Hydrological benefits

Introduction

Green infrastructure (GI) can provide hydrological benefits in two key areas: flood alleviation and water quality (improvement and protection). Urban and peri-urban trees (in the riparian zone and floodplain) can contribute to flood alleviation by delaying the downstream passage of flood flows, reducing the volume of runoff, and promoting rainfall infiltration into the soil, thereby reducing the rate of runoff. Green roofs, sustainable drainage systems (SUDS), wetlands and retention/detention basins also offer hydrological benefits through reduced runoff, increased storage and improved water quality.

Benefits

Benefits include: reduced flood risk, improved water quality, sustainable drainage and reduced human and environmental health risks.

Economic evidence

- The economic cost to the national economy due to urban flooding is estimated to be £270 million per year in England and Wales, where 80 000 homes are at risk (Parliamentary Office of Science and Technology, 2007). A foresight report suggests that if no action is taken the cost of urban flooding could rise to between £1 billion and £10 billion a year by the 2080s (Evans *et al.*, 2004).

- As a result of urban diffuse pollution such as runoff from contaminated land, poor drainage and accidental spills, 15% of rivers and 22% of groundwaters are at risk of not achieving the water framework directive objectives. Estimates of the cost of environmental damage due to pollutants is between £150 and £250 million per year based on 2004/05 values (Environment Agency, 2007)

- In the city of Aalborg, Denmark, the use of green infrastructure to improve drinking water quality has saved an estimated €489 ha^{-1} yr^{-1} (€440,000 per year) (Aalborg Municipality and European Commission, 2002).

Evidence linked to hydrological benefits of GI

Reducing flood risk

- Urban development and engineered flood defences have profoundly changed the natural shape of river beds, banks and shores of estuaries can exacerbate or reduce the nature and seriousness of flood and drought events by changing water volume, velocity and direction of flow (Defra, 2008).

- Vegetation, particularly trees, in the floodplain can delay flows, promote out-of-bank flows and increase flood storage, resulting in a lower but longer duration event (Thomas and Nisbet, 2006). This is mainly due to the hydraulic roughness of vegetation.

- Plants intercept precipitation and use water during transpiration, thereby reducing the volume of water flowing through a catchment and reducing runoff (Nisbet, 2005).

- Vegetation promoted rainfall infiltration into the soil and reduced the rate of runoff as the root systems of plants and associated fauna give rise to increased porosity allowing greater movement of water into the subsurface than non-vegetated land.

- Spatially, GI should not be restricted to urban centres but should extend to the peri-urban environment so that flooding and water quality benefits can be realised before water reaches urban centres (Defra, 2008).

- Studies at Pontbren in Wales found that infiltration rates were up to 60 times higher within young native woodland shelterbelts compared to grazed pasture, and so water storage was increased (Bird *et al.*, 2003; Wheater *et al.*, 2008).

- Nisbet (2006) showed that the increased hydraulic roughness associated with planting native floodplain woodland along a 2.2 km grassland reach of the River Cary in Somerset could reduce water velocity by 50%, and raise the flood level within the woodland by up to 270 mm for a 1 in 100 year flood.

- The use of green roofs was found to reduce runoff by 17.0-19.9% and 11.8-14.1% for 18 mm and 28 mm rainfall events, respectively (Gill *et al.*, 2007).

- Seters *et al.* (2009) indicated that green roofs discharge 63% less runoff than a neighbouring conventional modified bitumen roof. Runoff volumes from green roofs averaged 42% less than the conventional roof in April and November, and between 70 and 93% less during the summer months.

Improving water quality

- Sustainable drainage systems (SUDS) can be used in the control of pollution and for sediment retention (Heal *et al.*, 2006) and green roofs also provide pollutant retention potential (Napier *et al.*, 2009).

- Hatt *et al.* (2008) assessed the potential for retention basins to remove pollutants from stormwater. They found that loads of sediment and heavy metals were effectively retained.

- Seters *et al.* (2009) assessed the quality of runoff from an extensive green roof on a multi-storey building and found that most chemical variables in green roof runoff were lower than from a conventional roof.

- Stovin *et al.* (2008) note that urban trees provide all of the functions associated with SUDS, including the storage and interception of rainfall at source, filtration of pollutants in the canopy, and infiltration at the root zone, along with amenity and ecological benefits.

- Floodplain and riparian woodland can reduce diffuse pollution, primarily by enhancing siltation and sediment retention (Jeffries *et al.*, 2003), nutrient (phosphate and nitrate) removal (Gilliam, 1994) and fixing heavy metals (Gambrell, 1994). Furthermore, the action of riparian and floodplain woodland in encouraging out-of-bank flows and slowing down flood flows promotes sediment deposition and retention, reducing downstream siltation.

- Lowrance *et al.* (1984) found riparian woodland to be particularly efficient at both intercepting aerial drift of pesticides and trapping pesticides bound to sediment in runoff.

