The hydrology and biodiversity characteristics of an experimental raingarden at RBGE in Scotland

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Abstract

In recent years, the Royal Botanic Garden Edinburgh (RBGE) has witnessed changing weather patterns that reflect how climate change is impacting Scotland. Longer periods of dry weather, followed by heavy downpours of rain, have proved particularly problematic in terms of maintaining plant health and avoiding localised flooding issues. To cope with these challenges, an experimental raingarden (a shallow planted basin) has been created at one of the areas of the garden most prone to waterlogging and flooding. Raingardens offer a sustainable solution to flood mitigation by mimicking natural rainwater retention and infiltration characteristics, whilst also providing multiple benefits related to biodiversity, ecology, amenity, recreation, and education value.

This paper reports on the preliminary hydrological modelling of the raingarden and surrounding area, including details of the amended soils used to enhance rainwater infiltration rates within the raingarden to reduce runoff. Details are also provided on the biodiversity of the raingarden and, in particular, the selection of native and non-native plants able to tolerate occasional flooding that are being trialled. The creation and ongoing assessment of the raingarden will be helpful for understanding and planning future site management strategies for coping with an unpredictable and changing climate.

Keywords

Climate change, flooding, raingarden, biodiversity, hydrological modelling.

1 Introduction

The Royal Botanic Garden Edinburgh (RBGE) dates back to 1670 when it began as Scotland's first physic garden (RBGE, 2019a). It became one of Britain's first botanic gardens and today is a world-renowned centre for plant science, horticulture, education, and public engagement, see Figure 1a. RBGE now extends over four gardens (Edinburgh, Benmore, Dawyck, and Logan) curating a rich collection of native and non-native plants (of some 13,500 species) and welcoming over one million visitors each year.

In recent years, however, RBGE has experienced changing weather patterns that reflect how the climate is changing in Scotland. Longer periods of dry weather, followed by heavy downpours of rain, have proved particularly problematic in terms of maintaining plant health and avoiding localised flooding issues. With extreme weather events expected to become more frequent and intense over the coming decades, RBGE are working to increase the resilience of its gardens to reduce its vulnerability to future climate change (Martin, 2014).

A particular challenge has been dealing with more frequent heavy rainfall which has brought problems of water logging and localised flooding in some parts of the garden, causing damage to plant-beds lawns, and footpaths and impacting visitor access due to the closure of affected areas. An area of the garden that has been particularly affected is the Birch Lawn, see Figure 1b, which has suffered waterlogging and flooding during heavy rainfall events due, mainly, to its low-laying position within the garden.

To help reduce the susceptibility of the Birch Lawn to flooding, an experimental raingarden has been created with enhanced rainwater retention and infiltration characteristics. A raingarden is a shallow basin with absorbent, yet free draining, soil and planted with vegetation that can withstand occasional temporary flooding (Bray *et al.*, 2012). They offer a sustainable solution to flood mitigation whilst also providing multiple benefits related to biodiversity, ecology, amenity, recreation, and education value.

Figure 1: Location of (a) RBGE within the city of Edinburgh, and (b) the Birch Lawn within RBGE (source: Google Maps, © 2019 Google)

This paper reports on the preliminary hydrological modelling of the raingarden, including details of digital terrain model used, and the amended soils developed to enhance rainwater infiltration rates. Details of the biodiversity of the raingarden are also provided, in particular, the selection of native and non-native plants being trialled for their ability to withstand occasional temporary flooding within the raingarden. Finally, a short discussion of the planned long-term monitoring of the raingarden will be presented.

2 Changing rainfall patterns in Scotland

The climate in Scotland is changing, and the latest climate projections indicate that further change is expected over the coming century (SCCAP-CC, 2019). Extreme weather events are expected to become more frequent and intense over the coming decades.

2.1 Past trends and recent rainfall anomalies

In the past few decades there has been an increase in annual average rainfall over Scotland. Since 1970, the annual rainfall has increased by around 13% over Scotland compared with the average for the early decades of the 20th century (ASC, 2016). Heavy seasonal and annual rainfall events have also increased. Seven of the 10 wettest years for the UK have occurred since 1998 (Kendon, 2018).

