sewer and stormwater systems to keep pace with expected population growth*

i. Increasing conventional infrastructure service, including sewer and stormwater systems, generally involves very high levels of capital and maintenance costs, which may unduly burden small and mid-sized communities with limited budgets. Constructed wetland projects can provide these services, with significant reductions in cost.

e. *Site design review ordinance to reduce runoff, mitigation water temperature changes (particularly for the Coast Fork), and absorb water pollution*

    i. Constructed wetland projects are especially effective at storing stormwater runoff in high rainfall episodes and slowly releasing the excess over time. Additionally, the vegetative component provides excellent nutrient and sediment removal from stormwater, increasing the overall water quality of nearby aquatic resources.

f. *Encouragement of development practices which minimize runoff and contribute to groundwater recharge*

    i. Constructed wetland projects can help minimize stormwater runoff and contribute to groundwater recharge. Additionally, they can provide an increase in water treatment which may not be realized through more traditional runoff mitigation practices such as simple retention ponds[94].

Cottage Grove Case Studies

The following section further evaluates two specific sites from the Cottage Grove automated results. Each of these sites has been paired with an existing constructed wetland project case study based on similar location characteristics. These case studies are intended to provide a snapshot of how this tool can be elaborated on and utilized by planning or public works department employees.

Site One

Cottage Grove Site One: Tax Lot # 2003272000200

The following case study site has been chosen based on several land use characteristics which have made it particularly suitable for further evaluation. Specifically, the parcel is publicly owned, it is located in close proximity to the city's wastewater treatment facility, and it is part of a continuous undeveloped park and recreation resource space. These characteristics make it particularly appropriate for larger scale constructed wetland projects and natural wastewater treatment programs.

As a summary, the site has the following features:

- 47.9 acres
- Zoned for parks and open space uses
- Owned by the City of Cottage Grove
- Located in extreme Northeast portion of Urban Growth Boundary

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[94] CONSTRUCTED WETLANDS VS. RETENTION POND BMPS: MESOCOSM STUDIES FOR IMPROVED POLLUTANT MANAGEMENT IN URBAN STORMWATER TREATMENT. (2008, August 13). Retrieved from https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=81366

- Adjacent to the city's wastewater treatment plant
- Adjacent to the other large, city owned park and open space
- Adjacent to the Coast Fork Willamette River- 100 Year Flood Hazard Area
- Total county assessed value- $710,596

Existing Conditions Map

Site One Case Study: Fernhill South Wetlands, Forest Grove, Oregon[95][96]

Forest Grove is a mid-sized city located in Washington County, Oregon just west of the Portland metropolitan area. As of 2015[97], the city had a population of 22,823 persons with a total land area of 3,756 acres. The median household income was approximately $48,411. In 2012, the City of Forest Grove[98], the Fernhill Wetlands Council, and the regional water resources management utility, Clean Water Services (CWS)[99], began a partnership to convert publicly owned land into a combination natural wastewater treatment system, recreation resource, and wildlife habitat area. This project is explicitly intended to "improve water quality by removing nutrients, cooling, and naturalizing the water after conventional treatment."[100] Specifically, the project is intended to help achieve water quality commitment goals in the nearby Tualatin River.

The project was broken into yearly phases from 2012-2017. Each of these phases dealt with major physical features in the project area, including an upper wetlands component, a lower wetlands component, and visitor access facilities. The first phase began by decommissioning three sewage treatment lagoons occupying approximately 90 acres of land owned by CWS. Subsequent phases saw these lagoons engineered to precise contours designed to encourage the growth of wetland plants. Overall, approximately 750,000 native plants and 3.5 billion seeds were planted throughout the project area for the purposes of wildlife habitat and water treatment. As the project reaches completion, the facility will treat approximately 5-18 million gallons of water per day throughout the year. Additionally, numerous visitor recreation trails and education opportunities have been added including a water garden, the Dabbler's Marsh trail, a 1.1 mile loop trail, and a picnic shelter. These publicly-accessible areas are managed through a partnership with the City of Forest Grove Parks Department and the Fernhill Wetlands Council. Additionally, the site has become an educational resource, providing an outdoor classroom area for local students. In 2014-2015, middle school students from nearby Forest Grove Community School conducted a biological inventory to assess what effect the project had on wildlife resources in the area[101]. Finally, the site has become an economic attraction, hosting numerous benefit festivals and public events including the Portland Audubon Society's *Fernhill Birds and Brew Festival*[102].

The total project cost is estimated at approximately $18 million and is estimated to local save ratepayers about $13 million versus the cost of upgrading the existing conventional treatment facility.

95 Fernhill Wetlands: Clean Water Naturally. (n.d.). Retrieved from http://www.fernhillnts.org/

96 Studios, I. M. (n.d.). Connect with Biohabitats. Retrieved from http://www.biohabitats.com/projects/fernhill-south-wetlands-natural-treatment-system/

97 ACS 2015 (5-Year Estimates)(SE), ACS 2015 (5-Year Estimates), Social Explorer; U.S. Census Bureau

98 Home Page. (n.d.). Retrieved from http://www.forestgrove-or.gov/

99 OUR BUSINESS IS CLEAN WATER. (n.d.). Retrieved from https://www.cleanwaterservices.org/

100 (n.d.). Retrieved from http://www.fernhillnts.org/about.aspx

101 Fuller, K. (n.d.). Middle-schoolers conduct scientific 'critter count' Retrieved from http://www.pamplinmedia.com/fgnt/36-news/261776-133327-middle-schoolers-conduct-scientific-critter-count

102 Fernhill Birds and Brew Festival. (n.d.). Retrieved from http://audubonportland.org/about/events/fernhill-festival

Fernhill Wetland Pictures[103]

[103] WATER TREATMENT. (n.d.). Retrieved from http://www.fernhillnts.org/watertreatment.aspx


Neil Armstrong
Middle School
Fern Hill
Elementary School
Heather St
Maple St
Maple St
Tualatin Valley Hwy
47
SW Fern Hill Rd
SW Fern Hill Rd
Sewage Lagoon
SW Fern Hill Rd
Pruitt's Farm
Fern Hill Rd

