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Trail Impact Monitoring in Forest Park

**Master of Environmental
Management
Project Defense**

**Prepared By: James Mitchell
Prepared For: Portland Parks &
Recreation**

**Committee:
Dr. Jeff Gerwing (advisor)
Dr. Kelly Gleason
Jill Van Winkle**

Abstract

Forest Park is an appropriately named 5,200 acre natural area located in northwest Portland, Oregon. A recent study estimated park usage near half a million annual visits and found “trails” to be the park’s most highly valued feature. Unfortunately, many trails were not designed for such traffic as evidenced by slipping hazards, erosion and other ecological impacts. In response to these observations, I partnered with Portland Parks & Recreation to conduct an objective trail impact assessment prescribed by the Forest Park Natural Resource Management Plan. I modified methods from past studies to expand on a recently completed trail condition class assessment, which subdivided the Forest Park trail system into four classes of 250-foot trail sections. I observed soil loss and potential drivers at 120 transects in 40 trails sections, then constructed multiple regression models to determine relationships between variables. Results indicated field observed and GIS-derived average percent grade metrics explained soil loss and future assessments might be simplified with less field measurements. I then used these data to define sustainable trail layout based on recent recreation ecology literature. The collective methods of my research provide a template for expanding objective trail impact assessments throughout Forest Park, while results and recommendations can help prioritize management action, inform environmental reviews, and justify funding for trail system improvements.

Acknowledgements

A major theme of my Master of Environmental Management project experience was the tremendous support I received from friends, family members, classmates and committee members. First and foremost, I would like to thank my advisor Dr. Jeff Gerwing for his invaluable time investment and contributions throughout the entirety of the project. Even on sabbatical Dr. Gerwing was available and helpful, while showing a clear interest in the success of my project. Jill van Winkle at Portland Parks and Recreation, my project partner, also committed serious time to the project while stimulating my interest in recreation ecology. I'm very grateful she suggested the project and followed up with early study design and planning ideas, along with continuous support. On that note, I also cannot thank committee member Dr. Kelly Gleason enough for her study design and analysis suggestions that were ultimately implemented. Further, she made the extra effort to refresh and expand on my statistical abilities in coursework and beyond, significantly improving the overall quality of this report.

I'm also grateful for Eric Butler's assistance with nearly all of my field surveying. While helping me complete the assessment in a timely manner, Eric made numerous invaluable contributions to the project, as well as providing good company and moral support in the field. I'm thankful for my fiancé, Lauren Fuentes, for her continuous support, encouragement, and patience throughout my graduate studies. Finally, I would also like to thank Drs. Sarah Carvill, Chris Grant, and Cat de Rivera along with classmates Jim Holley, Becky Dorff, as their instruction and advice were instrumental in composition of this paper and my defense presentation.

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Introduction

Of the myriad ecosystem services provided by Forest Park, recreation may be the most valued by residents of Portland, Oregon and nearby cities (NRMP, 1995). A 15-month use study released in 2012, found “trails” to be the highest valued park feature over natural features like trees in a sample of 2,277 visitors (Elliot et al., 2012). The same report estimated 2011 park usage at 475,000 visits, a number that has likely increased along with regional growth of recreation popularity (Oregon State Parks, 2016; Outdoor, 2017). My preliminary observations of trail conditions in the park revealed erosion, vegetation trampling, and hydrologic system impacts, suggesting substantial use may have a negative effect on this high-value ecosystem (NRMP, 1995). While use levels and type have been shown to explain natural resource impacts in past research, environmental and management factors are also important drivers of recreation impacts. For example, trails built steeper than annual precipitation and soil type allow will inevitably cause erosion and subsequent soil loss regardless of use levels (Marion & Wimpey, 2017). Many trails in Forest Park fit this category as they evolved from various types of roads that weren’t built to minimize impacts (e.g., logging skid and various other access roads; NRMP, 1995).

Portland Parks & Recreation (PPR) is charged with managing 153 miles of trails including over 70 miles in Forest Park. PPR allows hiking and running on all trails, while mountain biking and horseback riding are limited to fire lanes and other wide, road-like trails (Forest Park Conservancy, n.d.). Despite limited funding, PPR managers are proactive in improving the trail system, as evidenced by a recently completed trail condition class survey divided the trail system into ~250-foot sections and classified them into one of five categories, ranging from ‘very good’ to ‘very poor’ (PPR, 2019; see Appendix A). Recreation impact data are essential as Forest Park provides habitat for at least 62 mammal and 112 bird species with 5,200 nearly continuous acres of urban forest (PPR, n.d.; NRMP, 1995).

Ecological research methods in other parks have shown that poorly built or inadequately maintained trails negatively affect wildlife and natural processes (Larson et al., 2016; Hammit et al., 2015). While trails are often taken for granted as a simple path in the woods, the quality of trail infrastructure defines the magnitude of natural resource impacts (Cole, 1983). Properly aligned and maintained trails are “hydrologically invisible” while minimizing vegetation impacts and optimizing user safety (Marion & Wimpey, 2017). Conversely, steep or neglected trails often channel precipitation and alter hydrologic systems. Such “unsustainable” trails channel precipitation unnecessarily destroying plant life, and compromising visitor safety (Wimpey & Marion, 2010; Eagleston, 2016). Managers of natural areas such as Forest Park experience an inherent conflict between recreation and preservation, which can be mitigated by investment in trails as they represent the interface between humans and nature (Marion et al., 2011).

Background

In support of PPRs management efforts, I partnered with the agency to conduct an objective trail impact assessment as prescribed by the Forest Park Natural Resource Management Plan (NRMP, 1995). I narrowed the study area to exclude fire lanes and trails derived from roads less than two meters wide in the Central Management Unit (CMU) of Forest Park, from which I randomly selected 10 sections from the four present condition classes (there were no 'very good' sections). I measured soil loss metrics and predictor variables at three subsample points within each section, providing quantitative data to assess and explain the impact. Research elsewhere suggests sustainable trails are built and maintained to minimize impacts given intended use, with soil loss being the most common degradation indicator (Olive & Marion, 2009; Marion & Wimpey, 2017). Although inspired by methods from such studies, this project is unique due to availability of ~250' classified trail sections supporting a stratified random sampling design (Appendix A). Application of historic impact indicator methods within and across respective groups provided an opportunity to evaluate condition classifications as a proxy for sustainability. I then found the percentage of trail sections within each condition class that meet literature-defined sustainability criteria and used these data to provide recommendations (Marion & Wimpey, 2017).

Forest Park Natural Resource Conservation Plan

The guiding document for park management is the Forest Park Natural Resource Management Plan (NRMP), created in 1995. Authors recommended city officials "establish a program to periodically monitor natural resources and recreation use impacts" (NRMP, 1995)." Although trail managers often perform formal and informal problem assessments, guidance from the NRMP and other planning documents recommends objective monitoring based on recreation ecology principles (NRMP, 1995; McAllister et al., 2009). The NRMP defines concepts of resource carrying capacity and limits of acceptable change (LAC) based on early recreation ecology recommendations and frameworks. Carrying capacity approaches, LAC and modern iterations such as Visitor Use Management prescribe indicator observations to define resource quality standards in support of management objectives (IVUMC, 2016).

More specifically, the NRMP prescribes regular visitor use surveys and a baseline inventory of trail-related resource impacts, followed by repeated impact assessments. If completed concurrently, use and impact studies can define the level of visitation allowed by resource conditions and theoretically lead to restrictions if these thresholds are exceeded (NRMP, 1995). The preferred response to deteriorating natural resource conditions is funding actions that increase carrying capacity such as building and maintaining trails to standards defined by objective trail impact assessments, which allows the highest possible use levels given resource restraints (NRMP, 1995). The fact

that only one use survey and no objective trail impact assessments have been completed underscores the lack of funding and resources available to park managers (Elliot et al., 2012).

