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Theodore A. Endreny

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## Storm Water Management for Society and Nature Via Service Learning, Ecological Engineering and Ecohydrology

THEODORE A. ENDRENY

SUNY ESF, Syracuse, NY, USA

**ABSTRACT** A framework for urban storm-water management that moves beyond flood control to improve societal and ecological services will maximize the functions and benefits of water resources management. Theoretical constructs for such work originate from the integration of ecological engineering, ecohydrology and service learning paradigms. Implementation consists of simulating, monitoring and reporting how storm-water design decisions to infiltrate or directly discharge runoff result in a complex set of linked adjustments to the dynamics of the water table, soil chemistry concentrations, plant stress/viability, terrestrial habitat, river loads/flows, and aquatic habitat patterns. Coordination of a socio-ecological-based urban storm-water management programme is discussed using a case study in the Onondaga Creek watershed that drains through the City of Syracuse, NY, USA. In Onondaga Creek, service learning-directed research gathered findings on the geomorphological characterization of a healthy stream, flood impacts of storm sewer separation, and channel stability with concrete removal. Unfortunately, linkages between systems will remain unexplored until the development of more tightly coupled channel-watershed simulation models.

### Background on Urban Storm Water Research Challenges

Social and ecological needs are often overlooked in hydrologically driven research (Bonell & Askew, 2000). However, urban water resources management offers unique chances for such coordination. Urban areas are the epicentres of global population growth (Johnson *et al.*, 2001), where land cover conversion and storm-water drainage (Brezonik & Stadelmann, 2002; Ierotheos *et al.*, 2003) lead to degradation of human health (Jackson, 2003) and aquatic ecosystem quality (Herrick, 1995; Borchardt & Sperling, 1997; Rogers *et al.*, 2002). Restoring and managing urban water resources will require innovative programmes that navigate the constraints of infrastructure, private lands, and competing social and political agendas. An approach presented in this paper addresses socio-ecologically based urban storm-water management via the integration of ecological engineering, ecohydrology and service learning paradigms.

### *Brief History of Urban Storm Water Management with Illustrations in Onondaga Creek Watershed*

Storm-water management has been a continual goal of hydrologists and engi-

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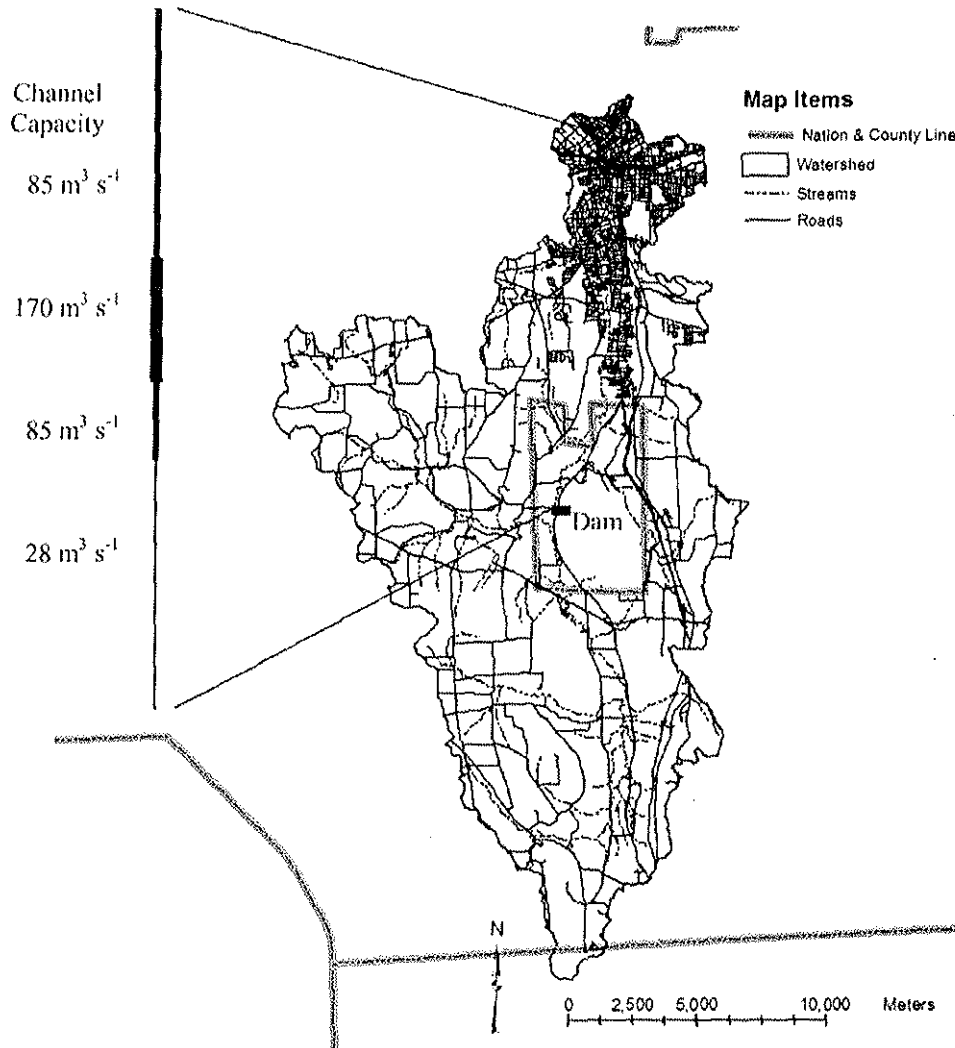
Correspondence Address: Theodore A. Endreny, SUNY ESF, Syracuse, NY, USA. Email: te@esf.edu

neers, with drainage systems developed by ancient Mesopotamian, Minoan, Greek and Roman civilizations (Butler & Davies, 2000). Most urban areas focused on flood control and prohibited the discharge of sanitary wastes in storm sewers until the 1800s when waterborne infectious diseases such as typhoid fever, dysentery and cholera were identified (Walesh, 1989; National Research Council, 2000). Removal of human wastes in storm sewers created an excessive conveyance and treatment demand. Combined sewer overflows (CSOs) relieved the infrastructural stress but stressed water quality and ecosystems (Butler & Davies, 2000). While separation was tried throughout Europe in the mid- to late 1800s, many European and US cities continued to design and build CSO systems through the mid-1900s (Walesh, 1989; Burian *et al.*, 2000).

Engineers have demonstrated interest in learning how to manage urban storm water. During the 1900s, urban storm-water processes have undergone engineering investigations of gutter and storm sewer hydraulics (Greeley, 1925; Li, 1954), flood exacerbation (Leopold, 1968; Anderson, 1970), river adjustment (Hammer, 1972; Leopold, 1973; Chin and Gregory, 2001), flood attenuation (Urbonas & Roesner, 1993; Nascimento *et al.*, 1999), and water quality degradation (USEPA, 1983; WEF/ASCE, 1998). Engineers traditionally remove storm water to protect lives and property, and in the USA nearly 80% of the population is served by nearly 800 000 km of sanitary- and storm-sewer pipework (USEPA, 1998). Concentrated development in floodplains, however, introduced a legacy of management stresses given that floods are a natural geomorphological event.

In the USA, Central New York State's Onondaga Creek watershed provides one approach for reducing stresses by linking terrestrial-aquatic storm-water drainage issues. Onondaga Creek watershed drains south to north from the central New York State's Appalachian Plateau at 587 m above sea level in a primarily rural headwater system through the glacially formed Tully Valley and the Onondaga Nation reservation and into the City of Syracuse's Onondaga Lake at 110 m above sea level, for a total area of 301 km<sup>2</sup>. Figure 1 uses road networks to show that while the headwaters are relatively undeveloped, with deciduous and evergreen forest, fruit orchards, and mixed agricultural land, the northern outlet is predominantly residential, urban, commercial and industrial. Native American Onondaga Nation peoples originally settled the Creek above the floodway, so the history of reactive storm-water management begins with the history of the City of Syracuse.