Site Two

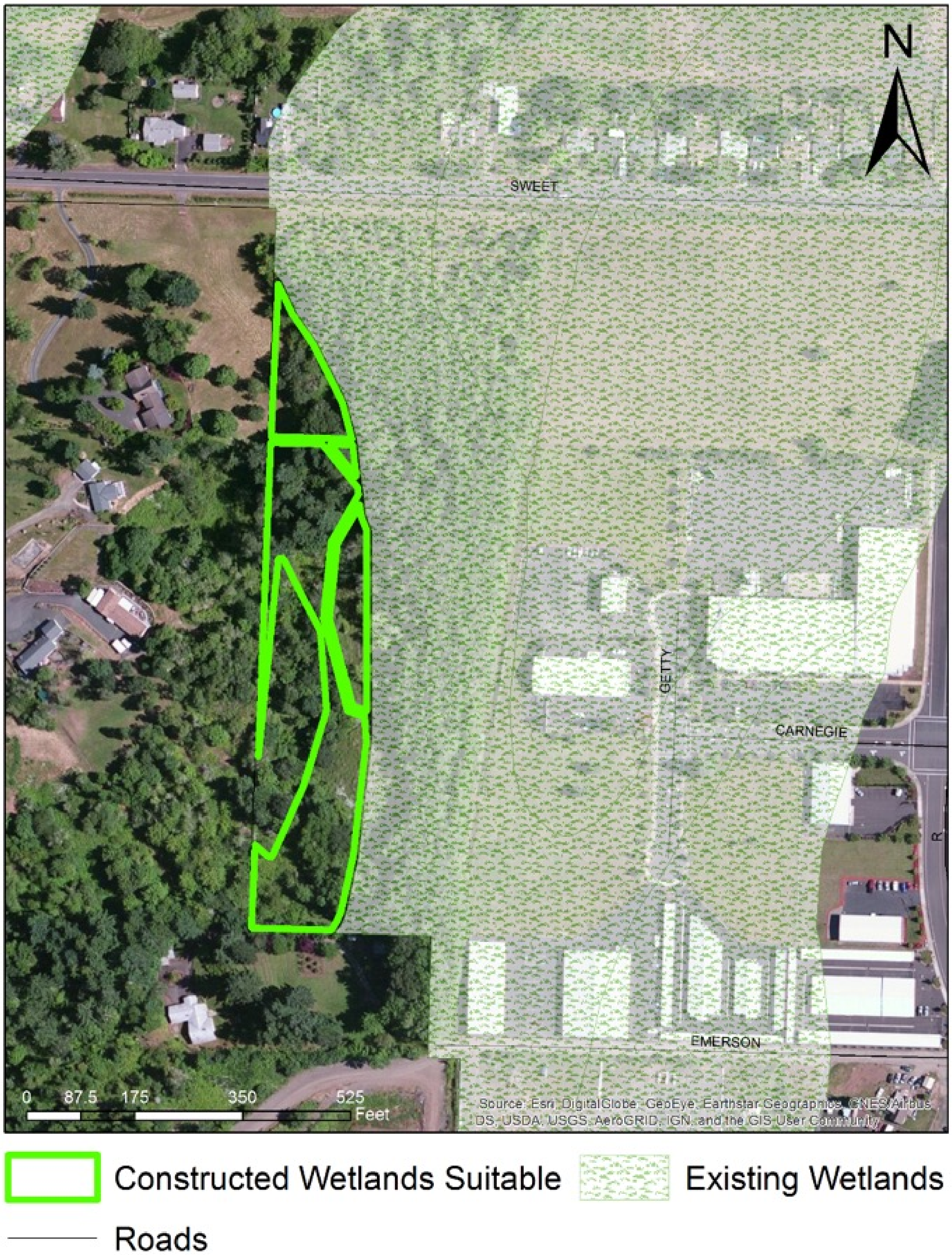
Cottage Grove Site Two: Tax Lot # 2003324301100, 2003324301200, 2003324301300

The following case study sites have been chosen based on several land use characteristics which have made them particularly suitable for further evaluation. Specifically, the parcels are partially publicly owned, they are located in close proximity to a large industrial area expected to see significant growth in the coming years, and they are located in close proximity to a large area mapped as wetland resources or hydric soils by the state of Oregon. These characteristics make it particularly appropriate for larger scale constructed wetland projects and stormwater storage programs.

As a summary, the site has the following features:

- 24.1 combined acres
- Zoned for industrial uses
- 7.6 acres, owned by the City of Cottage Grove, 16.6 acres owned by the Carolyn L. Workman Revocable Living Trust
- Located in extreme Southwest portion of Urban Growth Boundary
- Adjacent to a large area identified for industrial uses in the city's comprehensive plan
- Adjacent to a large identified natural wetland area
- Total county assessed value for all lots- $464,155

Existing Conditions Map



Site Two Case Study: Royal Park Stormwater Harvesting Project, Melbourne, Australia[104]

Melbourne is a large city located in south eastern state of Victory, Australia. As of 2016[105], the city had a population of 136,336 persons with a total municipal land area of 9,315 acres. In 1998, a design for an urban stormwater park was created following up on earlier ideas developed within the Royal Park Master Plan. The final wetlands project was completed in 2006 as part of Melbourne's larger "'City as a Catchment' plan which aims establish resilient water management solutions which buffer against the effects of drought and population growth, whilst simultaneously reducing the impact of stormwater on receiving waterways and improving the ecological health of the site."[106]

The park itself is located close to the city's central business district and a large urban development area. It is approximately 420 acres. The constructed wetland portion of the project is intended to capture water from a 462 acre catchment area and is primarily directed from the city's existing stormwater drainage network. The wetland itself is roughly two acres in size. Water is managed to allow only low volume flows at any given time into the treatment system. All treated water is then captured in a 12 million liter storage basin, before ultimately being allowed to flow into a local waterway known as Moonee Ponds Creek. Additionally, a five million liter storage tank holds additional treated stormwater flow for use in irrigating surrounding park lands, sporting fields, and a nearby golf course. Additional hookups are provided from the secondary storage tank to allow access by water trucks in irrigating streetscape vegetation.

The environmental and economic benefits of this project have proven significant. More than 80% of the total irrigation demand from the park is supplied by the wetland resources. Additionally, sedimentation and stormwater runoff rates into nearby Port Phillip Bay have been dramatically reduced. A majority of the project is supplied through gravity fed means which contributes to very low water rates of less than $2.00/kL for irrigation purposes. Additionally, the park and the wetland itself has seen large scale support from community members. The wetland serves as an outdoor classroom environment with signage to educate school groups visiting the site to learn about the fauna, flora, water treatment and cultural elements of the project area.