Heavy rainfall events have increased significantly in winter, particularly in northern and western regions, with an average increase of almost 60% in winter months in northern and western Scotland (2006). Data for the UK shows that summers have been on average 20% wetter than 1961–1990, with only summer 2013 drier than average (Kendon, 2018). Most recently, parts of north-east Scotland experienced more than twice the normal rainfall during May 2019 (Met Office, 2019a). Total rainfall from extremely wet days (days exceeding the 99th percentile of the 1961-1990 baseline) has increased by around 17% for the UK, however, changes are largest for Scotland.

2.2 Future rainfall projections

The UK Climate Projections 2018 (UKCP18) is a state-of-the-art climate analysis tool based on the latest developments in climate science (Met Office, 2019b). Climate projection for Scotland and the UK suggest a move towards warmer, wetter winters and hotter, drier summers. However, natural variations will mean that seasonal and regional differences will continue to vary in the future. For example, winter precipitation is expected to increase more over southern and central England whilst summer rainfall reductions tend to be largest in the south of England. Likewise, the west of Scotland is likely to see a greater increase in mean winter precipitation than the north and east of Scotland (Murphy et al., 2018). By 2070, in the high emissions scenario, average winter precipitation is projected to increase by up to 35% for the UK and, although summers are expected to become drier, the likelihood of individual wet summers reduces only slightly.

3 Extreme rainfall impacts at RBGE

Whilst individual weather anomalies and extreme rainfall events cannot be directly attributed to climate change as they occur, due to the natural variability of the climate, projections show that climate change will result in an increased frequency and severity of some extreme events such as storms, floods, and heatwaves (Martin, 2014). Observations of recent rainfall events at RBGE reflect an increased frequency and severity of intense events. Figure 2 presents the total annual rainfall recorded by the RBGE weather station (an official Met Office weather station) from 1976 until 2017.

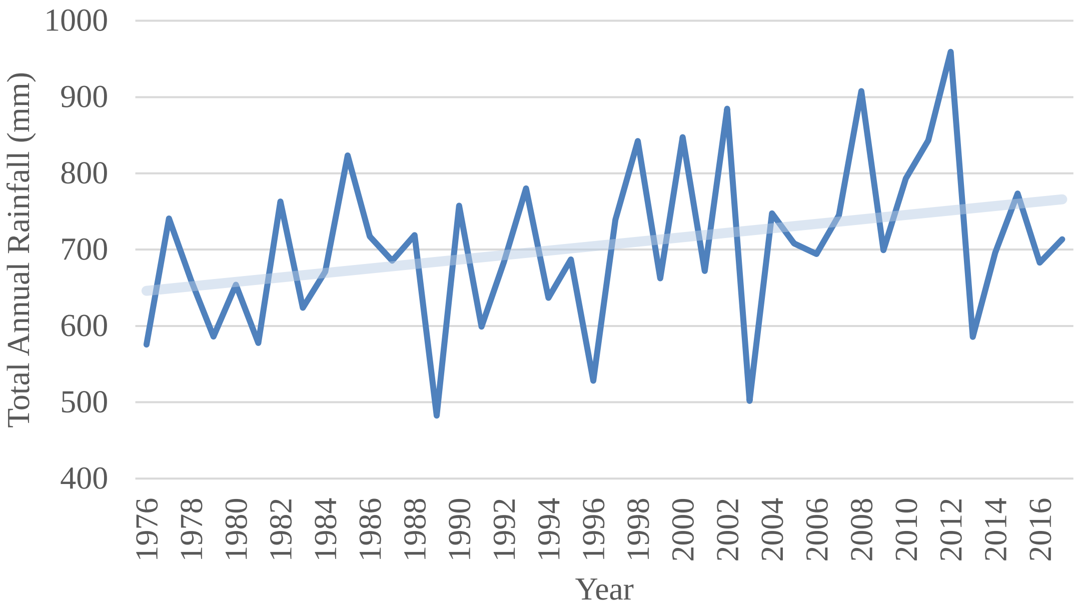

Figure 2: Total annual rainfall recorded at RBGE (1976 – 2017) illustrating both the annual variability and the increasing trend of total rainfall

Overall, 2012 was the wettest year on record at RBGE with a total of 960mm of rain; 136% of the long term annual average rainfall since 1976 [706mm]. During the same year, the UK annual rainfall was the second highest on record with a total of 1335mm of rain, narrowly beaten by 2000 with 1337mm of rain (Met Office, 2019a).