The City of Syracuse drainage underwent significant engineering in 1822 when the State Canal Commission (e.g. Erie Barge Canal) lowered Onondaga Lake by several feet to drain swamplands and address pestilence, flooding and land development needs. Warm rainfall on snow pack was typically associated with the largest floods on record, which were a devastating force at 57 m<sup>3</sup>/s, but reached more than 170 m<sup>3</sup>/s on a few occasions. Such a flood occurred in March 1920, causing US\$1.5 million in losses (USACE, 1956). Enlargement of the channel occurred incrementally from 1909 to 1952, from the Erie Barge Canal at its mouth to the municipality's southern end by city engineers, and upstream to Onondaga Nation by the US Army Corps of Engineers (USACE). Figure 1 illustrates how the capacity, designed under separate agencies and projects, changes from 20 m<sup>3</sup>/s in the Nation land to 85 m<sup>3</sup>/s, to 170 m<sup>3</sup>/s and back to 85 m<sup>3</sup>/s as it passes through the City of Syracuse. This 19.2-km section of channel is primarily grass and hard lined, has uniform longitudinal slopes



**Figure 1.** Watershed map noting the dense road and associated underlying storm sewer network at the north end, engineered changes in stream channel capacity from the rural to the engineered urban section, and the Onondaga Nation boundary.

averaging 0.001, and trapezoidal cross-sections with a base width between 5.5 and 8.5 m, and in the urban armoured area it has steep side slopes of 1:1.0 and 1:1.5 vertical to horizontal.

Extension of the deeper and wider channel in Onondaga Creek simultaneously resulted in the loss of floodplain and natural storage and resulted in larger flood flows, and the last round of channel enlargement upstream of the City required more complete storm-water management (Syracuse Intercepting Sewer Board, 1927). Construction of a dam in the watershed headwater, therefore, was a predictable management decision following passage of broad federal authorization via the Flood Control Act of 1941. Onondaga Creek's USACE dam was built in Onondaga Nation (Figure 1) with a reservoir storage capacity of 22.5 million m<sup>3</sup> provided by a rolled earth embankment 550 m long at a maximum

height of 20 m (USACE, 1947). At spillway level with a maximum head on the 2-m diameter outlet conduit, discharge capacity is 36 m<sup>3</sup>/s, inundating Nation floodplain lands upstream of the dam, but in compliance with storm-water management design flows downstream of the Nation. Flooding is exacerbated upstream of the dam, covering 5 km of Onondaga Creek and 3.4 km of its West Branch tributary with a reservoir of 2.43 km<sup>2</sup> (USACE, 1947).

Drainage was engineered to convey water from the impervious City of Syracuse urban watershed directly to storm sewers that discharge into the Creek or into combined storm and sanitary sewers that collect in a main interceptor that tracks Onondaga Creek to the METRO wastewater treatment facility at its outlet. For precipitation events that trigger unit runoff greater than 8.5 mm/h, CSO discharge occurs by jumping a regulating weir or dropping into a regulating orifice. Figure 2 shows a composite of residential flood areas and channel meanders made historical by the deepened and aligned channel with its impervious watershed cover, limited tree cover, numerous Creek CSO and storm sewer discharges. Onondaga Creek discharge and water quality data are recorded at two US Geological Survey gages: the upstream Dorwin Avenue gage (#04239000) is stationed at the transition between the rural/suburban to the suburban/urban land cover; the downstream Spencer Street gage (#04240010) is stationed near the Creek outlet. Water quality has suffered under the current storm-sewer and CSO-discharge system, with Figure 3 showing faecal coliform (cells/100 ml) CSO discharge during four storm events between June 2001 and June 2002. Figure 3 also shows how the storm-water runoff from residential and parkland in CSO 050 enters storm drains, which contributed to the greater pollution detected at Spencer Street. Rather than the waterway augmenting property values as in the nearby Seneca River or Skaneateles Lake, property is frequently abandoned or vacant (Figure 2).

Globally, urban engineering research has relatively recently considered ecological biodegradation processes for pollution abatement via best management practices in new development with larger footprint wetlands and in existing development with smaller footprint bioretention basins (Davis *et al.*, 1998; Scholes *et al.*, 1998; Braune & Wood, 1999). Urban engineers are possibly ready to expand this storm-water control and consider ecological feedbacks with water tables and riparian vegetation using findings from urban ecological investigations, such as the US Baltimore and Phoenix Long Term Ecological Research stations characterizing urban natural components and linkages (Grimm *et al.*, 2000; Pickett *et al.*, 2001). The US Clean Water Act (CWA) National Pollution Discharge Elimination System (NPDES) Phase II Rule implemented in 2003 requires urban storm-water runoff controls (USEPA, 2000) estimated at trillions of dollars (Congressional Budget Office, 2002), and serves as an impetus to link engineering and ecological theories for urban storm-water design. Indeed, urban population growth has been clearly linked to ecohydrological pressures (Johnson *et al.*, 2001), which are even more severe in poorer nations (Bonell & Askew, 2000), creating a global need for innovations that more effectively manage water for societal and natural ecosystems.

The United Nations Educational, Scientific, and Cultural Organization (UNESCO) Hydrology for Environment Life and Policy (HELP) Initiative (Bonell & Askew, 2000) has inspired hydrological research that better serves society. In an urban context, this research will re-characterize the urban storm-water problem, pushing the engineering design beyond re-routing moisture regimes for flood

