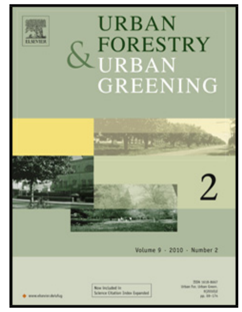
Article:

Wild, T.C., Dempsey, N. orcid.org/0000-0001-6642-8673 and Broadhead, A.T. (2019) Volunteered information on nature-based solutions — dredging for data on deculverting. Urban Forestry & Urban Greening, 40. pp. 254-263. ISSN 1618-8667

https://doi.org/10.1016/j.ufug.2018.08.019



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PII: S1618-8667(17)30755-0
DOI: https://doi.org/10.1016/j.ufug.2018.08.019
Reference: UFUG 26210

To appear in:

Received date: 20-12-2017
Revised date: 29-5-2018
Accepted date: 31-8-2018

Volunteered information on nature-based solutions – dredging for data on deculverting

Paper for Urban Forestry & Urban Greening - Special Issue on Urban Green Infrastructure

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HIGHLIGHTS

- **Volunteered data on objectives and outcomes of deculverting projects are reported.**
- **Reasons for deculverting include flooding, ecological restoration and redevelopment.**
- **Average costs of deculverting schemes were ~€21k/m (urban) vs ~€6k/m (non-urban).**
- **Volunteered geographic information may help fill knowledge gaps on NBS.**
- **Concerns over the veracity and accuracy of such volunteered data are discussed.**

Abstract

Much has been written about the potential contribution of citizen-science approaches to further urban environmental sustainability, and associated interventions such as nature-based solutions (NBS). Engagements between researchers and stakeholders relying on bottom-up information provision, for instance community mapping, are often purported to play a vital role in developing shared knowledge, achieving greater impact and stimulating innovation. However, relatively few studies within the realm of NBS have reported on experiences in using volunteered information, or their results. This reflects an important gap, not least because of the proliferation of proposals and bids that rely upon or integrate such methods into their approach. We report on experiences with gathering information using a 'bottom-up' map-based wiki tool, which effectively sought to crowd-source data, contributed by members of the public and professional stakeholders. As we approach the milestone of '10 years on' from the inception of the website www.daylighting.org.uk, we reflect on our approach, the opportunities presented, constraints encountered, progress made and results delivered. This is contrasted with other resources and data-gathering projects having similar aims for different urban NBS. Findings are presented on the substantive issue of the uptake of deculverting as a particular form of NBS, including land-use contexts, scheme costs and achievement of stated objectives. Reflections are given on potential contributions of such methods in relation to other, more established approaches and new techniques in urban knowledge co-production.

Keywords: deculverting; daylighting; nature-based solutions; green infrastructure; urban water; flooding.

Introduction

In recent years, stakeholders working with NBS and Green Infrastructure (GI) have witnessed a proliferation of initiatives to develop international, web-based databases, and information gathering approaches, based on mapping and GIS-type techniques (e.g. EEA, 2015; EC; 2016). These initiatives can be contrasted with the mapping of urban ecosystem services and GI at the level of individual cities and more local scales (e.g. Haase et al., 2012; Hansen and Pauleit, 2014). Such developments have made it easier for networks of cities and like-minded people to work together globally via the internet and utilising ICT applications such as smartphones, and to share their experiences in implementing NBS or 're-greening' urban environments. An important part of this story less often told however, is the link between the continuing scarcity of funding for long-term monitoring and evaluation, and the ubiquity of cheaper, web-based and network-derived resources used to augment more traditional modes of investigation.

In 2007, Michael Goodchild wrote a now seminal piece on the opportunities associated with 'Volunteered Geographic Information' (VGI). This represented an important early milestone in recognising the potential power and implications of this particular form of user-generated content, anticipating its growing importance, and reflecting on trailblazer initiatives like OpenStreetMap. Goodchild (2007) suggested that cost savings are a key driver for using VGI, highlighting the complementarity with other, centralised and labour intensive monitoring and mapping projects. However, drawing on earlier research into 'public participatory GIS' (PPGIS) and the social implications of GIS (e.g. Aitken and Michel, 1995; Pickles, 1995; Schroeder, 1996) others recognised important challenges. Noteworthy amongst these critical reflections is Flanagin and Metzger's (2008) questioning of the credibility of VGI. Their main concerns involved uncertainty as to who would provide information, motivations and the veracity of the data.

Around this time (2008) we started work to develop a web-based database, using mapping applications, to investigate deculverting. In developing the website resource, the main objectives were to generate information on a wider range of experiences, and to better understand such practices, by seeking to answer the following specific questions: (Q1) where are daylighting projects taking place and where can people go to see the results?; (Q2) what are the unique characteristics of projects in different types of location, and what are the implications for future planning?; and (Q3) how much do deculverting schemes cost? On the other hand, wider questions relating to the use of VGI in research were: (Q4) How can researchers use VGI to support deliberation, and how do they help those seeking to contest the results?; (Q5) How do these methods compare with and complement other research techniques?; and (Q6) How can we gauge good practice in the use of VGI to study NBS and GI?

Our aims for this paper are therefore twofold: firstly, to present and discuss new findings on the practice of deculverting; and secondly, to investigate the application of user-generated content approaches to support NBS and GI research. The rest of this paper provides introductory definitions and a brief synopsis of data collection techniques used, followed by a critical discussion of the findings and the role VGI played, reflecting on wider insights into urban knowledge co-production.

Urban NBS and GI

NBS can be defined as solutions to societal challenges "that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience, bringing more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions" (EC, 2018). Challenges including climate regulation, water flow regulation, erosion regulation, and disaster risk reduction can be addressed using NBS measures (EC, 2015) closely linked with deculverting:

- Reconnect rivers with floodplains to enhance natural water storage.
- Encourage re-vegetation of riverbanks.
- Reduce canalisation and create channel diversity to reduce speed of flood transmission.
- Re-meander rivers (where artificially straightened) to help reduce speed and height of flood peaks.

In an urban context, NBS can also be considered as re-greening interventions, potentially joined together as part of a wider multifunctional GI network. Under such interpretations, deculverting can be seen as a viable and invaluable NBS to address flooding, habitat loss and access challenges, alongside other interventions including urban river restoration, sustainable drainage, urban forestry and green corridor provision.

