Justin Drew

# An “Emerald Necklace” for the UMBC Campus

**Abstract**

Greenways have been shown to improve the quality of green spaces in terms of both environmental health and outdoor recreation. The fieldwork and analysis discussed here aim to determine where a greenway would be most effective and most feasible. Green spaces considered in this study were campus areas that whose land cover was predominantly woodland, and they were weighted in the connectivity analysis based on area relative to a 0.5-ha theoretical habitat requirement. The final number of study areas was eleven. The network configurations used to suggest possible connections were Paul Revere and Single Loop, and were then evaluated by the Gamma, Beta, and Cost Ratio indices. In the end, results showed that a Single Loop configuration involving all of the nodes produced the best network, but this would still require renewed maintenance of existing trails before the creation of new ones.

**Keywords: connectivity, green space, greenway, UMBC**

## Introduction

### Background

The “Emerald Necklace” is a famous greenway network in Boston, MA that is notable not only for connecting 30+ miles of parks throughout the city and surrounding area, but also for the multi-layered benefits it provides to the environment and human population. Mell referred to it as “an example of how a network can provide ecological (flood mitigation, habitats), economic (tourism, employment) and social (health, social cohesion) benefits for both the residents of… and visitors to the city,” (Mell, 2008). According to that paper, Olmsted originally designed the Emerald Necklace to combat flooding from the nearby Charles River, and the other benefits arose naturally as a result of linking the parks. This is why Mell goes on to describe this famous network as an antecedent of the modern concept of green infrastructure.

Benedict describes green infrastructure is described as “an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations,” (Benedict et al, 2002). For the purposes of this paper, the term “green space” is defined as an enclosed area within a developed space that has tree cover, and the connections between them will be called by the related term “greenway.” The reason this network is considered “infrastructure” is because these connections form an underlying support for the health of the ecosystem and its continued ability to provide ecosystem services.

In addition, green spaces, whether they be managed parks or natural environments, have been associated with the promotion of physical and psychological health benefits for human visitors. In fact, Mitchell has shown the presence of these spaces provide these benefits regardless of the conditions of the surrounding areas (Mitchell et al., 2015). The greenways linking these spaces are important not only to the health of these spaces, but also to the usability of these spaces in general. On a college campus, this is especially important as a means of stress relief for students.

However, there are few tools that measure such benefits in a quantitative way. Most quality assessment tools have tended to focus on physical activity alone, but the Natural Environment Scoring Tool (NEST) developed by Gidlow was intended to provide a means of measuring green spaces in terms of a variety of uses, including socialization and relaxation (Gidlow et al., 2017). According to Gidlow, the goal of NEST is to provide an “objective” quality assessment method for a variety of typologies (i.e. Urban Park, Woodlands, Lake, etc) that can be conducted “in situ” as opposed to using a GIS with remote-sensed imagery. This allows analysis to be conducted using the most up-to-date information possible, that being whatever is there on-the-ground in the moment of study.

To relate NEST back to the original point of mental health benefits, a past study by Wood found that higher NEST scores correlate with higher reported “psychological restorative benefits,” (Wood et al, 2018). Without having the time to conduct a species inventory at each study area, this provides a good shorthand for predicting biodiversity in these areas, which has shown the strongest connection to improving mental health.

The UMBC Campus is an interesting landscape for this analysis for several reasons. The campus itself is situated on a hill such that the north side of campus is at a noticeably higher elevation than the south side, which is flat at the entrance traffic circles and the main academic buildings just beyond there, with steep hills beyond that scaled by roads and staircases. The majority of campus buildings are within loop formed by Hilltop Circle with several marked crosswalks, but even so crossing can difficult or even hazardous at intersections of Hilltop Circle and roads leading off-campus. This is especially true at the southern entrance where are no marked crosswalks. Such hazard areas complicate the ultimate aim of this analysis to connect these green spaces, but more on that later.

Another reason that the campus is an interesting landscape is the existing functionality of its green space. With the exception of the Sculpture Garden just outside the Knoll (H4), these spaces are primarily used as conservation sites. Indeed, the meaning of the name CERA (H2) is “Conservation and Environmental Research Areas,” and the other prominent green space on campus, Herbert Run (H6S and H6N), is a frequent place of study for GES classes. Implementing a greenway to connect these spaces and others on campus would expand this existing functionality to include social and health benefits to the students on this campus for the reasons outlined earlier. A tangible way to see one of these benefits is to look at the current walking route recommended to new UMBC students: the loop formed by the interior sidewalk of

Hilltop Circle. This is about a one-and-a-half mile walk without much to look other than buildings. From Figure 1, it's clear that this route does pass by the Knoll (H4) and the Hillside Woods (H9), but what's not visible on the map is near lack of obvious entry points. The sidewalk-facing foliage at H9 is dense to the point of impassibility, and the Knoll can only be accessed by simply leaving the sidewalk at the western edge before the slope down from the sidewalk becomes uncomfortable to descend. A clear trail through both of these areas would provide better scenery to relax the student and, as the results of the potential network configurations will show, a much longer route to encourage physical activity.

