Improving flood management and deprivation in the Water of Leith through greenspace transformation

Group 1 - Flood management

Ryan Aherin, Liwen Fan, Maria Maily,
Haziq Suhaimee, Yunshi Liang and Rebecca Zhang

12 December, 2022

Abstract

The April 2000 flood demonstrated how ill prepared Edinburgh is for extreme weather events brought on by Climate Change. Due to the failure of traditional structures there has been a move towards natural defences. Natural river and flood management encourages a natural flow of the river and storage of water in plains, while also increasing water infiltration, but these strategies require a large amount of space. Steps have been taken to introduce defences at Scottish Environmental Protection Agency (SEPA) suggested opportunity sites, but many of these have missed the opportunity to create valuable green spaces for deprived communities.

By putting more weight on deprivation, this report sets out to find a new location of opportunity along the Water of Leith, which covers the areas under most flood threat in Edinburgh. Due to the limitation of generalised models, the environmental deprivation model used here focuses on freely accessible green spaces when using the Accessible Natural Greenspace Standards, and the social deprivation model combines the Scottish Index of Multiple Deprivation (SIMD) with the 20-minute neighbourhood concept to better reflect deprived areas. This resulted in the selection of the Murray Burn at Hermiston, as opportune site. Finally there is a proposal of how this site could be transformed to best suit flood management and users, and an evaluation of it.

This report uses detailed deprivation models to propose the restoration of the Murray Burn location, to improve flood management and reduce local deprivation.

Key Words: Water of Leith, flooding, natural river management, deprivation, greenspace.

Contents

1 Introduction

Over twenty years after Edinburgh's most recent major flooding event, the city is still struggling to find solutions for weather conditions that are increasing in frequency and severity due to climate change. The breaking of boundary walls across the city brought into focus the inadequacy of traditional flood management approaches[1, 2]. The consensus is that in addition to the existing flood management, a more natural approach for the entire catchment should be taken, working with natural features and processes rather than against them. Due to the lack of available space within cities, this often requires the transformation of already existing green spaces to better aid flood management.

This report will try to answer the question of how green spaces along the Water of Leith (WoL) can be transformed to better manage floods and reduce social and environmental deprivation.

The objectives are to:

- Evaluate river and flood management approaches in the WoL catchment
- Create social and environmental deprivation models to find locations that would benefit most from an improved greenspace and flood risk reduction
- Analyse methods to maximise the river restoration at the chosen location

1.1 Water of Leith catchment

The WoL flows through the North West Pentlands, through the city, until it joins the Forth Estuary at the port of Leith, see Figure 1. Over the past 200 years the river has been heavily modified through dams, weirs, lochs, and culverts to accommodate the economy and continuous urban development. But this has led to flood vulnerability in 73 km^2 of its 122 km^2 catchment[3, 1]. After the April 2000 flood, the city of Edinburgh implemented the Flood Risk Management Act and flood prevention schemes[1], for which walls, gates and other flood defences were built. The Harlaw, Threipmuir and Harperring reservoirs were also purchased to improve management.

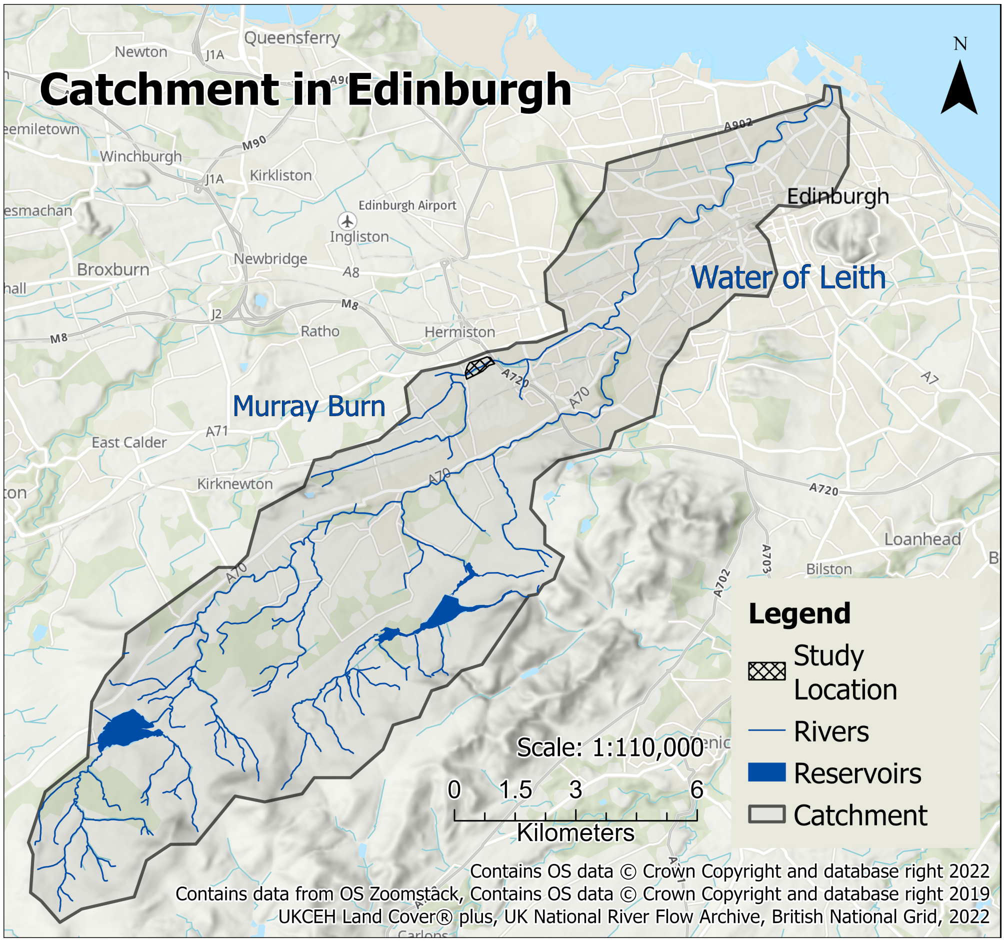


Figure 1: Water of Leith Catchment

According to Scottish Environment Protection Agency (SEPA) reviews, the catchment is of poor ecological status due to ten impassable barriers, the presence of invasive species, and sewage and farming runoff along the Murray Burn, 2 km of which are in a culvert[4, 1]. Despite the continuous riparian woodland along the main stream, increased use of the WoL Walk and new developments are causing fragmentation and deterioration of the corridor's quality.