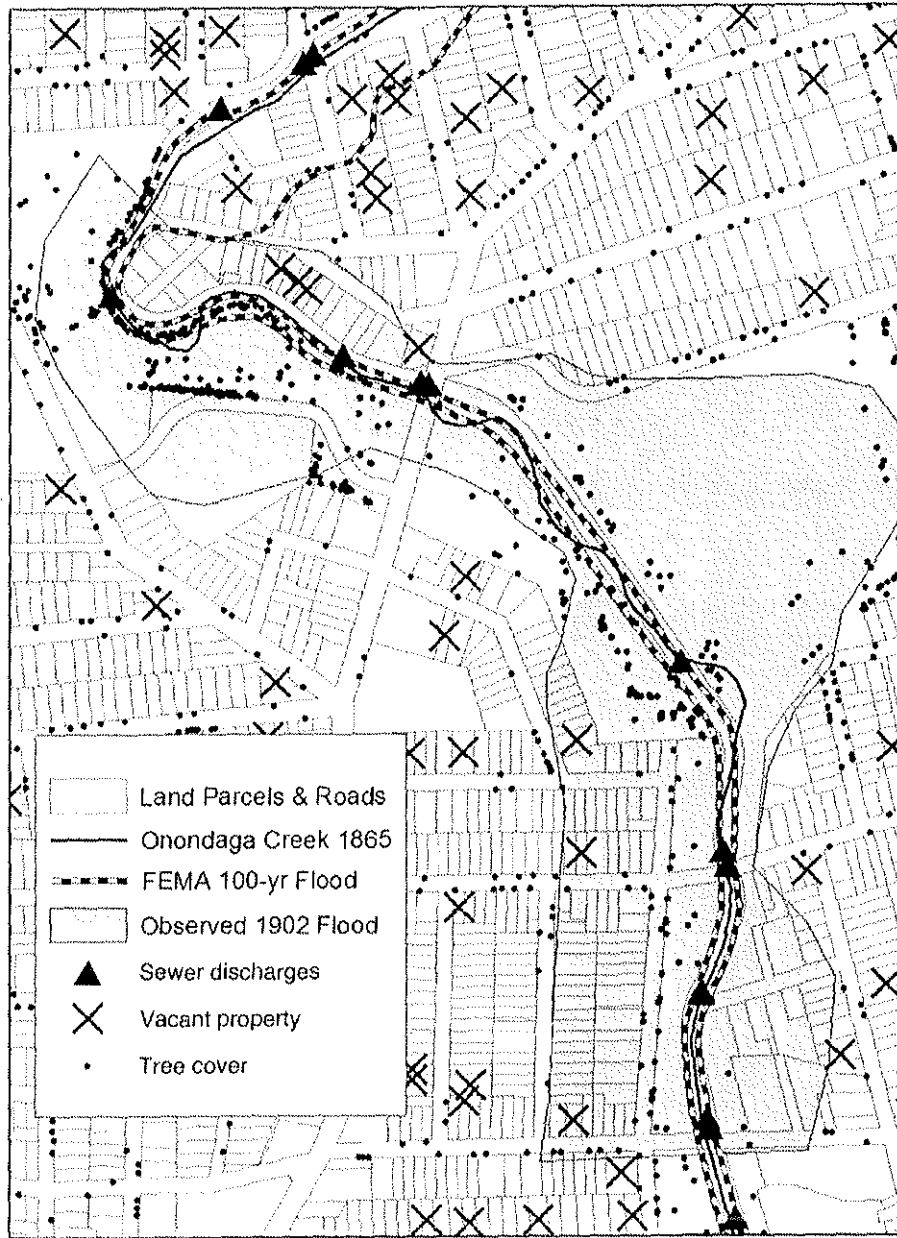
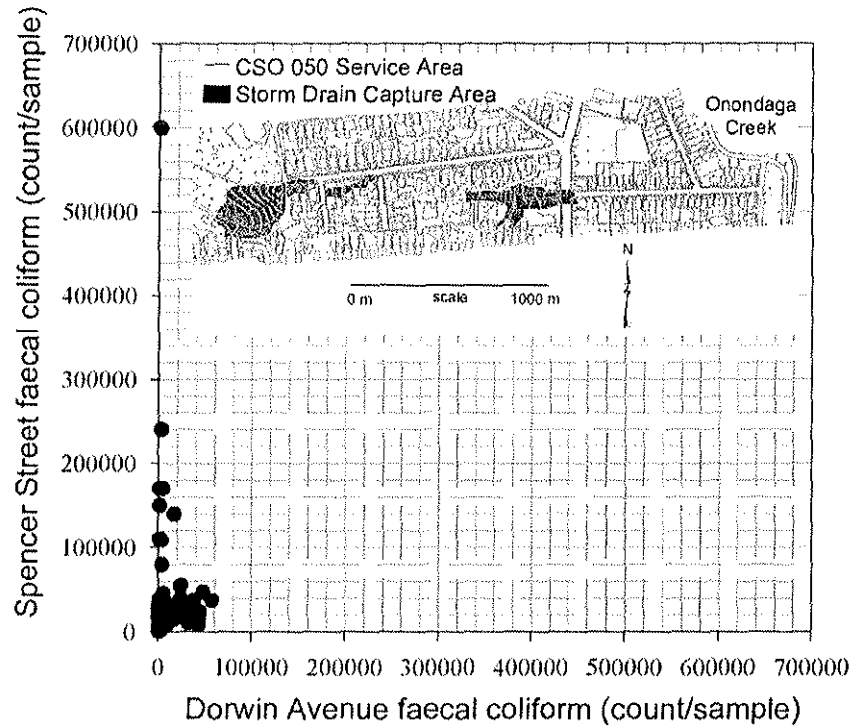
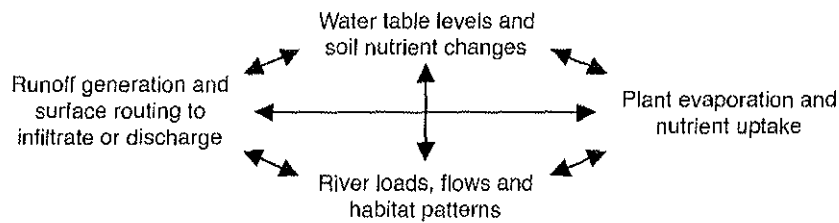


Figure 2. Private property parcels and park area along Onondaga Creek at the target restoration site. Circles denote vacant land now held by the City of Syracuse; triangles denote discharges into Creek (combined sewer, storm sewer and buried tributaries).

abatement (ASCE, 1993) or installing best-management practices for pollution mitigation (WEF/ASCE, 1998). A socio-ecological focus on urban storm-water management might consist of simulating, monitoring and reporting how storm-water design decisions to infiltrate or directly discharge runoff result in a complex set of linked adjustments to the dynamics of the water table, soil



**Figure 3.** Faecal coliform count (cells/100 ml) for four events in 2001 and 2002 in Onondaga Creek at Dorwin Avenue and Spencer Street, sampled by Onondaga County Water Environment Protection staff. (Insert: Map of the CSO 050 discharge site and storm-water capture).



**Figure 4.** Characterization of storm-water linkages for coupled societal and natural resource management of linked terrestrial and aquatic ecohydrological systems. It remains unclear how alternatives to traditional runoff routing through storm sewers affects water tables, soil nutrients, plant dynamics, and river loads and habitat.

nutrient concentration, plant viability and evaporation, and river loads, flows and habitat patterns (Figure 4).

## Storm Water Management Via Ecological Engineering, Ecohydrology and Service Learning

### *Ecological Engineering*

Ecological engineering emerged as a new idea in the early 1960s, but its definition has taken several decades to refine, its implementation is still undergoing adjustment and its broader recognition as a new paradigm is relatively recent. Ecological engineering was introduced by Odum *et al.* (1963) as using natural energy sources as the predominant input to manipulate and control environmental systems. Mitsch & Jorgensen (1989) wrote that ecological engineering is designing societal services such that they benefit society and nature, and later noted (Mitsch, 1993, 1996) that the design should be systems based, sustainable and integrate society with its natural environment. Odum (1989) later emphasized that self-organizational properties were a central feature to ecological engineering. Bergen *et al.* (2001) recently synthesized prescription that the new field should use ecological science and theory, apply it to all types of ecosystems, adapt engineering design methods, and acknowledge a guiding value system.

Implementation of ecological engineering as a new field has focused on the creation or restoration of ecosystems, from degraded wetlands to multicelled tubs and greenhouses that integrate microbial, fish and plant services to process human wastewater into products such as fertilizers, flowers and drinking water (Todd & Todd, 1994). Potential applications of ecological engineering in cities were identified for the fields of landscape architecture, urban planning and urban horticulture (Bergen *et al.*, 2001), which the present paper proposes to synthesize into a unified goal of socially and ecological responsive urban storm-water management. Design guidelines for ecologically engineered systems recently proposed by Bergen *et al.* (2001) for consideration by the scientific and engineering community are designed to be consistent with ecological principles, for a site-specific context, and for efficiency in energy and information, while maintaining the independence of design functional requirements, and acknowledging the values and purposes that motivate design.

