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The Geosciences in Europe's Urban Sustainability: Lessons from Glasgow and Beyond (CUSP) Preface

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In 2007, the proportion of the world's population living in urban areas exceeded that in rural environments for the first time in history. The global urban population is expected to rise by 66 % by 2050 (UN 2014). This threatens the sustainability of cities, which face huge infrastructure and planning challenges to meet the growing demand for urban living and to provide equitable economic and social benefits as well as environmental protection across communities.

The United Nations' (UN) Sustainable Development Goals acknowledge this in the UN's *Transforming our world: the 2030 Agenda for Sustainable Development*. Of the 17 'Global Goals', Goal 11 in particular focuses on sustainability (to achieve sustainable cities and communities by 2030), and other goals in the Agenda are also relevant to sustainable cities (e.g., Goal 6 addresses clean water and sanitation). Despite these goals, the potential importance, and contribution, of the subsurface to sustainable urban development (a combination of economic, social and environmental factors) is generally poorly appreciated.

The importance of the subsurface in relation to sustainable development is exemplified by the general recognition in the construction industry across the UK, Europe and the wider world that insufficient understanding of subsurface ground conditions is a key factor in overspending, project delays, overly conservative design and a barrier to development (e.g., Clayton 2001; Parry 2009; Baynes 2010).

To address this, in the city of Glasgow (UK), the British Geological Survey (BGS) has been working in partnership with Glasgow City Council and other organisations over a number of years. Under the Clyde-Urban Super-Project (CUSP), three-dimensional (3D) and four-dimensional (4D) subsurface models and other geoscience datasets (geochemistry, groundwater, engineering geology) have been developed specifically as an aid to planning and development.

This Special Issue of the *Earth and Environmental Science Transactions of The Royal Society of Edinburgh* comprises a collection of papers presented at the Conference on 'The Geoscience Context for Europe's Urban Sustainability: Lessons from Glasgow and Beyond (CUSP)', held in Glasgow, 29–30 May 2014. The Conference attracted delegates from 20 European countries and included over 40 oral and poster presentations, highlighting the challenges in understanding urban ground conditions to aid city regeneration and sustainable development. In addition to showcasing the work of the CUSP project in Glasgow, presentations included examples of urban subsurface characterisation from Germany, the Netherlands and Norway.

Thirteen of the conference contributions are presented in this volume. These focus mainly on the CUSP project. CUSP has also been used as an exemplar for other cities in Europe and the wider world. Lessons learnt in Glasgow have been shared especially through the European Cooperation in Science and Technology (COST) Action (SUB-URBAN: TU1206). This has focused on sustainable urban subsurface use, and transforming relationships between those who develop urban subsurface knowledge and those who can benefit most from it – the planners and developers of the cities of tomorrow. Therefore, SUB-URBAN has mirrored the original intentions, and the achievements, of CUSP and developed them more widely.

1. The Clyde-Urban Super-Project (CUSP)

Glasgow is Scotland's largest city and is built along the lower reaches of the River Clyde, which facilitated the seaward transport of goods historically. The population of Glasgow and the surrounding conurbation is approximately 1.2 million. In the past, Glasgow was a leading centre of industry and was renowned for its shipbuilding, extensive mining of coal and ironstone, and engineering, steel, chemicals and other industries. With the decline of these industries, Glasgow's economy, and its population, fell. However, Glasgow is now growing again, its economy is adapting to a new age and the city is experiencing a renaissance. Glasgow is typical of many cities that underwent rapid growth during the industrial revolution in the late 18th–mid-20th centuries, which waned during the latter decades of the 20th Century, but are now undergoing urban regeneration. Therefore, the issues faced by urban planners in Glasgow are similar to those of many post-industrial cities globally.

In the heart of post-industrial Glasgow are the Clyde Gateway, Clyde Waterfront and Sighthill areas, which together form a national urban regeneration priority for Scotland. This regeneration is a multi-decadal commitment on behalf of government, which is intended to stimulate sustainable development and economic growth, drive smaller community projects and tackle concentrated deprivation resulting from industrial decline. A challenge for the regeneration of these areas is a need to overcome the legacy of former industrial activities, including the geochemical footprints of former industrial uses in the soil and groundwater, and the extensive, abandoned mine workings, some of which are both at shallow depth and unrecorded.