The WoL management plan was set to address some of these issues but only focuses on 18 of the 31.7 km of the main stream, specifically on the popular WoL Walk[1]. The natural flow of this section was mostly maintained due to its hard rock river bed and has seen an increase in conservation efforts through numerous action plans. The Murray Burn on the other hand faces higher pressures with pollution and the culvert but has mostly been neglected by action plans and studies due to its smaller size.

1.2 Flooding

Due to a combination of coastal, surface and river flooding, SEPA declared 85% of the city of Edinburgh as "in need of protection", and stated that 284,000 homes, businesses and services were at risk of flooding in 2018, with an increment of 110,000 by 2080s, which could cost the government £31.5 million per year[5]. Factors such as an inadequate drainage systems, poor building construction techniques, and outdated flood defences, combined with homes and businesses already located in flood zones have amplified the risk of flooding[6, 7].

1.3 Natural river management

Natural flood management (NFM) uses natural processes to slow the flow of water through the landscape, see an overview of methods in Table 1. Creating flood plains, forests and meandering the river can have impacts such as: reducing the flood peak, water velocity and attenuating flow by slowing and storing floodwater with success ranging from 10% to 41%[8, 9, 10, 11, 12, 13]. Additional river restoration steps can aid this by securing the river banks, maximising filtration and improving the natural habitat.

Natural River Restoration Methods							
River restoration method	**Description**	**Slow down waterflow**	**Restore connectivity**	**Increase roughness**	**Delay peak**	**Storage**	**References**
Pond	A pond to store water.	✓					Turner, 2019
Leaky barrier	Formed by Timber, installed on watercourses and floodplains.		✓				Thomas and Nisbet, 2012
Brush	Planting shrub to protect the bank.	✓		✓			SEPA, 2020
Large wood & wads	Large wood and root wads on bends and fast flowing areas.	✓					Cashman, 2019
Live willow	Willows are tough and strong.	✓	✓	✓			SEPA, 2020
Catchment woodland	They can intercept, slow, store and filter water. This can help to reduce flood peaks, flood flows and flood frequency.	✓		✓	✓	✓	Krull et al., 2007
Floodplain woodland	Can slow flooding and increase the depth of water, to reduce and delay flood peaks.	✓		✓	✓	✓	Nicholson et al., 2020
Offline storage area	Provides temporary flood storage and can reduce peak flows.	✓	✓		✓	✓	Nicholson et al., 2020

Table 1: Description of natural river restoration methods

2 Methodology

2.1 Flood risk management & opportunities

For the risk map, flood data for high, medium and low risk are acquired from SEPA to observe the extent of the flooding (see Table 2). This was compared to the 2020 Scottish Index of Multiple Deprivation (SIMD) data, focusing on urban areas classified by the Digimap Land Cover Map. Only densely populated urban areas are chosen to better reflect the population affected by flooding.

The defences along the river are identified through fieldwork and gaps filled with SEPA data, which is stored in a Oracle database, to incorporate into the flood management map and webmap. Suggested opportunity locations reported by Working with Natural Processes and SEPA are taken into consideration for this project to evaluate the suitability of the proposed locations.

Dataset	Source	Year	Details on use:
Population estimate	OSGB	2021	Population numbers for data zones
Data Zone boundaries	OSGB	2011	Data zones in Edinburgh
SIMD	Scottish government	2020	Social deprivation model
WoL Catchment	UKCEH	2022	Modified to show full catchment
Phase V DTM	Fugro for Scottish Power Energy Network	2019	Flood simulation
Rivers	Digimap Environment	2017	River layer
Land use	Edinburgh Datashare	2017	SIMD filtered by land use
Flood map	SEPA	2020	Flood maps
Open Green Spaces	OS	2022	Greenspace accessibility
National Forest Inventory	Forest Research	2020	Environmental deprivation model
Natural Neighbourhoods	OSGB	2021	Create city outline
Schools	OSM	2022	Social deprivation model
Shops	OSM	2022	Social deprivation model
Health & social care	OSM	2022	Social deprivation model
Historic map	Digimap Historic	1853-1904	For website