Storm-water projects designed for integrated human and natural systems must test the efficacy of implementing such guidelines, and explore whether remote sensing and mapping sciences can characterize critical features of the urban environment. For example, detailed surface conveyances connecting urban storm-water runoff with soil and plant ecosystems need identification, possibly from remote sensing and *in-situ* mapping. In Onondaga Creek, such a systems-based engineering analysis of storm-water loading was conducted. Geographical information system research that coupled remotely sensed 0.6-m pixel EMERGE (green, red, near-infrared) land cover (Nowak *et al.*, 2001) and remotely sensed 0.3-m pixel elevation data with urban event mean concentration data enabled analysis of the CSO pollution loads for the six service areas abutting the target section of the Creek. Subsequent work with a US Environmental Protection Agency (USEPA) model PLOAD (2001) allowed the estimation of pollution reduction via low-impact development storm-water best management practices (WEF/ASCE, 1998) such as bioretention devices (USEPA, 1999; Davis *et al.*, 2003). Follow-ups on this load assessment enabled investigation of ecological engineering alternative designs, including separation of the CSOs. CSO separation projects and the resultant increase in storm-sewer discharges



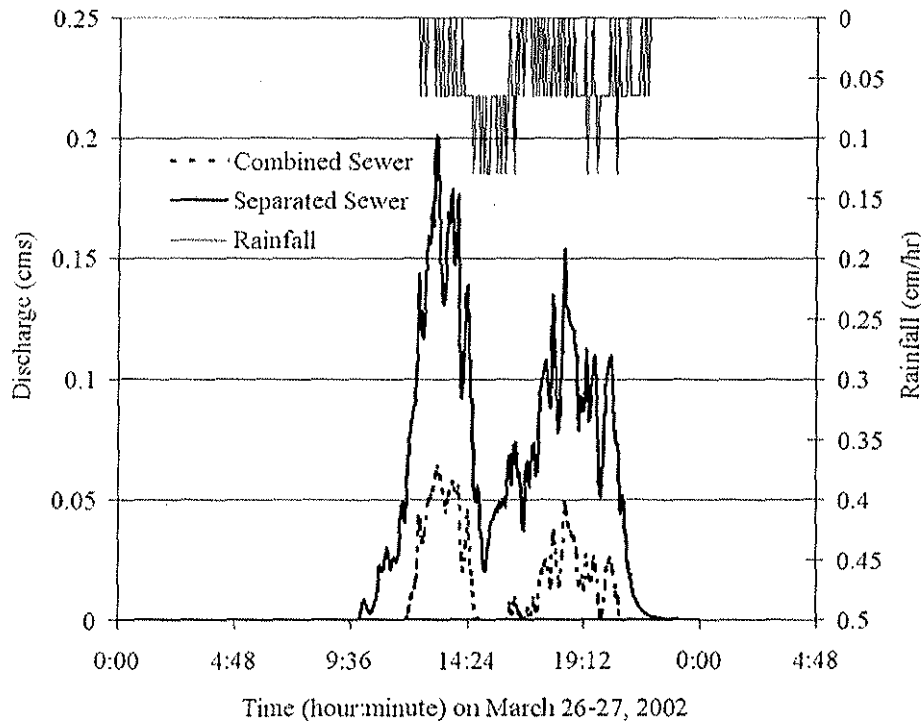


Figure 5. Storm Water Management Model (SWMM) simulated an increase in runoff ( $\text{m}^3/\text{s}$ ) into Onondaga Creek at CSO 050 during a storm in March 2002. Increased discharges resulted from the separation of combined sanitary and storm sewers and subsequent removal of storm-water diversions by the regulator.

where shown to increase the storm-water flows significantly when entering Onondaga Creek within the urban sections.

According to Storm Water Management Model (SWMM) simulations at CSO 050, the separation project will significantly augment in-Creek discharge (Figure 5) (Black *et al.*, 2003). While separation would reduce the faecal coliform observed earlier, SWMM predicted a magnitude of storm hydrograph influxes from CSO 050 that would cause hydraulic scour in the channel and destabilize any naturalized banks. Iterative linkages of the watershed alterations and Creek design are therefore in progress to ensure that the terrestrial and aquatic components are adequately designed.

Storm-water simulation for systems analysis of water tables and in-stream habitat requires more detailed delineations of the storm sewer drain inlet watersheds than ecosystem-independent storm-water management. Remote sensing imagery of urban elevation features, including road crowns and curb breaks, coupled with street surveys with hosing water around drainage inlets, provides a decent estimate of storm-water collection areas. Such collection areas often change with seasonal debris accumulation, road and driveway repaving, and winter road buckling. Without understanding the total runoff area, including the distinction between impervious cover and effective impervious cover directly connected to the Creek, it is difficult to predict how in Figure 4 a change in routing the runoff will change soil moisture, water tables and stream discharge. Walking tours without a hose determines drainage, and while this

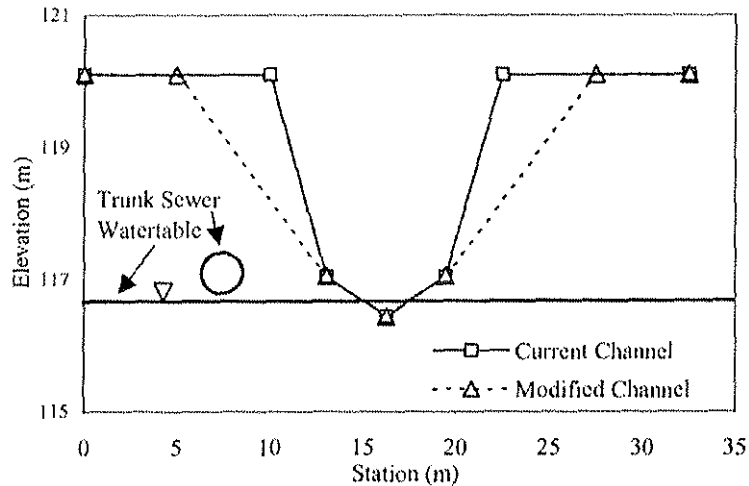
process took extra time, it engages the community with researchers as well as providing critical site-specific information for other SWMM inputs.

### *Ecohydrology*

Ecohydrology is loosely defined as the mutual interaction between the hydrological cycle and ecosystems, but has been implemented primarily as a coupled set of climate–soil–vegetation dynamic equations that attempt to replicate soil moisture and plant patterns in space and time (Rodriguez-Iturbe, 2000). Eagleson (2002) defines ecohydrology as the evaluation of the biophysical relationship between an idealized and ambient climate (e.g. temperature, precipitation, insolation) and the passive response of monoculture vegetation as it changes form (e.g. shape and structure of roots, stems, leaves, canopy) and function (e.g. biomass production). Eagleson develops a complete set of equations to simulate micrometeorological forcing and plant evolution, adroitly synthesizing what Harte (2002) identified as disparate Newtonian and Darwinian worldviews of the previously uncoupled engineer and ecologist. Eagleson intentionally simplifies some areas by neglecting the activities of bacteria, fungi and animals (including human management), and the constraints of soil chemistry, to focus on complexities of vegetation form and function. In the proposed application, ecohydrology should address features of the urban environment by simulating human activities such as storm-water management with the associated chemical constraints, such as road salt toxicity (Broecker *et al.*, 1971; Wegner & Yaggi, 2001) and the limits on sorption of urban metals (Davis *et al.*, 2003).

Rodriguez-Iturbe (2000, 2003a) has identified a major application area for the new field as representing hydrologic control on ecological processes through simulation where water may be a limiting factor due to scarcity or intermittent and unpredictable appearance. Water often has such a signature in urban environments (Collins *et al.*, 2000; Zhou *et al.*, 2002), making urban applications a natural extension for ecohydrological simulation (Rodriguez-Iturbe, 2003b). In the modelling applications, simulations capture years to decades of soil moisture dynamics, typically at a daily time step, which take on probabilistic patterns defined by the distributions of precipitation, evaporation, soil texture and root growth observed in nature (Guswa *et al.*, 2002; Porporato *et al.*, 2002). Urban storm-water design via ecohydrological simulations might consider representing the shorter hydraulic and hydrologic time step of urban storm water that determines allocation between runoff and infiltration rather than assigning probabilistic allocations.