The wettest month was August 2008 with 202mm of rain (323% of the average for August [63mm]), followed by July 2012 with 182mm of rain (272% of the average for July [67mm]), and June 2017 with 181mm of rain (289% of the average for June [63mm]). In fact, the summer season (from June to August) of those years have been the wettest on record at RBGE with summer 2012 being the wettest (410mm of rain), followed by summer 2008 (367mm of rain) and summer 2017 (344mm of rain). The wettest winter season (from December to February) was 2015/2016 with 360mm of rain falling during those three months. Winter 2015/2016 was also the wettest recorded for Scotland and the second-wettest for the UK, beaten by winter 2013/2014 (Met Office, 2019a). The wettest day recorded at RBGE was 27th July 1985 with 82mm of rain over a 24-hour period.

Heavy downpours of rain have brought problems of localised flooding and caused damage to plant-beds, lawns, and footpaths at RBGE (Martin, 2014). This has affected visitor access within the Garden due to the closure of waterlogged and slippery paths (see Figure 3). In some locations, tree and shrub roots have been submerged in rainwater with possible consequences for their health. Waterlogging of lawns have also affected garden maintenance, making grass cutting difficult, and causing soil compaction. After such events, remedial work has been necessary to repair the footpaths and plant-beds where soil and surface materials had been washed away.

Figure 3: Examples of problems at RBGE caused by heavy downpours of rain, including flooded footpaths, waterlogged lawns, and submerged roots.

Consequently, an ongoing review of rainwater drainage is now underway at the Garden. New drainage and soakaways were installed at critical areas where capacity was insufficient and when new areas of the Garden are upgraded, drainage and maintenance plans are reviewed and updated where necessary.

In addition to periods of wetter than average weather, RBGE has also experienced periods drier than average. The driest year from 1976 onwards was 1989 when only 483mm of rain fell (just 62% of the annual average), however, the driest year on record at RBGE was 1959 with only 436mm of rain (62% of the annual average). The driest month was February 1993 when just 3.7mm of rain fell (RBGE, 2019b). As a result, mulches are now being used to help conserve soil moisture during dry periods.

The impact of extreme wet and dry weather presents many challenges to the Garden, particularly in terms of plant health, garden maintenance, and visitor experience. The UK Climate Projects 2018 (UKCP18) suggest greater weather variability throughout the year and greater occurrence of extreme events. Climate change resilience planning is therefore crucial to minimise future risk.

4 Raingarden design

The experimental raingarden was designed to intercept, capture, and infiltrate rainwater during heavy rain events. The site of the raingarden is the Birch Lawn (see Figure 1b) which had previously suffered from flooded footpaths, waterlogged lawn, and submerged tree and shrub roots. Initial site conditions were assessed by measuring the infiltration rates of the existing soil. A digital terrain model (QGIS) was then used to assess the surface water flow characteristics at the site and the corresponding rainwater volumes generated under different design storms. An amended soil was then developed and incorporated into the raingarden site in order to enhance the rate of infiltration. Plant selection, undertaken by horticulturists at RBGE, included a number of native and non-native species chosen for their ability to help create habitat for wildlife, and their hardiness to thrive within both wet and dry conditions.

4.1 Soil infiltration tests

To understand the existing site conditions, the infiltration rate of the soil at the Birch Lawn was measured using a Mini Disc Infiltrometer by Decagon Device (see Figure 4). The Infiltrometer is designed to accurately measure the unsaturated hydraulic conductivity of any soil (i.e. the rate at which water can move through the soil).

The upper and lower chambers are both filled with water. The upper chamber controls suction to account for the effects of macropores within the soil which generally fill with air. The water within the lower chamber infiltrates into the soil at a rate determined by the suction selected in the upper chamber. A suction rate of 2 cm was selected as this is recommended by the manufacturer to be used for most soil types.

The bottom of the Infiltrometer has a porous sintered stainless steel disc that does not allow water to leak in open air. When the Infiltrometer is placed on soil, water begins to leave the lower chamber and infiltrate into the soil at a rate determined by the hydraulic properties of the soil. As the water level drops, the volume remaining can be read from the graduated cylinder of the lower chamber.