Table 2: Overview of project datasets

2.2 Environmental deprivation

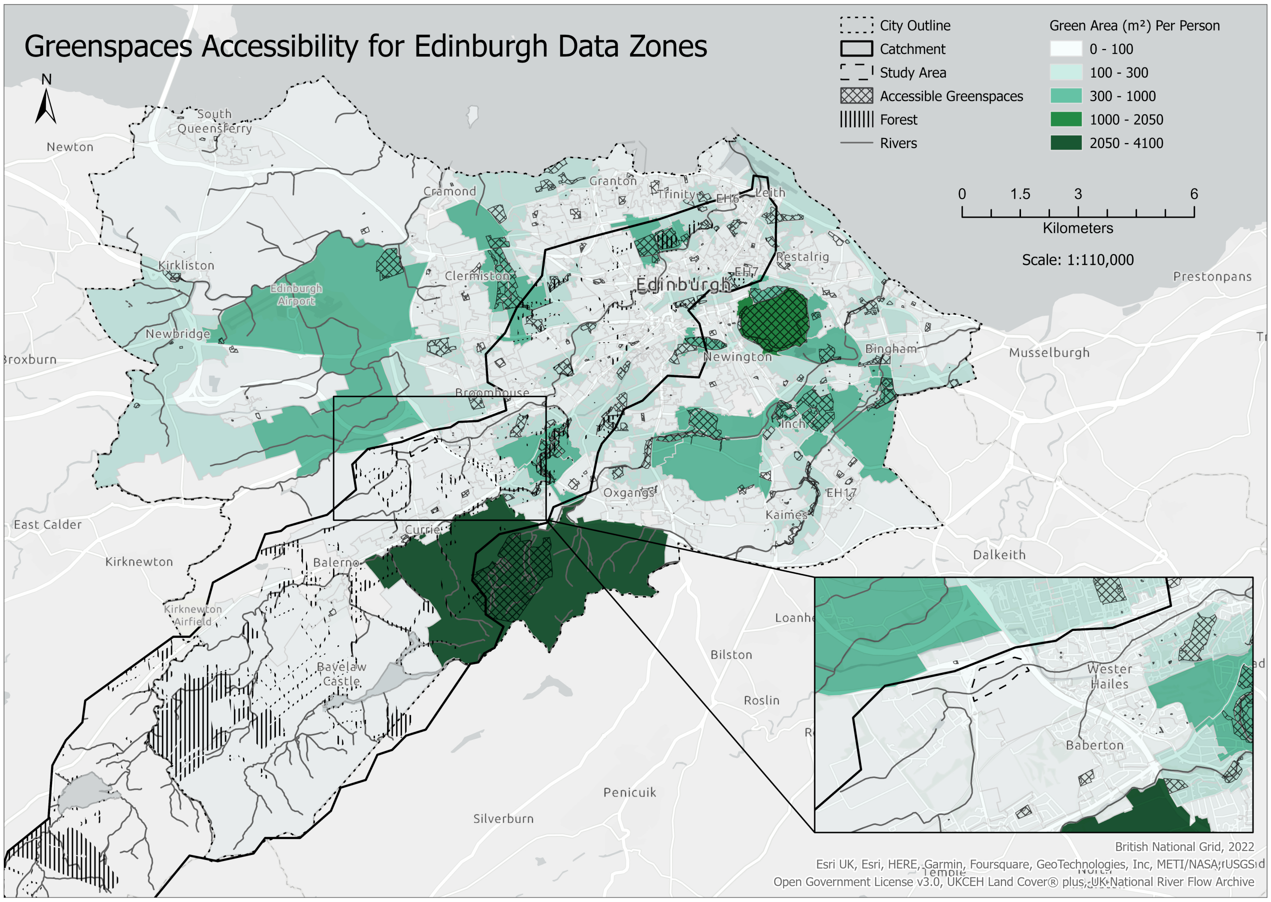


Figure 2: Access to greenspace

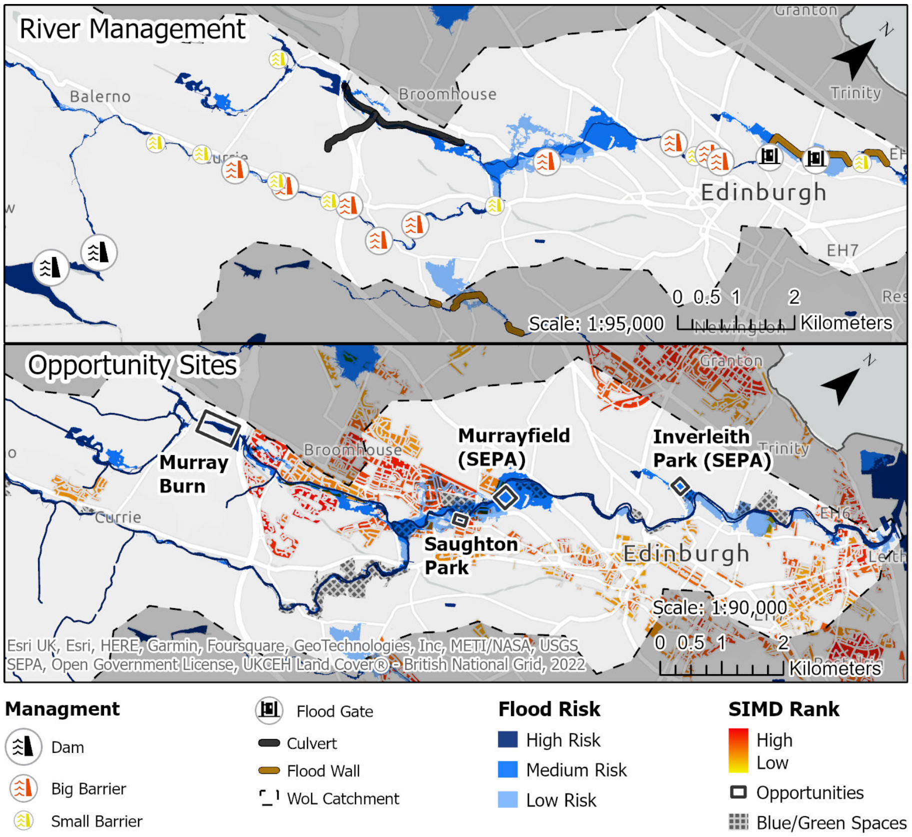
The accessibility of greenspaces of each 2011 data zone in Edinburgh is evaluated to reflect the environmental deprivation (see Figure 2). Zones with low accessibility are considered environmentally deprived. The Ordnance Survey (OS) Greenspace dataset was filtered by universally accessible greenspaces: Play Space, Playing Field, and Public Park and Garden (see Appendix 1 for descriptions). Using the Accessible Natural Greenspace Standards (ANGSt), the data zones were expanded using a 300m buffer to include greenspaces within a 4-minute walking distance[19]. Using 2021 population data, the areas of greenspaces accessible per person in each buffered zone are then calculated as the overall data zone deprivation (see Appendix 2 for details).

2.3 Social deprivation

To create a Social Deprivation Model, the potential impacts of flooding on pedestrian access to key amenities within the study zone were examined. Pedestrian service zones were created for schools, healthcare facilities and food shops based on the 20-minute neighbourhood concept, which suggests residents should have key amenities within a reasonable walking distance (800m) of their home[20]. After the service zones for each category were created, they were evaluated based on whether these amenities were within flood risk zones (see Appendix 3 for details).

3 Findings

3.1 Pressures



(a) Map of river management and opportunities


(b) Culvert


(c) Weir/Barrier


(d) Flood wall

Figure 3: River management in Edinburgh

Traditional river management (see Figure 3) like weirs, walls and culverts have been effective defences against small floods, but as seen in 2000 are not effective for bigger floods. They currently restrict the natural flow of the river and add additional pressure onto the system. The design of the culvert can easily lead to blockages due to debris, increasing the likelihood of flooding in the area[21]. The sewage system runs parallel to the culvert and its overflow is not restricted during flooding events[22].

New urban developments along the river were observed, which will not only be directly impacted by flooding, but also create more impermeable surfaces reducing water infiltration and increasing surface runoff[21].

3.2 Opportunities

Based on SEPA's Flood data, Population at Risk data and River Management data (see Figure 3), Murray Burn, Saughton Park, Murrayfield and Inverleith Park were considered flood management opportunities.

Following the natural river management guidelines, solutions such as offline storage areas, leaky barriers, creating floodplain and floodplain woodlands are to be considered. The efficiency of these methods depends on the number of storage areas and the total storage volume[23]. Considering the large amount of storage needed, Saughton Park only has limited potential as an offline storage area. Inverleith Park was deemed unsuitable for storage due to the topography of the area. Flood management schemes at Murrayfield are already improving the location. Murray Burn has frequent flooding (author's observation) and, due to the site's location in the greenbelt, it has the space required to implement a variety of methods.