The total cost of this project was approximately $8,020,000 (U.S.) spread across the following areas[107]:

- Wetland construction: $5,000,000
- Reticulated irrigation: $200,000
- Underground storage construction: $2,000,000
- Upgrade to pumping infrastructure: $320,000
- Extension of reticulated irrigation system: $500,000

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[104] Royal Park Stormwater Harvesting Project. (n.d.). Retrieved from https://www.clearwater.asn.au/resource-library/case-studies/royal-park-stormwater-harvesting-project.php

[105] Facts about Melbourne. (n.d.). Retrieved from http://www.melbourne.vic.gov.au/about-melbourne/melbourne-profile/Pages/facts-about-melbourne.aspx

[106] Royal Park Stormwater Harvesting Project. (n.d.). Retrieved from https://www.clearwater.asn.au/resource-library/case-studies/royal-park-stormwater-harvesting-project.php

[107] Royal Park Stormwater Harvesting Project. (n.d.). Retrieved from https://www.clearwater.asn.au/resource-library/case-studies/royal-park-stormwater-harvesting-project.php

Royal Park Stormwater Wetland Pictures[108]

[108] Trin Warren Tam-boore wetland. (n.d.). Retrieved from http://urbanwater.melbourne.vic.gov.au/projects/wetlands/wetlands-sample-project/


Trin Warren
Tam-Boore
Bellbird
Waterhole
Melbourne Royal Park
White's Skink Habitat
Vba Baseball
Ross Straw Field
Vaha Hockey Fields
Oak St
Galada Ave

Lessons Learned

There is currently no framework or tool for quickly evaluating a city's potential land resources for constructed wetland projects. Additionally, performing an accurate, general "site search" for suitable constructed wetland projects has been determined as one of a handful of major barriers for implementing these techniques across a wide range of municipalities[109]. The spatial analysis techniques involved in determining site suitability are not exceptionally complex, but they do represent a significant capital investment, both in terms of finances and employee labor, which are not guaranteed to produce significant benefits[110].

The existing literature is generally in agreement that constructed wetlands can reduce urban runoff effects, reduce the cost of extending stormwater infrastructure services to underdeveloped portions of a city, or increase the natural amenities of a community. This tool provides a quick and cost effective assessment of where constructed wetlands projects might be located to achieve these goals. These two qualities can be particularly valuable for smaller Oregon communities who may lack the financial resources, employee capacity, or technical knowledge to accurately assess their constructed wetland potential[111]. Additionally, these same areas are often facing shortages in state support for capital intensive projects such as stormwater treatment systems[112].

Research Contributions

The tool's sample results, and subsequent policy and design research, have provided a number of pertinent lessons for planning practitioners in Oregon. The tool provides a valuable service by evaluating existing land resources in a community and highlighting the initial viability or unviability of constructed wetland projects in these areas. Additionally, the tool itself can allow city staff to perform quick analyses within their city boundaries and determine whether the results warrant additional analysis or detailed follow-up studies.

Furthermore, a parcel's inclusion, or exclusion, from constructed wetland suitability could provide an additional data point when:

- Debating new land purchases for public open space
- Assessing action items for inclusion in Natural Hazard Mitigation Plans (NHMPs).
- Determining neighborhood scale areas which might avoid costly increases in expanding stormwater or wastewater infrastructure distribution systems

---

109 Hammitt, S. A. (2010). *Toward sustainable stormwater management: overcoming barriers to green infrastructure* (Doctoral dissertation, Massachusetts Institute of Technology).

110 Naumann, S., Davis, M., Kaphengst, T., Pieterse, M., & Rayment, M. (2011). Design, implementation and cost elements of Green Infrastructure projects. *Final report, European Commission, Brussels*, 138.

111 Keeley, M., Koburger, A., Dolowitz, D. P., Medearis, D., Nickel, D., & Shuster, W. (2013). Perspectives on the use of green infrastructure for stormwater management in Cleveland and Milwaukee. *Environmental management*, *51*(6), 1093-1108.

112 Godwin, D., Parry, B., Burris, F., Chan, S., & Punton, A. (2008). Barriers and opportunities for low impact development: case studies from three Oregon Communities. *Oregon Sea Grant: Corvallis, OR*.

While a more detailed and rigorous suitability analysis would inevitably entail greater levels of local commitment, this tool provides an important building block by removing an initial knowledge barrier and narrowing spatial data to a more manageable scale. For example, when evaluating the sample analysis performed in Cottage Grove, a few details from one particular area were demonstrated which are useful when considering constructed wetland feasibility:

- Cottage Grove's existing wastewater treatment facility is located within a floodplain hazard area. This risk could potentially be reduced through the use of constructed wetland projects.
- There are significant natural wetland and aquatic resources surrounding the existing wastewater treatment facility. Negative impacts to these natural resources could be mitigated through the use of constructed wetland projects.
- Based on estimates from the *Fernhill Wetland* and *Royal Park* Case Studies, if 50% of suitable site land area near the wastewater treatment plant were developed:
    - An additional 1.3-4.7 million gallons of wastewater could potentially be treated through constructed wetland practices
    - Stormwater from a catchment area of approximately 5,532 acres could be held in constructed wetlands and associated storage area

These estimates are not intended as robust descriptions of actual project performance, but rather as possible ideas which could be further evaluated through modeling or site evaluations. However, these estimates are illustrative of how this tool can be applied to produce a quick and inexpensive suitability analysis in a variety of communities.

While the tool itself could potentially be utilized by any Oregon city, it appears that the communities who would likely see the most benefit contain the following characteristics:

- **Planning or public works departments with limited resources**
- **Growing populations and increases in urbanized area**
- **Existing vacant or under-developed publicly owned land reserves**
- **Nearby aquatic resources which have water quality impairments and dedicated quality improvement targets**
- **Strained capacity of wastewater and stormwater infrastructure**

Limitations

There are some significant limitations associated with this suitability analysis tool which cannot be overlooked. These limitations are primarily related to complications in automating a multilevel geospatial analysis and the remaining requirement for site visitation to confirm suitability results definitively. The following areas are currently the least robust:

- **Weighting Criteria:** Presently all evaluation criteria and data sets are weighted evenly, with a basic binary "suitable" or "unsuitable" ranking. For certain criteria, such as the exclusion of special flood hazard areas, this simple methodology is sufficient for high level suitability analyses. However, additional criteria such as slope degree exclusions, could be greatly improved with further levels of detail. For example, constructed wetland projects may perform better within a narrower range of slope degrees than the < 20% used as a cutoff in this analysis methodology. As such, a range of suitability values when evaluating certain data sets would prove useful for decision makers when determining costs, benefits, or site preparation requirements. The following general datasets which are already included in the analysis tool deserve additional levels of refinement:

- *Slope Degree*
- *Impervious Surface Cover*
- *Proximity to Sensitive Natural Areas*
- *Assessed Property Valuations*
- *Land in Public Ownership*

To achieve appropriate weighting across various geographic attributes, additional research would be required to determine thresholds for a variety of suitability levels. A *discrete value* ranking scale would need to be determined and justified based on site design research or other appropriate engineering characteristics. This discrete value scale could then be included as part of a weighted overlay geospatial analysis. This particular data analysis falls within the same category as those automated for the previous raster data sets. Resulting raster data sets could then be converted to polygon feature classes for further analysis across tax lot files.

