Forecasting Multiple Watershed-level Benefits of Alternative Storm Water Management Approaches in the Semi-arid Southwest: Required Tools for Investing Strategically

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Abstract

The menu of alternative storm water management approaches and best practices has grown considerably over the last few years – even for densely urbanized areas. At the same time, watersheds have gained recognition as planning templates. Municipalities, counties, special districts, and private developers are now required to mitigate unavoidable impacts on aquatic resources of new and re-development projects in a watershed context. However, public agencies currently have few tools available, are faced with sometimes conflicting public policies, and often have insufficient expertise to translate the overwhelming choices on the LID menu into implementation guidance, let alone determine how to predict the off-site impacts of a project on watershed functions and processes. The role of watershed position in determining the effects small-scale, site-specific LID practices remains largely unexamined and unknown. Nor are the cumulative beneficial outcomes and cost-effectiveness of LID applications across a watershed sufficiently understood. As a result, scarce resources directed at alternative storm water management approaches are rarely maximized, although local government can ill-afford non-strategic approaches to LID. California has unique public financing constraints for storm water management and other public benefit expenditures. Therefore, any public investments using non-traditional management approaches have to pass a fairly high documentation threshold of anticipated environmental and public health and safety benefits, regardless of whether new expenditure requests are placed in front of the voters, or existing funds are re-prioritized.

For these reasons, we propose that initial investments in forecasting tools capable of predicting the cumulative benefits of site-specific applications of appropriate bio-engineering and design solutions are needed to guide implementation of appropriate mixes of runoff reduction, harvesting, re-use, and infiltration options in a climate with distinct dry and wet seasons. These up-front investments should include development and application of standardized monitoring infrastructure and protocols that are built

into pilot LID designs to document environmental benefits and generate data for model calibration. Ultimately, the systematic application of forecasting tools, supported by performance monitoring data, will enable resource economists to compare the benefits of individual LID projects and their implementation and maintenance costs at a watershed scale with more traditional, centralized, and capital-intensive public infrastructure investments.

We present examples that include interactive maps of existing natural and man-made runoff conveyance infrastructure, land use, land cover, and ownership, as well as other critical landscape characteristics at the appropriate resolution to model environmental outcomes prior to large-scale implementation.

Introduction

An increasing body of evidence suggests that urbanization, particularly altered hydrology associated with impervious surfaces (roofs, roads, driveways, parking lots, and compacted soils), adversely affects watershed processes, functions, and aquatic life (e.g., Wang et al. 2001, Pettigrove and Hoffman 2003, Greenstein et al. 2004). Initially, much of the research documenting declines in ecosystem services was conducted in temperate regions of the eastern United States and Europe (Borchard and Statzner 1990, Weaver and Garman 1994). For a definition of "ecosystem services, see Boyd and Banzhaf (2007).

Only recently have studies been undertaken in more arid regions with distinct wet and dry seasons or significant coastal influences to ascertain the extent to which aquatic biota in streams and other water bodies in urbanized and urbanizing watersheds are affected by impervious surfaces and the concomitant changes in stream hydrology and pollutant exposure (Beighley et al. 2003, Gersberg et al. 2004).

Documentation of watershed impairment thresholds due to new and existing development has led to relatively rapid adoption of alternative storm water management approaches in many states (e.g., Maryland, Illinois, Oregon, Washington), even in already developed urban areas. California, on the other hand, is lagging behind in the widespread application of site design strategies and retrofit techniques that reduce runoff and incorporate LID into an integrated palette of broad watershed design goals. A new trend for NPDES storm water permits in California to incorporate LID requirements is expected to be a powerful driver and further illustrates the need for better forecasting tools.

Choosing watershed-based approaches to storm water management is an integral part of restoring ecosystem services. Restoration of these services needs to consider water supply reliability, flood protection, pollution filtration and attenuation, sediment delivery, maintenance of critical fish and wildlife habitat, provision of recreational and esthetic amenities, and the maintenance of economic and social vitality of a region – all within the context of climate change adaptation. However, few local agencies are organized in a manner that allows for integrated management of multiple watershed functions, ecosystem services, and basic urban infrastructure. In addition, severe funding constraints enshrined in the California constitution, requiring super-majorities of voters to approve funding for general benefit infrastructure present powerful barriers to innovation. Traditional solutions to polluted runoff management and flood protection, channel maintenance, and single-purpose capital improvement projects tend to provide a path of least resistance in resource-strapped public agencies.

