Costs and Benefits of Storm-Water Management: Case Study of the Puget Sound Region

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Abstract: With rising expenses and scrutiny of storm-water programs, managers need information on costs and benefits to make rational funding decisions. Most, however, lack this basic information. This study sought to identify and quantify the economic and ecological costs of storm-water-related damage and storm-water-management programs, and to understand relationships between management activities and damage reduction. Data were collected from published agency budgets, damage assessments, and structured interviews with storm-water managers. We focused on a single region, the Puget Sound region of Washington State, where storm-water issues abound and annual storm-water expenditures average about $100/capita. Benefits of storm-water management, primarily avoided damages, were presumed to exceed expenditures, but most jurisdictions have not systematically evaluated program effectiveness. Moreover, ecological damage from storm water is significant but commonly neglected in funding decisions. Results indicate the need to (1) evaluate the effectiveness of storm-water-management expenditures; (2) consider nonmonetary and ecological impacts in management and funding decisions; (3) explore preventive measures that can be less costly than remediation; and (4) increase public awareness of storm-water problems to support objective funding decisions.

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Introduction

Across the country, jurisdictions have struggled for decades with how to manage storm water. They will likely face even greater future challenges as population and regulatory requirements both increase. Because jurisdictions must allocate limited funds among competing programs, storm-water-management programs are commonly underfunded relative to identified needs. In addition, expenditures on storm-water-management programs are rarely evaluated for effectiveness and so they may neither address the most critical storm-water problems nor resolve the problems for which they were designed. In total, these factors point to a critical lack of information on the nature of storm-water impacts, the magnitude of those impacts resulting from inadequate storm-water management, the potential benefits of storm-water programs, and the most effective means of using available funding.

In this paper, we assess both the costs of storm-water damage and the benefits of storm-water management, using an in-depth case study of the Puget Sound region in the state of Washington. Our goals differ from those of most prior studies, which have commonly tallied the costs and benefits of only a single storm-water impact or a selected best management practice (BMP). For example, Kalman et al. (2000) considered water quality to demonstrate the value of benefit-cost analysis to evaluate storm-water-management alternatives and the economic limits of storm-water management. Others have evaluated individual storm-water BMPs to identify opportunity costs and benefits (e.g., U.S. Environmental Protection Agency 1999; Braden and Johnston 2004; Johnston et al. 2006; Thurston 2006; Sample et al. 2003). This study seeks to add a new dimension to these investigations by documenting cumulative, jurisdiction-wide costs and benefits of storm-water management across a wide suite of impacts and practices. In taking this approach, this work offers three main contributions: (1) a regionally based, empirical assessment of the costs of both storm-water management and storm-water damage; (2) an application of an approach for gathering disparate, largely uncompiled and unpublished agency-specific data; and (3) an assessment of the additional information and analyses still needed for storm-water-management programs to be effective.

Approach

Systematically compiled storm-water-management expenditures and economic damages are generally unavailable for any given region in current literature. Existing assessments of storm-water-

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management benefits typically have relied on cost functions or benefit transfers, which may not capture the true magnitude or variability of storm-water-management costs at the local level. Therefore, we explored alternative methods and sources to obtain concrete data on both management and damage costs, specific to a single region. We began with a thorough review of agency and government reports and documents, of which virtually all are of only limited distribution. We also identified those storm-water managers in each jurisdiction with primary responsibilities for storm-water programs by identifying lead personnel, coupled with guidance and specific recommendations from regional and state staff. Repeated cross checking of our list with successive interviewees led to increasing confidence that we were, in fact, reaching those regarded as "experts" across the region.

With this list of managers, we conducted structured and semi-structured interviews, using a uniform set of questions with follow-up queries as indicated by the initial responses, to elucidate the following items: (1) their perception of significant storm-water impacts within their jurisdiction or the region as a whole; (2) the magnitude of these impacts and their quantification in economic terms, to the extent possible; (3) storm-water-related problems not readily addressed by current management programs; and (4) recommended improvements to current management activities.

The interview protocol for data acquisition and the preliminary information gained from literature reviews were reviewed by an external committee of stakeholders, storm-water managers, and state agency regulators before implementation. Information subsequently obtained from interviews was also reviewed by both the informants and the review committee. Ongoing review by interviewees and the external committee throughout the research process was a critical component of our effort that refined the data and validated the emerging picture of economic costs and storm-water impacts.

In total, we conducted 47 such interviews with storm-water managers, staff of nonprofit organizations, local officials, and other stakeholders within the study area. Although our sampling approach was designed to target key sources of expertise, as judged by officials and stakeholders throughout the region, it could not be expected to produce an exhaustive sample or a comprehensive collection of all storm-water costs within the region. This approach does, however, offer important data and insights into representative expenditures and first-hand estimates of the costs that the region currently endures.