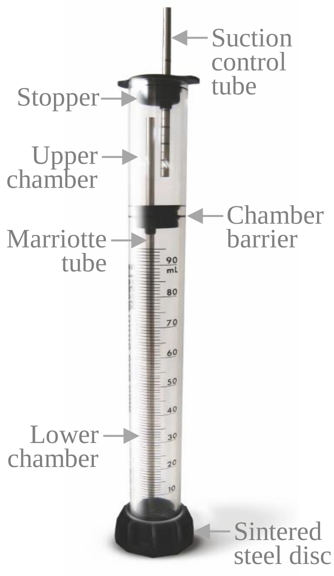

Figure 4: Mini Disk infiltrometer

Figure 5 illustrates the cumulative infiltration against the square root of time for four test locations on the Birch Lawn once the water volume recorded from the infiltrometer (in ml) has been converted to water depth (in cm). Test 1 and Test 2 measured the soil infiltration of the lawn itself, whilst Test 3 and Test 4 measured at bare soil around the base of existing trees. A clear difference can be seen between the infiltration of lawn soil (Figure 5a and 5b) and the bare soil (Figure 5c and 5d). The roots of the lawn appeared to help improve inflation, whilst the bare soil was found to be heavily compacted, thus reducing surface infiltration capability.

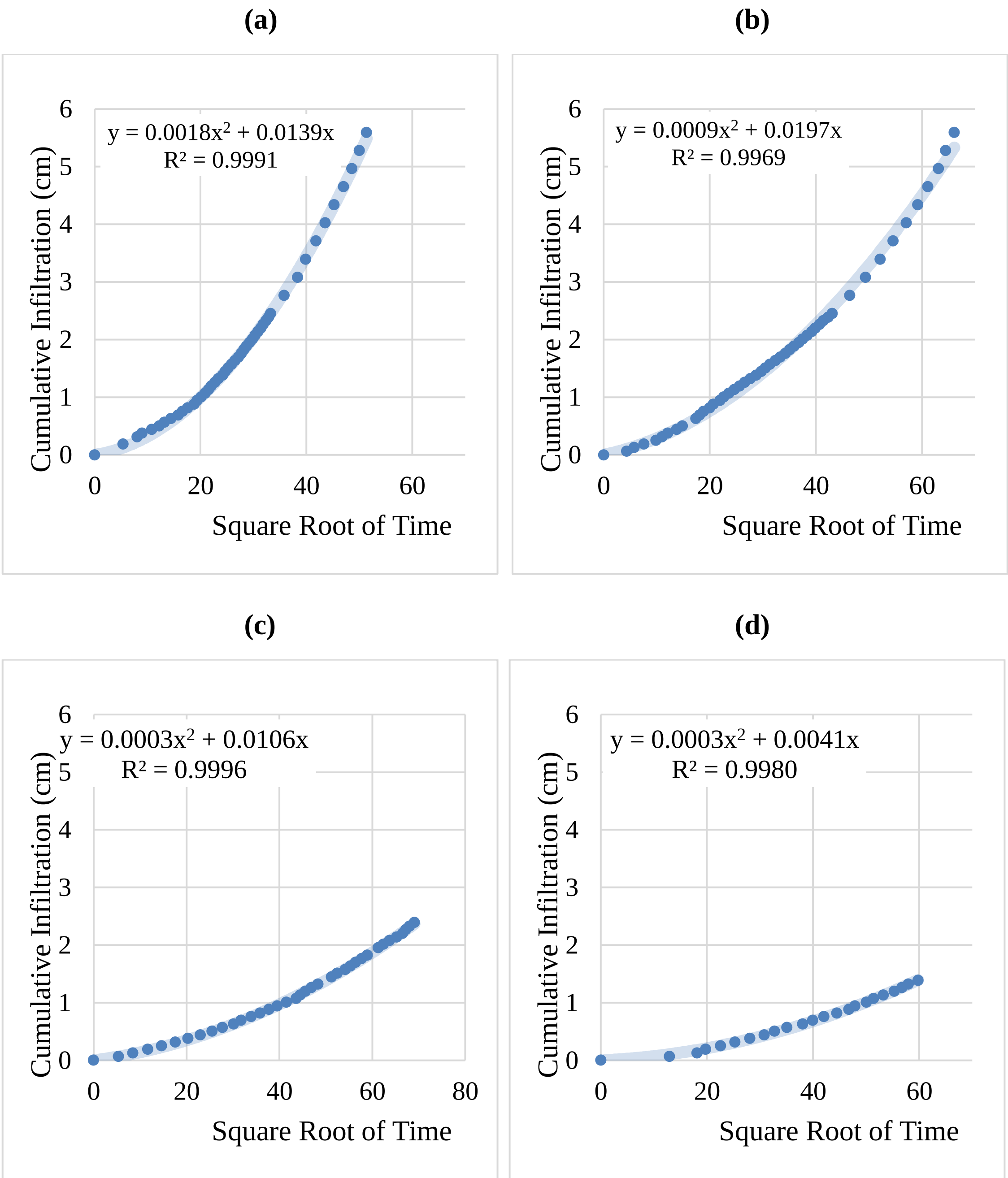

Figure 5: Cumulative infiltration of existing soil measured at four test locations on the Birch Lawn at RBGE: (a) Test 1, (b) Test 2, (c) Test 3, and (d) Test 4

Soil infiltration rate, *k*, can then be calculated from:

$$k = \frac{C_1}{A} \quad (1)$$

where C_1 is the slope of the curve of the cumulative infiltration versus the square root of time, and A is a value relating to the van Genuchten parameters for a given soil type to the suction rate and radius of the infiltrometer disk (Meter Group, 2018). Figure 6 illustrates the infiltration rates for each test across twelve soil texture types.