Prior Knowledge

Taylor showed that, in a landscape, the ecological importance of patch connectivity is its significance to animal movement and resource distribution within a landscape (Taylor et al, 1993). Historically, the green spaces on the UMBC campus have been discrete patches, completely disconnected from one another by roadways and a lack of navigable trails. This changed with the construction of the Herbert Run Greenway in 2015, and the resulting student testimonials on the website make it clear that greenways have an appreciable effect of making students aware of the green spaces and trails as places of relaxation (Herbert Run Greenway website, 2016).

Objectives

The primary objective of this study was to get NEST scores for green spaces on campus with the intent of examining their spatial relationships and how that did or did not affect the scoring. If the result of this showed that the spaces connected by the Herbert Run Greenway (see Figure 3) have a higher average score relative to other spaces on campus, this analysis would be furthered along to pursue the secondary objective of suggesting a new greenway to connect all, or as many as possible, of the green spaces on campus in a way that would be not only be feasible, but also provide effective corridors for human and animal use.

Hypotheses

Because the study areas on the southern side of campus are involved in an existing, developed greenway, those areas were expected to have a significantly higher NEST score than those at other locations around the campus. This would support a theory that the NEST score is sufficient for measuring the usability and value of these spaces for people on campus. If that was the case, NEST scores could also be used to evaluate the effectiveness of new greenways after they've been implemented. Additionally, it was expected areas that were nearer to each other would have more similar scores.

## Methods

Data Collection

Data was gathered through completing the NEST survey during site visits on two separate days. The first day of fieldwork had fair weather, and the following sites were visited during the time period from 9:00AM to 3:00PM: the CERA (H1), Pigpen Pond (H2), the woods near the AOK pond (HA), the woods around the northern half of Herbert Run on campus (H6 North), the woods in the southern portion of Herbert Run (H6 South), the northern part of the wooded area to the west and southwest of Campus (H3), and the north and east sections of the stream from Pigpen Pond to CERA (C1). There was originally another candidate study area in the traffic circle at the southern entrance to campus, but it was determined inaccessible due to the near-constant flow of traffic in that area (See Figure 1 for a map of the final study areas).

Sample points within each study area were selected systematically on a 60-m grid as a guideline for traveling to sites within each study area to make observations so that when the NEST survey was completed at the end of the visit, the results could be reflective of the entire area rather than just the spot at which the 47-item survey was completed. These points were more guidelines than mandatory observation points because they were selected using remote imagery which obfuscated on-the-ground obstacles and terrain differences that made getting to some of the selected points impossible.

The remaining areas, including parts of larger areas unvisited during the first day of fieldwork, were visited two weeks later. The weather was overcast that morning and it had rained recently, so conditions were noticeably different. The following locations were visited during the time period from 9:00AM to 2:00PM: the Knoll (H4), the remainder of the stream connecting Pigpen and CERA (C1), the wooded area south of Poplar Avenue (H5), the woods north of Hillside Apartments (H9), the woods northeast of Walker Avenue, and the southern end of wooded area on the southwest border of campus (H3). The weather did clear up by the end of the period, so it should be noted that neither change in weather conditions during that day nor the changes from the first field day to the second appeared to have an impact on the scoring.

Preliminary Analysis

The survey results were converted to scores via the processing document provided with NEST. This document also included different domain weights for calculating the overall score based on the typology of the area so that the result would better reflect the value of the space for what it was. Once all the data was tabulated, the mean and standard deviance was calculated for each domain score as well as the overall score in order to get a better idea of the quality of the campus as a whole. To test the first hypothesis, the measures were taken of just the study areas involved in the Herbert Run Greenway, namely the Knoll (H4), CERA (H1), Pigpen Pond (H2), and the stream between the latter two (C1), but this table is not shown because the results didn’t differ significantly from that of all the study areas.

GIS Analysis

To test the second hypothesis, that areas closer together would have more similar scores, the study area polygons were taken into ArcGIS, attributed with their corresponding NEST scores, and put through the Spatial Autocorrelation tool, which uses the Global Moran's I statistic.

Nodal Connectivity Analysis

To accomplish the secondary goal of this analysis, a network of the green spaces and walkable paths between them had to be established. This process began with creating a shapefile in ArcGIS of the walkways visible from the remote-sensed imagery and also parts of the trackline created with a Garmin GPS during the field visits, which reflected the actual walkable paths taken through wooded areas that would have otherwise been invisible. Walkways that were visible in the remote imagery that passed directly through intersections or active construction were not included. Some parts of the trackline were also disqualified under those conditions as they were taken on a Saturday when there was limited traffic and other human activity. The shapefile was then planarized using the Advanced Editor toolbar in order to prepare it for the creation of a network dataset, which was done using the ArcGIS Network Analyst extension.