Unfortunately, the creation of multiple feature classes associated with a discrete value scale and weighted overlay parameters would also likely place an additional burden on those seeking to utilize this tool. Due to the highly variable nature of individual constructed wetland projects, weighted overlays may not produce the intended result of greater confidence in site searches. For example, while certain sites may fall within a "lower suitability" ranking based on discrete value ranking scales, the tradeoff is likely to be associated with financial costs rather than pure geographic inappropriateness. Additionally, greater financial costs may be worthwhile if other concerns, such as greenspace preservation or flood protection, were determined to be greater. As such, the higher level of detail associated with weighted overlays may actually reduce the initial intent of this tool, by preemptively generating the impression that certain sites are inherently less suitable, rather than the reality of most suitable sites having a balance of costs and benefits.

- **Social & Demographic Data:** Currently, no information is included in the suitability analysis tool which deals with demographic information. Socially vulnerable communities are often those most affected by natural hazard events and environmental degradation[113]. Additionally, Green Infrastructure projects such as constructed wetlands can often be seen as a social amenity for a community and may serve to increase property values or community involvement[114]. Depending on the community, these factors may have significant weight when determining site suitability. As such, demographic information associated with datasets such as census block groups should be included to evaluate possible impacts from constructed wetlands on disadvantaged or marginalized communities.

[113] Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social science quarterly*, *84*(2), 242-261.

[114] Mell, I. C., Henneberry, J., Hehl-Lange, S., & Keskin, B. (2013). Promoting urban greening: Valuing the development of green infrastructure investments in the urban core of Manchester, UK. *Urban forestry & urban greening*, *12*(3), 296-306.

- **Wetland Inventories:** Currently, the wetland survey information is based on a statewide survey of existing wetland resource or mapped hydric soil conditions. However, the analysis tool does present the possibility of excluding some ideal constructed wetland sites due to the preference for maintaining natural wetland areas versus constructed projects. Some excluded sites may not have existing natural wetlands, but have potential for constructed wetland projects due to hydric soil characteristics. To mitigate against these exclusions, a comparison should be made between state wide mapped wetland resources and county or city resources mapping similar sites.

Future Research

Future research is broken into the following categories: *user interface* and *data refinement*.

User Interface

Currently, while relatively simple in terms of user application, this tool does require minor alterations of the source code to produce locally relevant results. A “Read-Me” document and detailed code commenting has been provided to guide practitioners in appropriate use of the tool. However, a simpler approach would include a Graphic User Interface (GUI) to reduce confusion and avoid the possibility of faulty results from mismanaged source code.

A functional interface would allow practitioners to choose their own priorities to most effectively highlight sites appropriate for individual needs. As an example, users could potentially set customized boundaries based on:

- Assessed property values
- Proximity to existing park and open space resources
- Size need for a specific amount of water treatment capacity

These additional parameters and data entries would add a level of customization which increases the applicability for communities looking to pursue constructed wetland projects. Allowing these changes through an easy to manipulate, in-program graphic interface would also increase the acceptability of these projects by creating a more transparent analysis resource for larger areas of the community beyond planners and public works employees.

Data Refinement

This tool, like all tools, is dependent on available information provided. Additional spatial and site based analysis can be performed on the initial results to produce greater levels of detail and relevant local meaning. For example, the addition of stormwater drainage basin information would give a clear idea of which natural waterways are most likely to be impacted by constructed wetland projects on particular sites. This particular data set would not necessarily change initial suitability results, but would provide additional context for how individual projects sites fit into a regional watershed.

The following data sets should be included in future iterations of the suitability analysis and automation code:

- Stormwater drainage basins
- Existing stormwater infrastructure
- Brownfield sites or other contamination information
- Building footprints, to determine appropriate setback characteristics