The objectives of this paper are to: (1) identify how scientific and technical barriers to implementation of low-impact development techniques contribute to the relatively slow adoption process of non-traditional approaches to storm water management; (2) propose practical solutions for removing these barriers; and (3) demonstrate potential uses of decision-support tools currently in development for evaluating anticipated environmental benefits of an appropriate and cost-effective mix of LID techniques.

Methods

Much of the driving force behind LID is derived from federal and corresponding state statutes regulating polluted runoff from various land uses. To ascertain to what extent local agencies charged with implementing these regulations are positioned to respond appropriately, we interviewed a broad spectrum of management staff housed in various city and county departments – from line-level staff to public works, parks and recreation, and planning directors. We also included a small group of private consultants, developers, architects, and contractors in our interviews. The purpose of the interviews was two-fold: (a) to identify the key institutional challenges associated with more rapid adaptation of non-traditional methods for reducing polluted runoff; and (b) to document the most-often cited information gaps that prevent planners and engineers to select appropriate LID techniques with a high likelihood of producing beneficial environmental outcomes.

As part of a planning and pilot implementation effort in three drainage areas designated as Critical Coastal Areas by the California Coastal Commission and the State Water Resources Control Board, we also used workshop settings in these three areas (mid-coast of San Mateo County, the Watsonville Sloughs area in Santa Cruz County, and the Sonoma Creek watershed in Sonoma County) to identify general decision-support needs by local agencies and landowners.

As a result of interviews and our needs assessments, we compiled a list of broad "issues of concern" for each of the three pilot areas and attempted to extract common management and assessment questions that related to storm water runoff, human health risks associated with pathogens, and impairment of aquatic life uses. We also used a related effort in the Napa River watershed to target a wide array of dispersed data sets that had heretofore not been integrated and synthesized to identify means of meeting sediment reduction and salmonid restoration goals. The purpose of this data synthesis effort was to develop forecasting tools that could assist local agencies charged with controlling polluted runoff to evaluate the broad range of anticipated environmental and potential economic benefits of management measures in a wide variety of environmental settings.

Results
Our interviews revealed the following key implementation barriers:

1) *A lack of fiscal flexibility that provides a powerful disincentive against "adaptive management," with little tolerance for targeted experimentation and possible failure*

   Special assessments and fees, such as those for storm water management, are restricted or prohibited without the consent by a super-majority of voters. Uncertainty, whether caused by lack of expertise or lack of information, is therefore creating even greater risk-aversion in California than what is commonly associated with governmental entities.

2) *Insufficient capacity in the public sector to keep pace with innovations and to integrate multiple professional disciplines*

   Cross-training opportunities among engineers, urban planners, hydrologists, environmental scientists, and information technology specialists are rare in the public sector. Interviews with urban planners revealed that the connections between re-development designs and water quality, drainage, water supply, passive recreational amenities, and wildlife habitat is frequently not recognized.

3) *A longer list of conflicting goals and policies between resource management, and public health and safety protection than other states*

   The list includes policies associated with fire hazards at the wildland-urban interface, extractive uses of surface and groundwater, vector abatement, earthquake and hill-slope failure hazards, and a number of anachronistic land-use and automobile-centric policies, all of which affect to some degree the speed of diffusion and adoption of appropriate low-impact development techniques.

4) *The lack of a broadly accepted methodology for development and application of forecasting tools employing regionally applicable empirical data that enable local governments to evaluate environmental and societal benefits as well as initial capital improvement costs and those for long-term operations and maintenance*

While many decision-makers recognize the need for forecasting tools, no systematic approach has yet emerged that could facilitate their development and broad-based application, as documented by a user survey administered as part of the Critical Coastal Areas Program (Orman and Strahan 2007). Respondents to the survey, following each workshop held in the three pilot drainages, strongly valued a set of tools with the following functions showing the spatial distribution of:

- Modification of stream beds and banks
- Water and sediment movement and storage
- Urban planning and development practices
- Agricultural practices
- Other rural land uses
- Infrastructure development
- Transportation
- Recreation and open space uses

However, these preferences were not necessarily based on a structured set of management questions related to desired environmental and social goals and omitted a number of geospatial datasets that are essential to optimizing the performance of LID designs, such as land-slide risk maps, groundwater recharge areas, and fuel load maps.