This extension provides a means of calculating the shortest path between a series of stops chosen and ordered by the user. Because of this, it was quite simple to create both the Paul Revere-style and Single Loop network configurations seen in Figure 2. In addition to the Paul Revere and Single Loop networks for all of the nodes, network configurations were also created between just the major nodes. For the purpose of this analysis, a node was considered "major" relative to the others if it was over a hectare in size and was also easily accessible. The only nodes that qualified under those conditions were the Knoll, CERA, and both parts of the Herbert Run woodland. All the rest that were of appropriate size either required going up or down a steep incline to get to it, was filled with foliage so dense that it was found to be impassable during the field visits, or both.

The fully connected configuration, created to have a baseline maximum connectivity model for the values of the connectivity indices of the other configurations, was a bit more of a challenge. From the Single Loop configuration that passed through every node, new stops had to be added in order to force links between nodes for which the shortest route between them actually was through another node. Once each network was created as a "Route" in the Network Analyst window, they were exported as a shapefile where they were planarized again to eliminate overlap from the Route doubling back on itself for the shortest route from node to node, especially in the Max model, and the geometry recalculated so that the total distance it covered would be accurate.

To ensure the network results would also reflect what would be best for the health of the patches involved, the stops at each node were ordered so that the next node to be linked had the highest level of interaction between the two based on the Gravity model,

$$G = \frac{N_a \times N_b}{D_{ab}^2}$$

where $N_{a/b}$ is the nodal weight of either node and $D_{ab}$ is the straight line distance between their nearest edges. The nodal weight was simply the area of the space multiple by 0.5, the minimum habitat area for a hypothetical indicator species derived from the minimum habitat areas of thrushes, woodpeckers, and other birds common to urban areas found in the work of Robbins (Robbins et al, 1989).

The areas were calculated by creating polygons of each green space by drawing canopy lines from remote-sensed leaf-on imagery and using the ArcGIS geometry calculator. The straight-line distance was calculated via manually drawing lines in ArcGIS between each node at the edges or vertices that appeared closest until every node was connected to every other and storing them in a shapefile.  The geometry calculator then also produced the length of each connection. With the area of each node and the distances between, the gravity interaction was calculated via a Python script written by the author that read in CSVs of both tables and produced the Gravity Interaction matrix.

Finally, after the matrix was calculated and the configurations constructed, the following connectivity indices were calculated:

$$\beta = \frac{\#\ of\ Links}{\#\ of\ Nodes} \qquad \gamma = \frac{\#\ of\ Links}{Max\ \#\ of\ Links} \qquad Cost\ Ratio = 1 - \left(\frac{\#\ of\ Links}{Total\ Distance}\right)$$

The number of nodes was simply the number of study areas and the total distance was directly calculated from the geometry of each shapefile, but determining the number of links involved took a bit more consideration. Because the networks were constructed to resemble possible greenways, none of the “links” were straight lines between the nodes. As such, some paths that appeared to be direct from one node to another were actually two links that connected to an from an intermediate node. To count the number of links as accurately as possible, each node was looked at one at a time and paths to other nodes were only counted as additional links if they passed through open areas and didn’t connect to a node that had already been examined.

**Results**

Relevant Evidence Gathered

The NEST scores were calculated and compiled into Tables 1 and 2. The overall scores themselves showed little variation and were just above average at best and far below average at worst. The individual domain scores showed a bit more variance in every category except for

Amenities and Incivilities since every study area was generally lacking in both, a moderate good for the former and the best case for the latter. Further analysis with the Spatial Autocorrelation tool confirmed what the scores were already showing: there was no significant correlation between the NEST scores of nearby areas (see Table 6). Even taking the mean and standard deviation of the scores of just the areas involved in the Herbert Run Greenway did not demonstrate significant difference from the statistics involving all the study areas. Together, these results proved both hypotheses false.

The nodal weights and the area used to calculate them are shown in Table 3, and the gravity interaction values between them are shown in Table 4. Though the interactions between C1 and both H1 and H2 are significant outliers due to the latter two being physically connected to the former, the majority of interaction levels are quite low. This is possibly due to the unit of distance used being meters, but at the scale of this study, the use of meters instead of kilometers or miles still seems more than reasonable. In either case, the network configurations constructed with the Gravity Interaction matrix as a guide are in Figure 2, and the resulting connectivity indices are in Table 5.

For a network analysis like this, the best potential configuration would the one with the lowest Cost Ratio, highest Beta, and highest Gamma, other than the Project Max, which would is considered infeasible. To explain why requires a clear understanding of what each of the indices actually mean. The Beta index can be seen as more of a general measure of connectivity in a network because it's just the number of links relative to the number of nodes. In contrast, the Gamma index is the connectivity relative to that of a theoretical, completely-connected network and is a measure of how well a given network approximates that connectedness. Finally, the Cost Ratio is cost per unit of distance, which is basically how connected a network is relative to the total distance of its links. For instance, in Table 5, it should be plain to see why configuration E had the highest cost ratio: with only one link more than configuration D, it added nearly 2 km more in distance.