Deculverting – the daylighting and restoration of culverted rivers

Pinkham (2000) describes daylighting as a 'radical expression' of river restoration. Here, we use the simple definition of deculverting: 'opening up buried watercourses and restoring them to more natural conditions' (Wild et al., 2011). Deculverting is receiving increasing international attention, perhaps because the problems associated with burying rivers in culverts – notably flooding, pollution and habitat loss – are becoming more prevalent or apparent. Coupled with the extent of the issue (e.g. Denmark and Switzerland have up to 15-20% of river lengths 'lost' to culverts), this has resulted in an upswing in interest in the mainstream media, popular culture, governmental policies, and practice (e.g. CIWEM, 2007; EEA, 2016). However, despite this increase in awareness and action, post-project evaluation and outcome reporting remains rare (Bernhardt et al., 2005).

Many deculverting schemes rely heavily on community involvement or are volunteer-driven (Smith, 2007). This can be seen a result of the growing number of people and community groups engaged in nature-based activities making connections with their local environment with the aim to improve, restore, renaturalise and reconnect places with people (Church et al., 2011). In this respect deculverting, as a form of urban ecological restoration perhaps sits close to Aldo Leopold's 'land ethic' vision (1949), and his hopes for conservation as a wide expression of community spirit.

Fostering participatory and inclusive governance with local communities can positively affect the ability of service providers to improve urban hydrological outcomes (Schifman et al., 2017). However, it would be naïve to assume that community spirit is always 'available' or will necessarily manifest itself in volunteer capacity to support deculverting schemes. This is bound up with issues of social equity and social cohesion (Kuller et al., 2018), and can help our understanding of why some daylighting projects may flourish or fail. Differences in community capacity and access to power, manifest through bottom-up action, may risk an unequal distribution of access to environmental quality improvements which may become more prevalent in more affluent districts (Dempsey et al., 2015; Mathers et al. 2015).

From a normative perspective, stakeholders in urban NBS should be vigilant that such strategies and actions seek to challenge, or at the very least do not exacerbate, environmental injustice. Kabisch and Haase (2014) stress the need to go beyond simplistic analyses of greenspace spatial distribution, and that user needs should be considered for successful GI planning and provision. Schifman et al. (2017) call for a nuanced understanding of the social aspects of specific, tangible examples of practices ('situating' or 'situated' GI). The challenge to utilise expert power c.f. 'indigenous spatial knowledge' (Sieber, 2006), presents important questions about *who volunteers information* (Goodchild, 2007). The juxtaposition between the lack of robust information about achieved daylighting objectives, and its close link with citizen involvement makes this topic interesting in terms of future directions in VGI. In describing the experiences, pitfalls and opportunities witnessed, we hope to provide some insights useful to people promoting daylighting and those seeking to develop, critique or interrogate information on urban NBS using VGI.

Methods

Research into deculverting in Sheffield started in earnest in 2008. Background to the development of the website www.daylighting.org.uk is provided in Wild et al. (2011), and Broadhead and Lerner (2013). Work commenced with support from the EPSRC-funded project www.*ursula*.group.shef.ac.uk, drawing on experiences of daylighting projects in Glasgow and Edinburgh (Darlow et al., 2003), and works in Zurich, Switzerland. The context for this research was the emergence of SCC's (2009) spatial planning policy including a presumption for developments to deliver deculverting. This provided rich research material, accessible to the group. However, the paucity of published case study information on achieved outcomes proved problematic. For this reason, a VGI approach was taken, experimenting to put together the 'patchwork' of data (Goodchild, 2007). This approach, novel at the time, provided an interesting contrast to earlier work to develop databases on urban NBS and GI performance (e.g. Wild et al., 2002).

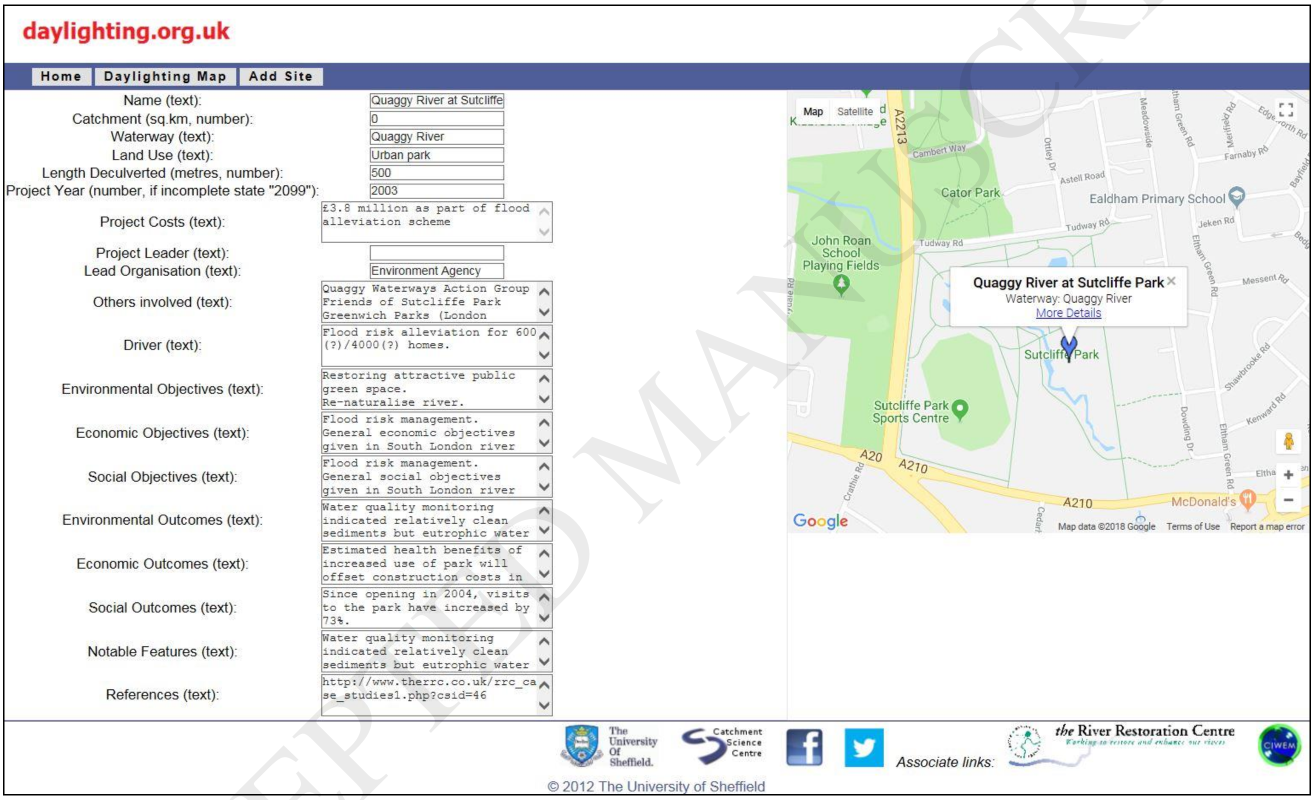
With a small grant of <£1,000, work by a computer scientist was commissioned to build the website integrating a geo-referenced database. This utilised links to Google Earth/Maps, enabling participants to quickly 'geo-tag' project locations (Fig.1). On entering a new case, participants would be prompted to click on the map to locate the deculverting scheme, providing access to a short table-based form, as a kind of 'survey'. Alternatively, participants could simply view other cases in the database, or download map files for their own use. From a technical standpoint, the website was set up to include a MySQL (open-source software) database. This included tables holding data reported for each scheme, and the location, using MySQL geographic data extensions. Doing so allowed users to view the map with links to the schemes on the webpage using the website-scripting language PHP (www.php.net). When adding a scheme, the webpage would require users to select positions on the map before data could be saved to the scheme table.