More specifically, uncertainties and a perceived lack of credible performance data related to the range of LID practices and designs were frequently cited. Where LID performance data were available from different climate zones, their applicability in California was often questioned. While site-specific guidance for developers exists (e.g., Bay Area Stormwater Management Agencies Association, 2003), it is not yet clear how to apply existing guidance to watershed-based mitigation requirements. This is a challenge common to agencies charged with managing polluted runoff, floodway maintenance activities, and dredge and fill operations, although the U.S. Environmental Protection Agency is advocating the development of detailed watershed plans that specify practices necessary to achieve specific restoration goals for designated uses, particularly those related to Total Maximum Daily Loads (TMDL, Section 303(d) of the Clean Water Act).

We propose that the development of a standardized approach to evaluating cumulative environmental benefits based on pilot project data could remove one of the key limiting factors in a more broad-based and rapid acceptance of appropriate LID techniques based on watershed or landscape characteristics. A methodology that could enable the user to forecast the cumulative outcomes of LID applications at the landscape or watershed scale would have to include not only evaluation of runoff and concomitant pollution reduction, but also enhancement potential of local water supply reliability through aquifer recharge or runoff storage for non-potable water uses, restoration of aquatic life uses and habitat, and maintenance of passive recreational and esthetic amenities.

We identified the following elements for forecasting environmental, social, and economic benefits of a variety of LID techniques at the watershed scale that integrate across multiple goals:

1) Apply a general landscape classification system (including urban landscapes) designed to select appropriate items from the LID menu of best practices and design elements (e.g., http://www.lowimpactdevelopment.org/lidphase2/practices_controls.htm) and

to exclude others that may pose significant risks to hill-slope stability, could cause other adverse off-site effects lower in the watershed, or are incompatible with community or urban neighborhood character.

2) Identify desired environmental and social outcomes across multiple jurisdictional boundaries, such as municipal storm water NPDES permittees, agencies focused on water supply, flood protection, re-development, public trust resources, and recreation and parks.
3) Compile and map the necessary geospatial data for each watershed in any given city, county, or region that correspond to the landscape classification system developed in Element 1 (e.g., soil infiltration or permeability classes, erosion risk ratings, end-of-dry season depth to groundwater, drainage density, storm recurrence intervals, average annual rainfall amount and distribution, climate zones, land cover and ownership, etc.).
4) Apply empirical pilot project data to predict expected cumulative performance in terms of all chosen environmental and social outcomes specified under Element 2 if applied in all areas with similar landscape and climate characteristics.

While the set of tools required to meet all LID evaluation needs is at this time far from complete, some promising case studies exist that provide a glimpse into the application potential of these tools. As part of a study designed to evaluate additional management measures to reduce water quality impairment by fine sediment inputs into the drainage system of the Napa River watershed, we developed a series of maps for spatial analysis. These included the pre-colonial drainage network, as described by Grossinger et al.(2007), the current drainage network, wetland location and distribution (http://www.wrmp.org/docs/No569_WRMP_BasemapFactsheet_finalMay09.pdf), topography, land cover and use, erosion risk, among others. We used these geospatial data layers to evaluate the potential for reducing runoff in a watershed whose drainage density, not including urban storm drains or agricultural subsurface drains, had increased by about 25%, with concomitant runoff increases. Figure 1 shows the pre-colonial distribution of natural channels and wetlands, contrasted with Figure 2 showing the current distribution of the drainage network in the same location near Yountville, CA.