The reason connectivity is so important to an ecological network has been explored by Taylor's work. He explains that a critical component to a population's survival is its ability to move through a landscape, which is directly affected by the connectivity of patches within that landscape (Taylor et al, 1993). Applying this framework to the connectivity indices above, the Beta index, as a measure of general connectivity, is directly correlated to the well-being of the species inhabiting the patches being used as nodes in the network. Similarly, the Gamma index reveals how healthy the connectedness of a network is relative to a theoretical optimum. Last but not least, Cost Ratio would also be valuable in this context as it provides an idea of how difficult a network is to traverse seeing as a higher cost ratio means longer distances between patches for an individual to cross.

Based off these explanations and from the connectivity indices in Table 5 alone, one might assume that the Project Max would be the best possible network, but as Rodrigue explains in his work on the *Geography of Transport Systems*, the construction of the Project Max network is purely to derive the Gamma index of the other models as it would be unrealistic to implement it (Rodrigue, 2017). This is true here as well due to what links can be seen in the Project Max configuration but not in any of the others pictured in Figure 2, namely those that cross the interior of the campus itself. The use of these links conflict with the stated goals of constructing a greenway on the UMBC campus: to promote the environmental health of the patches being connected and to promote social and mental health of the student population.

These links pass through Academic Row, a cluster of tall, brick buildings, and by all of the residential halls using the existing walkways there. As such, during the week, these paths are filled with students going to and from classes, so declaring them to also be part of a greenway would make no sense. From an environmental perspective, few new plants could be grown there to promote an ecological corridor for flora or fauna, and from a student perspective, this would mean that the greenway would be taking them through areas too crowded to comfortably move through that also have a pre-existing association with stressful activity for them, limiting any possible health or social benefits from its use. Given the infeasibility of the Project Max configuration, the next best choice is configuration C, the Single Loop with all nodes. Figure 4 provides a close-up of the greenway suggested by the model that goes through the studied patches and along the roads shown. Most importantly, the suggested greenway manages to hit each node and avoid most of the walkways interior to the campus.

Personal Observations

In the field, there was one observation that was made repeatedly and was only noteworthy in how rare it seemed to be: the presence of flowering plants in the study areas. UMBC has sparse usage of a certain breed of flower within the campus, but they were not present in any of the accessible areas. In fact, the most significant flower bed spotted during the field visits was located just north of H3 on a steep hill in an area surrounded by a rusting fence near a condemned building. Such flowering plants would have improved the NEST scores of the other areas had they been present, and they would likely make good decoration for a future greenway if one were to be built.

The only other pertinent observation not covered by the results is the condition of the Herbert Run Greenway. Since its mapping in 2016 for the Herbert Run Greenway website, the UMBC Event Center has been constructed at the site of the second landmark it was meant to pass through (see Figure 3). There is additional evidence that the greenway has not been maintained such as it only be marked by signs in a few places along its intended approximate 1.4

mile length (some of which were found knocked down during the field visits). Most telling, however, is the part of the trail that runs along the north border of the stadium area, which the site description refers to as the "most rugged" segment, has become overgrown and has several fallen trees to the point that what remains of the path is almost completely blocked.

**Discussion & Conclusions**

What Was Learned

Many of the smaller green spaces on campus don't seem meant for human access. They appear to all be wild and unmanaged, or built for a functional purpose. For instance, the woods by Hillside Apartments (H9) appeared to be nothing more than a large, semi-natural drainage ditch. Even the gap between the North and South Herbert Run woodlands (H6N and H6S) is a landfill meant to serve as a dam in the event the stream experiences a 1000-year flood event. Various other areas were simply too dense with vegetation for any walkable path to enter it.

There are few trails on the UMBC campus itself. In fact, outside of the Herbert Run woodland areas, which is a mostly anthropogenic structure to begin with from the location of the stream to the structure surrounding terrain, the only areas with a semblance of a path were those along the remnants of the Herbert Run Greenway. More to the point, the only observed areas that were clearly maintained were the undeveloped open spaces on campus, but, seeing as they lacked significant tree cover, they were outside the previously defined scope of this study.

Implications

With the lack of trails and density of foliage, it would seem that the campus's primary goal for the wooded green spaces on campus is conservation and research. That being the case, and with the seeming lack of care toward the Herbert Run Greenway, it is difficult to conclude with confidence that the earlier hypothesis about the existence of a greenway promoting NEST scores was indeed false. If that trail has been overtaken by the wild in the three years since its mapping, then the areas may have reverted to their pre-greenway states, which would be reflected in their scores.