The website project was developed with the input of a multidisciplinary research team including planners, landscape architects, civil engineers and environmental scientists. The resulting survey form (Fig.1) included both open and closed questions (including 'free text' boxes to record deculverting objectives and outcomes), enriching the types of information entered and gathered. The 'survey' was kept open with no deadline to submit returns; it remained live at the time of writing.

Promotion of the website was achieved via links with project partners, with awareness being raised via scientific articles and news bulletins widely distributed among researchers and stakeholders (Broadhead and Lerner, 2013). Recognition of the resource was increased via presentations and discussions at local, national and international events, and through fora covering river restoration, spatial planning, urban forestry and GI. The work was presented to potential audiences via a set of Sheffield-led European projects. The combination of these activities increased engagement with stakeholders from different sectors including research, public sector, businesses and not-for-profit organisations.

Later work entailed follow-up activities to encourage people to enter information into the online database. Different platforms where utilised to 'share' news about the work, particularly via social media and blogging. The authors have active social media accounts, with relatively positive experiences in linking research and practice via such networks. Automated search functions were used to identify mentions, with cases logged and followed up via additional research or by contacting individuals for further information. More recently, mainstream media channels were harnessed, as the work became better known to public audiences.

Figure 1. Website-based survey and linked map positioning function



The underpinning research agenda was developed with close links to practice and policy. From 2010-15, two deculverting projects were implemented locally, providing the opportunity to use co-production research methods. The two Sheffield projects were implemented in parallel, one being positioned in a central urban setting, the other in a rural location. Experiences gained through these practical projects, and associated policy links (e.g. with Defra), proved invaluable in refining research questions. Views and perspectives were exchanged with citizens, cities, researchers and policy-makers from across the EU and beyond. Table 1 shows images of the two contrasting initiatives. More broadly, these interfaces were vital in developing thinking about how to integrate NBS interventions into GI network strategies.

Table 1. Deculverting projects: urban and rural daylighting of culverted stretches of the Porter Brook, Sheffield, UK

	Urban - Matilda Street Porter Brook Pocket Park	**Rural** - Porter Brook Headwaters Deculverting
Before	 2011	 2011
During	 2012	 2012
After	 2016	 2013

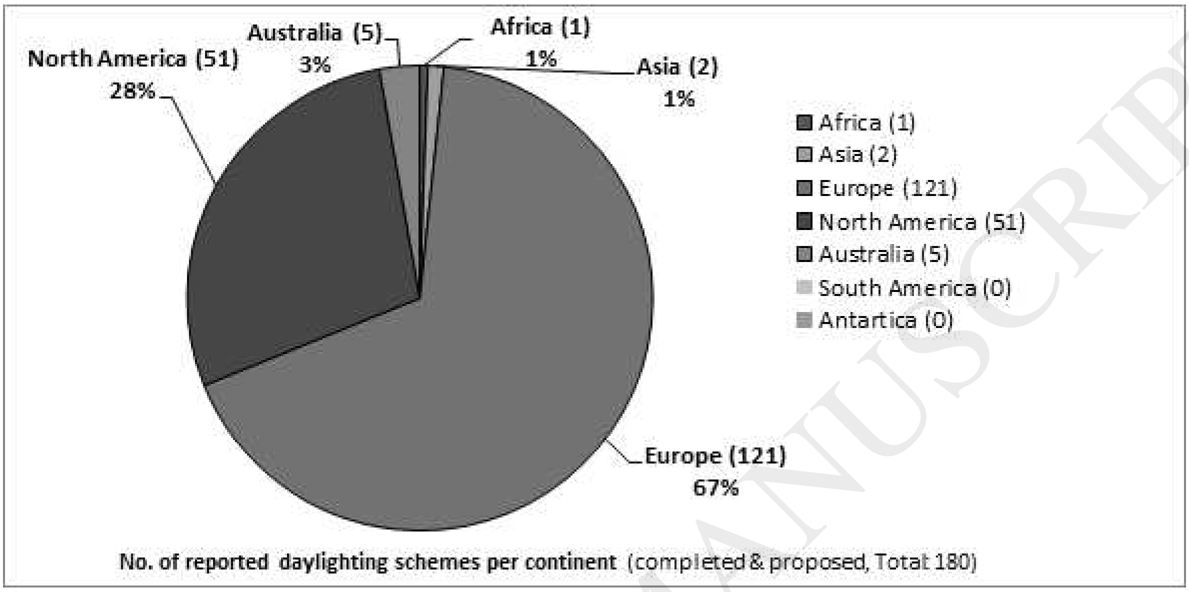
Data interrogation and interpretation was undertaken during 2017 using an iterative approach, with questions being reformulated following discussions of emerging findings. Data analysis was primarily undertaken using spreadsheets, following extraction of information from the SQL database. This process enabled further refinement of information to glean more details about cases. In particular, this involved using the embedded Google Maps functionality, including using time-lapse photography, to check locations. The mapping tool was also used to check for cases of contestation or debate over daylighting scheme details. Textual analysis was undertaken using a word-cloud formatting tool to help understand scheme objectives and outcomes. References, where provided by participants, were used to verify case study details, and to check the consistency of classifications. In some cases, contact was made with project stakeholders. Several large projects were reported in numerous publications, so some degree of data checking was possible using secondary sources. Emerging findings were presented and debated at international scientific conferences on urban rivers, GI and NBS, and via discussions with interested parties.