City of Portland Trail Condition Classification

Despite a tight budget, a PPR employed asset assessment engineer conducted a citywide condition class assessment of trails in 2019 (PPR, 2019). A rating system of '1' (very good) to '5' (very poor) was based on the 2009 trail design guidelines and metrics including soil loss, soil displacement, muddiness, and distribution of surface material (PPR, 2009; Appendix A; Appendix B). The initial citywide classifications guidelines were somewhat broad as they included paved trails in developed parks with conditions unlike those in Forest Park (e.g., Laurelhurst Park in southeast Portland). This issue was mitigated in Forest Park specific surveys by the inclusion of a professional trailworker and logical alterations of the class criteria, such as inclusion of BMP and literature supported 2-5 percent outslope (i.e., the gradient of the trail across the width, or perpendicular to trail direction; Olive, 2009; Figure 1).

Figure 1. Profile of nearly universal full-bench trail construction standards with outslope emphasized (IMBA, 2004).

While past research has demonstrated random point-based assessments provide the most objective data, condition class assessments supported by objective classification criteria are also informative (Marion & Leung, 2001). A much greater area can be assessed, and the results may require less statistical analyses to be of value (Marion & Leung, 2001). In this case, objectively defined criteria and surveyor

consistency have generated a comprehensive spatial overview of Portland trail quality. Existence of the condition class assessment with spatially defined and classified ~250-foot sections provided an opportunity to develop a novel and objective point-based study design allowing comparison of condition classes. Given that most of the condition class assessment indicators are related to soil loss, survey classification decisions were evaluated as representations of sustainability. Although inclusion of more metrics is desirable, the existing definition of trail sustainability is based on observations of soil loss and its drivers (Marion & Wimpey, 2017).

Past Studies on Trail Impacts

In response to ubiquitous underfunding of natural area recreation infrastructure, objective trail impact assessments have been completed elsewhere in the United States since the 1970s (Dale & Weaver 1974; Cole, 1983). Though relatively few in total, these studies have shown that trails can adversely impact wildlife connectivity, water quality, vegetation communities and soil resources (Ballantyne et al., 2014; Olive & Marion, 2009). Wildlife near trails display a range of responses that are difficult to measure, but researchers have observed disturbances hundreds of meters from a trail (Semlitsch & Bodie, 2003). Water impacts have been minimally studied, but one group of researchers conducted a stream crossing impact assessment showing significant decreases in water quality as a result of trail erosion (Kidd et al., 2015).

A more commonly studied issue is vegetation trampling associated with trails and other recreation infrastructure. This occurs when a trail is built too narrow for use levels and visitors pass each other on adjacent plant life and the effect is magnified on steep trails with heavy use and wet soils, such as Forest Park fire lanes in spring (Wimpey & Marion, 2010). Impacts to vegetation are further exacerbated by the introduction of invasive species, especially those of the ruderal variety driven by disturbance. Formal and informal trails throughout Forest Park and other natural areas provide channels for invasive species spread, presenting a major threat to ecosystem integrity and the resource quality Portlanders have come to expect (Van Winkle 2014; Pickering & Mount, 2010).

Soil Loss and trail sustainability

Of all measurable impacts, soil loss is considered the best proxy for sustainability because it is pervasive across natural areas and may be the most common natural resource impact (Olive & Marion, 2009). A trail experiencing soil loss can alter hydrological regimes, lead to safety issues and encourage the proliferation of informal trails as users avoid the muddy or treacherous planned infrastructure (Marion & Wimpey, 2017). Soil loss is tied to the most recent definition of a sustainable trail as one that “limits both trail degradation and annual maintenance while accommodating its intended amount and type of use,” with trail degradation in this context referring

specifically to soil loss (Marion & Wimpey, 2017). The most common sustainability metric in trail impact studies is cross sectional area (CSA) soil loss, which is a two-dimensional snapshot of the trail profile showing the current tread, or walking surface, compared to the assumed post-construction tread surface (Figure 2; Aust et al., 2005). Maximum incision or greatest depth from a transect line is another informative soil loss metric commonly observed.

Figure 2. The variable interval cross-sectional area measurement method with example. The formula is $area = (v_i + v_{i+1}) * I_i * 0.5$ for each row summed together. From Olive & Marion, 2009.

Two of the most important soil loss predictors observed in the literature are grade and trail slope alignment angle (TSA), with past studies typically finding a significant relationship between these variables and soil loss metrics (Leung and Marion, 1996; Olive and Marion, 2009). Yet despite significant findings, grade and trail slope alignment angle have been less explanatory of soil loss in past studies than expected (Marion & Wimpey, 2017). One possible explanation is the attention already focused on steep sections by trail managers in many parks, as best management practices (BMPs) discourage trails exceeding grades of 10 percent and recommend stone work to stabilize trails at grades over 15 percent (Cole, 1983; Wimpey & Marion, 2011; Davies et al., 2007). For TSA, literature mostly agrees with the “half-rule” which states that a trail shouldn’t be more than half as steep as the landform it bisects (except in cases of landform grades over 30 percent, as the half-rule would allow unacceptable grades in these instances; Olive & Marion, 2009). Trails that meet this rule along with a 2-5 percent outslope require minimal investment in drainage infrastructure, as excessive water continually exits the trail instead of causing erosion (Tomczyk & Ewertowski, 2013). Erosion can be further prevented by inclusion of grade reversals, which are depressions in the trail grade where water drains from two directions (Figure 3).

Figure 3. An example of grade reversals in a Forest Service road, with red arrows pointing to the features. Best management practices and literature maintain the importance of building grade reversals in concert with out-sloped tread and the “half-rule” (trail no more than half as steep as the landform). A side-hill trail meeting these criteria can be expected to minimize resource impacts and maintenance costs (Photo: USFS, n.d.; Marion & Wimpey, 2017).

Despite lower-than-expected soil loss explanation from grade and TSA in previous studies, the significance of these metrics inspired Marion & Wimpey to create a trail sustainability model with grade and TSA as predictors of soil loss (2017). They developed four sustainability ratings: ‘good’, ‘neutral’, ‘poor’ and ‘very poor’ and verified the model with actual soil loss numbers from three objective trail impact studies collectively analyzed for their 2017 manuscript. Although arguably an oversimplification, the trail sustainability index is a promising tool for managers, especially because grade and TSA variables can potentially be derived in GIS, greatly reducing the amount of work necessary to complete an objective trail impact assessment. Trails in the ‘poor’ or ‘very poor’ categories can be expected to have layout issues and may require realignment. Such “unsustainable” trails may require significantly more investment in drainage features and trail hardening (gravel or rock) than ‘sustainable’ trails. Sustainability in the literature reflects whether a trail is appropriately aligned and graded to minimize soil loss (Marion & Wimpey, 2017).

Several other variables have significantly explained soil loss including use levels, use type (e.g. horseback riding or hiking), soil texture, tread substrate and drainage feature construction (Aust, 2005). Soil texture can have a major influence as many soil types are more prone to erosion than others (Olive & Marion, 2009). Tread substrate, particularly whether the trail is hardened with rock or gravel, has been shown to impact soil loss on steep and/or equestrian trails (Aust, 2005). Regardless of methods, drainage metrics have only been significant in two studies (Olive & Marion, 2009; Eagleston, 2016). Researchers have attempted to classify drainage 10 feet above a soil loss transect by estimating the amount of water that will exit the trail after a rainstorm in four categories: 25%, 50%, 75% and 100%. Distance to a built drainage feature like a water bar has also been measured in 25-foot increments, but this metric ignores out-sloped trail drainage and natural drainage features, therefore potentially overestimating distance to effective drainage. (Olive & Marion, 2009; Eagleston, 2016).

Using GIS to predict trail soil loss

A few trail-focused recreation ecology studies have demonstrated the potential of GIS methods to predict soil loss. In 2011 Tomczyk evaluated sensitivity of natural resources along trails and in 2013 Tomczyk and Ewertowski used a regression tree analysis to determine the best layout for future trails. More importantly for this study, the most explanatory soil loss regression models have included GIS variables. A 2005 dissertation study by Cakir found that multi-scalar models inclusive of GIS methods such as curvature, aspect, and slope explained 0.63 R^2 of maximum incision compared to 0.42 R^2 with field data alone. In 2016 Eagleston expanded on Cakir's methods with several GIS tools and methods including Watershed, Flow Length and Curvature, as well as a precipitation model. Eagleston's model had a determination coefficient of 0.59 R^2 with CSA soil loss as the response variable. Both Eagleston and Cakir cited resolution of digital imagery as a limiting factor, as the best resolution digital elevation model a park manager can likely obtain is one meter (usually wider than the trail).