It remains conclusive, though, that NEST scores do not appear have significant spatial autocorrelation. There were eleven study areas considered, many of which were significantly closer to one another than to about half of the other nodes at least, so that pattern should have manifested in the data if it existed. The observed standard deviation also speaks to the lack of range across the measured study areas.

What Would Be Done Differently

When this study was originally conceived, it was meant to more closely resemble the Rudd's work but at a smaller scale (Rudd et al, 2002). Later, circumstances changed such that those goals became infeasible and the project shifted toward the idea of greenway construction. However, the conditions for node selection did not similarly change despite the fact the the evaluation method used is perfectly well suited for evaluating treeless open spaces. If this study were done again, it may be worth considering evaluating these spaces as well. Moreover, the criteria for selecting study areas is also worth refining altogether. The simplest example of why this is necessary is the wooded area to the southwest of campus (H3). There is no actual access point to this area, and only one opening in the foliage that didn't go down an unwalkable incline. Under those conditions, and given the narrowness of the walkway along the study area, it would be unreasonable to consider it part of any greenway on campus.

Future Study

Due to the time-constraints imposed on this project, several compromises had to be made in order to perform a study that could be considered close to complete. First among them is that, relative to the goal of this project, the choice of study areas and even network configuration was arbitrary. Given that the choices were meant to mirror the framework established by Linehan, there is reason to believe that the results are reasonable for the purpose of the study, but it is worth noting that the primary references for this study were both intended for bird habitat (Rudd et al, 2002; Linehan et al, 1995), not human use. This means that several considerations that may have relevant were ignored, which was the second major compromise in this study: topography.

All throughout this paper, it has been noted that differences in elevation and steepness of inclines raised questions of whether or not certain study areas should have been considered at all. Also, the changes in elevation within or near the study areas means that the measured path lengths are inaccurate since the network dataset was in 2-D. In this particular study, the added length would not have influenced much since the Cost Ratio was almost uniform out to three decimal places. Even so, it's clear now that it would have been sensible to use topography and other factors that indicate whether an area is accessible at all to determine which areas should or should not have been included in a study about greenways for human use.

Knowing of these compromises, an important question must be asked: is the Single Loop configuration seen in Figure 2C actually feasible? Just thinking of topography, entering and exiting both H3 and H9 involves traversing a very steep incline, and once inside, these areas are not altogether walkable due to the interior terrain and lack of trails. It also must be considered whether adding trails there harm the existing functionality. In the case of H9, which is as much a drainage ditch as it is a green space, adding a walkable trail may interfere with the slope leading to the drain and some small trees may even need to be uprooted for the path to be comfortable to navigate. That being the case, it may have been better if these two areas were never considered for the study at all. Beyond the topography of individual areas, there is also the problem of the paths dictated by the links themselves, specifically the ones that cross Hilltop Circle.

The road crossings toward H7 and the H6s don't use crosswalks. As the field visits were both conducted on Saturdays, campus traffic was at a minimum, so the roads were safe to cross at almost any point. Even though the paths presented in Figure 4 are at three-way stop intersections with clear views of incoming traffic from all sides, safety and traffic law would dictate that only marked crosswalks should reasonably be considered for the construction of a new trail. The network configurations would have to be reconstructed with these considerations in mind before could think about implementing them in the real-world.

As a final consideration for future work, it must be noted that the possible correlation of NEST scores and greenway effectiveness could not be effectively disproven. Field observations of the state of the Herbert Run Greenway suggests little to no active maintenance on large parts of it, so its seeming lack of influence on the NEST scores of the areas it connected was to be expected, but cannot be conclusive given the lack of spatial correlation anywhere based on the results of the Moran's I Summary given in Table 6. In any case, the first step toward the implementation of a new greenway should be the renewal of the existing one. This would take the form of adding new signs, replacing signs that have been knocked down or vandalized, and clearing trails of debris. The part of the greenway behind the track especially (see Figure 3) needs immediate attention as it is now almost overgrown and blocked by fallen trees. After such a renewal were completed, this study or one like it should be repeated in order to determine the truth of this hypothesis. If it is correct, then the NEST scores, taken at future intervals, could be used to monitor the state of the greenway and determine which areas need the most maintenance going forward.

**Tables and Figures**

Table 1. Area and NEST Scores

| Area | Full Name | Typology | Overall Score |
|---|---|---|---|
| H1 | CERA | Woodland | 51.6 |
| H2 | Pigpen Pond | Pond | 43.3 |
| H3 | SW Woods | Woodland | 48.3 |
| H4 | Knoll | Woodland | 55.2 |
| H5 | Woods South of Poplar | Stream | 37.9 |
| H6S | South Herbert Run | Woodland | 46.3 |
| H6N | North Herbert Run | Woodland | 56.2 |
| H7 | Woods near Walker | Woodland | 51.7 |
| H9 | Woods near Hillside | Woodland | 44.7 |
| HA | Woods West of AOK | Woodland | 39.0 |
| C1 | Pigpen-CERA Stream | Stream | 37.4 |