Results

Locations of deculverting projects

Geo-referenced locations and address details of cases were used to establish where daylighting projects had occurred, shown below at the continental level (Fig.2). Most cases reported were located in Europe (67%; 121 of 180 schemes), and in North America (28%; 51 of 180). Very few cases were reported for other continents. These results may reflect the location and language of publicity and awareness-raising activities undertaken, as described in Methods.

Figure 2. Locations of reported deculverting projects



Objectives, outcomes and reasons for deculverting projects

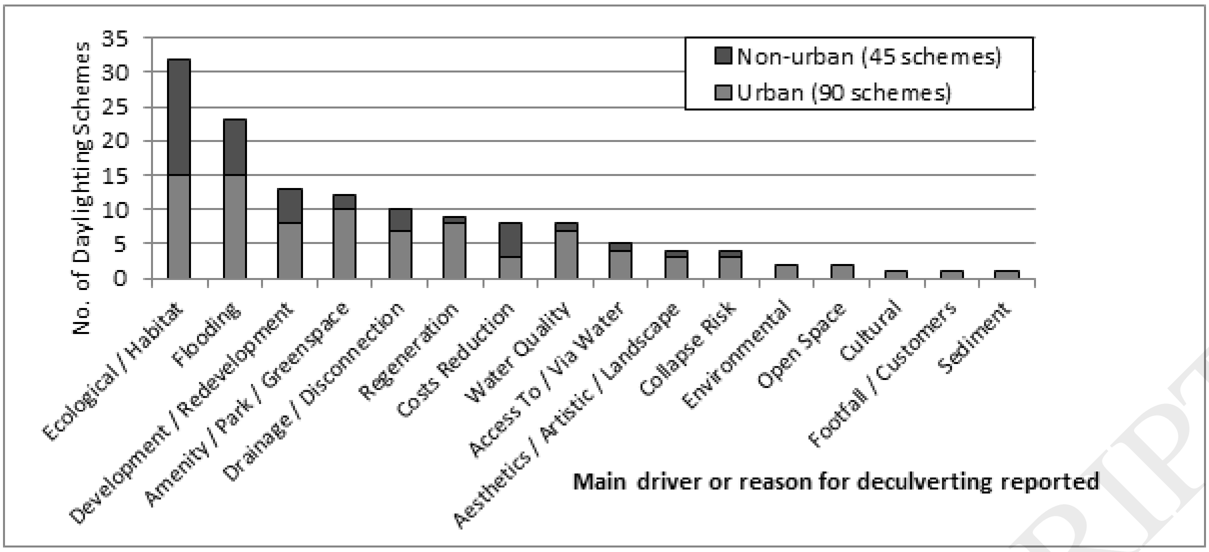
The website collected information about the reporting of outcomes against objectives for specific cases. Results were classified into three main categories of environmental, social and economic factors, or all three, in examples where respondents discussed broader sustainability contexts, or mentioned holistic considerations, e.g. 'community resilience' (Table 2). The most common objectives and outcomes reported were environmental (e.g. restoration of fish habitats). Relatively few projects featured economic objectives or outcomes. A striking finding is that only approximately one half of cases reported outcomes against stated objectives. Very few reported outcomes against all three sets of objectives (12 cases).

Table 2. Reporting of outcomes against objectives

Objectives & Outcomes/Criteria	Environmental	Social	Ecomomic	All three
Objectives Stated	70	66	41	29
Outcomes Reported	48	40	27	20
Objectives Stated & Outcomes Reported	36	28	19	12

To augment information about stated objectives, the survey included questions about the 'driver' for deculverting (Fig.3). This provided an opportunity to check the consistency of objectives and to understand the circumstances that precipitated action, and/or led to projects being realised on the ground. This line of enquiry was included because daylighting opportunities may emerge unpredictably or rapidly, e.g. due to unplanned events such as culvert collapse, blockages or extreme storms leading to flooding.

Figure 3. Drivers for daylighting - stated reasons why culverted rivers were opened up



Notes: reasons or 'drivers' reported for 90 of 124 urban schemes, and 45 of 56 non-urban projects.

The most common reasons given for deculverting were linked with habitat restoration and other ecological drivers. Flooding was also very frequently cited as a cause. Figure 3 presents these drivers broken down into urban c.f. non-urban locations. Of the total 180 schemes reported, 124 were located in urban settings, with 56 being situated in sub-urban or rural locations. Drivers for those projects were described in 135 cases, 90 being set in urban locations, and with 45 cases taking place in non-urban areas. Ecological drivers for deculverting were relatively more common in sub-urban and rural settings, whereas flooding was more often stated as the reason for daylighting in urban locations. Environmental mitigation for re/development was also common. In urban settings, greenspace amenity provision was frequently cited, and in rural and suburban locations costs reduction was named as a driver more often than in urban centres.

The results of textual analyses using word-cloud formatting (Fig.4a) reflect the quantitative results, with habitat and flooding reasons being the most prominent objectives described. Interestingly, both characteristics feature less strongly in a word-cloud of stated outcomes of projects (Fig.4b). Statements about reduced flooding being achieved, or flood risk management outcomes, were less prevalent than was the case for scheme objectives. It is interesting to reflect on the limited number of terms related to social objectives and outcomes (e.g. 'access', 'public'), with 'community' mentioned more frequently in the outcomes. Economic terms unsurprisingly relate to cost; they were less frequently mentioned than environmental and social terms respectively, indicating a strong tendency of participants to focus on the physical characteristics of deculverting.