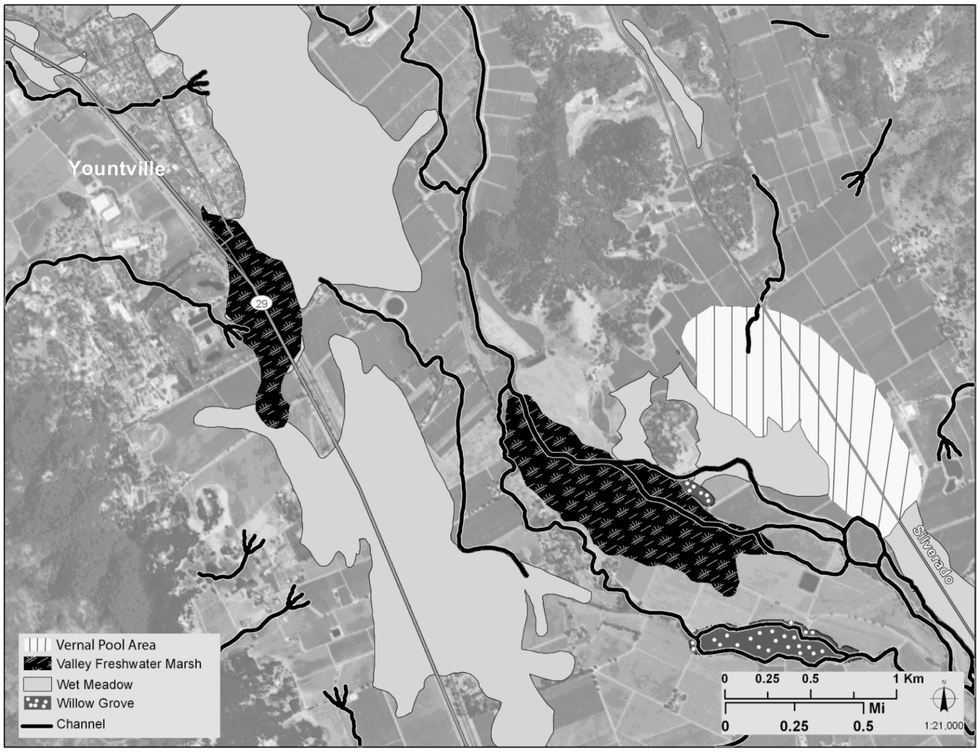

Figure 1. Pre-colonial distribution of channel network and wetland types in the Napa Valley near Yountville.

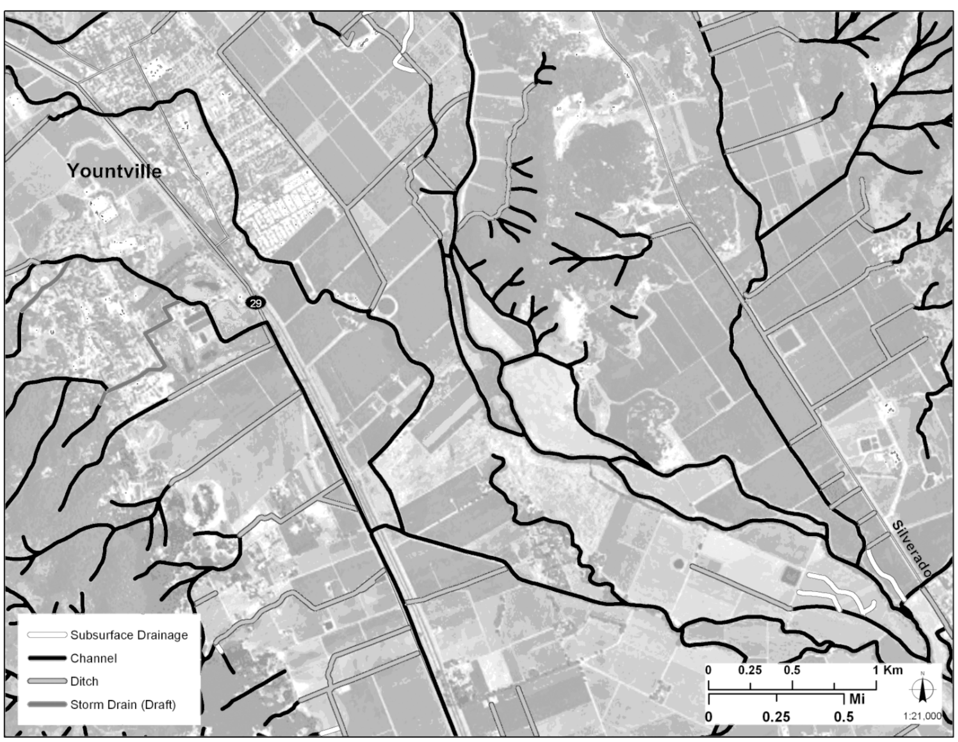

Figure 2. Current distribution of channel network near Yountville.