Knowledge of the subsurface is vital in planning and delivering successful construction and regeneration projects within time and budget, yet poor understanding of ground conditions is the largest single cause of construction project delay and overspending. Cumulative loss to the economy and to the community is substantial. Improving this situation demands much better and wider transdisciplinary use of data and knowledge than is currently the case. Therefore, to underpin Glasgow's regeneration, and to minimise construction problems especially related to so-called ‘unforeseen ground conditions', the BGS has undertaken a major multi-disciplinary project (CUSP), and a range of follow-on activities, focused on Glasgow's subsurface, and its surrounding catchment area.

Initiated in 2009, CUSP adopted a whole systems geoscience approach (Merritt *et al*. 2007; Campbell *et al*. 2009, 2010). Underpinning much of the work to characterise the subsurface of Glasgow, variously attributed, dynamic shallow-earth 3D models (both deterministic and stochastic) have been developed of the complex superficial deposits and faulted bedrock, which underlie the city. These are described at the start of this volume in the paper by Kearsey *et al*. (2018). The models are multi-scalar (catchment-wide, and conurbation, development area, linear corridor and individual site) and are the most ambitious high-resolution and conurbation-scale models of their type yet completed in the UK. They can help to address a host of geo-environmental issues such as identifying the sources, migration pathways and sinks of contaminants, resulting from a multiplicity of industrial legacies; and the extent of, and potential geohazards associated with, the former widespread extraction of natural resources (especially coal and ironstone) within the urban environment. In combination with various other CUSP datasets, related to groundwater, geochemistry of soil and water, engineering geological and geotechnical properties of the shallow sub-surface, the geological models also provide the basis for a geoscience strategy for the urban subsurface in general. Therefore, they will inform decision-making by those involved in planning, regulation and construction of the regeneration areas.

For example, the paper by Williams *et al*. (2018) describes how the geological models have been used in conjunction with geotechnical property data to estimate hydraulic conductivity in the Quaternary deposits under Glasgow to enhance understanding of groundwater flow. The paper by Ó Dochartaigh *et al*. (2018) then explains how a groundwater-head pilot monitoring network was established under the CUSP programme in Glasgow to address hydrogeological data gaps. Information from the network was combined with the geological models, hydraulic conductivity estimates and groundwater chemistry data to develop a conceptual hydrogeological model for the Quaternary deposits underlying Glasgow. This revealed that groundwater flow through the Quaternary aquifer system at a city-scale was dominantly down-valley, from SE to NW, and the connectivity between the Quaternary aquifer system and the River Clyde. This study, and the development of a tool to assess threats to shallow groundwater quality from soil pollution described in the Fordyce *et al*. (2018a) GRASP paper, also highlight the extensive anthropogenic alteration of the groundwater system in Glasgow and the impacts of the urban and industrial legacy on groundwater quality in the area.

The influence of Glasgow's urban and industrial history on environmental quality are explored further in systematic assessments of soil and stream water geochemistry carried out across the conurbation and wider River Clyde Basin. The soil paper by Fordyce *et al*. (2018b) reveals that metal concentrations in the urban environment (especially copper, molybdenum, nickel, lead, antimony, zinc and chromium) are typically up to 2.1 times (median values) those of rural soil, as a consequence of urbanisation. The bioaccessibility and mobility of arsenic, chromium and lead in Glasgow soil are evaluated further in the paper by Wragg *et al*. (2018). Similarly, Kim *et al*. (2018) document the extent of persistent organic pollutants (POPs) associated with various land uses in Glasgow and demonstrate that polycyclic aromatic hydrocarbons (PAHs) in the urban soil are largely derived from the combustion of fossil fuels. These soil contaminants represent a typical indicator suite of urban anthropogenic pollution, highlighting the post-industrial legacy, which is still evident 40 years after the period of major industrial decline. The paper by Bearcock *et al*. (2018) shows that concentrations of chromium are 2.5 times higher (median values) in urban than in rural stream water, reflecting the fact that the world's largest chromite-ore processing plant was located in the Glasgow conurbation until its closure in the 1960s. By contrast, lead concentrations in urban stream water are lower (due to limited solubility of the element) than in the surrounding upland rural areas, where humic acid waters and former metalliferous mining activity increase the mobility of lead. These city- and catchment-wide datasets facilitate the identification of pollution sources and pathways and help to place urban and industrial pollution impacts in the wider context, as an aid to planning and development, catchment management and environmental protection.