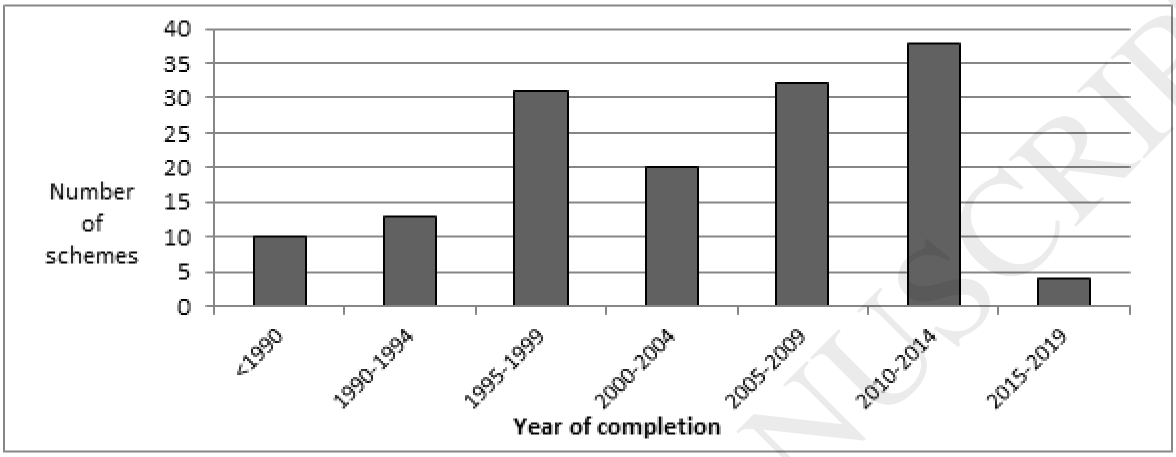
Figures 4a & 4b. Word clouds for scheme objectives and outcomes of reported deculverting cases

Use of the embedded mapping tool revealed no cases of contestation of project objectives or outcomes. Three instances were found to involve the apparent duplication of a single deculverting project in the same/similar location. In two of these cases, identical details were reported as separate entries. In the third case, the only substantive difference was the named lead organisation; even in this instance, the same project partners were listed in the survey tables.

Trends over time

Figure 5 shows an apparent increase in numbers of daylighting schemes completed, rising from ten occurring before 1990, to a peak of over 35 taking place between 2010-2014. A significant 'spike' is visible in the late 1990s, associated with a large number of schemes being completed in Zurich under the city's Bachkonzept strategy, reported elsewhere. Less clear however is whether there has been genuine drop in deculverting activity since 2015.

Figure 5. When did deculverting take place?

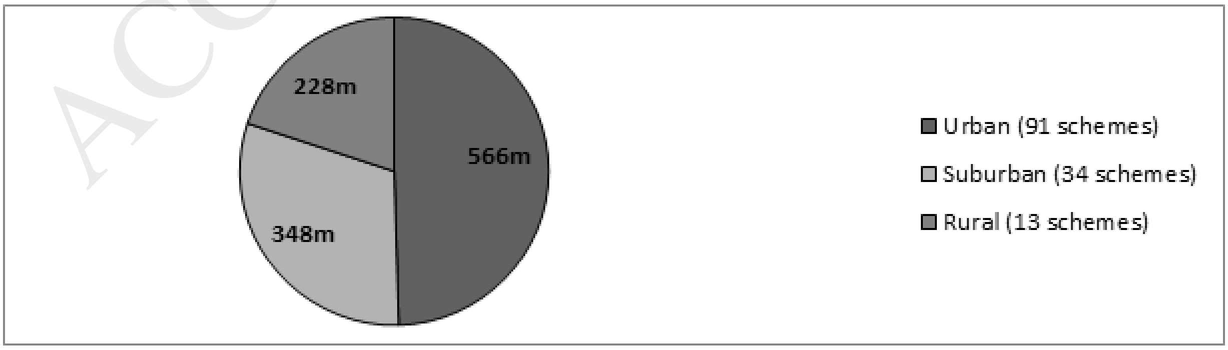


Lengths of rivers deculverted

The majority of cases reported involved daylighting less than 1km of river. Of 180 cases, 124 or 90% of projects involved removing culverts of <1km in length. This is perhaps unsurprising, since most culverts are relatively short compared with total river lengths (although many urban rivers pass through multiple culverts and open sections in close succession).

Experiences of the two Sheffield cases led to the expectation that daylighting schemes in rural or peri-urban locations would tend to be longer than those in towns and cities. This would seem reasonable, since the ownership of rural land tends to be less fragmented, which should theoretically make it simpler to coordinate the delivery of longer schemes. However, the results do not support this view. The mean length of urban, rural and sub-urban daylighting schemes was calculated (Fig.6). On average, urban deculverting projects were in fact longer than those located in sub-urban or rural locations.

Figure 6. Average length of deculverting schemes in urban, sub-urban and rural locations



To provide a clearer picture of the scale of activity, the data on lengths of deculverting schemes were broken down into a series of length classes (Table 3, all schemes <1km). The data indicate that greater river lengths were deculverted in town and city settings, as well as there being more projects in such locations: 78% of the summed length of all deculverting work reported took place in urban areas. Daylighting is primarily, though not exclusively, an 'urban endeavour' or intervention.

Table 3. Total lengths deculverted in urban, sub-urban and rural settings, broken down into length classes

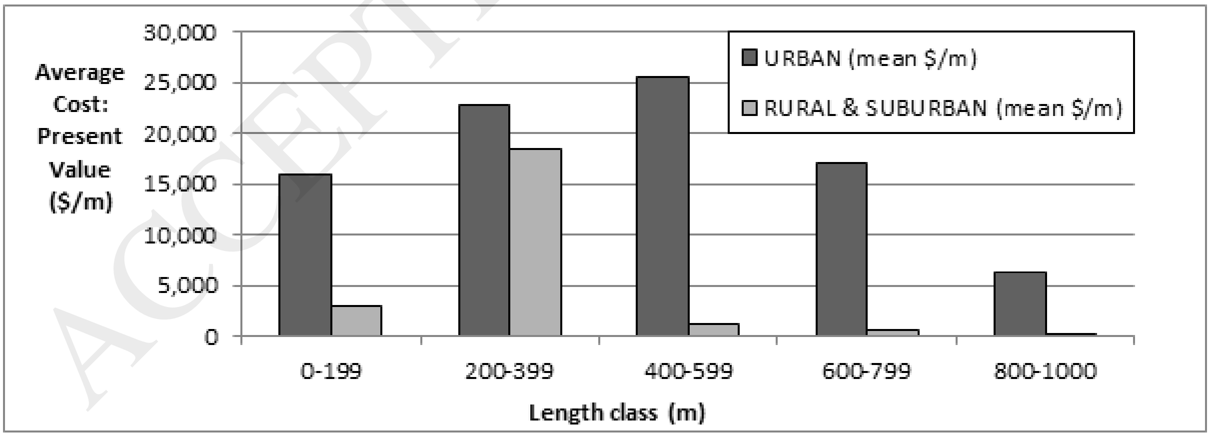
Total length in each length class (m)	**0-199**	**200-399**	**400-599**	**600-799**	**800-1000**
URBAN	3577	5583	4195	3862	4570
SUBURBAN	1405	2540	2290	0	1600
RURAL	275	540	0	1350	800

