Urban stream renovation: incorporating societal objectives to achieve ecological improvements

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Abstract: Pervasive human impacts on urban streams make restoration to predisturbance conditions unlikely. The effectiveness of ecologically focused restoration approaches typically is limited in urban settings because of the use of a reference-condition approach, mismatches between the temporal and spatial scales of impacts and restoration activities, and lack of an integrative approach that incorporates ecological and societal objectives. Developers of new frameworks are recognizing the opportunities for and benefits from incorporating societal outcomes into urban stream restoration projects. Social, economic, cultural, or other benefits to local communities are often opportunistic or arise indirectly from actions intended to achieve ecological outcomes. We propose urban stream renovation as a flexible stream improvement framework in which short-term ecological and societal outcomes are leveraged to achieve long-term ecological objectives. The framework is designed to provide additional opportunities for beneficial outcomes that are often unattainable from ecologically focused restoration approaches. Urban stream renovation uses an iterative process whereby short-term ecological and societal outcomes generate public support for future actions, which may provide opportunities to address catchment-level causes of impairment that often exist across broad temporal scales. Adaptive management, education, and outreach are needed to maintain long-term public engagement. Thus, future work should focus on understanding how ecological and societal contexts interact, how to assess societal outcomes to maintain stewardship, developing new methods for effective education and outreach, and multidisciplinary collaborations. We discuss potential abuses and the importance of linking societal outcomes to long-term ecological objectives.
Key words: stream restoration, urbanization, ecological, societal, adaptive management, stewardship, environmental education

As the global human population continues to grow, the need for strategies to mitigate anthropogenic impacts on stream ecosystems continues to increase. Researchers in applied stream ecology have responded by developing refined bioassessment protocols (e.g., Wright 2000, Bonada et al. 2006), land development strategies that minimize negative effects on stream environments (Dietz 2007, Ahiablame et al. 2012), and new or improved approaches to stream restoration (Fletcher et al. 2014, Roy et al. 2014). Stream restoration approaches have shifted from hard-engineered

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solutions focused on ecosystem structure to the use of natural channel forms and processes to support ecosystem structure and function (Niezgoda and Johnson 2005, Palmer and Febria 2012, Naiman 2013, Hale et al. 2015).

From an ecological perspective, consistently effective strategies for restoring streams in urban catchments are elusive (Sudduth et al. 2011, Violin et al. 2011, Laub et al. 2012). The primary ecological barriers for restoring streams in modified landscapes is the extent to which drivers of stream condition (e.g., flow, sediment supply, water quality, habitat availability, etc.) and patterns of dispersal are modified by human activities (Bond and Lake 2003, Palmer et al. 1997, Smith et al. 2009). Frameworks like the urban stream syndrome (USS; Walsh et al. 2005) or that proposed by Wenger et al. (2009), which summarize the processes by which humans alter stream ecosystems, can help identify stressors and guide restoration efforts. The effect of specific stressors can sometimes be quantified to inform project design (Craig et al. 2008, Vietz et al. 2014), but characterizing the relationships among all drivers of environmental degradation to inform stream restoration projects is challenging.

At the 3rd Symposium on Urbanization and Stream Ecology (SUSE3), a working group of scientists from 7 countries, including students and professionals from academia, government agencies, and private industry, sought to develop a framework that could increase opportunities for achieving beneficial outcomes from efforts to improve urban streams. Our primary objective was to develop a flexible alternative to ecologically focused restoration that would provide options for short- and long-term improvements to urban streams that may be pervasively impaired by human actions. As part of this primary objective, we intended to challenge the philosophy that restoration projects are futile unless they are able to address all the 'causes' of the urban stream syndrome (e.g., excess stormwater runoff; Moran 2007, Roy et al. 2008, Walsh et al. 2012, Fletcher et al. 2014). In so doing, we discussed the merits of a framework based on an integrated approach that considers both 'ecological' and 'societal' (Table 1) perspectives for achieving long-term improvements in ecosystem structure and function.

Our goal in this synthesis paper is to discuss the resulting conceptual framework developed from that working group. We briefly describe the ecological and societal characteristics of urban streams and discuss the deficiencies of traditional (ecologically focused) restoration approaches in urban settings. We introduce the concept of urban stream renovation as a complementary alternative to stream restoration in urban landscapes that leverages an integrative approach to accomplish long-term ecological improvements. We discuss: 1) the integration of societal outcomes, 2) the role of adaptive management, 3) ways to implement the framework, and 4) research needs and potential future directions required to develop this framework further. We think the product is a fresh take on improving urban streams based on a novel approach that addresses many shortcomings of restorations in urban settings.

Table 1. List of terms used to describe the urban stream renovation framework and how they are used in this manuscript (see also Fig. 2).

Term	Definition as used in this manuscript
Ecological	Biological, geophysical, and chemical structures (e.g., biodiversity, channel forms, etc.) and functions (e.g., nutrient cycling, discharge, etc.) of stream ecosystems.
Societal	Social, cultural, political, economic, and historical properties of stream ecosystems.
Action	Physical manipulation of the channel, riparian zone, floodplain, or catchment. Actions generate outcomes, which originate from project objectives. Outcomes can result directly and indirectly from actions.
Short-term outcome	Short-term ecological and societal responses by the stream or human population (e.g., local community) to the action(s) performed (societal outcomes lead to future actions supporting incremental steps towards long-term ecological outcomes).
Long-term outcome	Steady or dynamic ecological or societal state of the stream (long-term outcomes result from the cumulative short-term outcomes guided by adaptive management).
Objective	A general descriptor of the desired short- or long-term results of the individual actions (an objective's success is determined by the short- and long-term outcomes achieved as a result of project actions).

ECOLOGICAL AND SOCIETAL CHARACTERISTICS OF URBAN STREAMS

In this paper, we use 'ecological' to mean the biological, geophysical, and chemical structures (e.g., biodiversity, channel forms) and functions (e.g., nutrient cycling, discharge) of stream ecosystems and 'societal' to mean the social, cultural, political, economic, and historical properties of stream ecosystems (Table 1). Demographic and economic (societal) factors drive urban development, and urban land cover alters the biotic and abiotic (ecological) conditions of urban stream and riparian ecosystems (Findlay and Taylor 2006, Hong et al. 2009). The societal drivers of landuse development are rarely included in studies examining urban impacts on biological integrity. Integrative studies of stream condition may be limited by the differences in spatial and temporal scales of societal (city, state, etc.) and ecological (watershed, riparian, etc.) drivers (Hong et al. 2009), difficulties in taking a multidisciplinary approach, or other logistical or conceptual barriers. Regardless of these difficulties, the substantial influence of societal contexts for stream improvement projects in densely populated urban areas suggests that an integrative approach to improving streams would be beneficial (Eden and Tunstall 2006).