3.3 Best outcome at Murray Burn

In its current state, the study area could hold 188.323 m^3 of water. To improve the current agricultural land for flood management and habitat, wads, brushes, willows and other trees would be planted along the riverbanks to increase the roughness and prevent erosion. A leaky barrier could be introduced to slow the river, creating a pond for water storage(see Figure 4).

We would build paths, benches, information points and four entrance points to maximise public accessibility of the green space. We believe this plan can be helpful to reduce the flood risk in this area and reduce deprivation.

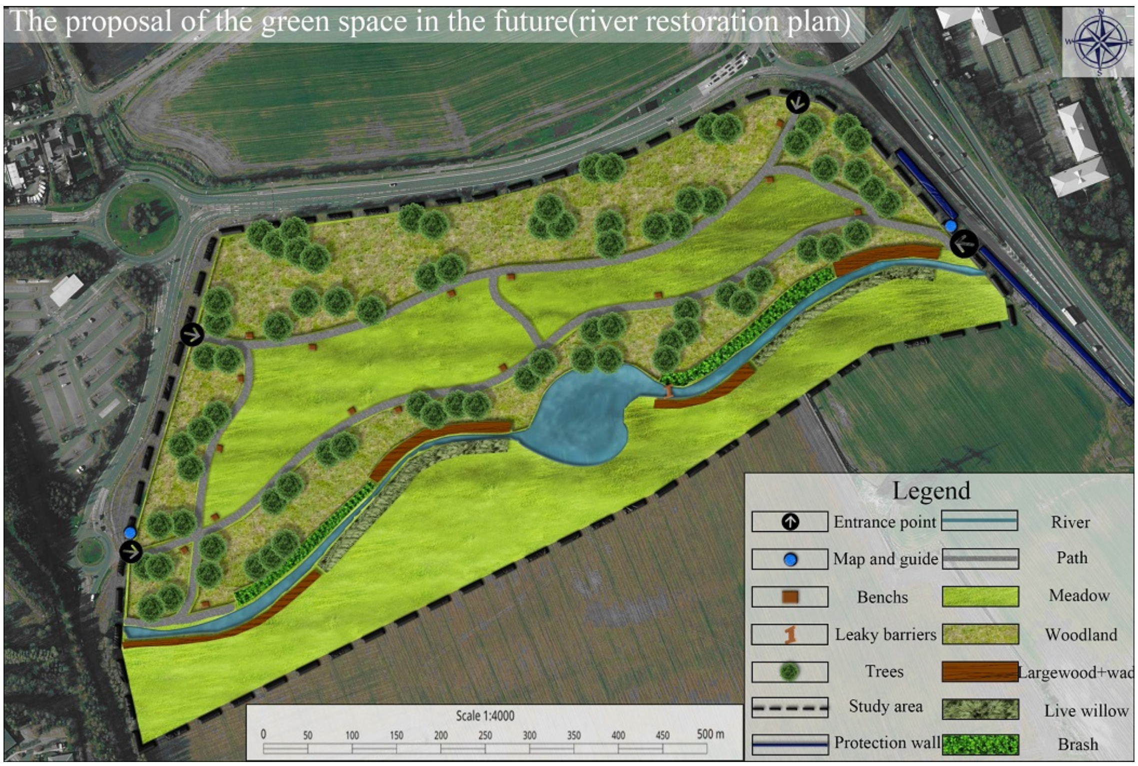


Figure 4: Proposed greenspace development

According to network analysis using the ANGSt index (see Appendix 4), an area of 10.4 km^2 , with an estimate of 1612 residents, many of them in deprived areas, would benefit (see Figure 5).