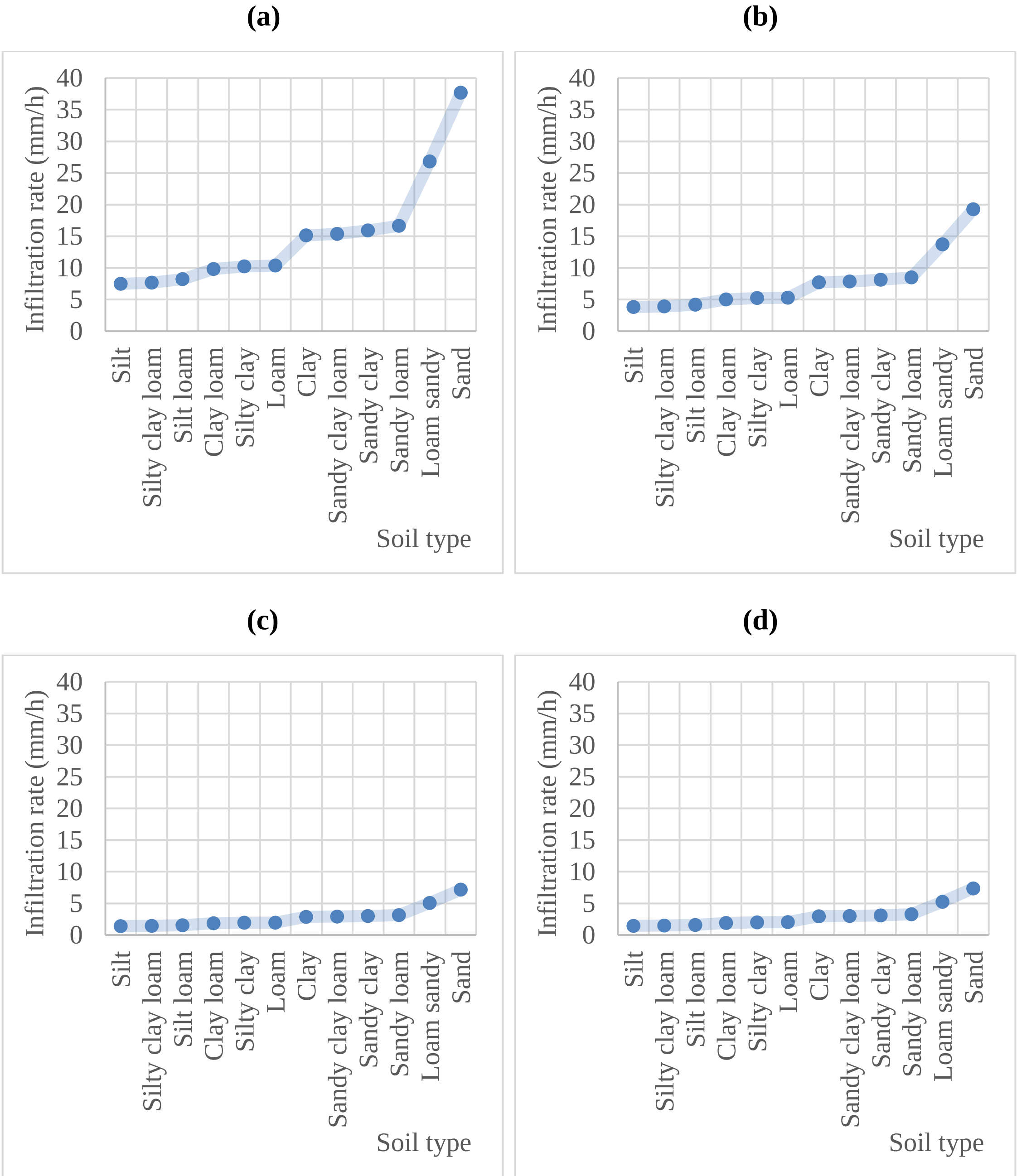

Figure 6: Infiltration rate of existing soil measured at four test locations on the Birch Lawn at RBGE: (a) Test 1, (b) Test 2, (c) Test 3, and (d) Test 4

Soil type can have a significant effect on infiltration rate. Course well-drained soils (such as loamy sand) have a high rate of water transmission and tend to display high infiltration rates, with the majority of rainfall being able to infiltrate into the soil. Finer clay soils tend to have very low rates of water transmission and so display low infiltration rates (Natural Resources Conservation Service, 1986). Saturated soils and compacted soils will also display lower infiltration rates.

Whilst the soil type for the Birch Lawn is still to be determined, looking across the range of soil types, the infiltration rates at each test location can be estimated: Test 1 (Figure 6a) shows an average infiltration rate of 15.1 mm/h (with a range of 7.5 – 37.7 mm/h); Test 2 (Figure 6b) shows an average of 7.7 mm/h (with a range of 3.8 – 19.2 mmm/h); Test 3 (Figure 6c) shows an average of 2.9 mm/h (with a range of 1.4 – 7.2 mm/h); and Test 4 (Figure 6d) shows an average of 3.0 mm/h (with a range of 1.5 – 7.4 mm/h).

Soil samples taken from the Birch Lawn are currently being prepared for particle size distribution (PSD) analysis and infiltration rate testing in order to determine the soil type classification.

4.2 Digital Terrain Model