A wealth of research shows that human effects in urban landscapes are diverse, interactive, confounded, and often pervasive. The hydrologic, chemical, physical, and biological attributes of aquatic ecosystems are severely and, sometimes irreversibly, altered in urban settings (Paul and Meyer 2001, Walsh et al. 2005, Wenger et al. 2009). Nevertheless, as seen during the SUSE3 conference and presented in other articles in this special issue (Cook and Hoellein 2016, Walsh and Webb 2016), an understanding of the mechanistic links among stressors and biotic and abiotic responses of stream ecosystems is evolving.

The relationship of urban streams with human populations is developed through a social process in which human experiences and the perceived characteristics of a location form a sense of attachment, belonging, or affinity for a particular geographic location, such as an urban stream (this framework is often referred to as 'sense of place'; Williams and Stewart 1998). That is, human perceptions of urban streams are derived from subjective valuations of aesthetic properties, ecological condition, historical significance, perceived threats to personal property, and functionality for commerce, transportation, recreation, among other factors (Ryan 1998, Ribe 2002, Findlay and Taylor 2006, Jähnig et al. 2011, Everard and Moggridge 2012, Seidl and Stauffacher 2013). How people relate to urban streams will differ among social groups (e.g., age, gender, socioeconomic status) and across different geographic extents (e.g., along the river network to globally; Ryan 1998, Williams and Stewart 1998, Matsuoka and Kaplan 2008). Individual relationships with urban streams may reflect sociocultural interactions that have little relationship to the stream itself (e.g., interpersonal interactions among members of the community) and can result from individual experiences at distant places other than urban streams (i.e., based on memories of and experiences in other places; Williams and Stewart 1998). Streams are remnant natural features in urban landscapes and, similar to other physical characteristics of built environments, they often reflect the sociopolitical character of cities in a positive and negative sense.

The importance of urban streams and riparian areas to local communities can be manifested in numerous ways (Wagner 2008). Ecological understanding of the structure and function of stream ecosystems is generally poor among local residents, and the characters that residents prefer or perceive as 'healthy' often do not match the current ecological state of the stream (Kaplan 1997, Mooney and Eisgruber 2001, Booth et al. 2004, Buijs 2009, Seidl and Stauffacher 2013, Winz et al. 2014), although preferences for certain components of streams (e.g., 'naturalness') may correspond to stream health (Junker and Buchecker 2008). Local communities often become more concerned with natural environments in their surroundings after environmental disturbances (Hunter 2011).

Larger rivers generally have a historical context in cities as central to commerce, industry, and transportation (e.g., municipal and industrial water supplies). The underlying shapes of metropolitan regions often reflect the banks of large waterways through urban landscapes (Spirn 1988). Large rivers are often more apparent within cities and more easily noticed by residents than smaller streams, which often are buried (Elmore and Kaushal 2008, Broadhead et al. 2013). Comparably fewer streams are found in urban than rural landscapes (Moran 2007), and remnant aboveground reaches often flow behind buildings and other infrastructure where they are inconspicuous and often neglected (Booth et al. 2004). Urban streams may either positively or negatively affect property values depending on their aesthetic and other physical properties (Kulshreshtha and Gillies 1993, Mooney and Eisgruber 2001). Streams are also often used as geographic boundaries, and may be viewed as important physical borders between neighboring communities with differing cultural or socioeconomic characteristics (Eden and Tunstall 2006).

DEFICIENCIES OF URBAN STREAM RESTORATION

Recognition of urban streams and rivers as valuable ecosystems that often possess pervasively degraded ecological states has led to diverse opinions about how to manage them in the face of increasing urban development. Large-scale sociopolitical movements aimed at restoring streams are generated by groups of people having the perspective that improving ecosystem structure and function has ecological and societal value (Eden and Tunstall 2006, Kondolf and Yang 2008). The discipline of restoration ecology has grown (Choi 2007), and its practice is becoming more common globally (Clewell and Aronson 2013). Current restoration frameworks range from specific (e.g., natural channel design; Rosgen 1996) to general (e.g., stream naturalization; Rhoads et al. 1999) and may include principles not linked to a particular environment (e.g., intervention ecology; Hobbs et al. 2011).

Reference-condition approach

The intent of restoration is to return the stream to some predisturbance condition, but the practitioners of urban stream restoration typically accept that regaining all structural and functional components of the predisturbance condition is unlikely (Booth 2005, Cockerill and Anderson 2014). Many project managers seek to remedy only specific issues (e.g., erosion, flooding) rather than the multiple issues needed for long-term structural and functional change (Palmer et al. 2014, Vietz et al. 2016). In either case, the target of most restoration projects for single or multiple issues is based on some reference condition indicative of a pristine or least-impaired state.

Approaches that attempt to return streams to a pristine or least-impaired state are particularly prone to failure when excessively erosive flows greatly modify geomorphic forms and processes, and channels are much larger than those of corresponding rural streams (e.g., Fig. 1; Choi 2007, Violin et al. 2011, Laub et al. 2012, Hawley et al. 2013, Vietz et al. 2014). Streams in urban landscapes often have irreversibly altered physical characteristics at small-to-broad spatial scales that prevent a return to natural hydrogeomorphic characteristics of reference conditions (e.g., unattainable channel slopes because of permanently altered local topographies; Wohl et al. 2005). Reference conditions for urban streams are often improperly characterized as single-thread systems with regular planform meanders and pool–riffle profiles, which is counter to the diversity of natural settings in plan (e.g., braided; Graf 1981) and profile (e.g., cascade, step–pool, forced pool–riffle; Montgomery and Buffington 1997). The need to protect local infrastructure (e.g., roads, bridges, sewer and stormwater pipes, houses, etc.) probably supports a bias toward characterizing reference condition as single-thread systems with stable channels and low structural variability. However, an understanding of the natural characteristics of streams in the region (i.e., the reference condition) is important for guiding project design and characterizing the success of stream restoration projects in urban settings. The disparities between realized project outcomes and expectations based on regional stream characteristics demonstrate the deficiencies of a reference-condition approach.