Costs of deculverting

Costs data were collated from the database, which allowed respondents to enter 'free text' on daylighting prices. Data were provided in 62 of 180 cases, again mostly from Northern America and Europe. This information was processed by calculating 2017 values, using currency conversion tools available at http://fx.sauder.ubc.ca/data.html, and standardising data using US Dollars as a base. Where scheme lengths were available (52 cases), average costs per metre were calculated, which ranged from a rather questionable zero, up to a staggering ~150,000$/m. The overall average cost daylighting was ~16,000$/m.

Following local debates around the Sheffield cases, an important question emerging regarded the relative costs of deculverting in urban- as compared with rural- settings. This question can be seen as a microcosm of wider discussions regarding the relative merits and costs of environmental improvements and ecological restoration in city versus countryside locations. Figure 7 presents average costs per metre of schemes of varying lengths in such locations. Our hypothesis for this was that urban projects should prove significantly more costly than daylighting in rural and sub-urban locations, due to a combination[1] of: (a) higher land values; (b) complexity of infrastructure networks (e.g. services requiring diversion); and (c) complications relating to wider planning issues, e.g. multiple land-ownership issues and more diverse management responsibilities.

Figure 7. Average cost per metre of deculverting in urban c.f. non-urban settings, by length class, for schemes <1km



Average costs per metre were considered for different length classes, to explore trends such as potential economies of scale. It does not appear to be the case that longer schemes work out cheaper, or vice versa.

[1] Of course this representation is an oversimplification. For instance, we are aware of some locations in European countries where agricultural land suitable for use in growing specific 'prized' crops can attract higher prices than nearby urban sites. However, the above assumptions seem reasonable to hold in most cases.

Average costs per metre of daylighting schemes were calculated, where information was provided. Relatively few cases included both cost and length data (Table 4: 52 of 180 cases - 33 urban schemes; 19 non-urban schemes). The mean cost of urban daylighting was approximately 21,000 $/m, whereas the mean cost for non-urban schemes was ~6,000$/m.

Table 4. Difference between mean costs per metre of urban c.f. non-urban daylighting schemes

Deculverting locations	mean $/m	S.E.	n	t	p < .02 2-Tailed
URBAN	**21.294**	5.946	33		
RURAL & SUBURBAN	**6.322**	3.233	22	02-Mar	Significant

Table 4 shows that these data exhibit a considerable amount of variability. Standard errors for both datasets are relatively high. Furthermore, the data showed a degree of skewness, thus a Mann-Whitney U-test was performed. The median urban scheme cost of 12,568$/m was significantly greater than the median non-urban scheme cost of 972$/m. Mean ranks were 32.5 and 16.0 for the urban and non-urban groups respectively; U=115, Z=3.8, p<0.01.

Contact details, comprehensiveness of reports, and accuracy of data

Returning to the theme of the volunteered nature of case reporting, outstanding questions related to the comprehensiveness and accuracy of reported data. Here, in only 40 of 180 schemes was a person's name given. Additionally, only 17 of 180 participants provided contact details; only 5 of those were linked with schemes where both costs and lengths were supplied. Thus, in the majority of cases it proved impractical to examine details of either costs or lengths of deculverting schemes. It also means that it may prove difficult to further improve on average costs per unit length data using the techniques described here. To give further insights into this issue, the likely rounding accuracy of lengths of schemes reported was investigated. Bearing in mind that schemes are highly unlikely to involve neatly rounded numbers in reality, those reported to the nearest 1m, 10m, 100m and 1000 metres were counted (Fig.8). The vast majority of cases exhibited figures reported in 10s or 100s of metres. Several schemes were measured to the nearest kilometre.

Figure 8. Likely rounding accuracy of reported lengths

Discussion

In setting out this paper, we sought to answer questions relating to variations in deculverting practices, and wider themes relating to VGI and NBS research. In both respects, questions about rigour and mechanisms for strengthening transdisciplinary research remain pertinent. The low cost of VGI methods may appeal but this is not the only consideration for researchers and other stakeholders. As Goodchild (2007) noted, websites like these "provide…sometimes the only source" of information. Judging by the rapid growth in interest, existing case study material on deculverting (largely in Northern America and Europe) has proved invaluable to practitioners and policy makers (e.g. EEA, 2016; EA, 2014). However, for such urban NBS where practice is evolving quickly and researchers face a paucity of data, more information is urgently needed, calling for innovative and complementary methods.

Question 1 posed in the Introduction concerned deculverting locations, and specifically where people could go to find project details. Given the importance of urban sustainability and the urgency of climate change adaptation, this is an important contribution. Simple-to-use mapping applications have the benefit of being available to a wide audience, and judging by the social media and mainstream press coverage, these results are interesting to many people. However, in terms of research, this is just a starting point. VGI resources like this can play an important role in pointing towards future case studies, a theme we return to later.

Question 2 related to project settings, objectives and outcomes. The results indicate that daylighting is primarily, though not exclusively, an 'urban endeavour' (Figs.3&7; Broadhead et al., 2013). This is perhaps because culverts are more prevalent and cause greater problems in urban areas. The fact that flooding is a primary driver for urban projects (Fig.3) attests to this conclusion. From an ecosystem services perspective, flood risk management may often provide an important 'key' by which deculverting might 'unlock the door' to provide a wide range of benefits in urban environments. In rural locations, where other reasons for deculverting (e.g. habitat and ecological drivers) are more dominant, different design criteria will apply.