To better inform the design of the raingarden, the topography of RBGE was assessed using the Digital Terrain Model (DTM), QGIS, which is an open source Geographic Information System (GIS). The DTM data used has a grid cell resolution of 2m and was sourced from the Environment Agency UK.

Figure 7a shows the extent of the RBGE site boundary within the DTM and Figure 7b shows the site elevations with the red areas being the highest points within the garden, and the blue areas the lowest points. The Birch Lawn watershed boundary, which is delineated by the blue polygon, can be seen to sit at a natural low point to its surroundings.

Figure 7c shows the watershed routing at, and adjacent to, the Birch Lawn. Assessment showed that the rainwater drainage routes within the watershed, slope at a steep fall of 1 in 10 and culminate at the footpath (indicated by the white line in Figure 7c) adjacent to the Birch Lawn.

Figure 7d shows the details of the Birch Lawn watershed boundary, including contour lines, indicating a change in elevation from the highest point (23.9 m) to the lowest point (19 m) of almost 5 m. The position of the raingarden, located at the lowest elevation point of the Birch Lawn in order to best capture the overland surface flow of rainfall runoff, is also indicated in Figure 7d.

The analysis completed in GIS allowed the drainage area and primary overland surface water flow routing at the Birch Lawn to be estimated. This key information was then used as input to the raingarden design.