Project Objectives

The overall goal of this project is to support PPR's management efforts to improve the quality of recreation infrastructure and minimize impacts in Forest Park. Specifically, this study is designed to provide quantitative data on estimated trail soil loss to supplement PPR's trail class condition assessment. The project meets the following objectives to:

Develop estimates of soil loss for Forest Park trails and identify drivers of the problem.

- a Adapt methods from the literature to conduct field assessments of trail soil loss.*
- b Apply field and GIS-based methods to determine the explanation of soil loss by grade and other management-related predictor variables.*

Incorporate estimates of trail soil loss and layout into an overall assessment of sustainable trail layout in Forest Park

- a Provide recommendations for future studies and management actions.*

Methods

Study Area

Forest Park is a 5,200-acre urban forest reserve with 70 miles of trails, including 30 miles of the National Recreation Trail designated Wildwood trail (PPR, n.d.). The park is part of the Tualatin Mountains adjacent the Willamette River and Oregon Coast Range (PPR, n.d.) Logging, fire and road introduction have created a novel ecosystem with no analog, yet much of the park has native northwest forest qualities (Dresner et al., 2017; personal observation). It was famously preserved by civic action and reports

of slopes unsuitable for development (NRMP, 1995). These reports were merited, as terrain in Forest Park is steep and prone to mass movement (NRMP, 1995).

The Central Management Unit (CMU) was selected as a sample from the greater Forest Park due to centrality and area (43% of the park; Figure 1). Use levels are assumed to be intermediate between the remote north unit and suburban south unit based on distance to downtown Portland (Elliot et al., 2012). Soils are exclusively Portland Hills Silty Loam, decreasing the necessity of controlling for soil texture (NRMP, 1995). I excluded horseback riding and mountain biking trails from this study to focus on soft-surface pedestrian trails. I included sections from ten trails from each of the four present condition classes were included in the study, with 50 percent representing the extensive Wildwood trail.

Selection of Trail Sections for Sampling

Sampling began following completion of the trail condition class assessment described above. I uploaded spatial condition class data to ArcGIS Pro then clipped with a CMU polygon to omit the north and south park units. I then excluded fire lanes and other “road-like” trails (>2 meters wide) before converting my new data to a table in excel. I used the RAND function in excel to randomly select 10 sections from each of the four condition classes found in the study area (there were no ‘very good’ sections). Finally, I imported data for the 40 total selected sections back into ArcGIS Pro and selected them in the GIS environment to display their spatial distribution (see Figure 4).

Each section had three sub-sample points where observations were recorded. The process began by generating endpoints for each section in ArcGIS Pro to pinpoint their latitude and longitude. The first sub-sample point for each section was based on section length and was calculated in a random number generator. Trail sections were rarely exactly 250 feet long, but a 250-foot section serves as the best example for this process. For a 250-foot section I subtracted 15 feet from section length then divided by three, providing an equal distance of ~78 feet between each point. I then used a random number generator to find a number between 15 and 78 for a starting point. Subtracting 15 from section length created a buffer to account for GPS inaccuracy and ensure each point was within the desired section.

The actual point sampling method differed from past studies due to the use of recently classified trail sections as starting points. Previous studies would begin at a randomly selected starting point, then systematically repeat measurements at a given distance such as 300 feet. Applying the new section-based approach, my sampling began at an end point for each section in the field from which we used a measuring wheel to locate our first subsample point. From there the next two subsample points were $\frac{1}{3}$ of the section length minus 15, creating 15 foot buffers for both ends of a section. Thus, a plausible scenario for a 250 foot section was measurement of indicators at 71 feet (randomly generated), 149 and 227 feet, with each point being 78

feet apart from each other ($[250-15]/3=78.3$). Once a defined survey point was reached, a transect was placed bisecting the trail to measure soil loss and other indicators described below.

Forest Park Central Management Unit

Figure 4. The Central Management Unit and trails included in the assessment. Notice the abundance of fair sections (found to exhibit minimal soil loss in this study) as well as the abundance of 'poor' (orange) and 'very poor' (red) sections in the south portion of the study area.

Field response indicators measured at each transect

Cross-sectional area soil loss and maximum Incision (post-construction tread surface).

At each sub-sample point, a string line with a dozen beads was placed perpendicular across the trail and secured by tent stakes. The line was placed at the assumed post-construction trail tread level and loose debris was removed before taking measurements (Figure 5). The beads were placed above changes in the micro-topography of the transect using the variable interval method described by Olive and Marion (2009; Figure 6). Cross sectional area (CSA) was then measured using the following formula $CSA = (V_i + V_{i+1}) \times \text{Interval (i)} \times 0.5$. Per previous literature, neither CSA nor maximum incision were recorded if the greatest distance from the current tread level to the post construction string line (maximum incision) was $< 2.5\text{mm}$ (Olive & Marion, 2009).

Figure 5. Post-construction tread surface cross-sectional area transect line placement practices by trail type. The vertical line with the greatest distance between the post-construction tread surface and the current tread surface is recorded as maximum incision. Figure from Marion & Wimpey, 2011.

Figure 6. The variable interval cross-sectional area measurement method with example. The formula is $area = (v_i + v_{i+1}) * I_i * 0.5$ for each row summed together. From Olive & Marion, 2009.

Grade

Trail grade was measured as percent slope between the center of each transect and the center of the trail 10 feet above each transect (Aust et al., 2005). Two surveyors measured grade values with a leveling rod and clinometer. On the rare instances I was without a research assistant, I placed the uphill leveling rod in a bipod and used a level to ensure the rod was exactly vertical or “plumb.”

Trail Width

Also based on past research, trail width is defined as the portion of the trail that receives >95 percent of user traffic (Olive & Marion, 2009; Wimpey & Marion, 2010). Boundaries are delineated by abrupt changes in vegetation due to original trail construction and/or hiker trampling (see Figure 7).

Figure 7. Trail width delineation. Note distinct changes in vegetation and detritus presence due to trampling by trail users.

Trail-Slope Alignment

At each transect I found the bearing of the trail using a compass, then we found the aspect of the landform bisected by the trail. The difference between these bearings is the trail-slope alignment angle (TSA; Olive & Marion, 2009). TSA values range from 0 degrees (representing a “fall-line” trail going straight up the landform) and 90 degrees (representing a trail contouring the landform; Figure 8).

Slope Alignment Angle	Degradation Potential	Trail Profile
0-22°	Very High – erosion from water draining along tread and muddiness from water trapped on treads
23-45°	High – draining water will be difficult in most places
46-67°	Low – easy to drain water while still changing elevation
68-90°	Very Low - easy to drain water but trail can't change elevation very fast

Figure 8. TSA examples. A zero-degree TSA means a trail is going straight up the landform, while a 90-degree TSA reflects a contouring, or essentially flat trail layout.

Distance to 100 percent effective drainage

This metric is the distance from a sub-sample transect to the nearest point uphill on the trail where 100% of flowing water is diverted by natural barriers, built drainage features, or outsloped trail tread (or the cross-slope of a trail perpendicular to its direction). Surveying in the winter was helpful, as was an understanding of trail drainage patterns. Experienced trail workers (and earth scientists) can read drainage processes on a trail to determine ~100 percent effective drainage. Small pebbles and forest detritus concentrations usually support this effort, but a grade finder and water were applied to the trail in cases of uncertainty.

Data preparation

The three sub-sample points for each of the 40 sections were aggregated back into their respective sections. Grade, width, drainage distance, and TSA were averaged across the three sub-sample points. CSA data from all three points in a section were summed to provide total CSA soil loss. The highest maximum incision values from sub-samples were used to provide maximum incision values for each section (e.g. maximum incision values of 4, 8 and 2 for section X would be recorded as 8).