It is beyond the scope of this paper to report in detail the reasons for differences between stated objectives and outcomes of particular cases (Figs.4a&4b). However, this result may open up new lines of enquiry (e.g. implications of 'community' emerging as a more frequent descriptor used in reporting outcomes c.f. objectives). Many more statements were made about relatively straightforward physical characteristics, such as hydro-geomorphological modifications completed - perhaps these results are easier and cheaper to qualify; it may be that respondents felt less confident in returning information about results achieved, particularly for newly completed schemes. Another reason for the disparity could be that outcomes were underreported where privately-led schemes involve confidential or commercially sensitive financial data. Proponents or contractors might also underplay disappointing results. In terms of flood risk management, it would be extremely difficult to prove that deculverting alone was the main reason for reductions in flooding, since (a) extreme rainfall events might not have occurred post-project; and (b) other factors might be responsible, such as concurrent changes in river catchments. While the absence of evidence is not evidence of absence, it is more common and simpler to rely on the results of hydraulic modelling of flood risk than to prove such an outcome *in situ*.

Our findings concur with Schifman et al. (2017) and Kuller et al. (2018) that biophysical site characteristics are better accounted for in GI projects whilst social and economic factors are more often overlooked. Clearly, key gaps in the literature remain around the social objectives and outcomes of deculverting schemes, judging by an over-reliance on the relevant strands of review papers or synopsis reports (e.g. Pinkham, 2000) or wider cases of river restoration (e.g. Westling et al., 2014). Whilst many authors have addressed the ecological and environmental results of daylighting (in terms of water quality and habitat, e.g. Beaulieu et al. 2015), or the economic and flooding impacts (Shin and Lee, 2006; Everard and Moggridge, 2012), social outcomes including community involvement and social inclusion remain relatively under-researched. Given the importance of the 'turn' in ecosystems research towards urban socio-ecological systems (e.g. Delibas and Tezer, 2017; Raymond et al., 2017), the relative paucity of social science research into specific urban NBS interventions seems to be a blind-spot requiring further attention. The result of textual analyses of stated objectives versus outcomes of deculverting schemes provides a useful jumping-off point for future work in this area.

The locations of deculverting projects can also be considered at a much broader scale. From a 'Global South' perspective, the bias towards reporting of cases in Northern America and Europe (Fig.2) is reflected in the literature. Using Scopus, we found that 11 of the 24 references citing an earlier paper on deculverting case studies (Wild et al., 2011) were published by authors from the United States, 6 were from the UK and 2 were from New Zealand. Only one publication came from what can be viewed as a 'Global South country', Jordan (a further paper came from Turkey). One scheme reported via the website relates to Morocco. Culverting is not unique to Global North countries. Beaulieu et al. (2015) note that stream burial has also been reported in Asia (Nam-choon, 2005) and that "given the expected expansion of urban areas worldwide, stream burial will likely increase over the coming decades". Thus, if daylighting is a useful NBS for climate change adaptation, regeneration and ecosystem restoration, new research into this topic needs to be carried out in the Global South. Comparative case study approaches on daylighting (e.g. Delibas and Tezer, 2017) may improve the robustness of research in different global contexts. Therefore, recent efforts by the EU to strengthen international cooperation in NBS are welcomed. These could be further enhanced by extending programmes to include other continents (e.g. Africa), and areas where daylighting research is well established (e.g. USA and Canada).

An important result relating to Question 3 was that the costs of deculverting reported here differ significantly from the literature. Pinkham (2000) provides figures of $1000/linear-feet, ranging from $15-5,000/linear-feet. The results presented here indicate an average costs per unit length of ~21,000 $/m for urban schemes and ~6,000 $/m for non-urban schemes. Pinkham (2000) remains the most commonly used reference on daylighting costs. Even taking into account inflation and differences in units, these results indicate that earlier costings estimates may be on the low side.

The volunteered data on costs suggest that urban deculverting schemes are more expensive than their rural and suburban counterparts (Fig.7; Table 4). This is unsurprising, since city-centre land would generally be expected to cost more, as would the more complicated infrastructure diversions and reconfigurations required. Along with the greater transaction costs of planning urban schemes, where there are larger numbers of landholders, stakeholders and interests, the expenditure required quickly mounts up. This was certainly the case for the examples on Sheffield's Porter Brook. However, there are simply more culverts causing greater problems in urban areas. The flood risks associated with culvert blockages, or rainfall events that quickly cause flows exceeding culvert capacities, can be expected to affect more homes and businesses than would be the case in non-urban locations. There is also increasing evidence of the 'spikes' in ecosystem services that restoration schemes in urban areas can deliver, as highlighted by Haase et al. (2014) almost 80 % of Europeans live in urban landscapes which are "becoming the everyday environment for the majority of the global population in the near future". The economic values of urban daylighting including regeneration benefits are considered elsewhere, notably in Shin and Lee (2006).

In reporting average costs for daylighting it is anticipated that the data prove helpful to people seeking to implement such schemes, noting that these average costs per unit length are an amalgamation of data from different places, and reflect present values calculated at the time of writing (i.e. the figures will rise over time). A potential criticism of this approach regards comparison of scheme costs from different countries, with varying economies, market institutions and land values. The relatively small number of daylighting cases globally means that it is not yet practicable to 'hone in' on very similar cases. However, drawing together comparable cost and values data is always likely to remain problematic, even from cities within the same country; it is important to understand local economic contexts for urban NBS and associated development dynamics (Wild et al., 2017). Market-failure areas exist in many cities, sometimes sitting right alongside thriving neighbourhoods; the availability of land can be both a constraint to and a driver for change. This raises important challenges for the development of future cost/benefit guidelines.

Perhaps more importantly, these costings data can only be indicative due to the limited accuracy of lengths data reported. Having said that, we and other proponents of daylighting would have found it helpful to have access to even rough cost approximations (irrespective of the above caveats). Whilst the results may have been subject to rounding errors made by those uploading cases - and the hope is that future studies will improve upon their accuracy - this is not considered to be particularly detrimental to the overall findings. Costs data remain a fundamental need for practitioners taking forward schemes and for researchers concerned with valuing ecosystem services e.g. using benefits transfer methods (e.g. Bateman et al., 2011).