Combining the theories of ecological engineering and ecohydrology was proposed by Zalewski (2000), an ecologist, who focused on river basin restoration and simulation of biotic, climatic and hydrologic regulation of nutrient and energy conversion that counter societal stresses. Few details of this union have been provided. Integrated storm-water design responsive to societal and natural needs should incorporate the ecohydrological theory that has linked the disparate engineering and ecological perspectives. In the City of Syracuse where CSO separation is considered, ecohydrological analysis could provide guidance on the efficacy of storm-water capture for water table recharge and the distribution of moisture for desired plant species. Given an understanding of the current distribution of trees, such as that inventoried in Figure 2, together with the drainage areas identified in Figure 3 and storm dynamics gathered by the



**Figure 6.** Onondaga Creek channel cross-sections showing the current and a proposed simple modification to the channel, along with the field-determined water table elevation and the 0.6-m diameter main trunk sanitary sewer line near CSO 050.

installed monitoring equipment, it would provide a basis for predicting runoff, water table, plant and stream linkages illustrated in Figure 4. An important aspect of linked terrestrial-aquatic analysis would be the development of a simulation package to predict the location and number of low-impact development best management practices bioretention devices (e.g. rain gardens) needed to recharge water tables and soils and to nourish vegetation.

Once surface and subsurface watershed terrestrial processes and controls on hydrology are adequately understood, discharges into the urban stream should be assessed. It is unlikely that the original storm-water engineered channel adequately handles the lower flows or higher flows. Figure 6 illustrates how (1) the deepening of the Onondaga Creek channel, performed in the early 1900s for this section along CSO 050, successfully drained the wetlands and resulted in a depressed water table; and (2) the uniform trapezoidal patterning and armouring of the channel removes gentle bank slopes and soil cover for establishment of riparian vegetation as well as removing a channel thalweg adequate for ecological habitat (e.g. fish passage). Figure 7 shows the range of discharge experienced along Onondaga Creek and a schematic diagram for creating thalweg to connect pools and riffles and to provide habitat in low flows for desirable fish species. Such an analysis represents the dimension of channel depth, connected longitudinally, ensuring that habitat exists at all levels in the profile. Indicator macro-invertebrate aquatic taxonomic groups, sampled at nine sites along Onondaga Creek in 1998, decreased from 13 in the headwaters to three in the City of Syracuse, and the number of individuals decreased from 100 to 30 along the same rural-to-urban transect (McKenna *et al.*, 1999). Spatial variability in fish community density has also been recorded to trend with urbanization impacts. Riffle-dwelling species, such as slimy sculpin (*Cottus cognatus*), longnose dace (*Rhinichthys cataractae*) and brown trout (*Salmo trutta*), as well as pool-dwelling species, such as blacknose dace (*Rhinichthys atratulus*), white sucker (*Catostomus commersoni*) and creek chub (*Semotilus atromaculatus*)

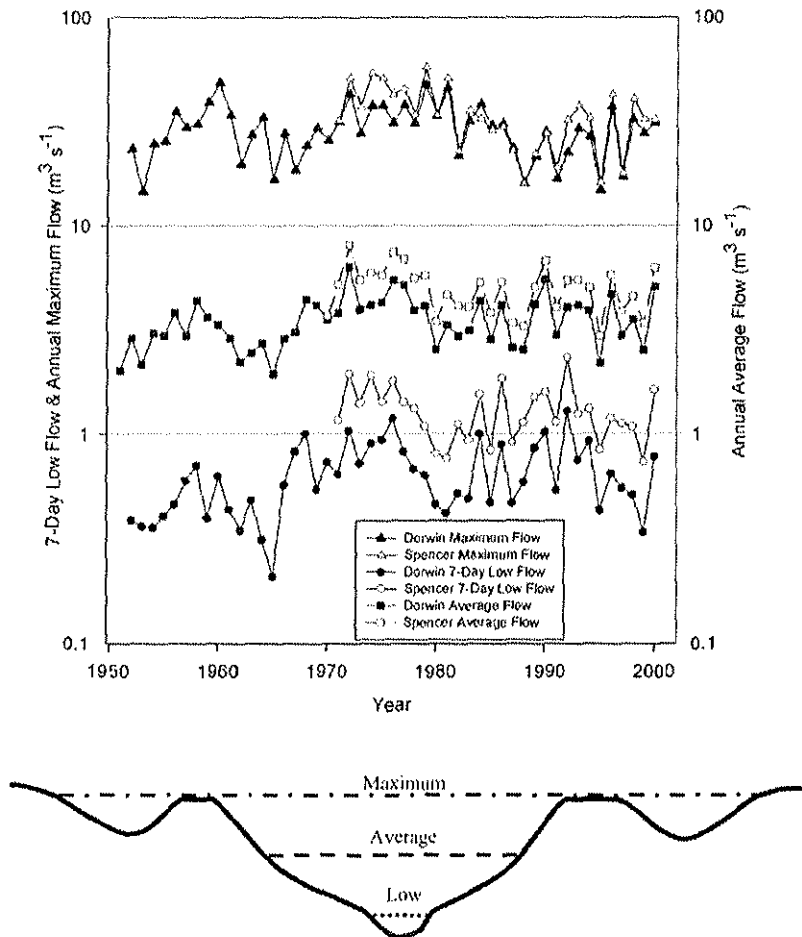
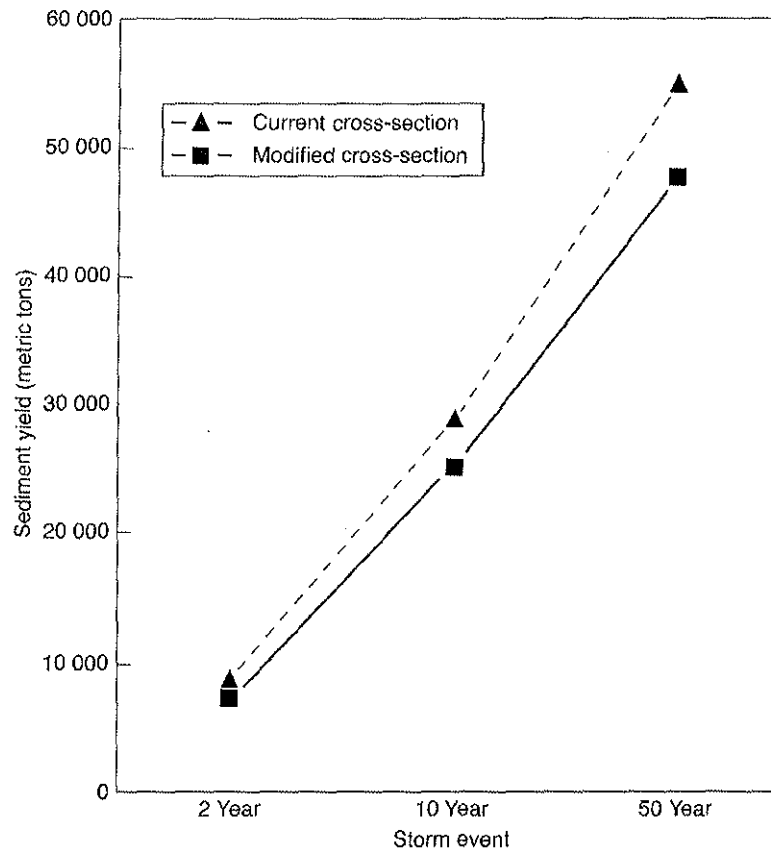


Figure 7. Flow regime ( $m^3/s$ ) on Onondaga Creek at Dorwin Avenue and Spencer Street showing the 7-day low flow, annual average flow and annual maximum flows for the period of record. The lower figure is a simple cross-section with thalweg for low flow and out-of-channel capacity for maximum flow.

were more resilient to flow fluctuations, found little habitat in the uniform armoured Creek.