Development of variables in GIS

Spatial Data

A 2014 bare earth digital elevation model (DEM) created by the Oregon Department of Geology and Mineral Industries yielded elevation data for this study (one-meter spatial resolution). The Oregon Metro RLIS provided the park boundary polygon and trail line features. As discussed, the trail condition class assessment from PPR provided a unique and invaluable starting point for study design.

Trail-Slope Alignment Angle (TSA)

The forty polylines representing each section were simplified and split at vertices, yielding 104 subsections. For each sub-section a midpoint feature was created (Figure 7). Using an aspect layer created from the DEM, each midpoint was assigned a numeric aspect value (0-360). After merging the midpoint features back to their respective subsections, the bearing for each subsection was calculated. TSA was determined as the difference between line bearing and aspect. Many line bearings required conversion to their backbearing, thus ensuring TSA values were not greater than 90 or less than -90.

Figure 9. Example of line simplification output. The orange line is a 'poor' trail section in the study area.

Average trail grade

Based on past studies and new tools in ArcGIS, four methods were used to calculate average section grade in GIS (see Cakir, 2005; Eagleston, 2016). First, the DEM was used to determine the elevation at each section end and the difference of these elevations was computed as *rise*. The section length was *run* and percent slope was calculated as *rise/run*. The second method was the same, only with the 104 simplified line subsections used for TSA computation input into the equation. The third method was application of the Add Surface Information tool in the ArcGIS 3D analyst toolbox. The final method involved breaking each trail section into ten-foot chunks, calculating *rise/run* of each chunk, then averaging the grade of all the chunks within each section (Eagleston, 2016). Preliminary analysis was completed on four GIS grade methods in the form of paired t-tests with response variables, attempted inclusion in the multivariate models below, and stepwise variable selection. The clear victor was the simple section rise over run method, which will hereafter be referred to as “GIS grade” (Field Grade~GIS grade t.test result=0.77).

Correlation and Linear Regression Analyses

First, I compared summary statistics between datasets with and without soil loss (19 and 21, respectively). Then I conducted Spearman’s rank correlation tests to assess all possible response and predictor combinations for correlation coefficients (ρ), which I followed by construction of multiple regression linear models to better understand drivers of soil loss in Forest Park. I built models for both response variables and included GIS grade and TSA along with all field observed predictors (grade, TSA, width and distance to 100 percent effective drainage). All models were constructed using R software version 4.0.3, and models included in findings below all met normality and heteroskedasticity assumptions. In order to build such models, response variables were both transformed. For all maximum incision models, the response variable was transformed using the Tukey ladder of powers method ($\lambda = 0.85$). CSA was cube root transformed using field data, and square root transformed for simple linear regression with GIS grade as the predictor. Applying Akaike information criterion (AIC) stepwise regression and Variable Inflation Factor functions (VIF), I reduced these models to create parsimony and eliminate multicollinearity issues. All reduced models for both soil loss variables were not significantly different than full models, except for the GIS grade CSA model due to a unique and necessary transformation (square root instead of cube root like the other CSA models). After finding the best overall model for each soil loss variable, I created simple regression models with GIS grade to compare against multivariate field predictor models. The importance of determining grade in GIS cannot be understated as doing saves serious time in contrast to field measurements. All reduced models for both soil loss variables were not significantly different than full models, except for the GIS grade CSA model due to a unique and necessary

transformation (square root instead of cube root like the other CSA models). An alpha value of 0.05 was used for all analyses in this assessment.

Sustainable Trail Layout and Condition Class Analyses

Trail sustainability is a hot topic in the literature and recent work by recreation ecologists has proposed criteria to define the term (Marion et al., 2011; Eagleston, 2016). Along with the above definition, researchers have proposed a Sustainability Rating Index model, which was validated with actual soil loss values from three of the largest objective trail impact assessments undertaken (Marion & Wimpey, 2017). The model classifies trail sustainability by soil loss response to grade and TSA, while showing soil loss increases in concert with grade increases and decreases in TSA (Marion & Wimpey, 2017).. For this assessment I simplified the model to classify trails as either sustainably or unsustainably *laid out* (or aligned). While I agree with the importance of soil loss as a key sustainability indicator, factors such as water and wildlife impacts would need to be included in a genuine trail sustainability model.

As this study and others have found TSA and grade to be collinear and grade is more significant here, TSA is excluded from my sustainable layout analysis (Eagleston et al., 2016). I classified trails as sustainably laid out if they are < 10 percent grade based on recreation ecology literature, BMPs and professional experience (Davies, et al., 2007). I use actual soil loss findings to verify my decision similarly to Marion and Wimpey's Sustainability Rating Index model (Marion & Wimpey, 2017). Finally, I examined the potential of the condition class survey as a proxy for sustainable layout, as focusing maintenance efforts on a certain class like 'very poor' may be helpful.

Key findings

Finding 1: Trail grade, (TSA), and distance to drainage explain soil loss

Sampled trail sections from Forest Park's CMU reflect a mostly well-aligned trail system with a shortage of drainage features and narrow tread reminiscent of designated wilderness area trails (personal experience). Many selected trail sections were effectively flat, likely due to high prevalence of sections from the Wildwood trail, which contours the entire length of Forest Park (n=20). Both the mean and median grade measurements of 7.6 and 4.8 percent slope were well below the ideal maximum grade of 10 percent cited in the literature and best management practices (BMPs) (Marion & Wimpey, 2017; Davies et al., 2007). Trail layout BMPs were also revealed by high mean and median TSA values of 77.8 and 87.2 degrees, significantly exceeding recommended minimum of 45 degrees. Distance to 100 percent effective drainage measurements displayed high variability, as revealed by the significant difference between mean and median findings (8.6 m and 2.6 m, respectively), and a noteworthy standard deviation of 12. Tread width initially appeared unremarkable aside from

unplanned width likely caused by the trail being built too narrow for actual use levels (see Wimpey & Marion, 2010).

Table 1. Predictor indicator observations from sections with and without soil loss.

Sections	Total	Width (cm)			Grade (% slope)			Distance to 100% Effective Drainage			TSA (degrees)		
		Mean	Median	Std Dev	Mean	Median	Std Dev	Mean	Median	Std Dev	Mean	Median	Std Dev
No Soil Loss	21	81.7	73.7	26.4	5.7	3.8	4.7	5.9	2.3	10.3	83.5	88.3	14.1
Soil Loss	19	100.9	103.7	28.7	9.8	9.3	6.1	11.5	7.8	13.3	71.5	81.3	24.1
Total	40	90.8	83.0	28.8	7.6	4.8	5.7	8.6	2.6	12	77.8	87.2	20.2

Characteristics of trail segments with and without soil loss

A total of 14,275.85 cm² of soil loss was measured in 19 of 40 trail sections. Those exhibiting soil loss had lower TSA, were steeper, wider, and further from drainage features than those with no soil loss (Table 1). Sections without soil loss had lower mean, median, and less variable grade values than those that did not (mean 5.7 percent, median 3.8 percent and 4.7 standard deviation, compared to mean 9.8 percent, median 9.3 percent and 6.1 standard deviation). TSA was lower and less variable in sections without soil loss than those exhibiting the impact, reflecting the prevalence of contouring trail design in sections without soil loss (no soil loss mean and median of 83.5 and 88.3 cm; soil loss mean and median of 71.5 and 81.3). TSA variability was notably higher in soil loss sections as values were less left-skewed than no soil loss sections (soil loss standard deviation = 24.1, soil loss standard deviation = 14.1). For trail width, variance across soil loss and no soil loss groups was not much different, although sections without soil loss were narrower than those with the measured impact (soil loss mean, median, and standard deviation = 100.9 cm, 103.7 cm, 28.7; no soil loss mean, median, and standard deviation = 81.7 cm, 73.7 cm, 26.4). Sections with soil loss had a higher distance to 100 percent effective drainage above field observation points (soil loss mean, median, and standard deviation of 11.5 m, 7.8 m, 13.3; no soil loss mean, median, and standard deviation of 5.9 m, 2.3 m, 10.3). Fifty-eight of the drainage features were grade reversals, 49 were out sloped trail and 13 were “other” such as natural features (e.g., tree roots) and constructed features that did not qualify as grade reversals (e.g., a ditch across the trail; see Figure 3).