Table 2. NEST Average Domain Scores and Standard Deviation

| Domain | Mean | SD |
|---|---|---|
| Accessibility | 34.34 | 18.23 |
| Recreation | 3.79 | 3.78 |
| Amenities | 64.77 | 5.06 |
| Natural Aesthetics | 36.36 | 22.82 |
| Non-Natural Aesthetics | 0.00 | 0.00 |
| Incivilities | 94.95 | 5.80 |
| Signature Natural Features | 60.61 | 13.48 |
| Usability | 26.45 | 9.59 |
| Overall | 46.51 | 6.70 |

Table 3. Area Size and Nodal Weights

| Area | Full Name | Size (ha) | Nodal Weight |
|---|---|---|---|
| C1 | Pigpen-CERA Stream | 3.8 | 7.7 |
| H1 | CERA | 24.2* | 48.3 |
| H2 | Pigpen Pond | 3.3 | 6.6 |
| H3 | SW Woods | 24.0* | 48.1 |
| H4 | Knoll | 2.6 | 5.1 |
| H5 | Woods South of Poplar | 1.1 | 2.2 |
| H6N | South Herbert Run | 13.9 | 27.8 |
| H6S | North Herbert Run | 7.3 | 14.6 |
| H7 | Woods near Walker | 0.77 | 1.5 |
| H9 | Woods near Hillside | 1.9 | 3.9 |
| HA | Woods West of AOK | 0.82 | 1.6 |

*The full size of these green spaces is much larger than the actual study area observed. The NEST scores only apply to the mapped study areas, but for the gravity interaction analysis, the full size was used.

Table 4. Gravity Interactions

| | H1 | H2 | H3 | H4 | H5 | H6N | H6S | H7 | H9 | HA |
|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 37,083.8 | 5,087.0 | 0.48 | 2.2 | 0.022 | 0.052 | 0.054 | 0.0014 | 0.0064 | 0.0035 |
| H1 | 0 | 11.4 | 2.3 | 0.27 | 0.024 | 0.12 | 0.11 | 0.0049 | 0.019 | 0.013 |
| H2 | | 0 | 15.0 | 0.11 | 0.0026 | 0.022 | 0.014 | 0.0011 | 0.0043 | 0.0038 |
| H3 | | | 0 | 0.36 | 0.013 | 0.16 | 0.092 | 0.021 | 0.052 | 0.10 |
| H4 | | | | 0 | 0.0074 | 0.041 | 0.039 | 0.0014 | 0.0078 | 0.0061 |
| H5 | | | | | 0 | 0.019 | 5.15 | 0.00034 | 0.0019 | 0.00055 |
| H6N | | | | | | 0 | 46.53 | 22.48 | 6.64 | 0.023 |
| H6S | | | | | | | 0 | 0.0081 | 0.21 | 0.0076 |
| H7 | | | | | | | | 0 | 0.097 | 0.0023 |
| H9 | | | | | | | | | 0 | 0.011 |

Because the resulting matrix is symmetrical, redundant cells were left blank and the C1 column and HA row, whose only unique values were a zero, were left out altogether.

Table 5. Connectivity Indices

| Network | Nodes | Links | Total Distance (m) | Beta | Gamma | Cost Ratio |
|---|---|---|---|---|---|---|
| A. Project Max | 11 | 23 | 14,802.03 | 2.09 | 1.00 | 0.998 |
| B. Paul Revere | 11 | 13 | 7,681.58 | 1.18 | 0.57 | 0.998 |
| C. Single Loop | 11 | 15 | 7,834.13 | 1.36 | 0.65 | 0.998 |
| D. Major Nodes (Paul Revere) | 11 | 5 | 2,935.64 | 0.45 | 0.22 | 0.998 |
| E. Major Nodes (Single Loop) | 11 | 6 | 4,893.48 | 0.55 | 0.26 | 0.999 |

Table 6. Global Moran's I Summary

| | |
|---|---|
| **Moran's Index:** | -0.302901 |
| **Expected Index:** | -0.100000 |
| **Variance:** | 0.101865 |
| **z-score:** | -0.635727 |
| **p-value:** | 0.524954 |

From the full report generated by ArcGIS: "Given the z-score of -0.635727217981, this pattern does not appear to be significantly different than random."

Figure 1. Map of Study Areas within Campus Boundary (as seen in the figures of UMBC 2018 Master Plan). Figure in style of Rudd et al, 2002.