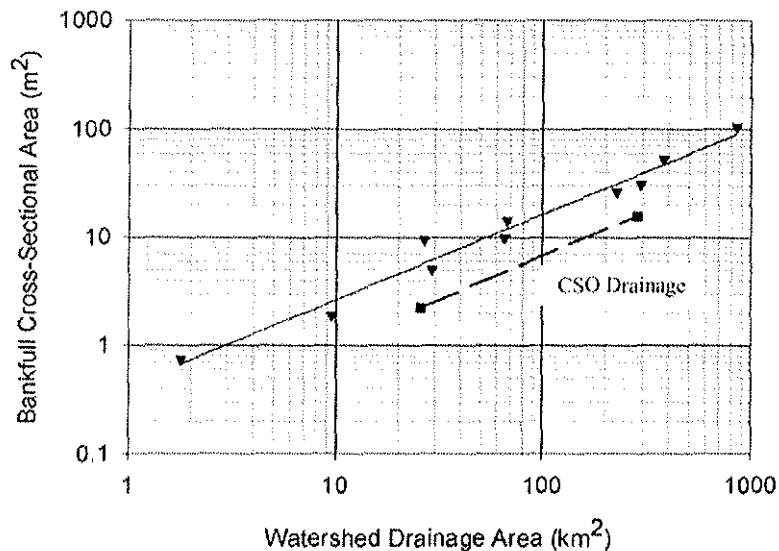
Bank stabilization projects for adjusting streams have required enormous amounts of money across the USA as the result of improper stream restoration design and/or implementation (Rosgen, 1996). Bank stabilization research for Onondaga Creek used a channel evolution model called CONCEPTS (Langendoen, 2000), developed as an unsteady dynamic flow and bank stability model developed by the US Department of Agriculture's (USDA) Sediment Laboratory. CONCEPTS' simulation was used to simulate channel evolution and sediment transport, without consideration of riparian plant tensile strength and overburden, for scenarios that removed concrete bank armoring and used existing bank slopes and more gently sloping banks (McDonnell & Endreny, 2003). The model was run with storm conditions corresponding to 2-, 10- and 50-year events, and illustrated that the stream responded positively by showing decreased sediment



**Figure 8.** Estimated sediment loss (1000 kg) exported by bank failure along the target reach due to 2-, 10- and 50-year flood hydrographs routed in CONCEPTS for the current and modified cross-sections shown in Figure 6.

yields and less bank scour under the modified conditions shown in Figure 8. However, the degree of success was minimal, and in-stream scour needs to be addressed by introducing more roughness, pool-riffle meanders or step-pool sequences, and accommodating for the clear water energy capacity from the armouring and dam. Research into the storm-sewer infrastructure revealed that any meander movement of the stream laterally, such as with meanders, will encounter a main trunk sewer (Figure 7). Longitudinal analysis ensures that the stream has continuity between pools and riffles and provides habitat and capacity along its extent.

Fluvial geomorphological analysis has the potential to reconnect the in-channel and watershed by reintroducing lateral flow dynamics that cycle both at the surface and subsurface by overland flow and hyporheic flow. Richards *et al.* (2002) review the ecological benefits of surface exchanges, while hyporheic dynamics have not been as well researched. Introducing increased flooding to an urban community is not a reasonable or viable target unless additional flood control measures, either active or passive, have been put into place. In Onondaga Creek, a fluvial geomorphological analysis of watershed and river equilibrium was used to perform a Rosgen Classification (Rosgen, 1994) of the



**Figure 9.** Bankfull cross-sectional area (m<sup>2</sup>) and watershed drainage area (km<sup>2</sup>) (log plot) for streams in the same physiographical region of Onondaga Creek. A USGS team surveyed half the data points. The lower line of Onondaga Creek at Spencer Street and Harbor Brook might be distinct due to the combined sewer overflow diversion of storm flow away from the stream and toward a treatment facility.

current condition for the CSO 050 area, given as G4, and several C4/3 'reference' reaches within the similar alluvial flood plain valley type. Regional curves, characterizing bankfull flow, were developed by surveying 20 bankfull widths at the two Onondaga Creek United States Geological Survey (USGS) gages and four nearby City of Syracuse USGS gages, and completed by using similar surveys for physiographically similar stream assessments conducted by the New York USGS office. Bankfull geometry is useful when determining candidate dimensions for assessment in hydraulic stability analysis with HEC-RAS models (DeKoskie *et al.*, 2002). In Onondaga Creek at Spencer Street and another storm-sewer-drained creek, the bankfull cross-sectional area was much smaller than for the reaches without upstream storm sewers (Figure 9). The reduced bankfull size may be due to the diversion of storm water away from the Creek to a treatment facility and must be further investigated before characterizing the design options. Here the analysis becomes complex as urban storm-water infrastructure and flow adjustments have obscured the findings from what is considered standard fluvial geomorphological assessment.

#### *Service Learning*

Much of the research presented above occurred under the auspices of service learning. Service learning has been defined to take on the nature of experiential learning (Milnes, 2003) and presents learning as a natural outcome of the problem-solving process, and directs the activity toward tackling a combined set of community and research problems (O'Grady, 2000). Active community engagement, problem identification, training in problem solving and scheduled

reflection are key components of service learning (Bringle & Hatcher, 1996). Integrating service learning into urban storm-water management brings numerous benefits. Of particular importance, the service learning paradigm provides the means to enter into a cooperative engagement with the urban community and map otherwise unavailable storm-water features needed to inform the present research and complement the set of remotely sensed products. The features and activities of most interest are private land impervious cover extent, its connectedness to street networks, and the irregular application of water and possibly pollutants through gardening, car washing and other activities.

Younos *et al.* (2003) and the Universities Council on Water Resources (Lewicki & Younos, 2001) identify additional benefits of applying service learning to watershed studies, including the ability for beneficiaries to include all participants, given that the community and university are engaged and/or vested in a unique problem. Reports on service learning highlight the benefits to traditional classroom students (Jacoby, 1996), and college students in many campuses have rallied their institutions actively to advance sustainable development and nurture their ecosystem and community through programmes such as service learning (Mansfield, 1998). The urban community, often aware of the storm-water problems such as surcharges that flood basements (Carr *et al.*, 2001) and degraded water quantity and quality (Johnson *et al.*, 2001), is interested in university partnering. Such degradation of water resources restricts or prohibits recreational use, yet neighbourhoods welcome innovative storm-water solutions (Kloster *et al.*, 2002) that improve neighbourhoods aesthetically and economically (Office of Housing and Urban Development, 1999; Fusco, 2001).

Community and academic interests overlap in the area of improved management of flooding, pollution and habitat degradation in Onondaga Creek. Once community interests are addressed, establishing a balance in community participation is critical. Riley (1998) notes success has been greatest for communities periodically or regularly engaged in tangible activity, such as planting, monitoring or cleaning, and not just passive participants in short or long planning meetings or reviews on the work of technicians. Background data sharing between the university and community occurred in public workshops on storm-water management and river restoration (Anon., 2003), where groups such as the Partnership for Onondaga Creek and Canopy motivated resident attendance. Action in the field to date has been through Cornell Cooperative Extension-sponsored annual cleanups, getting the community active while simultaneously improving habitat and aquatic resource utilization. Dialogue connected a broad array of groups interested in reclaiming the ecological and social function of Onondaga Creek and/or maintaining flood conveyance. Student-led service learning events have provided a perennial basis for introducing 'outsiders' removed from earlier obstacles and set to achieve objective science and engineering goals. Such efforts have respected an ethical obligation not to harm the ecosystem, including the social networks of community dialogue through which information and resources flow.

## Conclusions

A new concept is presented for socially and ecological integrated storm-water management that taps exciting developments in the paradigms of ecological engineering, ecohydrology and service learning. In combination, service learning

is the means connecting the university and community to address and map the common urban storm-water issue, ecological-engineering design is the framework to process the goals and constraints that uphold societal and natural system storm-water interconnections, and ecohydrology is the theory to parameterize a storm-water simulation and reveal watershed health and risk. Onondaga Creek analysis of terrestrial and aquatic exchanges has revealed the need for more robust and coupled simulation schemes. Initial fieldwork has shown how ecological function and social recreation might return to the Creek with removal of armoring, how hydrographs are initially exacerbated by CSO separation, and how storm-water diversions lower expected fluvial geomorphological bank-full values. Ideally, such integrated efforts will lead to restored and healthier watersheds, streams and communities.