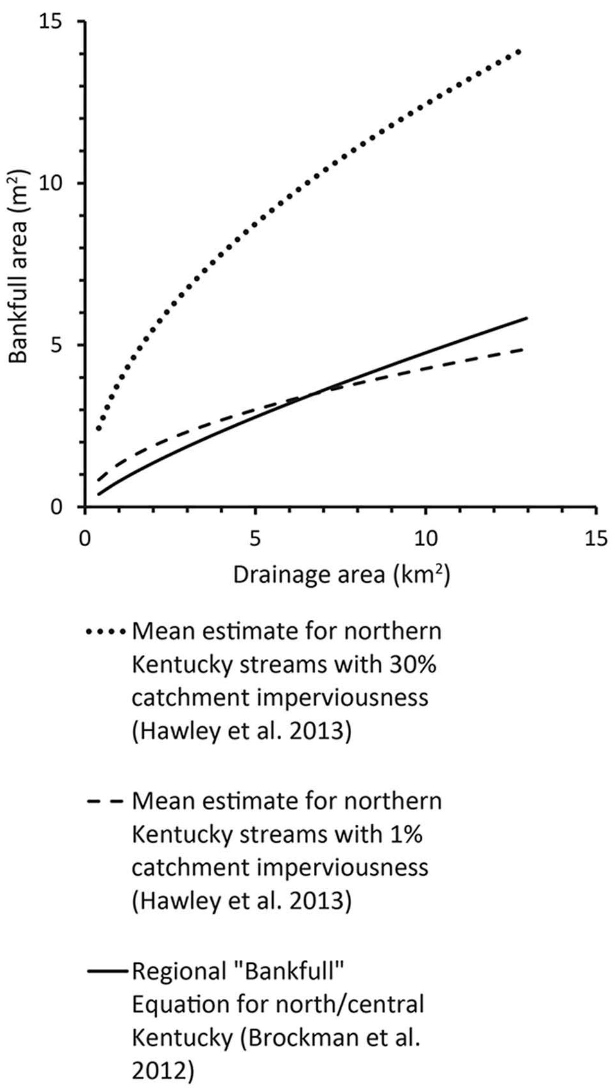

Figure 1. Relationship of bankfull area to drainage area for channels of undeveloped/reference streams and in urban catchments in northern Kentucky. All 3 curves increased predictably with drainage area, but area can be larger in urban than undeveloped or reference catchments (~2–3× larger for streams with 30% catchment imperviousness).

Legacy effects also limit the applicability of a reference-condition approach. Brown et al. (2009) identified antecedent land use as the most important explanatory factor in the response of streams to urbanization in the USA. The effects of altered land use on urban streams can persist long after the original stressors are removed (Harding et al. 1998, Cuffney et al. 2010, Hamilton 2012). In urban settings, the persistence and transformation of toxic chemicals in stream sediments (Meals et al. 2010; case study 4; Table 2, Appendix S1) and legacy agricultural sediments with elevated nutrient loads that can persist for several decades after land is taken out of production are particularly important (Dosskey et al. 2010, Meals et al. 2010). Legacy effects can also maintain channel forms that differ from predisturbance conditions (Walter and Merritts 2008).

Mismatch between temporal and spatial scale of effects and restoration projects

The temporal and spatial scales of restoration projects often are misaligned with the temporal and spatial scales of the causes of impairment (National Research Council 1999, Wohl et al. 2005, Naiman 2013, Cockerill and Anderson 2014). Reach-scale restoration projects are unlikely to affect water quality, the frequency of disturbance, or other functional or structural components of the stream system when human modifications to catchment landscapes are causing impairment (Hawley and Vietz 2016, Walsh et al. 2016). Reach-scale manipulations can affect ecosystem processes at small spatial scales, but many of the key processes affecting stream condition are controlled by properties of the catchment (e.g., hydrology, sediment, nutrient and organic-matter transport; Wohl et al. 2005, Imberger et al. 2011). As a result, catchment-scale manip-

Table 2. Summaries of 10 case studies that demonstrate how ecological and societal outcomes can be considered simultaneously in urban stream renovation projects (see Appendix S1). Emphasis describes whether outcomes: 1) were part of primary, secondary, or no project objectives, 2) resulted directly or indirectly from actions, and 3) occurred across broad or small spatial and temporal scales. A subjective measure on an ordinal scale describes the emphasis on ecological and societal outcomes based on the information available. This measure should be used only as a guide to investigate how a case study demonstrates ways to integrate ecological and societal outcomes. The codes are: 1 = indirect, not part of an objective, not planned or anticipated; 2 = indirect, part of a secondary objective, anticipated but minimally planned compared to the primary objectives; 3 = indirect, part of the primary objectives and required planning, but an indirect result of actions to accomplish the objective; 4 = direct, part of the primary objectives, accomplished by a single to few actions occurring over a small spatial scale (possibly a single reach); 5 = direct, part of the primary objectives, accomplished through multiple actions over a broad spatial scale (possibly catchment scale), required extensive planning.