Appendix

Automation Code

```
#-------------------------------------------------------------------------------
# Name:       Constructed Wetlands Suitability Analysis- Lane County Oregon
# Purpose:     Determines taxlot which are suitable for constructed wetland focused "green
infrastructure" projects based on a range of geographic characteristics
#
# Author:      Kyle Collins
#
# Created:     29/05/2017
# Copyright:   (c) kcollins 2017
# Licence:     <your licence>
#-------------------------------------------------------------------------------

import arcpy # Imports the arcpy module
from arcpy import env
from arcpy.sa import * # Imports the Spatial Analyst toolbox
basefolder = "C:\Users\kcollins\Desktop\GI_Suitability_Tool"
env.workspace = basefolder # Sets the workspace environment
arcpy.env.overwriteOutput = True # Allows newly created files to overwrite existing files with the same
name

arcpy.MakeFeatureLayer_management
("C:\Users\kcollins\Desktop\GI_Suitability_Tool\OregonUGB\UGB_2015.shp", "UGBlyr") # Creates a new
feature layer from the Oregon State Urban Growth boundary shapefiles
arcpy.SelectLayerByAttribute_management ("UGBlyr", "NEW_SELECTION", "NAME = 'Cottage Grove'") #
Selects the boundary of the city to be evaluated by the remainder of the script. The 'Cottage Grove"
must be altered to a new city in Lane County to change the evaluation
arcpy.CopyFeatures_management("UGBlyr",
"C:\Users\kcollins\Desktop\GI_Suitability_Tool\CityUGB.shp") # Creates a new shapefile for the
evaluated city Urban Growth Boundary

arcpy.Clip_analysis("C:\Users\kcollins\Desktop\GI_Suitability_Tool\LaneCountyTaxlots\Taxlot.shp",
"CityUGB.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\CityTaxlots.shp") # Clips the Lane
County, Oregon tax lot features using the evaluation city Urban Growth Boundary

arcpy.Clip_analysis("C:\Users\kcollins\Desktop\GI_Suitability_Tool\OregonRoads\OregonRoads.shp",
"CityUGB.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\CityRoads.shp") # Clips the Oregon
transportation network  features using the evaluation city Urban Growth Boundary

arcpy.Clip_analysis("C:\Users\kcollins\Desktop\GI_Suitability_Tool\OregonRivers\CityRivers.shp",
"CityUGB.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\GIRivers.shp") # Clips the Oregon river
and waterways features using the evaluation city Urban Growth Boundary
```

```
arcpy.Clip_management("DEM_10m.lyr","","CityDEM.tif", "CityUGB.shp", "#", "NONE",
"MAINTAIN_EXTENT") # Creates a new TIF file based on the Oregon 10 meter digital elevation model,
then clips these features based on the evaluation city Urban Growth Boundary
arcpy.Clip_management("C:\Users\kcollins\Desktop\GI_Suitability_Tool\NLCD2011_IMP_N42W102\ori
mpervious","","CityIMP", "CityUGB.shp", "#", "NONE", "MAINTAIN_EXTENT") # Creates a new image file
based on the Oregon Impervious Surface Land Cover File, then clips these features based on the
evaluation city Urban Growth Boundary

Elevraster = arcpy.Raster("CityDEM.tif") # Sets the 'Elevraster' raster feature as the city digital elevation
model TIF
Impraster = arcpy.Raster("CityIMP") # Sets the 'Impraster' raster feature as the city impervious surface
land cover image file
if arcpy.CheckExtension("spatial") == "Available": # Checks to see if the Spatial Anlayst license is
available
   arcpy.CheckOutExtension("spatial") # Checks out thr spaital analyst license
   CitySlope = Slope(Elevraster) # Performs a slope analysis on the Elevraster feature
   goodslope = (CitySlope < 20) # Sets the 'goodslope' feature as all slopes less than 20 percent
   goodIMP = (Impraster <= 49) # Sets the 'goodIMP' feature as all areas with impervious surface less
than or equal to 49%
   goodslope.save("CitySlope") # Saves the 'goodslope' feature as "CitySlope"
   goodIMP.save("GICityIMP") # Save the 'goodIMP' feature as "GICityIMP"
else:
   print "Spatial Analyst license is not available" # Print the stated line of text if the spaital analyst license
is not available

arcpy.RasterToPolygon_conversion("CitySlope",
"C:\Users\kcollins\Desktop\GI_Suitability_Tool\CitySlope.shp") # Converts the CitySlope feature to a
polygon file for future analysis
arcpy.RasterToPolygon_conversion("GICityIMP",
"C:\Users\kcollins\Desktop\GI_Suitability_Tool\GICityIMP.shp") # Converts the GICityIMP feature to a
polyogn file for future analysis

arcpy.MakeFeatureLayer_management("CitySlope.shp", "Slopelyr") # Creates a new feature layer from
the CitySlope shapefile
arcpy.SelectLayerByAttribute_management ("Slopelyr", "NEW_SELECTION", ' "GRIDCODE" = 1 ') #
Selects all layers in the CitySlope polygon which correspond to GridCode 1, which is all slopes less than
20%
arcpy.CopyFeatures_management("Slopelyr",
"C:\Users\kcollins\Desktop\GI_Suitability_Tool\GIslope.shp") # Saves the newly selected CitySlope
feature file

arcpy.MakeFeatureLayer_management("GICityIMP.shp", "IMPlyr") # Creates a new feature layer from
the CitySlope shapefile
arcpy.SelectLayerByAttribute_management ("IMPlyr", "NEW_SELECTION", ' "GRIDCODE" = 1 ') # Selects
all layers in the GICityIMP polygon which correspond to GridCode 1, which is all areas with less than 50%
imperviousness surface cover
arcpy.CopyFeatures_management("IMPlyr", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\GIimp.shp")
# Saves the newly selected GiCityIMP feature file
```

arcpy.Clip_analysis("C:\Users\kcollins\Desktop\GI_Suitability_Tool\OregonFlood\FEMA_FloodHazard.shp", "CityUGB.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\CityFlood.shp") # Clips the Oregon flood hazard features using the evaluation city Urban Growth Boundary
arcpy.MakeFeatureLayer_management ("CityFlood.shp", "FLOODlyr") # Creates a new feature layer from the clipped flood hazard polygon
arcpy.SelectLayerByAttribute_management ("FLOODlyr", "NEW_SELECTION", "FLD_ZONE = 'A' OR FLD_ZONE = 'A1' OR FLD_ZONE = 'A11' OR FLD_ZONE = 'A12' OR FLD_ZONE = 'A13' OR FLD_ZONE = 'A14' OR FLD_ZONE = 'A15' OR FLD_ZONE = 'A2' OR FLD_ZONE = 'A21' OR FLD_ZONE = 'A22' OR FLD_ZONE = 'A3' OR FLD_ZONE = 'A4' OR FLD_ZONE = 'A5' OR FLD_ZONE = 'A6' OR FLD_ZONE = 'A7' OR FLD_ZONE = 'A8' OR FLD_ZONE = 'A9' OR FLD_ZONE = 'AE' OR FLD_ZONE = 'AH' OR FLD_ZONE = 'AO' OR FLD_ZONE = 'V' OR FLD_ZONE = 'VE'") # Selects all areas associated with FEMA designated Special Flood Hazard Areas
arcpy.CopyFeatures_management("FLOODlyr", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\CityGIFlood.shp") # Saves the newly selected CityFlood feature file

arcpy.Clip_analysis("C:\Users\kcollins\Desktop\GI_Suitability_Tool\OregonSoils\OregonSoils.shp", "CityUGB.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\CitySoils.shp") # Clips the Oregon soil survey features using the evaluation city Urban Growth Boundary
arcpy.MakeFeatureLayer_management ("CitySoils.shp", "Soilslyr") # Creates a new feature layer from the clipped soil survey polygon
arcpy.SelectLayerByAttribute_management ("Soilslyr", "NEW_SELECTION", "hydgrpdcd = 'C' OR hydgrpdcd = 'D'") # Selects all soil types associated with Natural Resource Conservation Service classes 'C' or 'D'
arcpy.CopyFeatures_management("Soilslyr", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\CityGISoils.shp") # Saves the newly selected CityGISoil feature file

arcpy.Clip_analysis("C:\Users\kcollins\Desktop\GI_Suitability_Tool\OregonWetland\Oregon_Soil_Wetland.shp", "CityUGB.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\CityWetland.shp") # Clips the Oregon mapped wetlands features using the evaluation city Urban Growth Boundary