Although our interviewees were regarded as experts on our subjects of interest, they are not necessarily unbiased, because the programs they administer depend on broad public belief in the importance of the problems they are addressing. We sought to minimize this implicit bias by emphasizing concrete data (e.g., dollars spent or damage costs avoided) rather than subjective evaluations. In some cases, however, this approach yielded an unexpected outcome, namely, a recognition of the limited degree to which such data are actually available.

We applied this approach to the Puget Sound region of western Washington State. The Puget Sound basin itself covers 41,400 km^2, of which 80% is land and 20% water; it includes the second largest estuary in the United States. Its 4,000 km of shoreline provide many recreational, industrial, and tourism opportunities, and it supports a variety of natural resources that include shellfish and salmon. The Puget Sound basin is also home to more than 4 million residents with the population increasing at an annual rate of 1.7% (Office of Financial Management 2006). This rate of growth and urbanization within the region is threatening the environmental well being of the region, and a variety of studies have demonstrated qualitatively the role of storm-water runoff in exacerbating this degradation [e.g., Puget Sound Action Team (2004)]. The Puget Sound region was chosen for this investigation because of the relatively large amount of data available here on storm water, the accessibility to a multitude of reliable informants, and the range of advanced and emerging storm-water technologies that are being applied across the region.

Results

Due to the broad range of topics covered in the interviews and interviewees' open-ended responses, all responses were tabulated and categorized according to the questions asked and responses to these questions. The interview results are summarized in Table 1 with the exception of economic costs, which are incorporated into the discussion of storm-water consequences below. The types of interviewees are summarized in Table 2. Overall, local jurisdictions (cities and counties) and storm-water utilities were the most represented.

The interviewees were first asked what they thought were the most significant storm-water impacts. Overall, the interviewees felt that storm water has most significantly impacted water quality, with effects on biota and habitat being the second and third most significant impacts. The fourth most significant storm-water impact identified by the interviewees was flooding.

When asked what methods they used to measure storm-water impacts or the success of implemented projects, less than half of the jurisdictions offered any substantive response. Although some jurisdictions do employ monitoring in their storm-water programs, many of these jurisdictions indicated that the monitoring results were inconclusive or difficult to analyze, or that the monitoring was infrequent or did not encompass all of the areas within their jurisdiction.

Last, the interviewees were asked for suggested improvements for storm-water programs and management. The most frequent suggested improvements included increasing public awareness, education, and accountability; and improving storm-water regulations and the permitting process. Some jurisdictions expressed frustration with existing regulations and permitting, indicating that they were infeasible (i.e., too costly or too difficult to implement). Several interviewees noted that preventive measures (e.g., limiting development in flood-prone areas, preserving healthy habitats) were the best ways to prevent storm-water damage and were the most economical. Other responses included increasing monitoring efforts to evaluate the effectiveness of storm-water-management techniques and the condition of affected water bodies, increasing storm-water funding, prioritizing projects according to improvement potential, and using new and innovative storm-water technologies.

Storm Water Costs for the Puget Sound Region

The resulting data on consequences resulting from storm-water runoff were categorized into two types of economic costs: the costs of storm-water-management programs and activities, and the costs resulting from storm-water damage. The former category (management costs) includes the cost of facilities and the cost of government and private actions to reduce the damaging effects of storm water. The latter category (damage costs) includes the economic costs that are a direct or indirect result of

Table 1. Key Interview Responses according to Interviewee Type

Key issues	Environmental interest groups	Jurisdictions	Research groups	Private companies	State agencies	Tribal groups	Total	Percentage
Significant impacts								
Water quality	2	10	—	1	5	—	18	38
Effect on biota	4	3	1	1	2	2	13	28
Habitat	2	5	1		1	1	10	21
Flooding	—	6	1	—	—	—	7	15
Difficulty in identifying source	—	1	—	—	3	—	4	9
Maintenance issues	—	2	—	—		1	3	6
Contamination of sediments	2	—	—	—	—	—	2	4
Managing storm water in older communities	—	2	—	—	—	—	2	4
Erosion problems		1			1	—	2	4
Decreased opportunity for recharge	1	—	—	—	—	—	1	2
Methods of measurement and assessment of storm-water impacts								
Monitoring	1	8	—	—	—	—	9	19
Pollution patrol	2	—	—	—	—	—	2	4
Modeling in planning stages	—	2	—	—	—	—	2	4
Maps of storm-water system	1	1	—	—	—	—	2	4
Survey of citizens	1	—	—	—	—	—	1	2
Adaptive management	1	—	—	—	—	—	1	2
Map of problem areas	—	1	—	—	—	—	1	2
Assign costs to environmental impacts	—	1	—	—	—	—	1	2
Difficulties encountered and suggested improvements								
Increase public awareness, education and accountability	1	5	1	—	2	—	9	19
Improve regulations/permitting process	1	7	—	—	—	—	8	17
Utilize preventive measures (i.e., limit development in flood-prone areas, preserve healthy habitats)	5	—	1	1	—	—	7	15
Increase monitoring to evaluate effectiveness and condition of habitat and water quality	1	2	1	1	—	—	5	11
Increase funding	—	4	—	—	1	—	5	11
Prioritize projects according to improvement potential	—	1	1	1	2	—	5	11
Use new, innovative technology	2	2	—	—	—	—	4	9
Apply storm-water research findings to practice; increase storm-water research	1	3	—	—	—	—	4	9
Difficulty implementing new, innovative technology; need more guidance	—	3	—	—	—	—	3	6
Treat storm water at source	1	1	—	—	—	—	2	4
Document damage in terms of loss of water quality and biota	—	—	1	—	1	—	2	4