### Acknowledgements

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### References

- Anderson, D. G. (1970) *Effect of Urban Development on Floods in Northern Virginia*. Water Supply Paper No. 2001C.22 (Reston, VA: US Geological Survey).
- Anon. (2003) Onondaga Creek is topic of discussion at ESF, in: *Proceedings of The Post-Standard*, 24 March 2003, Syracuse, NY, p. 1.
- ASCE (1993) *Design and Construction of Urban Stormwater Management Systems*. ASCE Manuals and Reports on Engineering Practice No. 77 (Reston, VA: American Society of Civil Engineers).
- Bergen, S. D., Bolton, S. M. & Fridley, J. L. (2001) Design principles for ecological engineering, *Ecological Engineering*, 18, pp. 201–210.
- Black, J., Endreny, T. A. & Leopold, D. J. (2003) Comparison of sewer outputs: combined and separated sewer systems. Presentation at the Great Lakes Research Consortium Annual Conference, Syracuse, NY.
- Bonell, M. & Askew, A. (2000) *The Design and Implementation Strategy of the Hydrology for Environment, Life and Policy (HELP) Initiative* (Paris: HELP Task Force/United Nations Educational Scientific & Cultural Organization).
- Borchardt, D. & Sperling, F. (1997) Urban stormwater discharges: ecological effects on receiving waters and consequences for technical measures, *Water Science and Technology*, 36, pp. 173–178.
- Braune, M. J. & Wood, A. (1999) Best management practices applied to urban runoff quantity and quality control, *Water Science and Technology*, 39, pp. 117–121.
- Brezonik, P. L. & Stadelmann, T. H. (2002) Analysis and predictive models of stormwater runoff volumes, loads, and pollutant concentrations from watersheds in the Twin Cities metropolitan area, Minnesota, USA, *Water Research*, 36, pp. 1743–1757.
- Bringle, R. G. & Hatcher, J. A. (1996) Implementing service learning in higher education, *Journal of Higher Education*, 67, pp. 221–239.
- Broecker, W. S., Schwartz, B., Sloan, N. & Ancona, P. (1971) Road salt as an urban tracer, in: R. H. Hawkins (Ed.) *Proceedings of the Street Salting–Urban Quality Workshop*, pp. 24–38 (Syracuse, NY: SUNY ESF).
- Burian, S. J., Nix, S. J., Pitt, R. & Durrans, S. R. (2000) Urban wastewater management in the United States: past, present, and future, *Journal of Urban Technology*, 7, pp. 33–62.
- Butler, D. & Davies, J. W. (2000) *Urban Drainage* (New York: E&FN Spon).
- Cart, R. W., Esposito, C. & Welsh, S. G. (2001) Street-surface storage for control of combined sewer surcharge, *Journal of Water Resources Planning and Management*, 127, pp. 162–167.



- Chin, A. & Gregory, K. J. (2001) Urbanization and adjustment of ephemeral stream channels, *Annals of the Association of American Geographers*, 91, pp. 595–608.
- Collins, J. P., Kinzig, A., Grimm, N. B., Fagan, W. F., Hope, D., Wu, J. & Borer, E. T. (2000) A new urban ecology, *American Scientist*, 88, pp. 416–425.
- Congressional Budget Office (2002) *Future Investment in Drinking Water and Wastewater Infrastructure*. CBO 58 (Washington, DC: Congress of the United States).
- Davis, A. P., Shokouhian, M., Sharma, H., Henderson, C. & Winogradoff, D. A. (1998) Bioretention for the treatment of urban runoff: laboratory and field results, in: WEFTEC '98, Surface Water Quality and Ecology I & II 4, pp. 421–434.
- Davis, A. P., Shokouhian, M., Sharma, H., Minani, C. & Winogradoff, D. A. (2003) Water quality improvement through bioretention: lead, copper, and zinc removal, *Water Environment Research*, 75, pp. 73–82.
- DeKoskie, D., Higgins, M., Endreny, T. A., Black, J. & Leopold, D. J. (2002) Restoration feasibility study for Onondaga Creek, Syracuse, New York, in: Association of State Wetland Managers Conference, Bear Mountain, NY (New York: ASWM).
- Eagleson, P. S. (2002) *Ecohydrology: Darwinian Expression of Vegetation Form and Function* (New York: Cambridge University Press).
- Fusco, D. (2001) Creating relevant science through urban planning and gardening, *Journal of Research in Science Teaching*, 38, pp. 860–877.
- Greeley, S. A. (1925) Some notes on relation between the capacity of combined and storm sewers in the frontage assessment, *Journal of the Western Society of Engineers*, 30, pp. 13–24.
- Grimm, N. B., Grove, J. M., Pickett, S. T. A. & Redman, C. L. (2000) Integrated approaches to long-term studies of urban ecological systems, *BioScience*, 50, pp. 571–584.
- Guswa, A. J., Celia, M. A. & Rodriguez-Iturbe, I. (2002) Models of soil moisture dynamics in ecohydrology: a comparative study, *Water Resources Research*, 38, pp. 510–515.
- Hammer, T. R. (1972) Stream channel enlargement due to urbanization, *Water Resources Research*, 8, pp. 1530–1540.
- Harte, J. (2002) Toward a synthesis of the Newtonian and Darwinian worldviews, *Physics Today*, October, pp. 29–34.
- Herricks, E. E. (Ed.) (1995) *Stormwater Runoff and Receiving Systems: Impact, Monitoring, and Assessment* (New York: CRC Lewis).
- Ierotheos, Z., Dimitriou, E. & Koussouris, T. (2003) *Estimating Land Cover Changes and Associated Environmental Impacts on Wetlands by Coupling Remote Sensing and Hydrological Modelling*, pp. 247–254 (Wallingford, UK: IAHS-AISH).
- Jackson, L. E. (2003) The relationship of urban design to human health and condition, *Landscape and Urban Planning*, 64, pp. 191–200.
- Jacoby, B. (1996) Service-learning in today's higher education, in: B. Jacoby *et al.* (Eds) *Service-Learning in Higher Education—Concepts and Practices*, pp. 3–25 (San Francisco, CA: Jossey-Bass).
- Johnson, N., Revenga, C. & Echeverria, J. (2001) Managing water for people and nature, *Science*, 292, pp. 1071–1072.
- Kloster, T., Leybold, T. & Wilson, C. (2002) Green streets: innovative solutions for stormwater and stream crossings, in: Proceedings of the Ninth International Conference on Urban Drainage, 8–13 September 2002, Portland, OR, USA, pp. 1–18 (Reston, VA: American Society of Civil Engineers).
- Langendoen, E. J. (2000) *CONCEPTS: Conservation Channel Evolution and Pollutant Transport System*. Research Report 16.160 (Oxford, MS: USDA-ARS National Sedimentation Laboratory).
- Leopold, D. J. (1968) *Hydrology for Urban Land Planning: A Guidebook on the Hydrologic Effects of Urban Land Use*. Circular 554.18 (Reston, VA: US Geological Survey).
- Leopold, L. B. (1973) River channel change with time: an example, *Geological Society of America Bulletin*, 84, pp. 1845–1860.
- Lewicki, C. & Younos, T. (2001) *Integrating Universities' Knowledge and Student Service-Learning into Community-Based Watershed Management Programs* (Carbondale, IL: Universities Council on Water Resources).
- Li, W.-H. (1954) Hydraulic theory for design of storm-water inlets, in: Proceedings of the Thirty-third Annual Meeting of the Highway Research Board, Johns Hopkins University, MD, USA.
- Mansfield, W. H. I. (1998) The greening of the campus: students are beginning to hold their institutions of higher learning to a higher standard, *World Watch*, 11, pp. 24–30.
- McDonnell, T. & Endreny, T. A. (2003) *Dynamic Simulation of Storm Induced Geomorphic Adjustments in Onondaga Creek, NY with Concrete Lining Removal. Spotlight on Student Research and Outreach* (Syracuse, NY: SUNY ESF).