In addition, the total length of tributary channels that today are directly connected to the main stem had increased by about 50% since the early settlement period, not only providing additional delivery mechanisms for fine sediment to the main stem of the Napa River, but also contributing to much greater peak flows, less water retention, and increased bed and bank erosion contributing to the TMDL listing for sediment. By mapping opportunities for effective decreases in drainage density via application of LID techniques specific to landscape characteristics in any given hydrologic unit, multiple benefits can me modeled at any scale – from urban neighborhood to river basin. The degree of hydromodification from pre-colonial to current condition depicted in Figure 3.

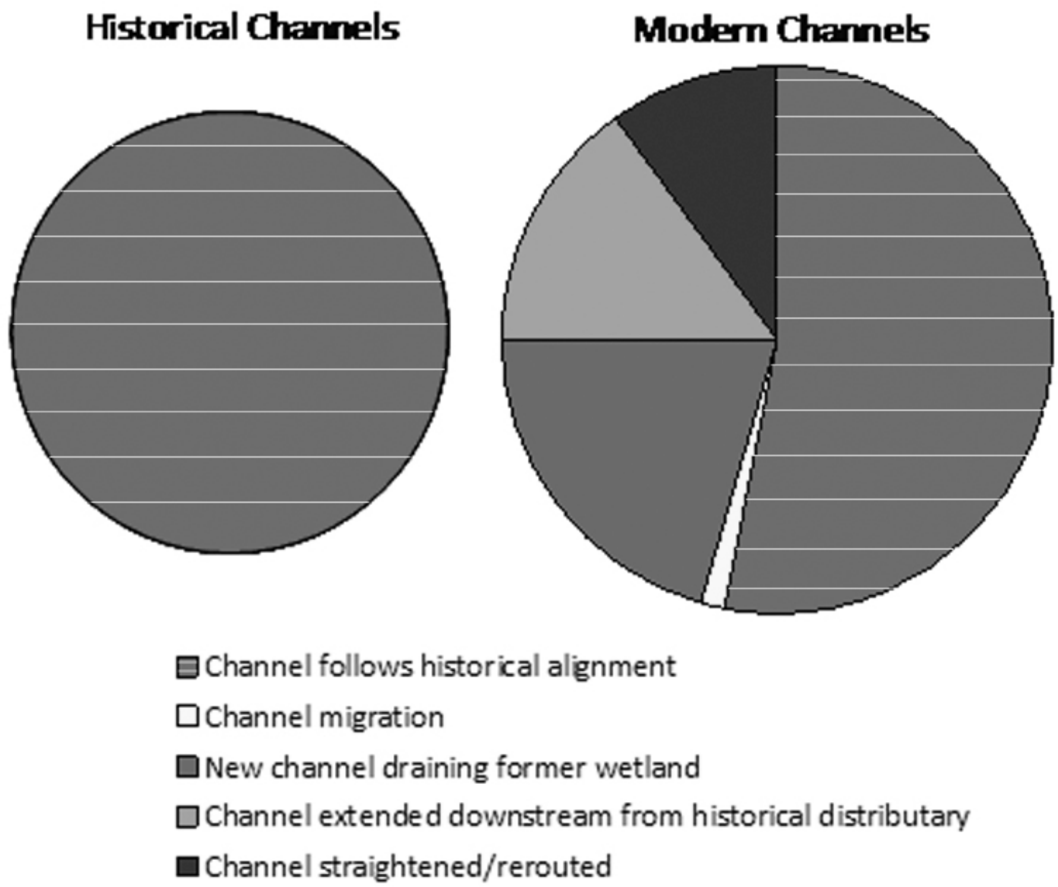

Figure 3. Degree of hydromodification in the Napa River watershed

We used a modified sediment transport model (Cui 2007) to estimate the potential for channel stabilization and thereby reductions in fine sediment inputs from channel erosion under reduced effective discharge scenarios achieved through disconnecting tributaries. Preliminary model results indicated that a reduction of approximately 20% of the drainage area of the main-stem above the Napa River Gauging Station might reduce scour forces to a point where the system could achieve a more stable condition similar to its present cross-sectional and plan forms. Similar approaches can be taken for other pollutants, even in densely urbanized areas where opportunities for decreasing effective drainage density are more limited.