arcpy.Clip_analysis("CityTaxlots.shp", "GIslope.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\GITaxlot1.shp") # Clips the evaluation city taxlot features using the approproate slope characteristics features

arcpy.Clip_analysis("GITaxlot1.shp", "GIimp.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\GITaxlot2.shp")# Clips the evaluation city taxlot features using the approproate impervious surface features

arcpy.Clip_analysis("GITaxlot2.shp", "CityGISoils.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\GITaxlot3.shp") # Clips the evaluation city taxlot features using the approproate soil drainage features

arcpy.Erase_analysis("GITaxlot3.shp", "CityGIFlood.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\GITaxlot4.shp") # Erases the evaluation city taxlot features using the identified Special Flood Hazard Areas arcpy.Erase_analysis("GITaxlot4.shp", "CityWetland.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\GITaxlot5.shp") # Erases the evaluation city taxlot features using the identified wetlands or hydric areas

arcpy.MakeFeatureLayer_management ("GITaxlot5.shp", "VacantTaxlyr") # Creates a new feature layer from the newly Clipped and Erased evaluation city taxlots
arcpy.SelectLayerByAttribute_management ("VacantTaxlyr", "NEW_SELECTION", "PROPCLDES = 'COMMERCIAL, RESIDENTIAL ZONE, VACANT' OR PROPCLDES = 'COMMERCIAL, VACANT' OR PROPCLDES = 'FARM, EFU, VACANT' OR PROPCLDES = 'FARM, UNZONED FARM LAND, VACANT' OR PROPCLDES = 'FOREST, UNZONED FARM LAND, VACANT' OR PROPCLDES = 'INDUSTRIAL, UNZONED FARM LAND, VACANT' OR PROPCLDES = 'INDUSTRIAL, VACANT' OR PROPCLDES = 'MULTI-FAMILY, VACANT' OR PROPCLDES = 'RESIDENTIAL, WATERFRONT, VACANT' OR PROPCLDES = 'RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT' OR PROPCLDES = 'RESIDENTIAL, VACANT' OR PROPCLDES = 'TRACT, VACANT' AND IMPVAL < 1000") # Selects all taxlots from the feature layer identified as 'Vacant and with improvement values of less than $1,000

arcpy.MakeFeatureLayer_management ("GITaxlot6.shp", "AcresTaxlyr") # Creates a new feature layer from the newly selected improvment value and vacany evaluation city taxlots
arcpy.SelectLayerByAttribute_management ("AcresTaxlyr", "NEW_SELECTION", '"MAPACRES" > 1') # Selects all feature layer larger than 1 acre
arcpy.CopyFeatures_management("AcresTaxlyr", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\GITaxlot7.shp") # Saves the newly selected CityTaxlot feature file

arcpy.Buffer_analysis("GITaxlot7.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\GITaxlot8.shp", "-5 Feet") # Performs a buffer analysis on the newly selected CityTaxlot feature of -5 feet and saves the result

arcpy.Buffer_analysis("GIRivers.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\GIRiversBuffer.shp", "75 Feet") # Performs a buffer analysis on the newly buffered CityTaxlot feature of 75 feet from identifited city rivers and saves the result

arcpy.Erase_analysis("GITaxlot8.shp", "GIRiversBuffer.shp", "C:\Users\kcollins\Desktop\GI_Suitability_Tool\FinalGIFiles\FinalGITaxlots.shp") # Erases the city river buffer analysis results from the city Taxlot Feature and saves the results

“Read Me” User Guide

The following section outlines a specific user guide for practitioners to implement this suitability tool. It presents a step-by-step approach collecting data and performing an automated analysis.

Steps:

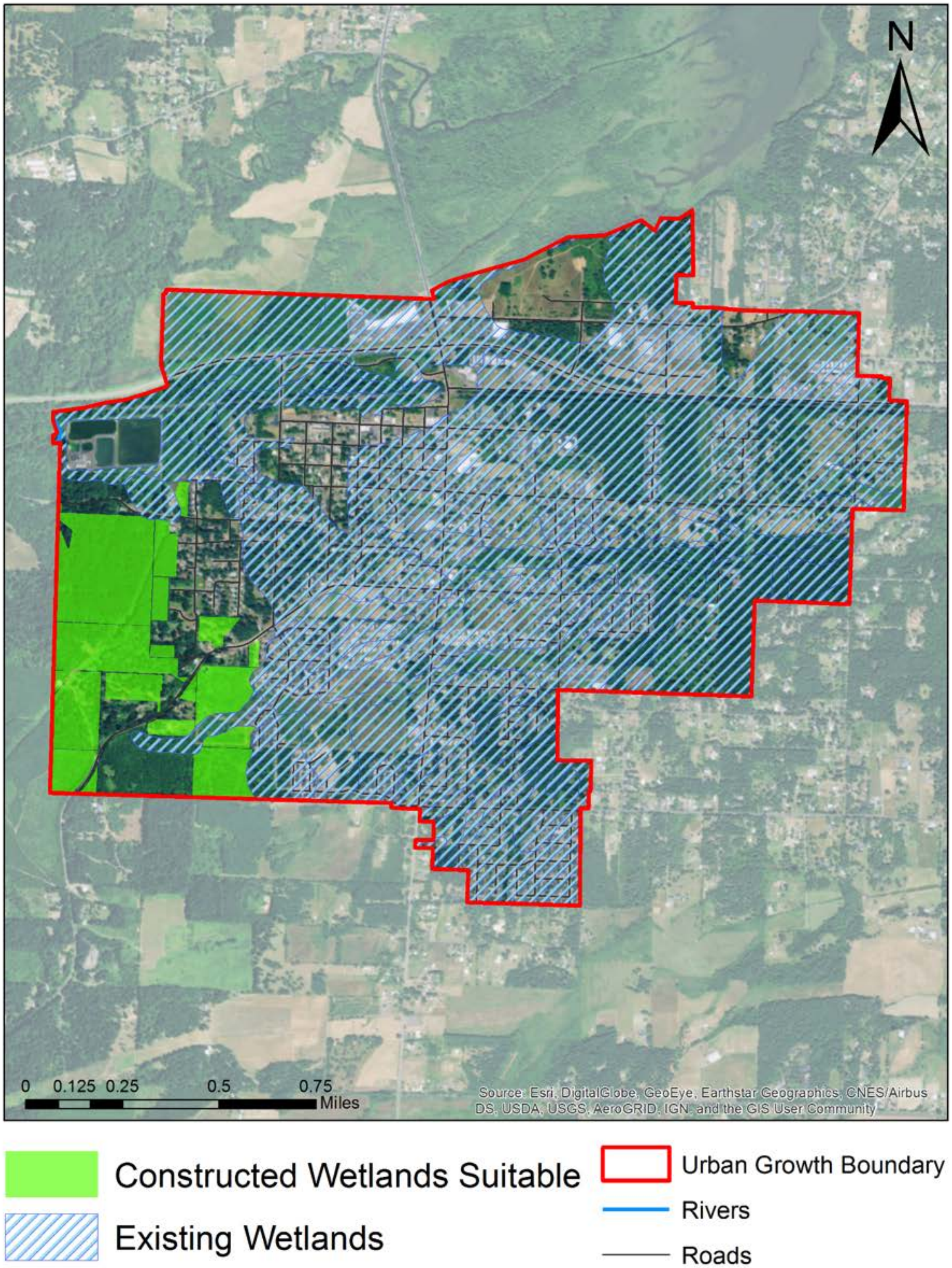
1) Create a folder on your computer’s Desktop with the title “**GI_Suitability_Tool**”
2) Data Collection (Place all downloaded data in the **GI_Suitability_Tool** folder):
    a. Download the following data files from Oregon’s Spatial Data Library:
        i. Oregon Digital Elevation Model (DEM) - 10 Meter Resolution
        ii. Oregon Statewide Flood Hazard Database - FEMA Flood Insurance Studies
        iii. Oregon Urban Growth Boundaries - 2015
        iv. Oregon Soil Survey Geographic Database (SSURGO) from State Soil Geographic Database (STATSGO) Soils Compilation
        v. Oregon Rivers- River Reach
        vi. Oregon Transportation Network - 2015
        vii. Oregon Mapped Wetlands and Hydric Soils
    b. Download the following data files from the National Land Cover Database:
        i. Oregon National Land Cover Database- Percent Developed Imperviousness 2011
    c. Place the evaluation community’s tax lot data file in the **GI_Suitability_Tool** folder
3) Download one of the following pieces of Python scripting software:
    a. Pyscripter
    b. IDLE
4) Copy and paste the entire suitability tool source code into one of the Python scripting applications
5) Data Management:
    a. Create the following folders within the **GI_Suitability_Tool** folder:
        i. “**FinalGIFiles”**
        ii. **“OregonUGB”**
            1. Place the Oregon Urban Growth Boundary data in this folder
        iii. **“OregonRoads**”
            1. Place the Oregon transportation network data in this folder
        iv. **“OregonRivers**”
            1. Place the Oregon rivers data in this folder
        v. **“OregonSoils”**
            1. Place the Oregon soils data in this folder
        vi. **“OregonFlood”**
            1. Place the Oregon FEMA flood data in this folder
6) Code Customization and Alterations:
    a. Make the following changes to the source code:
        i. Change **ALL** mentions of the “**C:\Users\kcollins\Desktop\GI_Suitability_Tool**” filepath, to the local **GI_Suitability_Tool** folder filepath

ii. **Line 8**: Change the '**Cottage Grove**' text to represent the city boundary you wish to evaluate

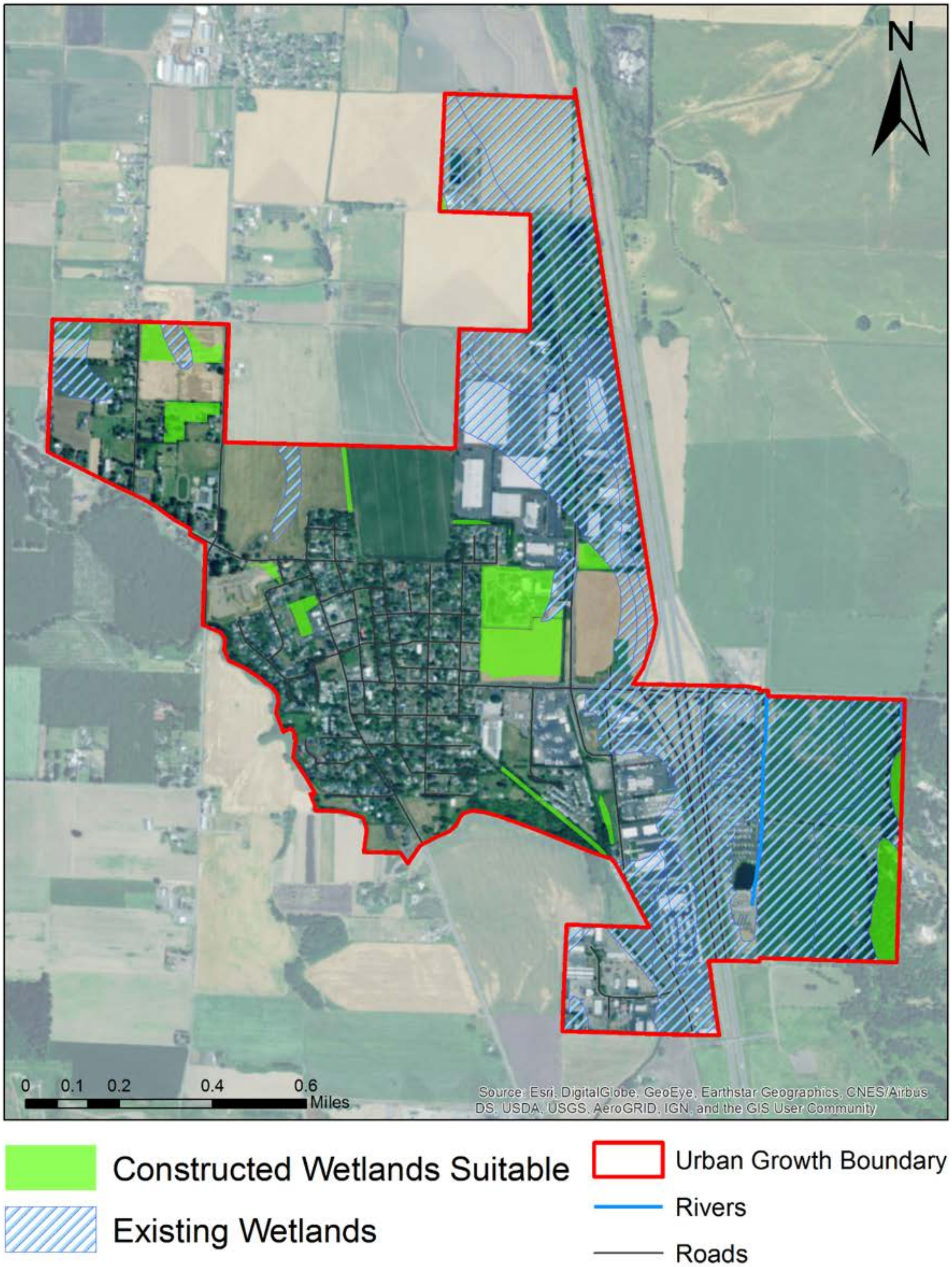
iii. **Line 10**: Change the "C**:\Users\kcollins\Desktop\GI_Suitability_Tool\LaneCountyTaxlots\Taxlot.shp**" filepath to the local filepath associated with the community's tax lot data