Project/stream, location	Summary description	Emphasis[a]
1. Little Barrier Island, Auckland, New Zealand (LBI)	Island restoration: 100+-y restoration effort including reforestation, exotic species eradication, and limiting public access to 20 people/d.	Ecological: 5, societal: 1 (traditional restoration)
2. Little Stringybark Creek, Melbourne, Australia (LSC)	Watershed restoration (stormwater): 5+ y of disconnecting conventional stormwater drainage from Little Stringybark Creek using rainwater harvesting strategies.	Ecological: 5, societal: 2
3. Urban stream restoration, Portland, Oregon, USA (USP)	Prioritized reach-scale restoration: implementation of 4 reach-scale habitat projects based on watershed-scale understanding of aquatic and riparian habitat, fish passage, channel erosion, water quality, and impacts on public infrastructure.	Ecological: 5, societal: 3
4. Hagbygärdediket, Kalmar, Småland, Sweden (HAG)	Pond/wetland-based water quality reclamation: construction of 3 large ponds/wetlands to reduce nutrients, metals, and organic compounds from a heavily urbanized and previously untreated catchment draining to the Baltic Sea via Hagbygärdediket, designed with recreational, ecological, and cultural objectives.	Ecological: 4, societal: 4
5. Donnybrook and Hollywood Branch, Montgomery County, Maryland, USA (DHB)	Sewer, stormwater, and reach-scale restoration: multifaceted projects to address water quality, stream erosion, habitat, and ecological objectives in urban watersheds that incorporated stakeholder engagement and input for prioritization and design.	Ecological: 4, societal: 5
6. Lick Run, Cincinnati, Ohio, USA (LKR)	Stream daylighting, stormwater, and sewer overflow mitigation: publicly supported watershed approach to combined sewer overflow mitigation that included stormwater disconnection, capture, and treatment via stormwater control measures, and ~3.2 km of stream habitat reconstruction of reaches that had been buried for >100 y.	Ecological: 3, societal: 5
7. River Quaggy, London, UK (RQY)	Stream remeandering in urban park: 500-m habitat restoration project, including flood storage ponds, riparian area naturalization, and public education signage with limited ecological recovery because of upstream sewer misconnections or unmitigated combined sewer overflows.	Ecological: 3, societal: 4
8. Boulder Creek, Boulder, Colorado, USA (BCR)	Flood mitigation and greenway: the flood mitigation project primarily involved purchasing adjacent property and enlarging the channel, but also incorporated development of a greenway and construction of some in-channel habitat features.	Ecological: 2, societal: 4
9. Gum Scrub Creek, Melbourne, Australia (GSC)	Constructed flood-control waterway: provides flood control through a new development that included a mix of inset rock-lined and natural channels, a 100-m-wide riparian zone, native plantings, and is an aesthetic amenity for the development.	Ecological: 2, societal: 4
10. Quebrada Ortega, Quito, Ecuador (QBO)	Riparian sanitation: 12-y riparian recovery project to remove trash/debris, install landscaping and recreational facilities along riparian zones of streams in Quito.	Ecological: 1, societal: 5

ulations are being developed to address causes of impairment to urban streams (e.g., Walsh et al. 2009), and researchers and managers in several regions are pursuing approaches that address in-channel and catchment-scale drivers of impairment (e.g., City of Portland 2005, Hawley et al. 2012, Rios-Touma et al. 2015). In addition, causes of impairment that operate outside of catchment boundaries (e.g., dispersal barriers, atmospheric deposition, climate change) may require action at broad spatial scales that are difficult to accomplish (Bond and Lake 2003, Kaye et al. 2006, Hughes 2007, Nelson et al. 2009).

Lack of integrating societal benefits

The lack of integration of societal considerations often is regarded as one of the key reasons for the failure of restoration efforts, especially in urban systems (Eden and Tunstall 2006, Naiman 2013, Yocum 2014). A lack of stewardship and support by surrounding urban communities and local governments can hinder the ecological success of a project with long- and short-term goals (Booth 2005, Yocum 2014). As a result, recent frameworks in restoration ecology have highlighted a need to: 1) incorporate societal benefits, 2) promote a sense of stewardship by local communities, and 3) include multiple stakeholders in the design, implementation, and assessment of restoration projects (e.g., Booth et al. 2004, Palmer et al. 2005, Clewell and Aronson 2006, Petts 2006, Kondolf and Yang 2008, Hager et al. 2013).

A potential shortcoming of many contemporary approaches is that societal benefits are often opportunistic or indirect outcomes of actions intended to achieve ecological improvements (Booth et al. 2004, Clewell and Aronson 2006, Kondolf and Yang 2008, Hager et al. 2013). Hesitancy to incorporate actions with the primary purpose of generating societal outcomes may result from: 1) the complexity of interactions among ecological and societal contexts (described above), 2) the potential opportunities for spurious conclusions about project success without ecological evidence (e.g., a project deemed a success based on surveys showing high local community satisfaction despite little ecological improvement; Bernhardt and Palmer 2007), or 3) purposeful acts akin to a form of ecological 'greenwashing' (superficial actions to deal with substantial ecological and societal impairment; Beatley 2011).

URBAN STREAM RENOVATION

We define *urban stream renovation* (USR) as a unifying framework that incorporates ecological and societal outcomes (Table 1) to achieve long-term ecological improvement to stream ecosystems. The USR framework incorporates 2 evolving perspectives in restoration ecology: 1) restoration should more fully incorporate potential societal benefits (Clewell and Aronson 2006, Eden and Tunstall 2006, Ramalho and Hobbs 2011,Yocum 2014) and 2) restoration goals should be flexible and align more with future scenarios than past conditions (i.e., less focus on a reference-condition approach; Choi et al. 2008, Hobbs et al. 2011). We think that these 2 perspectives can potentially lead to an expanded set of beneficial outcomes. From a practical perspective, USR incorporates core restoration concepts: 1) stating objectives clearly, 2) mandating that the best remaining habitats be protected, and 3) examining ecosystem structure and function (US National Research Council 1992, Roni et al. 2002, Bernhardt and Palmer 2007, Palmer and Febria 2012). The USR framework is not constrained by reference conditions, but the framework allows incorporation of characteristics of local natural environments to support project design and evaluation when appropriate (e.g., Violin et al. 2011, Rios-Touma et al. 2015).

We posit that if projects are designed properly, short-term actions intended to achieve societal benefits can result in increased public support for actions to achieve short- to long-term ecological improvements to urban streams. Positive interactions of people with natural areas can promote an affinity for the environment and its conservation and improvement (Spirn 1988, Purcell et al. 2002, Turner et al. 2004, Beatley 2011, Özgüner et al. 2012). The USR framework uses increased flexibility for setting ecological and societal objectives (by avoiding an ecologically focused reference-condition approach) to achieve additional ecological and societal outcomes. The increased stewardship and public support for stream improvement resulting from additional societal benefits can generate a feedback loop in which communities and governments allocate public resources to support successive ecological or societal actions (Fig. 2; Rogers 2006). This iterative process can be designed so that the cumulative effect of manageable short-term ecological outcomes can accomplish improvements of stream ecosystem structure and function at broad spatial and temporal scales that potentially could be used to address catchment-level drivers of stream degradation (Hermoso et al. 2012, Palmer et al. 2014).

From a societal perspective, the short-term and small-scale projects that compose this iterative process are highly suited for generating community support for broader initiatives (Yocum 2014). Some residents may have difficulty seeing links between small-scale actions, catchment processes, and overall stream health. However, practitioners can combine reach-scale activities with outreach and education to inform the public about the benefits of additional actions throughout the catchment (Church 2015). The case study for Donnybrook and Hollywood Branch (Table 2, Fig. 3, Appendix S1) shows how continued outreach to the community currently is supporting catchment-level alterations that followed reach-level projects.