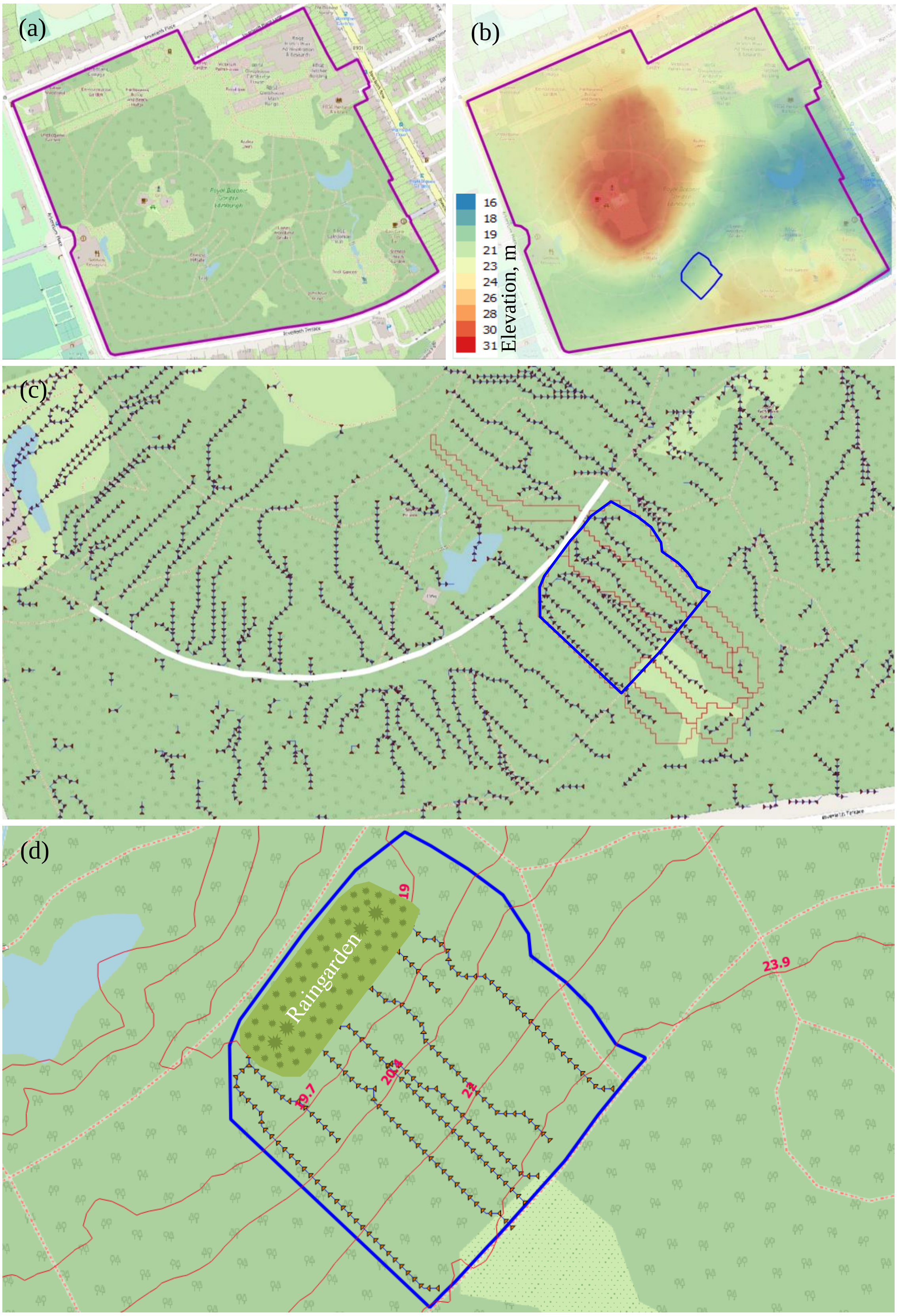

Figure 7: Simulation of the watershed routing using the DTM, QGIS: (a) the RBGE site boundary, (b) the RBGE site elevations, (c) watershed routing adjacent to the Birch Lawn, and (d) watershed routing at the Birch Lawn and raingarden

4.3 Planning and design (location, size, and shape)

As mentioned above, the raingarden was planned to be located at the lowest elevation point within the Birch Lawn watershed boundary in order to capture the overland surface water runoff. The design objective of the raingarden was to intercept the runoff, retain the collected rainwater, and then allow it to infiltrate into the soil naturally for storm events up to a 30-year return period.