Question 4 addressed the potential role of online geographical resources in supporting deliberation. An advantage of the mapping tool used was that an infinite number of cases could be lodged about the same place, allowing anyone to volunteer or contest views about specific projects. In common with the river restoration wiki-map https://restorerivers.eu, no cases were found where the website was used to debate the objectives of deculverting projects or to contest the results. However, the results are there to be seen, meaning they can be further debated and researched using similar or other techniques; the interactive map viewer provided by this journal makes these data available for further discussion by a wider audience.

Of course, there are some troubling aspects of this work. Most notable is that the apparent reliance of daylighting initiatives on volunteering effort, which risks that the only voices to be heard will be those that can afford the skills, time, technology and capacity to make their voices heard. As Sieber (2006) noted, it is important to consider who provides information, and who are the experts that portray public perceptions. Different people may hold diverging views of what counts for success or failure of deculverting schemes. Harris and Weiner (1998) highlight that there are 'multiple realities of landscape' at play, and representation of those different perspectives demand further attention. This comes into sharp relief in considering differences between stated goals versus recorded results (after Bernhardt et al., 2005). Watching the newly resident trout rise in a secluded, re-naturalised urban river shielded by trees might be delightful - and provide a respite from the city on a hot stuffy day - but the self-same setting at night might represent a dark, intimidating and threatening environment, with views obscured by overgrown vegetation. Elwood (2008) warns of the need to be vigilant for under-representation in deprived or challenging areas where the information is incomplete, in areas of great need, where researchers might be most reticent to go.

Question 5 asked how VGI methods compare with or complement other research techniques. From varying disciplinary perspectives, such datasets represent rich opportunities to initiate detailed comparative analyses of NBS cases. The opportunity exists to go back to neighbouring communities for schemes around the world, and to discuss the objectives and results with citizens. Several cases highlighted the social outcomes of daylighting projects, including the value of engagement with citizens (including school children), the input of volunteers, and 'place-making' opportunities afforded by daylighting. These processes - coupled with the wider wellbeing benefits of reduced flood risk and access to greenspace - represent important chances to strengthen links between social capacity and the physical aspects of restoration, design, and climate resilience that are central to NBS concepts.

In taking forward new internet-based methods, researchers working on NBS need to evolve relevant and appropriate tools for co-production that fit with these techniques. Doing so could also better support what Connolly et al. (2014) refer to as "the specific strategies of civic engagement required to create this hybrid institution where the roles and responsibilities between civic groups and government become intertwined".

These wider discussions are linked with the points raised above regarding contestation and deliberation, and social cohesion and equity. With specific reference to deculverting, Dicks (2015) called for a new paradigm in urban hydrology, integrating bottom-up initiatives and lateral cooperation between the various actors and stakeholders of the urban water cycle. In this respect, important parallels exist with the growing body of 'place-keeping' research (Wild et al., 2008; Dempsey et al., 2014; Mattijssen et al., 2017).

Question 6 concerned how to gauge good practice in using VGI. The following recommendations and remarks can be made, drawing on lessons from this and other projects.

Firstly, important distinctions should be made between centrally-directed versus bottom-up database initiatives. Other projects, for instance on sustainable drainage (e.g. Wild et al., 2002), are notable in that once work finishes, the resources created quickly become outdated, even if the results remain relevant when nothing takes their place. There are exceptions, including the US Best Management Practices database, but this is the result of huge collaborative effort costing millions. Such funding is not always available - particularly when emerging and under-researched innovations have not received wider attention, or have not yet 'broken through' into the mainstream. Therefore, efforts to gather user-generated content may be cautiously encouraged to generate new performance data about untested NBS interventions, from an early stage. Nevertheless, VGI approaches do not come 'for free' and are reliant on sufficient engagement by potential contributors. Here, ~500 hours of researcher time was required to seek out projects, contact practitioners, and support follow up. Therefore, a key lesson is that such platforms may need to rely on either a handful of enthused champions or on a large social network of engaged users. Since the website inception, Web 2.0 approaches have developed considerably, and there is future scope to adapt the case study collection to make better use of applications for improved citizen engagement and more attractive visual media for improved user experience to encourage volunteers' buy-in and sustain effort.

Secondly, some of VGI's reported drawbacks could perhaps have been minimised by enabling users to provide feedback within the website itself. Researchers could then have uploaded questions or comments about the relevant schemes, to establish contact with those volunteering information, thereby starting a dialogue. Another important practical recommendation is to include some form of version control for data entry, in which the users generating content are asked/required to provide names or organisational details. However, this in itself poses further challenges linked with personal data protection. Wikipedia's revision history method solves this problem by giving users control of the information they provide about themselves and their work. OpenStreetMap takes a similar line, but explicitly links user information to geographical locations. Other platforms use different methods to help 'find' and report case studies e.g. Oppla, (https://www.oppla.eu/case-study-finder), including more traditional yet tried-and-tested routes to moderate material centrally via a formal data platform, providing organisational details so that interested parties can verify information and find out more.

Thirdly, a good practice is to enable users to search results using free text queries or pre-defined questions. The Restore website does so, covering: reasons for implementation; measures used; monitoring results; and costs. Although these functions increase the cost and complexity of VGI-based resources, they represent helpful additions for both platform users and analysts.

Fourthly, researchers planning to use VGI-type approaches are well-advised to build in review points and allocate resources for upgrading, as well as populating online resources. The opportunities and requirements associated with web-based platforms change rapidly. An example would have been to build in language translation facilities, to help strengthen global coverage. However, such simple measures would not obviate the need for strategic investment to strengthen international research cooperation across continents.

In conclusion then, where does this leave us regarding the questions over credibility raised by Flanagin and Metzger (2008), and the dangers of 'context deficit' (Eysenbach and Diepgen, 1998) in limiting the usefulness of VGI? The problems encountered here in establishing contact details, and associated questions over the accuracy of data (Fig.8) reinforce Goodchild's point that "who may volunteer has much to do with the quality of the resulting information". However, that does not mean that the data are redundant; rather they can be seen as a starting point for further research, to improve upon results using other data collection methods. Here, we adopted a mixed-methods approach in interrogating the data, employing comparative case studies to help frame the questions, and to better understand these contexts. In doing so, the research also had the rewarding outcome of challenging preconceptions. In conclusion, whilst we acknowledge the challenges and shortcomings of this work, it is clear that without the website we would not have any data. To quote Goodchild (2007): "the most important value of VGI may lie in what it can tell about local activities in various geographic locations that go unnoticed by the world's media, and about life at a local level".

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