The incremental approach we present must be systematic and should not take the form of a piecemeal approach to improving stream ecosystems (Hermoso et al. 2012). Urbanization is a long-term, severe press disturbance that profoundly alters the biotic and abiotic components of streams and rivers (Paul and Meyer 2001). The process of improving the structure and function of urban stream ecosystems is a similar long-term, gradual process of coordinated landscape modifications at small and broad spatial scales. USR efforts are expected to be long term because of

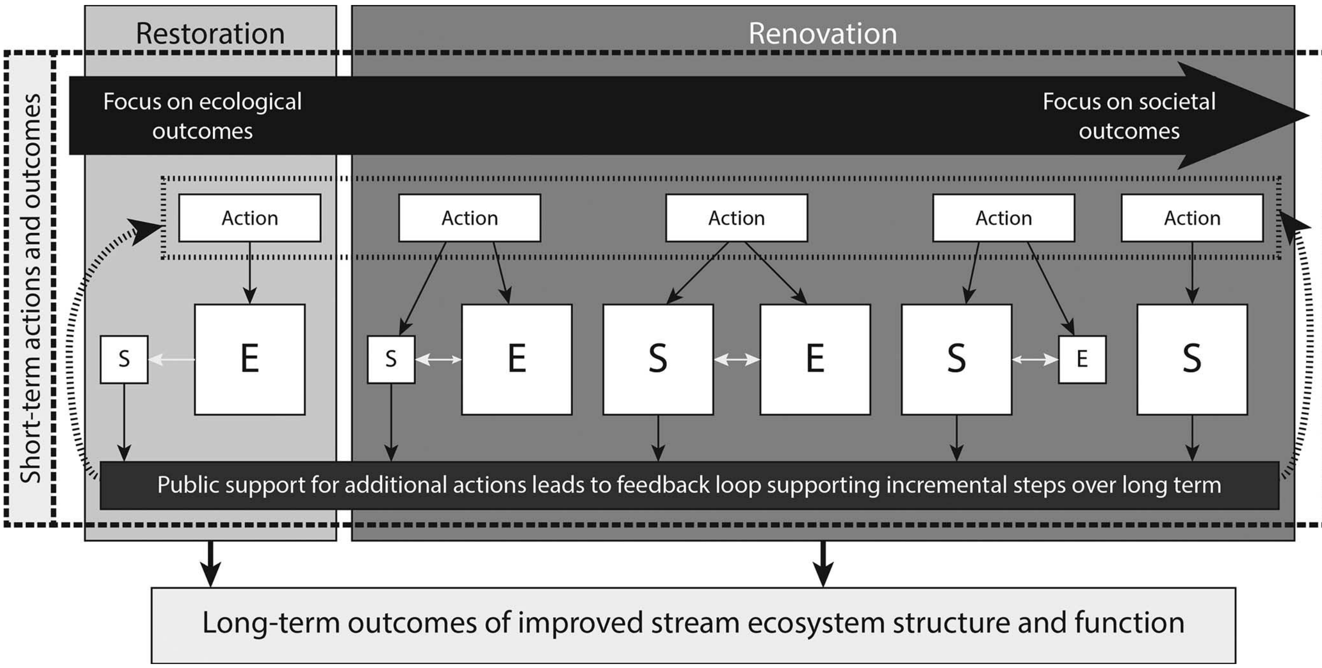

Figure 2. Conceptual diagram showing how short- and long-term outcomes are linked and the relative emphasis of ecological (E) and societal (S) outcomes along a gradient. Actions and outcomes in support of short-term objectives are surrounded by a box with a thick, dashed border. Large boxes indicate a primary objective, and small boxes indicate a secondary objective (or not an objective for restoration; see Table 2). Projects with primary E and S objectives (equal-sized boxes) are ideal. White arrows connecting E and S outcomes demonstrate how they are integrated and that outcomes may occur as an indirect effect (unequal arrow heads). We represent S outcomes in traditional restoration as a secondary effect of the ecological outcome, but some modern approaches are integrative (see Little Barrier Island, Auckland, New Zealand example, Table 2). Black arrows between S and the box representing public support begin the feedback loop supporting additional actions. Actions leading to only S outcomes (far right) can support urban stream renovation (USR) through feedbacks, but care should be taken to ensure that it will support long-term ecological outcomes. S outcomes that do not contribute to feedback loops are not part of USR and were omitted.

the severe nature of urban damage. Thus, practitioners face the difficult task of maintaining public support over long time scales to achieve long-term ecological outcomes (see below).

The USR framework aligns with several concepts of intervention ecology including: 1) a flexible approach to managing ecosystems for future states rather than past (i.e., reference) conditions, 2) explicit consideration of the site's history, and 3) an interdisciplinary approach incorporating ecological and social sciences (Hobbs et al. 2011). However, the USR framework differs from intervention ecology by: 1) considering future, current, and past ecological and societal conditions rather than focusing on the ecology, 2) integrating ecological and societal contexts rather than nesting ecological within societal contexts, 3) addressing societal support (e.g., stewardship, policy) directly through societal outcomes rather than extraneous actions, and 4) integrating ecological and societal components further through an iterative process that relies on feedbacks among outcomes generated from short-term actions (Fig. 2). In addition, the temporal aspect of the USR framework, whereby ecological and societal outcomes can be realized at different points in time, and the setting of clear a priori objectives for ecological and societal outcomes are what differentiate it from naturalization (see Rhoads et al. 1999). A criticism of intervention ecology is that the flexibility to set objectives that do not conform to reference conditions and the integration of societal outcomes may limit overall ecological benefits (Palmer et al. 2014). However, we think that the iterative approach and the requirement that all societal objectives support actions to achieve long-term ecological outcomes are consistent with the framework's intended use as an integrative approach that does not sacrifice ecological benefits.