- McKenna, J. E., Chiotti, T. L. & Kappel, W. M. (1999) *Ecological Status of Onondaga Creek in Tully Valley, New York—Summer 1998* (Ithaca, NY: US Geological Survey).
- Milnes, J. (2003) *Field Work Savvy: A Handbook for Students in Internship, Co-Operative Education, Service-Learning and other forms of Experiential Education* (Springfield, VA: National Society for Experiential Education).
- Mitsch, W. J. (1993) Ecological engineering—a cooperative role with the planetary life support systems, *Environmental Science and Technology*, 27, pp. 438–445.
- Mitsch, W. J. (1996) Ecological engineering: a new paradigm for engineers and ecologists, in: P. C. Schulze (Ed.) *Engineering Within Ecological Constraints*, pp. 114–132 (Washington, DC: National Academy Press).
- Mitsch, W. J. & Jorgensen, S. E. (1989) Introduction, in: W. J. Mitsch & S. E. Jorgensen (Eds) *Ecological Engineering: An Introduction to Ecotechnology*, pp. 3–12 (New York, NY: Wiley).
- Nascimento, N. O., Ellis, J. B., Baptista, M. B. & Deutsch, J.-C. (1999) Using detention basins: operational experience and lessons, *Urban Water*, 1, pp. 113–124.
- National Research Council (2000) *Watershed Management for Potable Water Supply: Assessing the NYC Strategy* (Washington, DC: National Academy Press).
- Nowak, D. J., Walton, J., Myeong, S., Hopkins, P. & Brock, R. H. J. (2001) Tree cover in Syracuse, in: D. J. Nowak & P. R. O'Connor (Eds) *Syracuse Urban Forest Master Plan*. Technical Report NE-287, pp. 6–8 (Newtown Square, PA: US Forest Service, Northeastern Research Station).
- O'Grady, C. (2000) *Integrating Service-Learning and Multicultural Education in Colleges and Universities* (Mahwah, NJ: Lawrence Erlbaum).
- Odum, H. T. (1989) Ecological engineering and self-organization, in: W. J. Mitsch & S. E. Jorgensen (Eds) *Ecological Engineering: An Introduction to Ecotechnology*, pp. 79–101 (New York, NY: Wiley).
- Odum, H. T., Siler, W. L., Beyers, R. J. & Armstrong, N. (1963) *Experiments with Engineering of Marine Ecosystems* (Austin: Institute of Marine Science, University of Texas).
- Office of Housing and Urban Development (1999) *The State of the Cities, 1999, 3rd Annual Report* (Washington, DC: US HUD).
- Pickett, S. T. A., Pouyat, R., Zipperer, W., Costanza, R., Cadenasso, M. L., Grove, J. M. & Nilon, C. H. (2001) Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas, *Annual Review of Ecology and Systematics*, 32, pp. 127–157.
- Porporato, A., Ridolfi, L., Rodriguez-Iturbe, I. & D'Odorico, P. (2002) Ecohydrology of water-controlled ecosystems, *Advances in Water Resources*, 25, pp. 8–12.
- Richards, K., Brasington, J. & Hughes, F. (2002) Geomorphic dynamics of floodplains: ecological implications and potential modelling strategy, *Freshwater Biology*, 47, pp. 559–579.
- Riley, A. L. (1998) *Restoring Streams in Cities: A Guide for Planners Policymakers and Citizens* (Washington, DC: Island).
- Rodriguez-Iturbe, I. (2000) Ecohydrology: a hydrologic perspective of climate–soil–vegetation dynamics, *Water Resources Research*, 36, pp. 3–9.
- Rodriguez-Iturbe, I. (2003a) Hydrologic dynamics and ecosystem structure, *Water Science and Technology*, 47, pp. 18–24.
- Rodriguez-Iturbe, I. (2003b) *Urban Ecohydrology* (Princeton, NJ: T. Endreny).
- Rogers, C. E., Brabander, D. J., Barbour, M. T. & Hemond, H. F. (2002) Use of physical, chemical, and biological indices to assess impacts of contaminants and physical habitat alteration in urban streams, *Environmental Toxicology and Chemistry*, 21, pp. 1156–1167.
- Rosgen, D. L. (1994) A classification of natural rivers, *Catena*, 22, pp. 169–199.
- Rosgen, D. L. (1996) *Applied River Morphology* (Pagosa Springs, CO: Wildland Hydrology).
- Scholes, L., Shutes, R. B. E., Revitt, D. M., Forshaw, M. & Purchase, D. (1998) The treatment of metals in urban runoff by constructed wetlands, *Science of the Total Environment*, 214, pp. 211–219.
- Syracuse Intercepting Sewer Board (1927) *Report on Onondaga Creek Flood Prevention* (Syracuse, NY: City of Syracuse).
- Todd, N. J. & Todd, J. (1994) *From Eco-Cities to Living Machines: Principles of Ecological Design* (Berkeley, CA: North Atlantic).
- Urbanas, B. R. & Roesner, L. A. (1993) *Hydrologic Design for Urban Drainage and Flood Control. Handbook of Hydrology* (New York, NY: McGraw-Hill).
- USACE (1947) *Definite Project Report on Local Flood Protection: Onondaga Creek, Syracuse, NY* (Buffalo, NY: War Department, Corps of Engineers).
- USACE (1956) *Onondaga Dam & Reservoir: Reservoir Regulation Manual* (Buffalo, US: Army Corps of Engineers).
- USEPA (1983) *Results of the Nationwide Urban Runoff Program, Vol. 1: Final Report*. NTIS Accession No. PB84-185552 (Washington, DC: US Environmental Protection Agency, Water Planning Division).

- USEPA (1998) *1996 Clean Water Needs Survey Report to Congress—Assessment of Needs for Publicly Owned Wastewater Treatment Facilities, Correction of Combined Sewer Overflows, and Management of Storm Water and Nonpoint Source Pollution in the United States*. EPA-832-R-97-003 (Washington, DC: US Environmental Protection Agency).
- USEPA (1999) *Storm Water Technology Fact Sheet: Bioretention*. EPA-832-F-99-012.8 (Washington, DC: US Environmental Protection Agency, Office of Water).
- USEPA (2000) *Storm Water Phase II Final Rule*. EPA-833-F-00-002.2 (Washington, DC: US Environmental Protection Agency).
- USEPA (2001) *PLOAD Version 3.0: An ArcView GIS Tool to Calculate Nonpoint Sources of Pollution in Watershed and Stormwater Projects*. (4035) EPA-WDC0101-HSQ.48 (Washington, DC: US Environmental Protection Agency, Office of Water).
- Walesh, S. G. (1989) *Urban Surface Water Management* (New York, NY: Wiley).
- WEF/ASCE (1998) *Urban Runoff Quality Management* (Alexandria, VA: Water Environment Federation & American Society of Civil Engineers).
- Wegner, W. & Yaggi, M. (2001) Environmental impacts of road salt and alternatives in the New York City watershed, *Stormwater*, 2, pp. 24–31.
- Younos, T., De Leon, R. & Lewicki, C. (2003) Integrating service-learning into watershed management programs: opportunities and challenges, *Journal of the American Water Resources Association*, 39(1), pp. 1–5.
- Zalewski, M. (2000) Ecohydrology—the scientific background to use ecosystem properties as management tools toward sustainability of water resources, *Ecological Engineering*, 16, pp. 1–8.
- Zhou, S. L., McMahon, T. A., Walton, A. & Lewis, J. (2002) Forecasting operational demand for an urban water supply zone, *Journal of Hydrology*, 259, pp. 189–202.