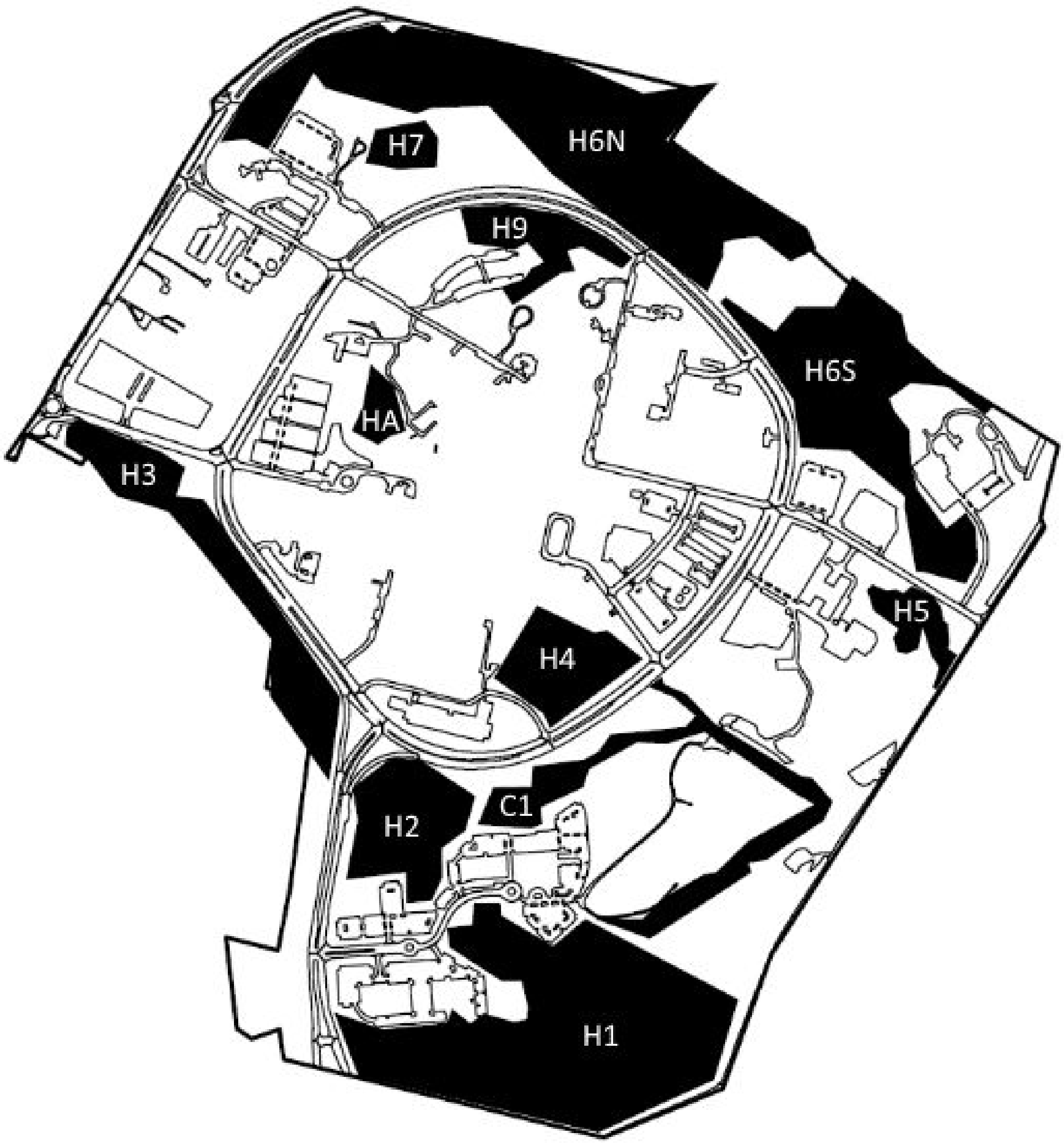

Figure 2. Potential Greenway Configurations. In style of Linehan et al, 1995.