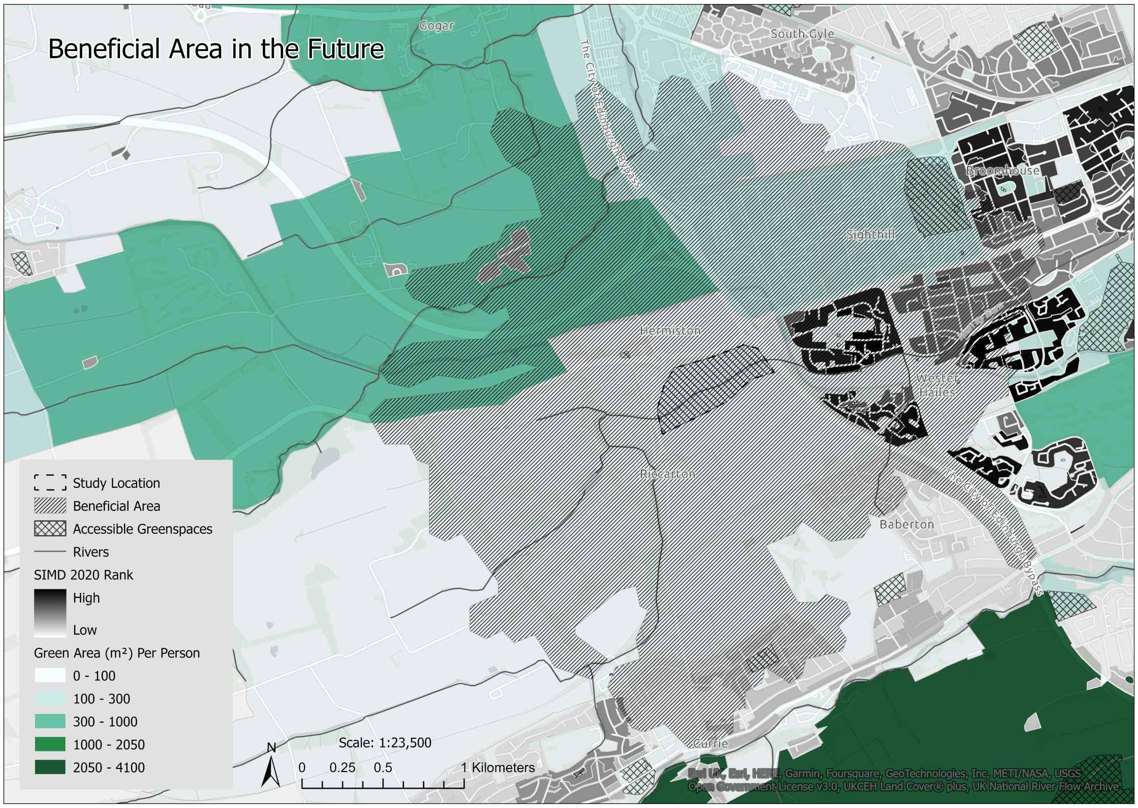


Figure 5: Improved greenspace accessibility

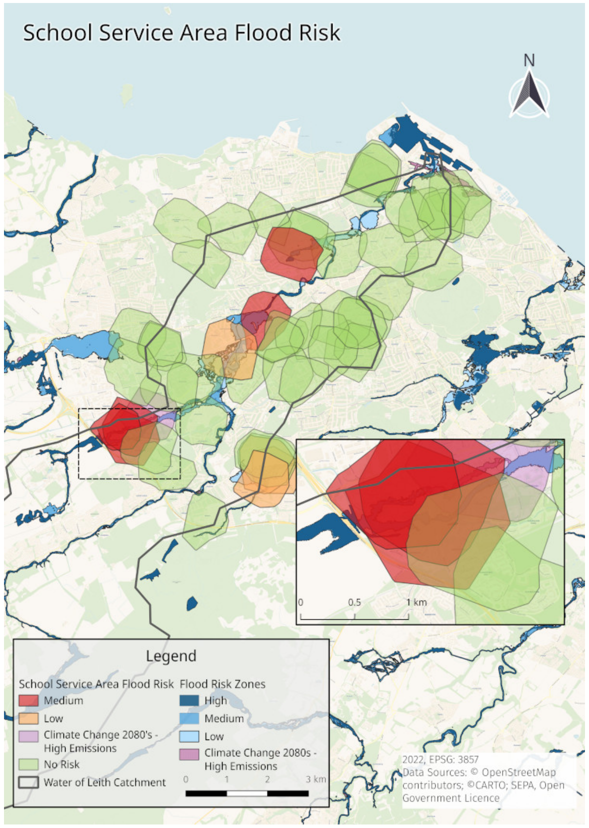
4 Discussion

4.1 Strengths

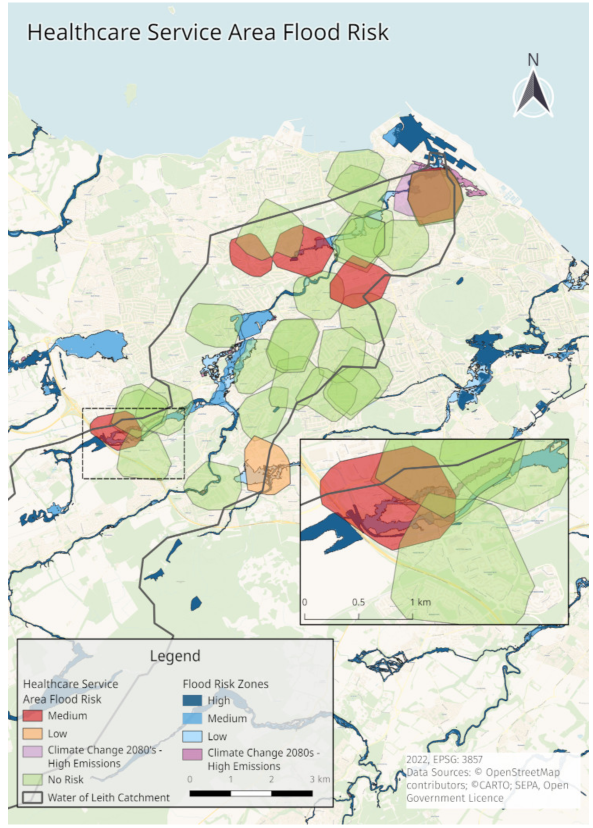
Generalised models sometimes struggle to reflect small areas accurately, we selected key methods to analyse social and environmental deprivation and modified them to improve them.

One of the key problems with the SIMD data regarding accessibility was that the Geographic Access indicator relies on automotive and public transport distances. In deprived areas, these methods of transport may be unattainable for residents. Due to the large number of green spaces with restricted access, the environmental model benefited from filtering these since deprived populations would not have access to them (see Figure 6). With the location being in the greenbelt next to the bypass, the network analysis was important to get a more accurate reflection of accessibility.

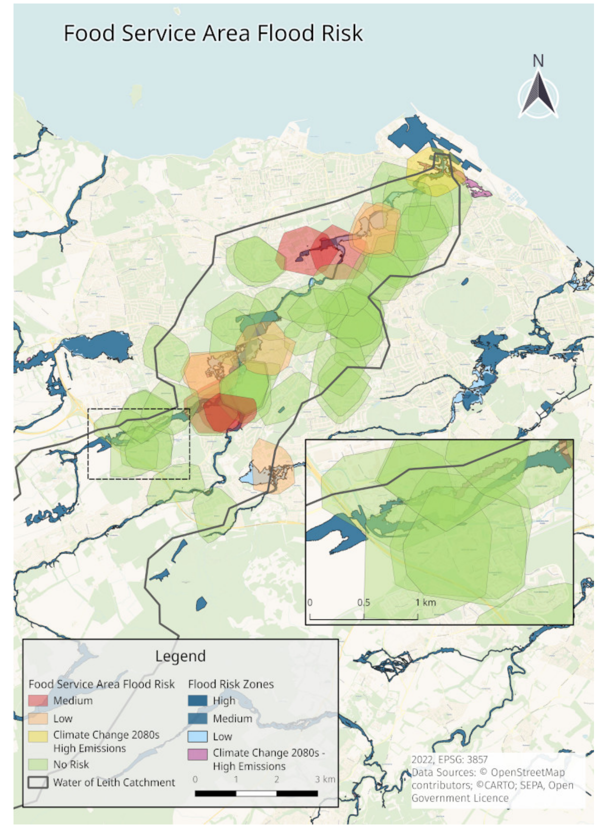
The proposed location balances the effectiveness of the flood management against the positive impact a green space would have for the neighbouring community, but SEPA opportunity sites do not take this into account. The Forth River Trust was consulted and confirmed that it is an understudied location that could be a promising location for flood management (Louis J. 2022, Personal Communications, 26th October).



(a) Flood risk to education services



(b) Flood risk to healthcare services



(c) Flood risk to food services

Figure 6: Flood risk to community amenities

4.2 Limitations

There are, however, some limitations to our approach that should be considered. Our models for urban population flood risk and population impacted by the recommended improvements relies on the data zones, which have not been updated since 2011. It is possible that demographics within these zones have since changed. Due to time and resource constraints, we only considered flooding risks to the service locations and not the pedestrian networks connecting communities to services, this could increase the level of deprivation faced by the local communities during a flood.