Integrating societal objectives

Cities across the globe have a wide range of histories and conditions that affect the social connection to, and support for, efforts to improve streams. USR may be an adaptable approach to use across this range of socioeconomic settings. We expect outcomes to vary among cities in response to differing histories, conditions, and connections. For example, a centuries-old city like Quito, Ecuador, where untreated sewage discharges, flood debris, and trash

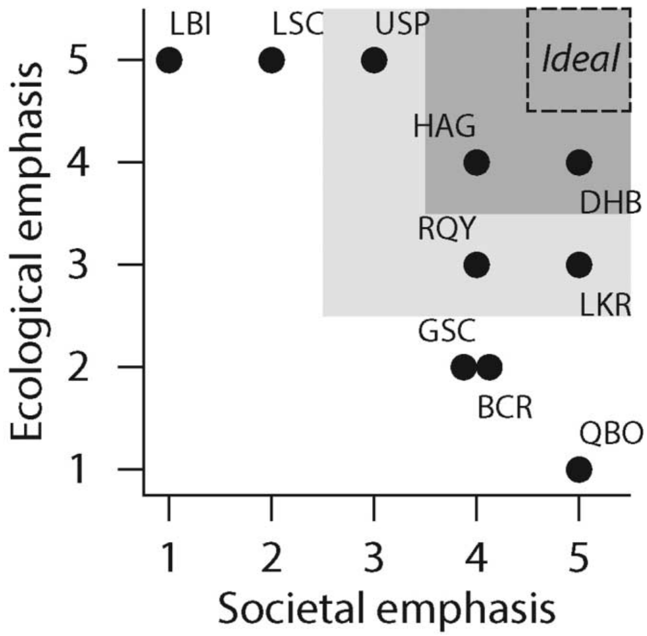

Figure 3. Plot showing the relative emphasis on ecological (E) and societal (S) outcomes for the 10 case studies presented in Table 2 and Appendix S1. See Table 2 for 3-letter case-study codes and descriptions of the categories on each axis. The light gray box indicates projects with E and S primary objectives, the dark gray box indicates projects with actions that directly resulted in E and S outcomes, the dashed box labeled ideal indicates projects with E and S primary objectives, actions with direct effects on all outcomes, and outcomes of both types occurring over broad spatial and temporal scales. No case study was classified as ideal.

accumulation are major stressors to river health, might first prioritize trash removal and the treatment of sewer discharges. This step would allow rivers and streams to transition from being viewed as unsightly human health threats to recreational, ecological, and aesthetic amenities (Table 2). Future initiatives taking a comprehensive approach to improving stream and river ecological health might be supported and implemented as the community's affinity for local streams and rivers slowly increases. In contrast, sewage and stormwater treatment have progressed in relatively young cities like Portland, Oregon (USA), and improvements to water quality are supported, in part, by the populace's strong cultural connection to the local rivers and their iconic residents, salmon (Table 2). Improving urban streams is critical to regional salmon recovery because the city is situated near the mouth of the Columbia River, which was historically one of the greatest salmon rivers in the world (McConnaha et al. 2006). The progression toward improved urban stream health might be more rapid and might reach a greater level of improvement in young cities like Portland than in older cities with similar cultural connections to local rivers. These examples highlight how: 1) geographic and historical contexts of cities interact to influence environmental degradation and are important for assessing the feasibility and trajectories of long-term ecological and societal improvements (Yocum 2014) and 2) the process of urbanization differs among cities of different ages and generates variability in societal and ecological contexts among urban areas (Pickett and Zhou 2015).

The same factors that determine an individual's relationship with urban streams will affect their perceptions of USR projects. Ecological and societal perspectives are colocated and may interact in urban landscapes (Cockerill and Anderson 2014). Thus, ecological and societal contexts should be integrated but should account for different perspectives and goals for improving stream environments among stakeholders (e.g., Funtowicz and Ravetz 1993, McDonald et al. 2004, Smith et al. 2014). The use–value concept proposed by Hillman et al. (2011) describes potential or actual links between people and the river environment based on how human groups appreciate or use the river. Therefore, these use–values are understood as culturally specific and demonstrate how societal–ecological links are context dependent (Palmer 2006).

Local residents may value certain nonecological outcomes (Cockerill and Anderson 2014). For example, aesthetics are often considered the most important component of restoration projects by local communities (Buijs 2009, Özgüner et al. 2012), and public support for projects generally increases when aesthetic preferences are incorporated into project designs (Hunter and Hunter 2008). Thus, aesthetics may be important for maintaining long-term public support. Ideally, projects can improve ecosystem function while promoting the aesthetics of channel and riparian forms, but accomplishing both with a single action may not be feasible. The case study for Cincinnati, Ohio (USA) (Table 2, Fig. 3, Appendix S1) demonstrates how calibrating an urban channel design to incorporate aesthetic properties desired by the community can be done without sacrificing environmental objectives. Aesthetic preferences vary among people, and they may be influenced by landscape and regional environmental settings that cannot be altered (e.g., preference for a mountainous landscape surrounding the city; Asakawa et al. 2004). Moreover, practitioners should be careful that actions resulting in societal outcomes, particularly those increasing the aesthetic value of streams, do not skew stakeholders' subjective interpretations of what a healthy stream 'looks like' by promoting an affinity for stream reaches with little ecological integrity (Cockerill and Anderson 2014).

Role of adaptive management

Adaptive management should be applied to short-term actions and across successive project iterations to reach long-term ecological objectives (Fig. 2). Adaptive management can improve ecological outcomes by adjusting protocols in response to environmental change, unforeseen environmental responses, new methods, and other factors that limit the effectiveness of current approaches. Changes in attitudes and values of the local community and political entities occurring over long time frames can be substantial barriers to long-term project success (Spirn 2005, Eden and Tunstall 2006). Thus, adaptive management to counteract potentially pervasive, swift, and broad changes in stewardship, public support, and financial support will be crucial for achieving long-term ecological outcomes. At the very least, adaptive management can help accommodate the intended increase in public support resulting from societal outcomes.

Implementation

The emphasis on ecological and societal outcomes for short-term actions occurs along a gradient (Table 2, Fig. 2). The emphasis given to each type of outcome should result from scientist, manager, local community, and other stakeholder inputs based on the ecological and societal contexts of the region. The only requirement is that project designs link short-term ecological and societal outcomes to long-term ecological objectives. Preferably, short-term actions will include primary objectives with ecological and societal goals that incorporate actions and outcomes occurring over broad spatial and temporal scales (Table 2, Figs 2, 3).