Rainfall data for the RBGE site was obtained from the Flood Estimation Handbook (FEH) 2013 rainfall model (Centre for Ecology and Hydrology, 2013). This model is widely used for storm drainage design in the UK and is based on the statistical assessment of historic observed rainfall records, providing an estimate of total rainfall depth corresponding to a particular event duration and return period. To account for future climate change, a 20% uplift was applied, giving a target design rainfall intensity for a 30-year return period event of 32.8 mm/h. Inflow to the raingarden, Q, was calculated using the rational formula:

$$Q = ciA \tag{2}$$

where, c is the runoff coefficient, i is the rainfall intensity, and A is the drainage area. Based on an assumed raingarden infiltration rate of 30 mm/h (based on a review of the literature) and an existing soil infiltration rate of 5 mm/h (equivalent to clay soil) below the depth of the raingarden, the raingarden was designed to have an overall area of 130 m^2, a central depth of 450 mm, and an overall volume of 59 m^3.

4.4 Amended soil

The SuDS Manual (Woods-Ballard *et al.*, 2015) sets out design recommendations for the filter medium of bioretention systems such as raingardens. For optimal design, the filter media should be adequately permeable to enable rainwater to infiltrate through it, so that the surface of the raingarden does not become water logged. It should also contain sufficient organic material and nutrients to support planted vegetation.

A soil infiltration rate of between 100 mm/h and 300 mm/h is recommended to accommodate rainfall flowing from contributing areas. To allow for clogging, the design infiltration rate should be based on 50% of the target soil infiltration rate. In order to improve infiltration (see Section 4.1) whilst ensuring sufficient organic materials and nutrients, an amended soil composition of 30% existing soil, 55% sand, and 15% compost is suggested (Woods-Ballard *et al.*, 2015). With advice from the RBGE horticulturalists, in addition to the suggested composition, an amended soil retaining 45% existing soil was also developed to assess the long-term impact of soil composition on plant health. Table 1 summarises the composition of the two amended soils. In each case, the existing soil was mixed with compost made on site at RBGE, and sand and fine gravel (to the specified particle range size) obtained from a local supplier.

Table 1: Composition of the two amended soils developed for use in the raingarden

	Existing soil	Sand	Fine gravel	Compost
Soil type 1	30%	45%	10%	15%
Soil type 2	45%	35%	8%	12%

4.5 Planting and biodiversity

A selection of both native and non-native plants were selected for the raingarden. Each will be monitored and compared to assess how well they cope with occasional temporary flooding within the raingarden. Plants native to Scotland provide the benefit of creating a naturally occurring ecological community, however, they may prove less hardy than the non-native equivalents. The plants within the raingarden will help to enhance biodiversity value and, ideally, be characterised by relatively high rates of evapotranspiration. The selected native plants include: *Saxifraga granulate, Succisa pratensis, Anthyllis vulneraria, Filipendula ulmaria, Knautia arvensis,* and *Festuca altissima.* The selected non-native plants include: *Aruncus gombalanus* (China), *Ligularia fischeri* (E Asia), *Aquilegia Formosa* (Western N America), *Primula poissonii* (China), *and Hosta sieboldiana* (Japan).

A number of established native and non-native trees were already growing at the Birch Lawn, including: *A. glutinosa* (native), *B. pendula* (native), *C. avelana* (native), *Quercus robur 'filicifolia'* (cultivar of a native species), *A. japonica* (Japan), *Alnus rubra* (N. America), *Betula alleghaniensis* (NE North America), *Betula papyrifera* (N North America), *B. nigra* (USA), *Corylus sieboldiana* (Japan, Korea), and *Populus alba* (S and central Europe). In addition, a non-native herbaceous plant, *Gunnera manicata* (Brazil), is also growing at the Birch Lawn.

5 Discussion and conclusion

In recent years, the Birch Lawn at RBGE had suffered from waterlogging and localised flooding following heavy rainfall events. The results from the DTM show that the Birch Lawn sits at one of the lowest elevation points within the garden and so watershed from surrounding slopes culminate at this point. In addition, infiltration tests of the soil within the Birch Lawn indicate overall very low rates of soil infiltration. The creation of an experimental raingarden at the Birch Lawn, with enhanced infiltration capacity, aims to capture and retain the rainfall, allowing it to infiltrate naturally into the ground.

Going forward, the raingarden will function as a "living laboratory" to learn more about raingarden hydrology and associated plant health, particularly native Scottish plants and their ability to cope with occasional temporary flooding. It will also act as a valuable demonstration tool for public engagement on sustainable flood management techniques. The raingarden will also be helpful in understanding and planning future site management strategies for coping with an unpredictable and changing climate, and ensuring uninterrupted provision of the important public amenity at RBGE.

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