There are some limitations and assumptions made in our proposed greenspace development site at Murray Burn that will have to be addressed. For example, the costs of the proposed developments were not calculated, but we estimate a cost of £2 million, based on similar restorations. To provide pedestrian access to the site either via a pedestrian overpass of the Edinburgh City Bypass (A720) or by expanding the tunnel under the road in the south east section of the green space would require considerable work. Any development of the site would also require permission from the owner of the farmland. The utilities near the location are limiting the capacity and would have to be further investigated.

Finally, we found that community benefits from proposed improvements would not be limited in the short-term, but would increase in the long-term as plants and wildlife have an opportunity to establish themselves.

5 Conclusion

Based on our research, the City of Edinburgh faces the challenge to manage increasing flood risk with limited available options for improved management. Flooding poses a significant threat to worsening social deprivation within the WoL catchment, which are among some of the most-deprived communities in the city. Existing traditional flood management along the WoL contributes to environmental degradation by restricting wildlife movement and does not contribute to the reduction of environmental deprivation of local communities.

Our proposed Murray Burn site would provide much-needed flood relief for the surrounding communities and would contribute modest relief downstream. It would also improve environmental deprivation for the local community.

Further research is needed to evaluate demographic changes, since the SIMD data zones were created in 2011, in order to facilitate more accurate estimates of flood management impacts for local communities. Due to the limited availability of flood management solutions within city limits, more research should also be carried out on possible opportunities in the surrounding green belt.

The next step for the project is to set up an interactive webpage, which will be used to illustrate the current issues and opportunities to stakeholders such as the Water of Leith Society, Forth River Trust, the community and local government to increase awareness and support decision making in the hope to create change.

6 References

1. SEPA. *Forth Estuary Local Plan District 10/18 – Water of Leith catchment* Accessed: 28/11/2022. https://www2.sepa.org.uk/frmstrategies/pdf/pva/PVA_10_18_Full.pdf (2022).
2. Forbes, H., Ball, K. & McLay, F. *Natural Flood Management Handbook* Accessed: 15/11/2022. https://www.sepa.org.uk/media/163560/sepa-natural-flood-management-handbook1.pdf (2022).
3. Gittings, B. *Water of Leith* Accessed: 28/11/2022. https://www.scottishplaces.info/features/featurefirst2805.html.

4. SEPA. *Water of Leith catchment profile* Accessed: 28/11/2022. https://www.sepa.org.uk/media/75024/doc-16-water-of-leith.pdf.
5. Werritty, A., Houston, D., Ball, T., Tavendale, A. & Black, A. Exploring the social impacts of flood risk and flooding in Scotland (2007).
6. Price, D. J. & McKenna, J. E. *Climate Change: Review of Levels of Protection Offered by Flood Prevention Schemes: UKCIP02 UPDATE* (Scottish Government, 2003).
7. Evans, E. *et al. Foresight: Future Flooding Volume I and Volume II* (UK Government Office of Science and Technology, 2004).
8. Acreman, M., Riddington, R. & Booker, D. Hydrological impacts of floodplain restoration: a case study of the River Cherwell, UK. *Hydrology and Earth System Sciences* **7,** 75–85 (2003).
9. Keesstra, S., Kondrlova, E., Czajka, A., Seeger, M. & Maroulis, J. Assessing riparian zone impacts on water and sediment movement: a new approach. *Netherlands Journal of Geosciences* **91,** 245–255 (2012).
10. Sholtes, J. S. & Doyle, M. W. Effect of channel restoration on flood wave attenuation. *Journal of Hydraulic Engineering* **137,** 196–208 (2011).
11. Liu, Y., Gebremeskel, S., De Smedt, F., Hoffmann, L. & Pfister, L. Simulation of flood reduction by natural river rehabilitation using a distributed hydrological model. *Hydrology and Earth System Sciences* **8,** 1129–1140 (2004).
12. Sear, D., Kitts, D. & Milligan, C. *New Forest Life-III monitoring: the geomorphic and hydrological response of New Forest streams to river restoration* (University of Southampton, 2006).
13. Kim, H. Y. Analyzing green space as a flooding mitigation–storm Chaba case in South Korea. *Geomatics, Natural Hazards and Risk* **12,** 1181–1194 (2021).
14. Turner, R. E., Layne, M., MO, Y. & Swenson, E. M. Net land gain or loss for two Mississippi River diversions: Caernarvon and Davis Pond. *Restoration Ecology* **27,** 1231–1240 (2019).
15. Thomas, H. & Nisbet, T. Modelling the hydraulic impact of reintroducing large woody debris into watercourses. *Journal of Flood Risk Management* **5,** 164–174 (2012).
16. Scottish Environment Protection Agency. *Sustainable Riverbank Protection Reducing Riverbank Erosion - A best practice guide for farmers and other land managers* (2020).
17. Krull, E. *et al.* Development of a stable isotope index to assess decadal-scale vegetation change and application to woodlands of the Burdekin catchment, Australia. *Global Change Biology* **13,** 1455–1468 (2007).
18. Nicholson, A. R., O'Donnell, G. M., Wilkinson, M. E. & Quinn, P. F. The potential of runoff attenuation features as a Natural Flood Management approach. *Journal of Flood Risk Management* **13.** https://doi.org/10.1111/jfr3.12565 (2020).
19. Comber, A., Brunsdon, C. & Green, E. Using a GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups. *Landscape and urban planning* **86,** 103–114 (2008).
20. O' Gorman, S. & Dillon-Robinson, R. *20 Minute Neighbourhoods in a Scottish Context* tech. rep. (2021).
21. Local Government Association. *Managing flood risk* Accessed: 09/12/2022. https://www.local.gov.uk/topics/severe-weather/flooding/flood-and-coastal-erosion-risk-management/managing-flood-risk (2022).
22. Local Government Association. *Surface water (pluvial) flooding* Accessed: 09/12/2022. https://www.local.gov.uk/topics/severe-weather/flooding/flood-and-coastal-erosion-risk-management/surface-water-pluvial (2022).
23. UK Environment Agency. *Working with natural processes to reduce flood risk* Accessed: 09/12/2022 (UK Environment Agency, 2021). https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/working-with-natural-processes-to-reduce-flood-risk (2022).
24. Greenspace Scotland. *The third state of Scotland's Greenspace Report* Accessed: 11/12/2022. 2018. https://www.greenspacescotland.org.uk/FAQs/greenspace-mapping.