- Both a mature, managed woodland (50 m wide) and a newly restored woodland (38 m wide) achieved almost complete pesticide reduction (Lowrance *et al.*, 1997; Vellidis *et al.*, 2002).

- The presence of large woody debris (LWD) dams within the stream channel act to delay flood flows, promote out-of-bank flows and increase flood storage. (Anderson *et al.*, 2006).

Practical considerations

Recent modelling studies present conflicting results on the effects of woodland on flood flows, with some predicting a considerable reduction in peak flows (Jackson *et al.*, 2008) whilst others suggest a relatively small effect on flood flows (Park and Cluckie, 2006). The contrasting results may be because these studies do not address the impact of woodland planting on the low infiltration rates of soils damaged by agricultural activities, where the benefit of woodland could be expected to be greatest (Nisbet *et al.*, in press).

To be effective at a larger catchment scale would require extended reaches of riparian woodland and associated LWD dams along tributary streams. There is also a risk of LWD dams causing flood damage and acting as a barrier to migrating fish, factors which need to be considered when their suitability is being assessed.

Links to climate change

There are significant links between the hydrological benefits of green infrastructure and climate change. The effects of climate change on hydrological processes include rising sea levels, intense rainfall and increased surface runoff, and these are contributed to by extreme seasonal temperatures and an increased urban heat island effect. Winters will become wetter with more days of rain and a greater volume of precipitation, and this can lead to an increased flood risk of up to 200%. As urbanisation can also affect the local climate and hydrological processes, urban stormwater management systems can reduce the flood risk and can also provide wider benefits in terms of biodiversity and climate regulation (Bartens, 2009).

Tools

South East Water Management Climate Change Adaptation Planning Toolkit
This toolkit from Land Use Consultants (2005) focuses on three key areas of climate change adaptation for 'water-related' impacts, and how these measures can be delivered through the planning system.

Toolkit for evaluation of land parcels for green space planning
This toolkit (Kramer and Dorfman, undated) provides information on five categories: water quality, farmland protection, economic impact, wildlife protection and cultural protection.

Toolkits for Greener Practices
Toolkits for Greener Practices (Minnesota Pollution Control Agency, undated) are Low/No Discharge Stormwater Management Strategies with two aims. Firstly, to reduce quantity of storm water runoff from the site or, secondly, to improve the quality of site runoff before it discharges to storm sewers that deliver runoff to area lakes and rivers and before it percolates into groundwater.

Polyscape
This multiple criteria GIS tool is designed to be used with GIS software to evaluate the impact of land use change (specifically the creation of new woodland) on the hydrology, productivity and biodiversity of agricultural landscapes. Contact: f.l.sinclair@bangor.ac.uk at Bangor University

HYDRUS 1D, 2D and 3D computer programmes
Microsoft Windows based modelling environment for the analysis of water flow and solute transport in variably saturated porous media. HYDRUS can accurately predict runoff especially for small rain events.

HYdrology of Land Use Change: HYLUC
The purpose of HYLUC is to assess the magnitude and direction of changes to runoff based on changes in land management. Contact: j.a.harrison@ncl.ac.uk The Centre for land use and water Resources (CLUWRR) at Newcastle University.

Case studies

Parrett Catchment Project - Somerset Water Management Partnership
Ripon Multi-object Project
Swale and Ure Washlands Project
Pontbren – peri-urban setting. Pontbren Farmers, North Powys, Wales
Cost Benefit Analysis of woodland planting to protect water resources

Knowledge gaps

There are few established case studies that evaluate the effectiveness of different green space measures for water protection, including street trees, riparian buffer areas, floodplain woodland, infiltration basins, SUDS and green roofs.

Few publications have quantified pesticide load reductions by riparian woodland buffers and there have been no studies in the UK. Further work is required to evaluate the role of these controlling factors in order to improve guidance on the best design and management for pollution control.

There is little evidence on the effect of management (tree type, green roof vegetation type) and strategic planning on the efficacy of measures for diffuse pollution control and flood alleviation.

There is the need to identify key locations for green space establishment in order to realise flood management and water quality benefits and to investigate the negative impacts of GI on water resources (e.g. increased water use).

Citations of national policies/priorities

The European Water Framework Directive
http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2000L0060:20090113:EN:PDF

European Directive on the Assessment and Management of Flood Risks (2007/60/EC), also known as The Floods Directive
http://ec.europa.eu/environment/water/flood_risk/index.htm

Government's strategy for flood risk management in England and Wales (Environment Agency)
http://publications.environment-agency.gov.uk/pdf/GEHO0609BQDF-E-E.pdf

A strategy for England's Trees, Woods and Forests (Defra, 2007)
http://www.defra.gov.uk/rural/documents/forestry/20070620-forestry.pdf

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