Figure 10. Box and whisker plot comparisons of each predictor variable in sections with soil loss ($n=19$) and no soil loss ($n=21$).

Strong determination coefficients between predictor variable and soil loss observations

The Spearman's Rank Correlation Coefficient (rho) matrix displayed significant correlation coefficients (rho) between the four predictor and two response variables, ranging from rho = 0.31 (width effect on maximum incision) to rho = 0.5 (grade effect on maximum incision; Appendix C). Strong multicollinearity was observed between all predictor variable except width, with rho = 0.58 between TSA and field-observed grade standing out. By far the most significant result presented in the correlation matrix was the rho = 0.98 between CSA and maximum incision soil loss response variables. This finding suggests time consuming CSA measurements can be omitted in favor of simple maximum incision observations.

Seven multiple regression models created for this study further explained soil loss (Tables 2 and 3). The maximum incision full model significantly explained the response variable with a p-value = 0.04 and adjusted $r^2 = 0.32$. The reduced model proved to be a better fit and more accurately determine soil loss (p-value = <0.001, adjusted $r^2 = 0.35$; Table 2). The simple regression model for GIS grade and maximum incision yielded a similar output and was not significantly different from the full maximum incision model (p-value = <0.001, adjusted $r^2 = 0.26$; ANOVA $\text{Pr}(> F) = 0.18$). This suggests GIS grade alone may be sufficient to predict soil loss in the study area. Further, a model with GIS grade was strengthened by the inclusion of field derived width as verified by AIC stepwise results. While the model fit improved with width inclusion, the difference was minimal (p-value = 0.001, adjusted $r^2 = 0.28$; Table 2).

Table 2. Maximum Incision Soil Loss Linear Model Comparisons.

Variable	Full Model	Reduced Model	GIS Grade + Width Model	GIS Grade Simple Model
Field Width	1.78 ^a (0.086) ^b	1.7 (0.098)	1.44 (0.157)	
Field Grade	1.76 (0.085)	4.2 (<0.001)		
GIS Grade	-0.7 (0.494)		3.5 (0.001)	3.85 (<0.001)
Field TSA	0.14 (0.947)			
GIS TSA	-1.4 (0.181)			
Distance to Drainage	0.14 (0.894)			
p-value	0.04	<.001	.001	<.001
Adjusted r^2	0.32	0.35	0.28	0.26

^a Coefficients of Maximum Incision

^b Two-tailed t-test significance

Model output for CSA revealed similar results to maximum incision across the board, but width was not included in the CSA~GIS grade model due to non-normal data despite all common transformation methods (Table 3). The CSA full model displayed p-value = 0.004, adjusted $r^2 = 0.32$. Unsurprisingly, with the CSA~maximum incision $\rho = 0.98$, the AIC stepwise model selection outputs for CSA were similar to those for maximum incision, with the first predictors removed being field-derived TSA and distance to 100 percent effective drainage. The CSA reduced model was similar to the CSA full model, with field grade plus width being the AIC selected predictors (p-value = <0.001, adjusted $r^2 = 0.32$). As in the maximum incision model, simple regression with GIS grade as the predictor variable for CSA revealed similar outputs to the full model (p-value = 0.26, $r^2 = 0.26$). The noteworthy differences were higher residual standard error than the CSA full model and the inability of the width metric to improve soil loss explanation of GIS grade.

Table 3. CSA Soil Loss Linear Model Comparisons

Variable	Full Model	Reduced Model	GIS Grade Simple Model
Field Width	2.5 ^a (0.017) ^b	2.35 (0.024)	
Field Grade	1.58 (0.123)	3.48 (0.001)	
GIS Grade	-0.91 (0.370)		3.86 (<0.001)
Field TSA	-0.505 (0.617)		
GIS TSA	-1.7 (0.099)		
Distance to Drainage	-0.51 (0.819)		
p-value	0.004	<0.001	<.001
Adjusted r^2	0.32	0.32	0.26

^a Coefficients of CSA

^b Two-tailed t-test significance

The final reduced models explained soil loss with higher r^2 and lower p-values than most past studies, although more complex GIS models created by Cakir and Eagleston yielding higher determination coefficients ($r^2 = \sim 0.6$; Cakir, 2005; Eagleston, 2016; Marion & Wimpey, 2017). After accounting for multicollinearity between all predictor variables except width, outputs from the above models suggest that grade can be used as the sole predictor of soil loss in the Forest Park CMU. Importantly, maximum incision and CSA still explain when the GIS grade method is substituted for field grade (p-value = <0.001 and $r^2 = .026$ for both response variables). The maximum incision model r^2 output drops only 0.09 and CSA model output drops 0.06 when reduced to a

simple regression with GIS grade as the predictor. These are helpful findings for future researchers who can justify determining field grade in Forest Park using the simple section rise/run method in GIS.

While field TSA correlates with both maximum incision and CSA soil loss ($\rho = 0.43$ and 0.4 , respectively) multicollinearity of this metric with grade is evident, as seen in the AIC reduced models above and in the Spearman's correlation matrix (Appendix C). Although field and GIS TSA had lower correlations with each other, their correlations with the other variables and soil loss prediction power were similar. Modeling above suggests TSA as unnecessary to predict soil loss in Forest Park, but studies in other natural areas might benefit from the GIS methods above. Based on this study and other literature, objective trail impact assessments probably don't need to measure both TSA and grade due to their inherent interrelatedness (e.g., a TSA value of 45 degrees means the percent grade of the trail is half the grade of the landform. High TSA almost always means low grade and vice versa; Aust, 2005).

Multicollinearity with grade metrics also caused removal of distance to 100 percent effective drainage in the two full soil loss models, despite notable ρ values of 0.38 with CSA and 0.39 with maximum incision. Notwithstanding falling out of linear models early by AIC, highly significant differences in the metric were found between sections with and without soil loss (means 5.9 and 11.5 respectively). Clearly draining water off the trail is essential to minimizing soil loss as grade increases. This idea is further supported by a notable correlation between drainage and grade ($\rho = 0.53$). These results suggest there is not a perfect number of drainage features necessary to minimize soil loss without accounting for grade, meaning grade should be central to drainage feature location decision making.

Width was a unique metric in this study as it did not correlate with other predictor variables and it exhibited the lowest correlations with maximum incision and TSA. Still, AIC model reduction methods included width in final models, if for no other reason than an increased area for potential soil loss. The more notable width-related issue seen in Forest Park is the obvious creation of unplanned width due to trails being built too narrow for a popular urban forest. Matching wilderness trail width standards of 18-24 inches is aesthetically pleasing, yet doing so has led to avoidable soil loss and vegetation trampling as trail users step off the trail to avoid others.

Finding 2: Soil Loss and Portland Parks & Recreation's Trail Classifications

Inclusion of PPR's recent condition class survey promoted a stratified study design with observations from the four present condition classes. Table 4 shows the two best condition classes ('good' and 'fair') and the two worst condition classes ('poor' and 'very poor') have much different grade and TSA values compared to each other. 'Good' and 'fair' sections had low grade and high TSA, with 'good' sections almost perfectly contouring the landform ('good' TSA median = 90 degrees). Conversely, 'poor' and 'very

poor' sections are notably steeper and aligned further from the contour. As expected based on the regression model outputs, width does not help determine condition class, as the probable effect of the metric is simply increasing area for potential soil loss.