However, situations may arise where the emphasis should be placed on either ecological or societal outcomes (Fig. 2). Prioritization of ecological or social outcomes would be defined ideally on the basis of empirically tested, standardized methods. Short-term actions should also be designed to maximize indirect outcomes when possible (Fig. 2; Kondolf and Yang 2008). However, this approach potentially requires that project planners accept an emphasis on short-term societal outcomes, provided they are part of a strategy for achieving long-term ecological objectives. The case studies presented in Table 2 and Appendix S1 (also see Fig. 3) provide examples of the various ways that improvement projects can emphasize ecological and societal outcomes and specifically how each: 1) can result directly or indirectly from actions, 2) may or may not be primary objectives of projects, and 3) can occur over different temporal and spatial scales.

Incorporating societal outcomes to the extent proposed for the USR framework is likely to generate the same concerns about potential abuses that typically accompany integrative frameworks. The framework's central rule is that all societal objectives must be couched within a larger coordinated effort to support short- to long-term ecological outcomes. We present several additional points of emphasis for preserving this central rule that we think will limit its misuse.

1. Predetermined short- to long-term objectives must be properly documented, agreed upon, and maintained throughout the project. Stakeholders should not use this framework as a way to claim 'success' retrospectively for projects with poorly defined objectives.
2. Specific procedures within the stakeholder group must be agreed upon before projects are implemented but should allow for adaptive management in response to unexpected situations. A priori thresholds that trigger alternative strategies must be decided upon prior to project implementation whenever possible. All stakeholders must be informed and must agree to changes resulting from adaptive management during short and long time frames.
3. Inclusion of societal outcomes should not be used as a means to justify ignoring legal obligations to maintain a healthy ecosystem. However, societal benefits are an implied outcome of a successful renovation project. Thus, monitoring societal outcomes as part of this framework can provide a direct assessment of the realized societal benefits of the specific actions used to comply with environmental regulations.
4. The framework should not be applied to situations where ecological objectives are knowingly unattainable. Actions with no intention of supporting any ecological outcomes at any scale are a sociocultural exercise that falls outside the USR framework. In addition, societal outcomes should not reduce the potential for ecological outcomes in the future (e.g., hard channel lining to increase public access).
5. Integration of ecological and societal components should be complete and should occur throughout the project for the framework to function properly. However, the ability to integrate them will depend on the knowledge of those implementing the project and the available resources (Rogers 2006).

Regardless of the emphasis on ecological and societal outcomes, any project that seeks to improve urban streams will require high levels of interaction among people and has a high potential for conflicts (Eden and Tunstall 2006). Conflicts can be limited when project design incorporates effective strategies for gathering and deciphering diverse opinions from stakeholders (e.g., structured decision making; Gregory et al. 2012). Conflicts may exist among various stakeholder-group preferences, and they may exist between stakeholder and professional preferences focused on improving ecological conditions (Eden and Tunstall 2006, Pahl-Wostl 2006). Managers also must try to avoid negative feedbacks that diminish public support (e.g., long-term maintenance procedures that have adverse societal impacts). This sensitivity includes being aware of the potential for gentrification of urban areas after broad-scale environmental improvements (Wolch et al. 2014).

GENERALIZATIONS

The goal of any standardized framework is to increase the ability to make generalizations that may otherwise be difficult to make across projects because of differences in ecological or societal contexts. New integrative approaches to managing water quality, such as the European Union Water Framework Directive (EU-WFD; European Union 2000), requires applicability across broad spatial and temporal scales. The USR framework aligns with the EU-WFD's: 1) use of an integrative approach, 2) focus on catchment-level processes of impairment, 3) reliance on local stewardship, and 4) focus on education and outreach. Regardless of the need to make generalizations, implementation must take into account potential regional and global differences in the ecological and societal characteristics of urban systems and how they interact (Cabin 2007, McHale et al. 2015, Pickett and Zhou 2015, Booth et al. 2016, Capps et al. 2016). We developed the USR framework to be specifically applicable to urban landscapes and intentionally avoided discussion of lentic environments, which may be integral to broad management directives.

RECOMMENDATIONS AND FUTURE DIRECTIONS

The case studies (Table 2, Fig. 3, Appendix S1) demonstrate that ecological and societal objectives can be incorporated together in varying degrees when attempting to improve the structure and function of stream ecosystems. Insights can be drawn from examples like these, but methods for achieving short- and long-term outcomes must be tested and critiqued. The need for future work is particularly important for identifying how best to integrate ecological and societal outcomes as advocated in our paper. In developing this framework, we identified several areas where future research is needed to inform its development and improve its implementation.

Defining methods to assess societal outcomes

The USR framework requires methods to assess societal outcomes quantitatively (Eden and Tunstall 2006). Many suitable measures exist in social science, economics, public health, and other disciplines, but a thorough analysis of the applicability of existing measures to USR projects is needed (Eden and Tunstall 2006). New methods specific to the framework also may have to be developed. Empirical studies examining the effectiveness of these measures are preferred over expert opinion, but development should draw upon the discipline within which the measure originated. Sociocultural characteristics of local populations and physical characteristics of landscapes affect each other (i.e., as feedbacks) to form contemporary societal and ecological contexts of human-dominated landscapes (Nassauer 1995). Thus, societal assessments must account for potential interactions with ecological contexts (and vice versa).

Most stream improvement projects fail to generate useful ecological monitoring data despite the fact that monitoring is accepted as critical for project success (Bernhardt et al. 2005). Remedying this deficiency is particularly important for the USR framework, but the priority to incorporate proper monitoring should be extended to include ecological and societal assessments. One reason for a lack of monitoring is that many stream-improvement projects are conducted without proper scientific input, and projects are designed with minimal consideration of the complexities of stream ecosystems that affect project success (Wohl et al. 2005). This deficiency often results in a vast divide between project objectives and the monitoring plan (Z. K. Rubin and G. M. Kondolf [University of California], BR-T, and M. E. Power [University of California], unpublished data). Societal monitoring also must occur over long enough time scales to assess societal outcomes. For example, in the same way that channel and riparian manipulations are disturbances that can cause short-term decreases in biotic integrity followed by long-term recovery (Muotka et al. 2002), community perceptions of urban streams may be unfavorable immediately following physical manipulations and improve over time as the stream recovers (Åberg and Tapsell 2013). Monitoring regimes also may have to be altered to deal with the incremental approach in which short-term outcomes are used to achieve long-term objectives. However, we think that increased local stewardship could lead to citizen-scientist monitoring programs, which could expand monitoring and improve assessments of project success (Lepori et al. 2005, Naiman 2013, Smith et al. 2014, Rios-Touma et al. 2015).