A recent desktop evaluation of controls for PCBs and mercury (Mangarella et al. 2006) estimated annual mercury and PCB loading from storm water runoff by four general San Francisco Bay Area land use categories. For PCBs, estimated load reductions for industrial land uses, covering an area of 374 km^2, amounted to almost 40% of the total PCB load making its way into the drainage system region-wide. Once land uses are mapped at the appropriate degree of resolution, additional landscape features can be added to strategically select LID retrofits that might achieve load reduction targets..

A study conducted in Los Angeles County (Community Conservancy International, 2008) estimated the number of acres needed for retrofit or conversion from impervious to pervious surfaces (reduction of effective drainage density) to address polluted runoff and help meet water quality improvement goals. Parcels in public ownership alone were able to accommodate nearly 40% of polluted runoff clean-up needs, while also providing open space and recreational benefits. This initial study did not identify the specific LID retrofits based on parcel classes with similar site characteristics. However, geospatial data layers developed under the methodology outlined above could be used to match appropriate LID techniques with the landscape classification system, including densely populated urban areas, and aggregate runoff reduction and other benefits addressing environmental and social goals on a watershed scale for more accurate forecasts.

Discussion

By applying the suggested methodology containing the four key elements outlined above, the predictive models of cumulative performance of *all* anticipated environmental, public safety, and social benefits could be linked to expected life-cycle costs and compared to the costs of traditional approaches that are not specifically designed to provide multiple benefits per dollar invested. Flood protection districts, public water purveyors, re-development agencies, recreation districts, and public works departments tend to manage their own capital improvement and maintenance budgets in isolation from each other. As a result, public and private "hard" and "soft" infrastructure investments are rarely considered and accounted for holistically in terms of cross-jurisdictional cost-savings. For example, dry-weather urban runoff diversion structures to the sanitary sewer system with the goal of preventing pollutants from reaching a receiving water body are clearly designed to fulfill a single purpose (pollution reduction via engineered treatment). Construction of large-scale runoff harvesting devices under school parking lots positioned strategically in the watershed, on the other hand, would contribute to both pollutant load reduction *and* enhancement of local water supply reliability, thereby reducing the need for separate investments in reclaimed water distribution infrastructure for turf irrigation on a school's athletic fields. Similarly, diversion of runoff to designated groundwater recharge areas could achieve similar multiple benefits.

Application of the LID selection methodology would enable the development of a broad range of user-friendly planning and decision-support tools that could accomplish strategic investments of LID techniques in a watershed context with potentially significant implementation cost and long-term maintenance savings. Performance data collected as an integral part of pilot project implementation would form the foundation of geospatially predictive models capable of estimating the cumulative outcomes of appropriate items on the LID menu in the proportion of watershed area in the same landscape classes as the pilot sites. In addition, these predictive models could be used to quantify opportunities for avoiding duplicative capital improvement and maintenance investments. Without investment in geospatial data development and forecasting tools, low-impact development could easily revert to the "single-purpose" solutions of the traditional, 19^{th} and 20^{th}-century engineering approaches.

Documentation of cumulative and multiple benefits compared to costs might also facilitate the creation of climate change adaptation partnerships with agencies less constrained by constitutional limits on taxation and public benefit assessments than storm water management and flood protection agencies. Increased reliance on local water supplies via runoff harvesting and beneficial re-use as a structural LID technique at various public and private parcel scales (thousands of gallons to thousands of acre-feet) would enable flood protection agencies to cost-share with water purveyors that might be able to avoid or defer water development and recycled water conveyance infrastructure investments.

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