Table 4. Field observations by condition class

Trail Class	Grade (% slope)			TSA (degrees)			Width (cm)		
	Mean	Median	Std Dev	Mean	Median	Std Dev	Mean	Median	Std Dev
Good	3.4	3.5	2.1	89.4	90	1	97.5	99.7	28.7
Fair	6.3	4.6	5.1	81.9	88.3	19	80.6	71.2	28.4
Poor	10.8	11.7	6.2	71.1	77.3	19.1	90.4	93.8	33.5
Very Poor	10.2	10.1	5.7	68.8	84.8	26.9	94.8	83	25.9
All	7.6	4.8	5.7	77.8	87.2	20.2	90.8	83	28.8

Soil loss variations across condition classes

The two best condition classes together ('good' and 'fair') exhibit dramatic differences in CSA and maximum incision soil loss metrics than the two worse ('poor' and 'very poor'; Table 5). Only four out of 20 total 'good' and 'fair' sections displayed soil loss as opposed to 15 out of 20 'poor' and 'very poor' sections. There was little difference between 'good' and 'fair' classes while 'poor' and 'very poor' sections also yielded similar results to each other. 'Poor' sections had the most soil loss, the highest mean and median grade, as well as the lowest median TSA. These findings suggest that the condition class assessment can be a proxy for soil loss, which is noteworthy because the specific impact was not systematically measured for analysis (condition class assessments are fairly rapid).

Table 5. Sustainable Trail Layout

Class	Number of sections in each grade category (GIS Grade)				Percent Sustainably Laid Out Sections	Soil Loss Sections (n)	CSA Soil Loss	Maximum Incision
	0-5%	6-10%	11-20%	>20%				
Good	8	2	0	0	100%	2	685	4
Fair	7	2	0	1	90%	2	551	5
Poor	2	2	4	2	40%	8	7706	14
Very Poor	4	2	2	2	60%	7	5335	10

Trail sustainability by condition class

Recreation ecologists describe a sustainable trail as one that is laid out to limit impacts and maximize acceptable use, while suggesting both TSA and grade are the primary drivers of soil loss and therefore trail sustainability (e.g., horseback, hiking, etc.; Marion & Wimpey, 2017). Two issues with the contemporary trail sustainability definition were exposed in my study. First, as described above, TSA and grade are inevitably multicollinear so measuring both may be unnecessary. The question for other natural areas is which of the two layout predictor metrics to choose, with grade being the default best choice because it is easier to predict in GIS than TSA. Further, despite the importance of trail layout, a well-aligned trail can be unsustainable if it promotes vegetation trampling, habitat connectivity issues, and reduces water quality.

For this study, I further simplified Marion & Wimpey's sustainable trail model with GIS grade as the sole predictor of soil loss (Table 5). I compared these data across condition classes to further examine the condition class assessment as a proxy for sustainable trail layout. Both professional and past research guidance suggest that trails should rarely be steeper than 10 percent grade unless hardened by rock or gravel, so I classified trails as sustainably or unsustainably laid out based on the 10 percent grade BMP and actual soil loss from this study (Aust, 2005; Davies, 2007 et al.). The unsustainable layout group (GIS grade > 10) included 11 sections, with eight exhibiting 10129.9 cm² total CSA soil loss. On the contrary, in the sustainable layout group (GIS grade < 10), 11 out of 29 sections displayed 4,146 cm² total CSA soil loss. Ninety-five percent of 'good' and 'fair' sections (n=20) and 50 percent of 'poor' and 'very poor' (n=20) met sustainable layout criteria, suggesting 'poor' and 'very poor' trails ought to be prioritized for future maintenance.

Table 5. Sustainable Trail Layout and Soil Loss totals

Class	Number of sections in each grade category (GIS Grade)				Percent Sustainably Laid Out Sections	Soil Loss Sections (n)	CSA Soil Loss	Maximum Incision
	0-5%	6-10%	11-20%	>20%				
Good	8	2	0	0	100%	2	685	4
Fair	7	2	0	1	90%	2	551	5
Poor	2	2	4	2	40%	8	7706	14
Very Poor	4	2	2	2	60%	7	5335	10

Recommendations

Future Research

I encourage an expansion of this assessment in the CMU as a higher number of observations will strengthen findings. Similar studies ought to be conducted in the North and South Management Units, as heterogeneous use levels and trail construction methods may lead to findings divergent from this study. On that note, impact

assessments should be completed concurrently or temporally close to visitor use surveys at trailheads, perhaps in conjunction with trail user counting devices strategically placed throughout the park. Further, I recommend continued partnership with Portland State and other northwest universities for recreation ecology studies. There are bound to be other earth science students who would be happy to conduct theses and management projects that involve hiking in Forest Park.

Future studies should also include observations along fire lanes, quantification of gravel or rock hardening, and soil loss measurements at all transects. Fire lanes provide excellent infrastructure for wildfire containment but were not built with sustainability in mind, although many have been hardened with rock or gravel. Past studies elsewhere have demonstrated that trail hardening decreases erosion, suggesting a hardening metric quantifying gravel and/or rock would be useful for all trails in the park (Marion & Wimpey, 2011b; Aust et al., 2005). Although past researchers have opted not to measure soil loss variables at transects if maximum incision is < 2.5 cm or 1 inch order to save time, doing so in this study severely limited the number of sections with a CSA or maximum incision measurement to 19 out of 40 (39 out of 120 subsample points). Future research results will be more robust if soil loss measurements are taken at all transects.

Narrowing indicators based on findings from this study will save time on future Forest Park pedestrian trail impact assessments in the future. First, untransformed CSA and maximum incision measurements revealed a remarkably high Spearman's $\rho = 0.98$, meaning they are essentially the same as far as this study is concerned. CSA is much more time consuming to measure so eliminating the metric in favor of maximum incision will be very beneficial. Furthermore, this study suggests determining grade in the field may be unnecessary, and soon will be if future digital elevation models have 0.5-meter resolution or lower (see Eagleston et al., 2016). A future trail assessor could use GIS to determine the grade of all sections in a study area, then randomly selecting sections to confirm findings. In the field they would theoretically only need to measure maximum incision and width, the latter included because it isn't multicollinear with the other predictors and the extended tape measure measuring width is often at the post-construction level, from which maximum incision is measured. Distance to 100 percent effective drainage should still be measured with a focus on determining criteria for determining average drainage feature requirements by percent grade.

Ideally sampling points would be repeatable and GIS application would expand in future assessments. In the past markers have been placed to identify past transects but vandalism, natural forest processes, and aesthetic issues limit repeatability (Cole, 1983). Identifiers get removed, trees fall, and visible flagging is an eye sore. More recent studies avoided creating landmarks at transects, instead relying on transect location photos and GPS coordinates (Svajda et al., 2016). Due to micro-topographic variations and dynamic environments associated with trails, I caution against reliance

on this method, especially with standard handheld GPS units. If researchers can obtain backpack or advanced handheld Trimble GPS devices, future studies may be repeatable. Furthermore, precise field location methods allow determination of survey points in GIS. Such is likely the case for the Eagleston's 2016 dissertation, where the author used a Trimble XH, 6000 to find GIS-derived survey points in the field. Along with developing a repeatable transect method, an analysis similar to mine should be completed perhaps every five years in the future after a section or subsection is improved. Big projects and whole sections are easy to identify in the field and completing future studies that statistically show the value of trail improvement might catalyze more investment in park infrastructure. Finally, the overall potential of GIS to predict soil loss and other impacts cannot be underestimated, as seen in Cakir's and Eagleston's doctoral dissertations with soil loss determination coefficients around r^2 0.6 (Cakir, 2005; Eagleston, 2016).

Trail Management

The condition class assessment was shown to reflect sustainable trail layout and may be used as a tool to prioritize future trail maintenance. 'Good' and 'fair' sections accounted for only 9 percent of soil loss in the study in addition to being 95 percent sustainably laid out (i.e., < 10 percent grade; Table 5). Also encouraging was the fact that 50 percent of 'poor' and 'very poor' sections *are* sustainably laid out, suggesting half of them can be maintained with less expensive drainage features like reclamation of 2-5 percent outslope. According to the Forest Park Natural Resource Management Plan and observations from this study, some trails in Forest Park may require relocation to support continued use with minimal impacts (NRMP, 1995). Trail reroute efforts can directly draw on this and past trail sustainability research as well as best management practices (BMPs) for grade and drainage feature construction guidelines (Olive & Marion, 2009).