Education and outreach

The USR framework depends on education of and outreach to local communities. Outreach and education should be considered a component of project design with the specific roles to: 1) solicit support by the community for project activities and 2) alter the values of local communities to develop a sense of long-term stewardship (Williams and Stewart 1998, Egan et al. 2011). Community engagement must be proactive and designed to maintain a sense of stewardship over long periods of time. Similar to preproject biological assessments, the societal context of sites should be assessed before project implementation to decide how to begin the project with stakeholder support and incorporate additional stakeholders during the project (Seidl and Stauffacher 2013). The most effective ways to communicate with and involve stakeholders typically will differ among individuals (Tunstall et al. 2000).

Easy-to-follow methods for effective outreach and education are needed by managers and scientists who do not have a background in community engagement. Developing empirically based strategies for education and outreach that: 1) are science-based (ecological and social), 2) are specific to urban systems, 3) address different demographics, and 4) incorporate modern technology would augment strategies developed from the experiences of agency personnel and other practitioners (Hudson 2001, Groffman et al. 2010). Education and outreach strategies should draw from concepts in environmental education (see examples in Hudson 2001) and avoid methods stemming from a 'deficit model' based on the assumption that a lack of public support stems from scientific illiteracy (Eden and Tunstall 2006, Groffman et al. 2010). Moreover, approaches for outreach to policy makers may differ from on-the-ground outreach in local communities but should be incorporated into societal outcomes.

USR projects also are likely to benefit from incorporating outreach activities that differ from traditional environmental education (e.g., to address logistical issues such as public support, land access). The Montgomery County, Maryland, Department of Environmental Protection (MC-DEP), which conducted the Donnybrook and Hollywood Branch restoration (Appendix S1), has developed draft procedures for education and outreach during restoration projects based on experiences from past projects. In addition to themes from general environmental education, their procedures include activities to build relationships with local communities that are not primarily educational activities (e.g., a ribbon-cutting ceremony). Education and outreach activities are likely to take on many forms, and project members should design activities that combine education with other project objectives whenever possible (e.g., education of citizen scientists as part of a monitoring program: Middleton 2001; incorporating educational institutions, such as visitor centers and museums, within complex socioecological management strategies: Olsson et al. 2007).

Generating multidisciplinary collaborations

Development and implementation of the USR framework will require multidisciplinary research with equal contributions from ecological and social science backgrounds. Multidisciplinary teams could include social scientists, landscape designers, architects, economists, lawyers, and public health officials in addition to individuals from multiple subdisciplines in stream ecology (e.g., hydrologists, entomologists, geochemists, fisheries biologists, etc.). Collaborations can be developed through educational institutions, professional societies, or opportunities for cross-disciplinary synthesis projects. In addition to developing empirical methods for achieving short- and long-term outcomes, multidisciplinary teams also are needed to effectively guide integrative adaptive management strategies. Ideally, these teams should be maintained throughout the project.

Multidisciplinary collaborations also may help the USR to promote broader ecological and societal benefits beyond improving urban streams. For example, projects that increase green spaces and the naturalness of urban areas (e.g., part of broad-scale biophilic landscape designs) can: 1) lead to public support of general environmental initiatives (e.g., climate change), 2) encourage individual activities by residents that benefit the environment (e.g., reduced automobile use), 3) promote human well-being (human health, economics, social justice, and education), or 4) encourage further study in ecology by residents of urban communities who may typically be underrepresented in science, technology, engineering, and math (STEM) fields (Spirn 2005, Matsuoka and Kaplan 2008, Beatley 2011, Bunch et al. 2011, Russell et al. 2013).

We think that the multidisciplinary nature of the USR framework also can help project managers draw from a larger potential funding/support base than would be available for projects with fewer societal considerations. Multidisciplinary collaborations may lead to new or creative funding opportunities by providing opportunities to develop projects with the broader impacts described above. Moreover, scientists studying the biological, chemical, and geomorphological characteristics of streams can look for opportunities to conduct experiments that mix ecological and societal objectives by partnering with landscape architects, urban designers, and local residents (e.g., through 'urban design experiments'; Felson et al. 2013). Collaborating with public works offices may lead to novel designs of public works projects that achieve ecological and social benefits at a lower cost than separate projects carried out in isolation (Hawley et al. 2012). In addition, leveraging resources used for public works projects can provide dual benefits to the stream environment and the local community (Donnybrook and Hollywood Branch, Urban Stream Restoration; Table 2, Appendix S1).

CONCLUSION

The USR framework recognizes that ecological and societal objectives are intrinsically linked. Even though the framework explicitly incorporates societal objectives and goes as far as emphasizing short-term societal outcomes over ecological ones, its end result is focused on improving the ecological state of urban streams. We think the end results of the framework can be: 1) increased opportunities for achieving beneficial outcomes, 2) greater societal support for improving urban streams, 3) fewer conflicts between ecological and societal factors, and 4) opportunities to address catchment-level drivers of stream degradation.

A substantial challenge to implementing the USR framework may be the adoption of integrative approaches by project leaders. Multidisciplinary approaches have logistical and conceptual challenges. Learning how to assimilate information from and communicate with collaborators from other disciplines and the general public is difficult (Groffman et al. 2010). Stream ecologists must avoid the comfortable choice of defaulting to an emphasis on ecological objectives.

Some urban stream ecologists may argue that considering societal outcomes to the extent we advocate will limit ecological improvement. We acknowledge that actions to achieve societal outcomes require resources (time, money, etc.) that could be used for actions to achieve ecological outcomes directly (Palmer et al. 2014). While admittedly untested, we believe that societal outcomes can be accomplished without sacrificing ecological objectives, and greater societal support can help accomplish ecological outcomes that would otherwise be unattainable (Fig. 2). The USR framework is based on the idea that resource allocation to societal objectives can have a net ecological benefit for urban streams by increasing public awareness and support for broader environmental issues. The USR framework requires testing, but an understanding of how to integrate societal and ecological objectives in projects to improve urban streams clearly is needed to support all emerging integrative approaches. Our hope is that critiques of this framework lead to methods that effectively incorporate societal outcomes as a means to improve the ecosystem structure and function of streams in urban landscapes.

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