7 Appendix

Appendix I: Definitions on greenspace functions

Table 1.1 shows the functions of Greenspace and the definitions set out by Greenspace Scotland [24].

Function	Description
Public park or garden	Areas of land designed, constructed, managed and maintained as a public park or garden. These normally have a defined perimeter and free public access, and generally sit within or close to urban areas. Access is granted for a wide range of uses and not normally restricted to paths or tracks within the area. May include areas with managed facilities such as benches and flowerbeds, and more natural areas.
Private garden	Areas of land normally enclosed and associated with private residences and reserved for private use.
School grounds	Areas of land normally enclosed that is associated with a school and primarily reserved for their use.
Institutional grounds	Areas of land normally enclosed and associated with institutions. Grounds may be reserved for private use or have restricted access. Includes: universities, hospitals, nursing homes, emergency services, prisons, military sites, government and community buildings providing public services, libraries, museums, zoos and theatres.
Amenity – residential or business	Landscaped areas providing visual amenity or separating different buildings or land uses for environmental, visual or safety reasons. Where the area is better described by another category this will be used in preference (e.g. playing field, public park, play space).
Amenity – transport	Landscaped areas providing visual amenity or separating different buildings or land uses for environmental, visual

Function	Description
	or safety reasons when related to a transport function, such as a road, or within a transport hub.
Play Space	A specially prepared area intended for children's play, usually linked to housing areas or parks and containing purpose build equipment. Not captured if within schools or paid-for tourist attractions.
Playing field	Large, flat areas of grass or specially designed surfaces, generally with marked pitches, used primarily for outdoor sports, i.e. football, rugby, cricket.
Golf Course	A specially prepared area intended for playing golf.
Tennis Court	A specially prepared area intended for playing tennis.
Bowling Green	A specially prepared area intended for playing bowls.
Other sports	Land used for other sports not specifically described by other categories. Includes facilities for sport spectating (e.g. stadiums) as well as participation.
Allotments or community growing space	Areas of land for growing fruit, vegetables and other plants, either in individual allotments or as a community activity. Produce is for the growers own consumption and not primarily a commercial activity.
Religious grounds	Areas of land associated with churches and other places of worship.
Cemetery	Areas of land associated with burial areas or crematoriums.
Camping or caravan park	An organised area of ground designated for tents or caravans, intended for temporary occupation by holidaymakers.

Function	Description
Land use changing	Areas of land that are currently under development or awaiting redevelopment.
Natural	Land use areas with no other greenspace function but with Form attribute of woodland, open seminatural, open water, beach or foreshore.

Table 1.1: Greenspace functions

Appendix II: Details for environmental deprivation analysis

Figure 2.1 shows the procedure of environmental deprivation analysis. The source data includes data zones polygons, population statistics table, polylines of transport network, and open greenspace polygons. Network analysis was used in extending the data zones to 300 meters. In Network Analysis, instruments can only be points, but the data zones we meant to extend are polygons. As a result, the outlines of data zone polygons are sampled to points by 10 m distance to apply the analysis.

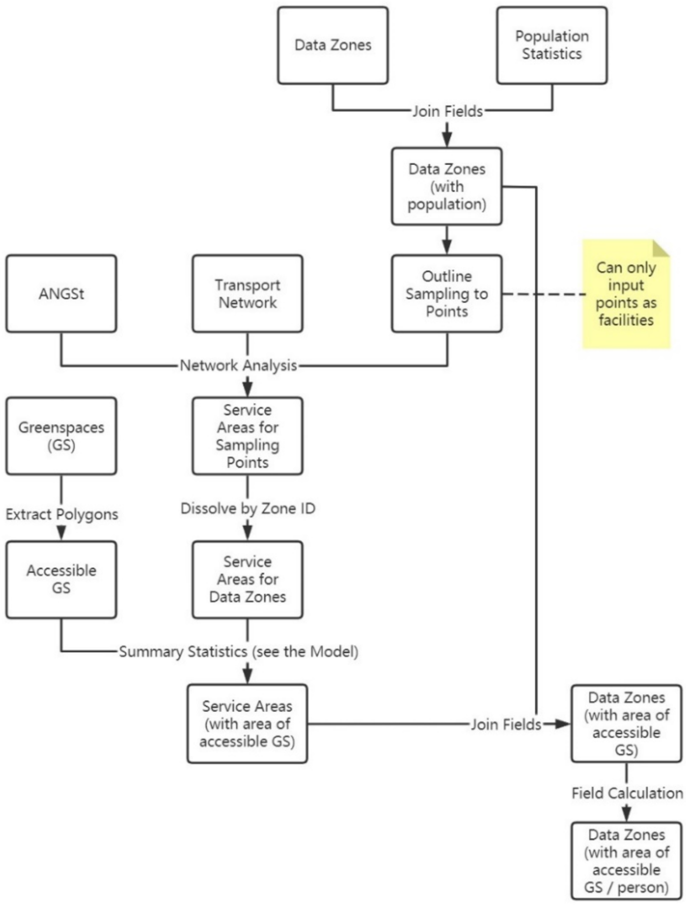


Figure 2.1: Flowchart for Environmental Deprivation Analysis

The next step is to calculate the area of accessible greenspace per person of each service area. An iterate processing model show in Figure 2.2 was created to achieve this using Model Builder in ArcGIS Pro, which allows us to do the calculation in iteration automatically.

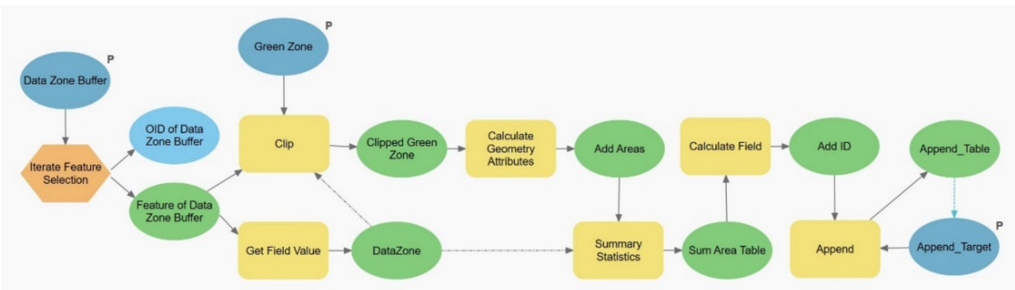


Figure 2.2: Data processing model

Appendix III: Details for social deprivation analysis

Table 3.1 shows the data information used in social deprivation analysis.