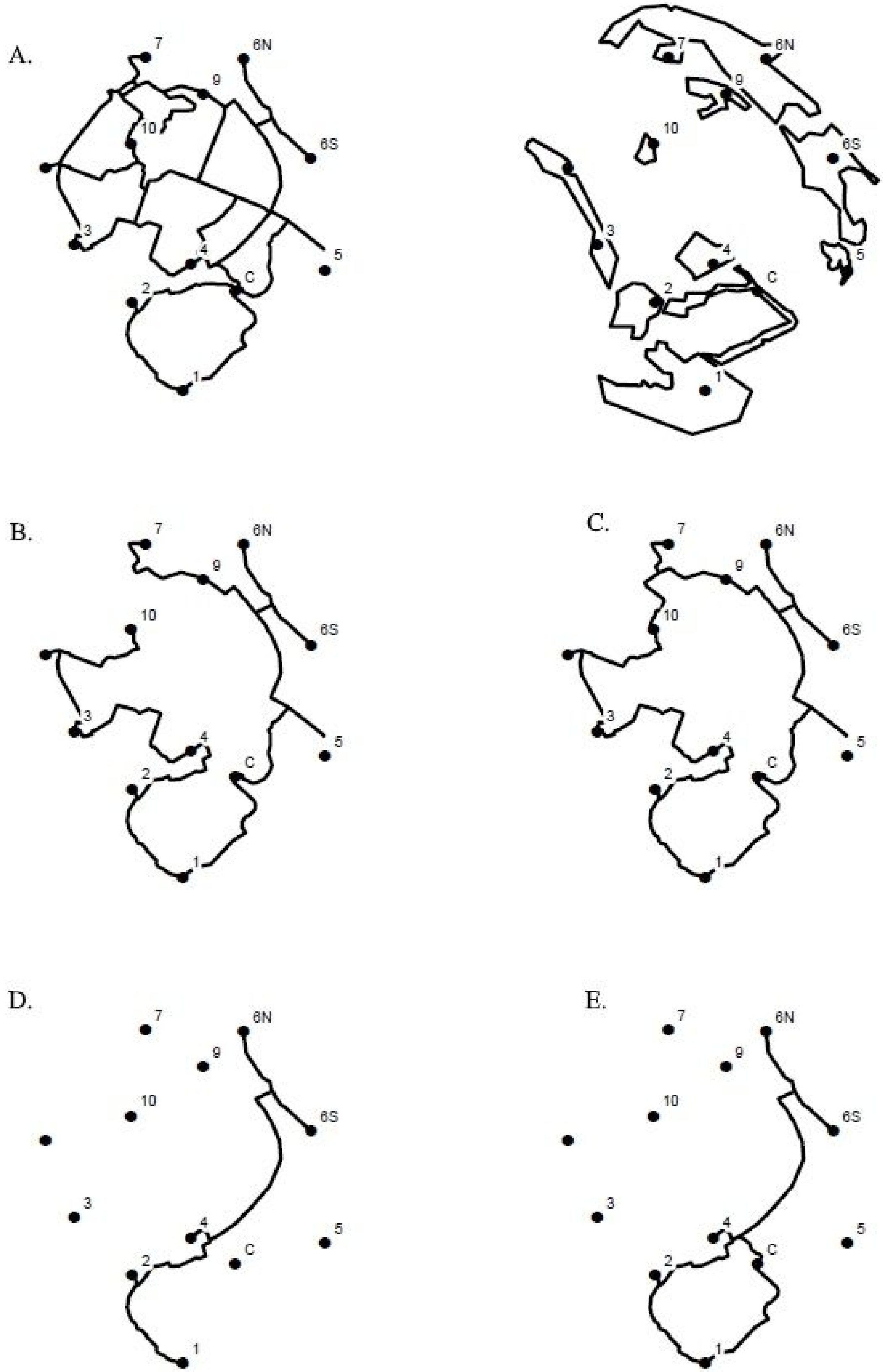

Figure 3. Approximation of Herbert Run Greenway in 2019

Figure 4. Single Loop Configuration (Close-Up)

## References

Benedict, T., and McMahon, E. (2002). Green infrastructure: smart conservation for the 21st century. [PDF] Retrieved from https://www.merseyforest.org.uk/files/documents/1365/2002+Green+Infrastructure+Smart+Conservation+for+the+21st+Century..pdf

Gidlow et al. (2017). Development of the natural environment scoring tool (NEST). Retrieved from https://doi.org/10.1016/j.ufug.2017.12.007

Herbert Run Greenway (2016). [Website] Retrieved from https://herbertrungreenway.wordpress.com/

Linehan et al. (1995). Greenway planning: developing a landscape ecological network approach. Retrieved from https://doi.org/10.1016/0169-2046(94)02017-A

Mell, I.C. (2008). Green infrstructure [sic]: concepts and planning. [PDF] Retrieved from https://www.researchgate.net/profile/Ian_Mell/publication/228664177_Green_Infrstructure_concepts_and_planning/links/54fea3f50cf2672e223fe87a.pdf

Mitchell et al. (2015). Neighborhood environments and socioeconomic inequalities in mental well-being. Retrieved from https://doi.org/10.1016/j.amepre.2015.01.017

Robbins et al. (1989). Habitat area requirements of breeding forest birds of the Middle Atlantic states. Retrieved from https://www.jstor.org/stable/3830692

Rodrigue, J. (2017). Gamma index in a graph. Retrieved from https://transportgeography.org/?page_id=6157

Rudd et al. (2002). Importance of backyard habitat in a comprehensive biodiversity conservation strategy: a connectivity analysis of urban green spaces. Retrieved from https://doi.org/10.1046/j.1526-100X.2002.02041.x

Taylor et al. (1993). Connectivity is a vital element of landscape structure. Retrieved from https://www.jstor.org/stable/3544927

UMBC 2018 Facilities Master Plan. [PDF] Retrieved from https://fm.umbc.edu/files/2015/07/2018-FMP-Report-COMPLETE-compressed.pdf

Wood et al. (2018). Not all green space is created equal: biodiversity predicts psychological restorative benefits from urban green space. Retrieved from https://doi.org/10.3389/fpsyg.2018.02320