This study supports the central trail construction BMP asserting that trails in Forest Park (and most natural areas) should remain under 10 percent grade without hardening (e.g., stonework or gravel; Aust et al., 2005; Marion & Wimpey, 2017; MDOCR, 2019). In most cases, a trail on a hillside with less than 10 percent slope and a 2-5 percent out-slope can continuously shed water and minimize impacts if regularly maintained (Davies et al., 2007). Since outslope drainage may require more maintenance than resources allow, I again echo literature and BMPs in suggesting frequent construction of drainage features such as water bars and grade reversals. The average distance to a drainage feature in no soil loss sections of the CMU is 5.9 meters, suggesting a potential guideline, but actual water diverting feature construction is very site specific. Still, all sources agree that new trail construction should use natural features like rolling terrain to integrate grade reversals (Olive & Marion, 2009; MDOCR, 2019; Aust et al., 2005, Figure 3).

In unsustainable sections where realignment is too expensive or impractical I recommend construction of check dams, which are a series of steps spanning the width of the trail to decrease water velocity (Appendix D). Stone forms the most durable check dams, although large fallen limbs and imported dimensional lumber can have the same effect. Each check dam is installed to span the width of the trail with ends buried in the trail cut bank. After the wood or stone is level and solid in the trail, a level walking surface is created by back-filling the vacant space above the new check dam with stone and/or gravel. The process is repeated in a cascading effect with frequency of check dams increasing as grade steepens. Each check dam should be no higher than six inches above the previous check dam and the entire system should look like a level staircase. In fact, a staircase with continuous stone and minimal gravel has the effect of being the most durable type of check dam. Regardless of construction material, water bars should be installed throughout a series of check dams wherever water can be diverted from the trail and resources allow (see Appendix D).

Although several trail sections in the Central Management Unit did not meet sustainable layout criteria, most of them did. This especially holds true when one considers the underrepresentation of 'fair' classed trails (90 percent sustainable layout, n=312 of 481 total). While there are many 'poor' trails (n=109, 40 percent sustainable layout) and a handful of 'very poor' trails that may ultimately need realignment, most trails in the CMU can be improved by more frequent maintenance and investment in drainage infrastructure. It is noteworthy that many of the 'very poor' sections in the unit are on sustainably aligned portions of the popular Wildwood trail adjacent to the South Management Unit. Despite proximity to the southern portion of the park, this southeast part of the central unit is somewhat isolated from trailheads compared to much of Forest Park, which may explain the observed lack of maintenance and erosion on well-graded trails in that area. The fact that such degradation exists on the National Recreation Trail designated Wildwood trail could hopefully warrant public or private investment for improvements.

Funding and Labor Acquisition

The most significant barrier to monitoring and improving trails in Forest Park is a chronic lack of funding to acquire necessary resources and personnel. PPR relies on revenue from the general fund and fees from various recreation centers, the latter of which has been negligible due to COVID-19 closures (Powell, 2020). Unfortunately, the general fund supports police, fire, and other essential bureaus, while recreation center fees are insufficient and not intended to fund natural areas (Bellduboset, 2020). The COVID-19 pandemic, an 11 percent cut in maintenance funding over the past decade, and budget shortfalls discovered in 2019 have exposed the inadequacy of existing funding sources (Portlanders, 2020). The Portland Police Bureau is stretched thin,

decreasing the likelihood of any “extra” funding from the city’s general fund, while recreation centers have been shuttered due to the virus.

Fortunately, there is some hope on the horizon in the form of ballot measure 26-213, approved by voters on November 3rd, 2020. Passage of 26-213 will fund the renewal of recreation programs and reopening of facilities shuttered due to COVID-19. The five-year levy expects to generate an average of 48 million in annual revenue for PPR services while providing a funding source independent of fees and the general fund (Multnomah, 2020). Unfortunately, this amount of funding should only be enough to keep PPR programs, recreation centers, parks, and natural areas afloat, especially if city leadership can remove or decrease entry fees to allow equitable access. The new funding source may not address the \$450 million maintenance backlog and the trail rehabilitation recommended in this study, as the initial focus will be reopening essential city programs such as Stand with Refugees and Immigrants (Bellduboset, 2020; Portlanders, 2020). While COVID-19 shut down these programs, the ensuing budget decreases were likely to keep them closed in the absence of ballot measure 26-213 (Powell, 2020).

In addition to the parks levy, I recommend PPR consider an adult conservation corps potentially with funding from The Portland Clean Energy Community Benefits Fund, a local version of a “Green New Deal.” Although the actual 2021 figures may be lower this year due to lack of retailer profits, 20-25 percent of an estimated \$44-61 million annually will go to green job workforce development (Portland Auditor, 2018). While green jobs described in the ballot measure text appear to focus mostly on energy efficiency, restoration work to preserve forests for the long term can certainly qualify as a green job. There is lots of work to be done in Forest Park and lots of people who would do it for a living wage. Not everyone enjoys forests and arduous manual labor, but those who do find trailwork to be an extremely rewarding job.

Regardless of revenue sources, city, and PPR management will be challenged to devote necessary funding to mitigate and prevent natural resource impacts. The nature of trail-driven disturbances is low intensity and difficult to passively observe in the short term, yet trail impacts can have a “snowball effect,” exponentially increasing over time (Aust, 2005). While this phenomenon is certainly not as drastic as the sudden loss of summer youth programs, the costs will increase over time and impacts will become more visible to the average park user. Best management practices and recreation ecology literature assert that trail impacts are more costly the longer they are allowed to endure (Marion, Wimpey & Park, 2011a; Davies, Hesselbarth, Vachowski, 2007). In fact, observations of increasing costs due to insufficient maintenance funding have been ubiquitous throughout my 20 years working on trails in public lands. I’ve seen countless two-week projects that could have been prevented with two minutes of annual drainage maintenance. In the case of Forest Park, the snowballing cost phenomenon despite tremendous public support will likely continue without quinquennial renewal of

the 26-213 parks level and outside funding. The public needs to understand the long-term ecological consequences of underfunded trails and value of donating to the Forest Park Conservancy, a non-profit responsible for considerable quality work, or directly to PPR. Further, Pacific Northwest outdoor industry giants that financially benefit from the existence of Forest Park trails should consider making meaningful annual contributions. Future funding must reflect the popularity and ecological value of the park.

Literature Cited

Aust, M. W., Marion, J. L., & Kyle, K. (2005). Research for the development of best management practices for minimizing horse trail impacts on the Hoosier National Forest. *U.S. Forest Service Research Report*.

Ballantyne, M., Gudes, O., & Pickering, C. M. (2014). Recreational trails are an important cause of fragmentation in endangered urban forests: a case-study from Australia. *Landscape and Urban Planning*, 130, 112-124.

Ballantyne, M., & Pickering, C. M. (2015). Differences in the impacts of formal and informal recreational trails on urban forest loss and tree structure. *Journal of environmental management*, 159, 94-105.

Bellduboset, A (2020). *Portland Parks & Recreation 2020-21 Budget Review*. Portland City Budget Office. <https://www.portlandoregon.gov/cbo/article/714602>

Cakir, J. 2005. Modeling Trail Degradation Using Field and GIS Methodologies: A Dissertation, *North Carolina State University*.

Cole, D. N. (1983). Assessing and monitoring backcountry trail conditions (Vol. 303). *US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station*.

Cole, D. N. (2004). Environmental impacts of outdoor recreation in wildlands. *Society and resource management: A summary of knowledge*, 107-116.

Dale, D., & Weaver, T. (1974). Trampling effects on vegetation of the trail corridors of north Rocky Mountain forests. *Journal of Applied Ecology*, 767-772.

Davies, M.A., Hesselbarth, W., Vachowski, B. (2007). Trail Construction and Maintenance Notebook. *USDA Forest Service Technology and Development Program, Missoula, MT*.

Dresner, M., Van Winkle, J., & Copp Franz, S. (2017). Tree composition and abundance patterns differ in two watersheds of Forest Park, a large Pacific Northwest urban forest. *Arboricultural Journal*, 39(4), 208-225.

Eagleston, H. A. (2016). Integrating Geospatial Technology and Ecological Research in the Analysis of Sustainable Recreation Infrastructure. (*Doctoral dissertation, Virginia Tech*).