7) Ensure the "**Spatial Analysis**" tool is available and checked out within ArcGIS or similar mapping software
    a. This is done by selecting the "Spatial Analysis" box under the "Extensions" toolbar
8) Run the analysis tool
    a. The resulting suitable tax lot shapefile will be located in the "**FinalGIFiles**" folder

Additional Suitability Maps
Veneta, Oregon



Coburg, Oregon



Cottage Grove Suitable Lots Information

OWNNAME	ADDR1	OWNERCITY	OWNERPRVST	OWNERZIP
CITY OF COTTAGE GROVE	400 E MAIN ST	COTTAGE GROVE	OREGON	97424
KRISTEN A WOODARD LIVING TRUST	2480 PIONEER PIKE	EUGENE	OREGON	97401
SOLESBY LOWELL	PO BOX 1232	COTTAGE GROVE	OREGON	97424
STARFIRE LUMBER CO	PO BOX 547	COTTAGE GROVE	OREGON	97424
CITY OF COTTAGE GROVE	400 E MAIN ST	COTTAGE GROVE	OREGON	97424
OUR LADY OF PERPETURAL HELP CATHOLIC CH	1025 N 19TH ST	COTTAGE GROVE	OREGON	97424
EMERALD HEIGHTS LLC	PO BOX 51330	EUGENE	OREGON	97405
EMERALD HEIGHTS LLC	PO BOX 51330	EUGENE	OREGON	97405
COOP DUANE & DOROTHY JEAN	PO BOX 65	COTTAGE GROVE	OREGON	97424
SUNRISE RIDGE LLC	PO BOX 10545	EUGENE	OREGON	97440
SUNRISE RIDGE LLC	PO BOX 10545	EUGENE	OREGON	97440
LAWLER HELENE E TE	31701 RUDOLPH RD	COTTAGE GROVE	OREGON	97424
WILLIAM & MAUREEN ELLIS LIVING TRUST	375 N Q ST	COTTAGE GROVE	OREGON	97424
WILLIAM & MAUREEN ELLIS LIVING TRUST	375 N Q ST	COTTAGE GROVE	OREGON	97424
WILLIAM & MAUREEN ELLIS LIVING TRUST	375 N Q ST	COTTAGE GROVE	OREGON	97424
EGRESS INVESTMENTS LLC	2205 LASATER BLVD	EUGENE	OREGON	97405
DAILY WILLIAM L & DIANE M	PO BOX 1611	COTTAGE GROVE	OREGON	97424
YOSS STEVEN & SHERRY	707 SHIELDS LN	COTTAGE GROVE	OREGON	97424
SHIELDS CEMETERY ASSN	PO BOX 165	LORANE	OREGON	97451
ESCHETTE GERALD J & JUDITH P	36205 CAMP CREEK RD	SPRINGFIELD	OREGON	97478
LUCAS JAMES W & SARAH P	3318 W CECIL CRT	VISALIA	CALIFORNIA	93291
CKK ACQUISITION LLC	PO BOX 10666	EUGENE	OREGON	97440

OWNERCNTRY	ASSDTOTVAL	IMPVAL	LANDVAL	TAXABLE_VA	LATITUDE	LONGITUDE	PROPCLDES
UNITED STATES	$710,596	0	1865385	0	43.8093459	-123.0445263	COMMERCIAL, VACANT
UNITED STATES	$44,672	0	90345	44672	43.79620837	-123.0447376	RESIDENTIAL, VACANT
UNITED STATES	$274	0	35500	274	43.79433456	-123.0437825	FOREST, UNZONED FARM LAND, VACANT
UNITED STATES	$51,924	0	81774	51924	43.79611739	-123.0406531	INDUSTRIAL, VACANT
UNITED STATES	$190,321	0	453332	0	43.80636862	-123.0501269	COMMERCIAL, VACANT
UNITED STATES	$227,733	0	230045	0	43.80386213	-123.0498233	RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT
	$112,752	0	1802807	112752	43.80354498	-123.0687016	RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT
	$113,766	0	1388254	113766	43.80278185	-123.0651231	RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT
UNITED STATES	$47,727	0	97037	47727	43.80073342	-123.0486261	COMMERCIAL, VACANT
UNITED STATES	$2,191,287	0	2200448	2191287	43.8070155	-123.0742203	RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT
UNITED STATES	$230,000	0	230000	230000	43.80174051	-123.076977	RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT
	$22,554	0	259555	22554	43.80532473	-123.0800196	FOREST, UNZONED FARM LAND, VACANT
UNITED STATES	$45,118	0	138890	45118	43.80044495	-123.0747421	RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT
UNITED STATES	$49,580	0	202265	49580	43.79972098	-123.0751881	RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT
UNITED STATES	$41,449	0	70021	41449	43.80044592	-123.0757707	TRACT, VACANT
	$30,271	0	173370	30271	43.79158236	-123.0507917	RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT
	$36,830	0	141826	36830	43.79156797	-123.0495369	RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT
UNITED STATES	$29,964	0	65218	29964	43.7907899	-123.0497606	TRACT, VACANT
	$11,052	0	17754	0	43.79002002	-123.0500343	TRACT, VACANT
UNITED STATES	$46,806	0	271711	46806	43.79298067	-123.0460706	RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT
	$42,603	0	134844	42603	43.79341449	-123.0479979	RESIDENTIAL, POTENTIAL DEVELOPMENT, VACANT
UNITED STATES	$89,040	0	152180	89040	43.76829722	-123.0829843	INDUSTRIAL, VACANT