Like many of the world's major cities, Glasgow is located on the lower reaches of a river and at the head of an estuary. Estuaries are important habitats for fish, shellfish, birds and mammals, but they are also sinks for sediment and contaminants from urban, industrial and recreational activities upstream, along shore and in the adjacent coastal zone. Before the CUSP project was instigated, there had been relatively few detailed studies of sediment pollution in the estuaries around the UK. The next set of papers in this volume document the assessments of sediment quality in the River Clyde and Clyde estuary, carried out in conjunction with Glasgow City Council and the Scottish Environment Protection Agency as part of the CUSP project. As the paper by Jones *et al*. (2018) describes, these data show the areal extent of different pollutants in the sediments and their distribution with depth. From the latter, a contamination history has been deduced, especially using POPs, lead isotopes and radionuclides. To aid assessments of sediment inputs, the paper by Lopes Dos Santos *et al*. (2018) uses glycerol dialkyl glycerol tetraethers to distinguish terrestrial from marine sources of organic carbon in the river system. Two papers by Vane *et al*. (2018a, b) compare the distribution of POPs and of mercury/n-alkane/unresolved complex mixture (UCM) hydrocarbons, respectively, in sediments from the upper rural sections of the River Clyde, the lower urban reaches of the river and the Clyde estuary. These reveal the impact of the urban and industrial environment on river quality, as mean sediment concentrations of PAH; total petroleum hydrocarbons and poly-chlorinated biphenyls are up to 60 times higher in the urban tributaries than in the upper rural river environment. However, concentrations of these contaminants dissipate to some extent downstream of Glasgow in the inner Clyde estuary. Mercury, n-alkane and UCM concentrations in sediment show a similar pattern, but concentrations are highest in the outer estuary because of anthropogenic activities such as the historic dumping of dredge spoil in the area. The results show that sediment saturated n-alkanes are of terrestrial origin in the upper Clyde. In the urban reaches of the river and the Clyde estuary, UCMs dominate as a consequence of anthropogenic inputs such as biodegraded crude oil, sewage discharge and urban run-off. Such improved understanding of the sources, pathways and sinks of natural inputs and anthropogenic pollutants in an urban/industrial impacted river system should aid catchment management in the future. This could help, for example, meeting legislative environmental protection requirements (such as the European Union Water Framework Directive (CEC 2000)), and to repurpose urban rivers from their industrial past to beneficial blue–green city assets in the future.

The experience gained from the CUSP project in Glasgow has been shared through a European Union COST Action called SUB-URBAN (TU1206). SUB-URBAN has established 'A European Network to Improve Understanding and Use of the Ground Beneath our Cities' (Campbell *et al*. 2017; Gogu *et al*. 2017; Mielby *et al*. 2017). Key issues addressed by the SUB-URBAN partners (in >30 countries and cities) are similar to those in Glasgow, and include:

1. **(1)** The creation of digital free-flow and online accessibility of subsurface data between those who develop subsurface knowledge and the planners and developers who need to use it.
2. **(2)** Development of 3D and 4D multi-scalar models to encapsulate, share and visualise the improving knowledge of the (shallow) urban subsurface and its (engineering) geological, geotechnical and geochemical properties; real-time groundwater and geothermal monitoring and modelling.
3. Planning of the subsurface, ideally in 3D and volumetric, and fully integrated with above-ground planning.

The final paper in this volume by Dick *et al*. (2018) emanates from planning experts from within the COST SUB-URBAN partner network. They describe lessons learned from Glasgow, and, in the wider context, from Rotterdam in The Netherlands and Oslo in Norway, in improving urban subsurface knowledge. The paper outlines recommendations on how best to integrate that knowledge into planning and policy in the future. It recognises that it is only by greater understanding and communication between city planners/developers and the geoscience community, that the subsurface ecosystem services, on which urban areas depend, often unknowingly, can be managed to mitigate risks and maximise opportunities, economic, social and environmental benefits for the cities of tomorrow.

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