Name	Year	Type	Source
School Points and Ways	2022	XML	OpenStreetMap Contributors
Hospital Points and Ways	2022	XML	OpenStreetMap Contributors
Food Shop Points and Ways	2022	XML	OpenStreetMap Contributors
Edinburgh Roads and Footpaths	2022	GEOJSON	OpenStreetMap Contributors
Flood Levels	2022	GeoDataBase	SEPA
SIMD Indicators	2020	Excel	Scottish Government
Post Code boundaries	2022	ESRI Shapefile	National Records Scotland

Table 3.1: Data used in analysis

The analysis steps are shown below:

1. Data pre-processing
   a) Extract road and footpath data from OSM using overpass turbo
   b) Extract school points and ways from OSM using overpass turbo
      - filter for schools and nurseries
      - using Edinburgh council data as a reference, remove private schools from the extracted data
   c) Extract healthcare points and ways from OSM using overpass turbo
      - filter for hospitals, surgeries, medical centres, doctors, clinics, chemists and pharmacies
   d) Extract food shop points and ways from OSM using overpass turbo
      - filter for supermarket, convenience, greengrocer, butcher, baker and newsagent

e) Add missing points and associations

- Not all of the amenities had points associated with them or the points in the OSM data were not given names linked to their associated entities. Missing points were added by using associated symbology on the OSM basemap tile where available or by using Google Street View to determine the points of entry. Unnamed points were given the name of the ways (building polygons) that they intersected or were in closest proximity to (such as an entry gate for a school barrier).

f) Create spatial join between food shops and postcodes

- Food shops from the OSM data needed further specification due to the presence of chain shops in order to distinguish each shop when creating polygons. Therefore the points were given a spatial join to their corresponding postcode.

2. Determine service areas for each category of amenities.

a) Using QGIS the service zone of each amenity category was determined using the Network Analysis Service Area (from point) tool. The OSM roads and footpaths layer was used for the network data and the points for each of the amenity categories was used for the points data. The travel cost was set to 800m, in line with the 20 minute neighbourhoods principle.

b) Service areas were then filtered to keep those that fall within the study area, which is the catchment zone for the Water of Leith. Those amenities that did not have service areas within or intersecting the catchment zone were removed.

3. Identify amenities that lie within flood zones

a) Each entity table was given a column labelled 'IsFlood' and was given an indicator determining the highest level of flood risk category from the SEPA data as follows:

- H - High
- M - Medium
- L - Low
- CC - Climate Change 2080s
- N - None

b) The indicators were determined by inspecting whether the amenity or means of entry (such as school grounds or parking lots) were within the SEPA flood zones.

4. Create polygons for the service areas

a) Polygons representing each amenity's service areas were created using the 'Convex Hull' tool in QGIS.

b) At this stage, we now had polygons for each of the entry points for all of the amenities. In order to have a single polygon for each amenity, we used the 'Dissolve' tool with the Dissolve field set to 'Name'.

c) In order to determine the potential impact of flooding on the study area, the symbology for the service area polygon layers was adjusted so that polygons were colour-coded based on whether their associated amenities were within the flood zones using the 'IsFlood' column data created earlier. The polygon colours were set as follows (there were no amenities from any of the categories that fell within high risk flood zones):

- Medium risk - red
- Low risk - orange
- Climate Change 2080s - yellow
- None – green

Appendix IV: Methodology for ANGSt

Regression analysis was used to identify the linear relationships between a predictor variable (size of greenspace) and a response variable (distance from the greenspace). Once the decision about direction has made. Next step is to describe the mathematical function: $Y = f(X)$. We apply the function f to each value of the variable X to generate the corresponding value of Y and the linear function is:

$$Y = \beta_0 + \beta_1 X \qquad (1)$$

where β_0 is intercept, $\beta_1$is slope.

From Accessible Natural Greenspace Standards which is shown in Table 4.1, it recommends that everyone should have an accessible greenspace. After conducting statistics analysis, the linear relationships between the square root of the size of greenspaces and distance from the greenspace was found. Figure 4.1 shows its relationship. The linear function is:

$$Y = 458.69\,X - 60.83 \qquad (2)$$

Size of Greenspaces	The distance from Greenspaces
2 hectares	300 meters
20 hectares	2000 meters
100 hectares	5000 meters
500 hectares	10000 meters

Table 4.1: Accessible Natural Greenspace Standards

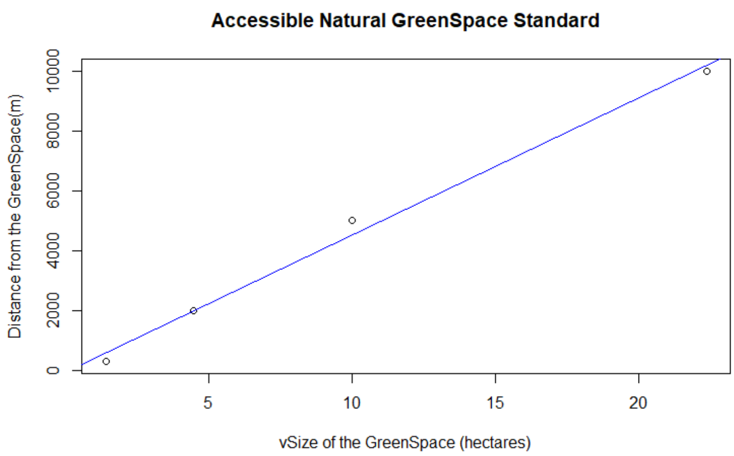


Figure 4.1: Accessible Natural Greenspace Standards

Code used to identify the relationship between the size of greenspace and the distance from greenspace using British Accessible Natural Greenspace Standard coefficient

```
distance<-c(300,2000,5000,10000)

size<-c(sqrt(2),sqrt(20),sqrt(100),sqrt(500))

shapiro.test(distance)

shapiro.test(size)

cor.test(distance, size,method = "spearman")

re<-lm(distance~size)

summary(re)

plot(size,distance, xlab="√Size of the GreenSpace (hectares)",ylab= "Distance from the GreenSpace(m)",main="Accessible Natural GreenSpace Standard")

a<-coefficients(re)[1]

b<-coefficients(re)[2]

abline(a=a,b=b,col="blue")
```