Elliot, D., & others. (2012). Forest Park Recreation Survey. *Portland State University and City of Portland*. <https://www.portlandoregon.gov/parks/article/317545>

Forest Park Conservancy. (n.d.). *Forest Park Facts*.
<https://forestparkconservancy.org/forest-park/facts/>

Hammit, W. E., Cole, D. N., & Monz, C. A. (2015). *Wildland recreation: ecology and management*. John Wiley & Sons.

Interagency Visitor Use Management Council (IVUMC). (2016). *Visitor Use Management Framework: A Guide to Providing Sustainable Outdoor Recreation*.

Kidd, K. R., Aust, W. M., & Copenheaver, C. A. (2014). Recreational stream crossing effects on sediment delivery and macroinvertebrates in southwestern Virginia, USA. *Environmental Management*, 54(3), 505-516.

Larson, C. L., Reed, S. E., Merenlender, A. M., & Crooks, K. R. (2016). Effects of recreation on animals revealed as widespread through a global systematic review. *PloS one*, 11(12).

Leung, Y. F., & Marion, J. L. (1996). Trail degradation as influenced by environmental factors: A state-of-the-knowledge review. *Journal of soil and water conservation*, 51(2), 130-136.

International Mountain Biking Association. (2004). *Trail Solutions: IMBA's Guide to Building Sweet Singletrack*. International Mountain Biking Association.

Manning, R., Valliere, W., Anderson, L., McCown, R. S., Pettengill, P., Reigner, N., ... & Hallo, J. (2011). Defining, measuring, monitoring, and managing the sustainability of parks for outdoor recreation. *Journal of Park and Recreation Administration*, 29(3).

Marion, J. L., & Leung, Y. F. (2001). Trail resource impacts and an examination of alternative assessment techniques. *Journal of Park and Recreation Administration*, 19(3), 17-37.

Marion, J. L., Wimpey, J. F., & Park, L. O. (2011a). The science of trail surveys: Recreation ecology provides new tools for managing wilderness trails. *Park Science*, 28(3), 60-65.

Marion, J. L., Wimpey, J. F., & Park, L. (2011b). Informal and formal trail monitoring protocols and baseline conditions: Acadia National Park. *Virginia Tech College of Natural Resources & Environment*.

Marion, J. L., & Wimpey, J. (2017). Assessing the influence of sustainable trail design and maintenance on soil loss. *Journal of environmental management*, 189, 46-57.

Massachusetts Department of Conservation and Recreation (MDOCR). (2019). *Trails guidelines and best practices manual*. State of Massachusetts: Boston, MA.
<https://www.mass.gov/files/documents/2019/07/26/DCR%20Guidelines%20July%202019.pdf>

McAllister, D., & Others. (2011). *Forest Park Desired Future Conditions*. City of Portland.
<https://www.portlandoregon.gov/parks/article/335638>

Multnomah County Elections Division. (2020). *Ballot Measure 26-213*.
<https://multco.us/elections/ballot-measure-filings-november-2020-general-election>

National Park Service. (1983). *NPS Trails Management Handbook*.
https://home.nps.gov/orgs/1804/upload/NPSTrailsManagementHandbook_1983.pdf

Portlanders for Parks. (2020). *Measure 26-213*. <https://portlandersforparks.org/about-the-levy>

Powell, M. (2020, October 12). *Measure 26-213 asks voters to fund Portland parks, community centers*. Oregon Public Broadcasting.

Olive, N. D., & Marion, J. L. (2009). The influence of use-related, environmental, and managerial factors on soil loss from recreational trails. *Journal of environmental management*, 90(3), 1483-1493.

Oregon State Parks. (2016). *Oregon Trails 2016: A Vision for the Future*.
<https://www.oregon.gov/oprd/PRP/Pages/PLA-statewide-trails.aspx>

Outdoor Industry Association. (2017). *Oregon Recreation Report*.
https://outdoorindustry.org/wp-content/uploads/2017/07/OIA_RecEcoState_OR.pdf

Pickering, C., & Mount, A. (2010). Do tourists disperse weed seed? A global review of unintentional human-mediated terrestrial seed dispersal on clothing, vehicles and horses. *Journal of Sustainable Tourism*, 18(2), 239-256.

Portland Parks & Recreation, Planning Bureau. (1995). *Forest Park Natural Resource Management Plan*. <https://www.portlandoregon.gov/bps/article/103939>

Portland Parks & Recreation. (2009). *Trail Design Guidelines for Portland's Park System*. <https://www.portlandoregon.gov/parks/38306?a=250105>

Portland Parks & Recreation. (2019). Portland Parks & Recreation Trail System Condition Class Assessment. Location: City of Portland PPR and Asset Management.

Portland Parks & Recreation. (n.d). *Forest Park*. <https://www.portlandoregon.gov/parks/finder/index.cfm?action=ViewPark&ShowResults=yes&PropertyID=127>

Semlitsch, R. D., & Bodie, J. R. (2003). Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. *Conservation Biology*, 17(5), 1219-1228.

Svajda, J., Korony, S., Brighton, I., Esser, S., & Ciapala, S. (2016). Trail impact monitoring in Rocky Mountain National Park, USA. *Solid Earth*, 7(1), 115-128.

Tomczyk, A. M., & Ewertowski, M. (2013). Planning of recreational trails in protected areas: Application of regression tree analysis and geographic information systems. *Applied Geography*, 40, 129-139.

United States Forest Service. (n.d.) *Sustainable ATV Trails: Grade Reversals*. https://www.fs.fed.us/t-d/atv_trails_site/build/keeping-water-off-the-trail/grade-reversals.html

Van Winkle, Jill Elise, "Informal Trails and the Spread of Invasive Species in Urban Natural Areas: Spatial Analysis of Informal Trails and their Effects on Understory Plant Communities in Forest Park, Portland, Oregon" (2014). *Dissertations and Theses*. Paper 1841. https://pdxscholar.library.pdx.edu/open_access_etds/18410.15760/etd.1840

Wimpey, J. F., & Marion, J. L. (2010). The influence of use, environmental and managerial factors on the width of recreational trails. *Journal of Environmental Management*, 91(10), 2028-2037.

Appendixes

Appendix A: Condition Class Assessment Guidelines

Rating	Guidelines
1	<ul style="list-style-type: none"> • Brand New, just established, or recently maintained to restore condition • Tread meets all guidelines; well-defined tread with proper outslope • No pumping or sunken • Surface material is well distributed over the trail • Density of surface material is good • Surface is well graded and stable
2	<ul style="list-style-type: none"> • Surface material is not well distributed over < 10% • Tread condition outside of guidelines <10% • No pumping or sunken • Density of surface material is good • Surface is well graded and stable
3	<ul style="list-style-type: none"> • Surface material is not well distributed over 10% - 30% • Tread condition outside of guidelines 10-30% • Pumping or sunken is less 4.0"; erosion and/or muddiness <10% of tread • Density of surface material is fair, needs some soil amendments/hardening
4	<ul style="list-style-type: none"> • Surface material is not well distributed over 30% - 60% • Tread condition outside of guidelines 30-60% • Pumping or sunken is 4.0" – 6.0"; erosion and/or muddiness 10-30% of tread • Density of surface material is poor; almost no hardening
5	<ul style="list-style-type: none"> • Surface material is not well distributed over > 60% • Tread condition outside of guidelines >60% • Pumping or sunken is > 6.0"; erosion and/or muddiness >30% of tread • Density of surface material is poor; no hardening

Appendix B: 2009 Trail Design Guidelines: Hiking Trail

Appendix C: Spearman's Rank Correlation Coefficient Matrix

Appendix D: Check Dams and Stone Stairs

This staircase is also an example of a series of check dams, with the effect of slowing water on the trail and minimizing erosion (stairs and check dams have the same effect and are often used interchangeably by trail workers). Creative commons photo obtained at <https://pxhere.com/en/photo/738062>.

A stone staircase I built in Olympic National Park. Continuous stone staircases like this function as high quality check dams. Prior to construction, these rocks were in a chaotic jumble with water coming from up-trail and a seasonal stream to the left of the staircase. Soil loss and safety issues are no longer here. Photo by the author.