storm water and a variety of other "costs" that are difficult to quantify in economic terms, but are perceived as no less real to broad groups of affected parties. We found that these storm-water costs, both economic and noneconomic, could be usefully organized according to subcategories of impacts: flooding and property damage, water-quality degradation, destruction of estuarine and freshwater habitat, and other natural resource losses. These sub-categories were based on the reoccurring themes of damages identified by our literature review and echoed by the interviews.

Costs of Storm-Water Management

In the Puget Sound basin, the annual budget of individual storm-water and flood-management programs can be on the order of hundreds of thousands to millions of dollars, depending on size and population of the area. Major storm-water programs costs by jurisdiction are displayed in Table 3 and Table 4. The largest jurisdictions in the region are covered under National Pollutant Discharge Elimination System (NPDES) Phase 1 permits; in aggregate they reported annual expenditures of \$138.2 million

Table 2. Interviewee Affiliation

Category	Interviewees
Jurisdiction/storm-water utility	20
State agency	11
Environmental interest group/nonprofit organization	4
Research group	3
Private consulting firms	3
Native American tribes/tribal organizations	3
Total	47

Table 3. Average Annual Capital Improvement Budgets Including Division of Costs

Jurisdiction	Population[a]	Land area (km^2)	Average yearly budget[b] ($)	$/capita	Flooding and drainage (%)	Landslide mitigation	Habitat (%)	Water quality (%)
Friday Harbor[c]	1,989	3.52	117,541	57.46	100	—	—	—
City of Issaquah[d]	11,212	21.81	857,068	78.78	67	—	33	
City of Mill Creek[e]	11,525	9.25	1,501,584	126.68	62	—	33	5
City of Olympia[f]	42,514	43.28	1,607,003	36.75	47	—	28	25
City of Kirkland[g]	45,054	27.66	5,142,411	110.98	25	—	40	35
City of Bellevue[h]	109,569	79.64	1,789,559	15.88	49	—	25	27
Thurston County[i]	207,355	1,882.93	1,172,470	5.50	45	—	18	37
City of Seattle[j]	563,374	217.56	19,541,161	33.73	60	15	7	18

[a]Population of jurisdictions from *U.S. Census 2000* (U.S. Census Bureau 2001).
[b]Calculated by the writers.
[c]Gray and Osborne, Inc., Consulting Engineers 2005.
[d]City of Issaquah 2005.
[e]City of Mill Creek 2005.
[f]City of Olympia 2003.
[g]City of Kirkland 2005.
[h]City of Bellevue 2005.
[i]Thurston County 2005.
[j]Seattle Public Utilities et al. 2004.

(Table 3). These tabulated costs probably underestimate total storm-water-management costs, however, because jurisdictions were only required to report expenditures needed to meet the 1995 NPDES permit.

Examination of capital improvement plans from other various-sized jurisdictions revealed some examples of the division of costs associated with managing storm water and mitigating storm-water-related problems within the region (Table 4). The relative costs of different types of storm-water-management improvements vary widely, but systematically, between different jurisdictions. Efforts to reduce flooding and improve drainage are the largest costs among all jurisdictions, regardless of population or area. Overall, our data show that program-area spending, region-wide, range from 25–100% of program budgets for flooding reduction and drainage improvement, 0–15% for landslide mitigation, 0–52% for habitat improvement, and 0–37% for improved water quality.

Table 4. 2003 NPDES Phase I Municipal Storm-Water Expenditures

Jurisdiction	Population[a]	Total expenditures (2007 value) ($)	$/capita
City of Tacoma (Tacoma Public Works Department 2004)	193,556	35.3million	182
Pierce County (Pierce County 2004)	700,820	26.6million	38
King County (King County 2004)	1,737,034	58.9million	34
City of Seattle (Seattle Public Utilities 2004)	563,374	11.7million	21
Snohomish County (Snohomish County 2004)	606,024	5.8million	10
Total	3,800,808	138.2million	36

[a]Population of jurisdictions from *U.S. Census 2000* (U.S. Census Bureau 2001).

Available data provide only a minimum estimate of planned storm-water and surface-water capital improvement costs, because these costs may also be shared with departments of parks and recreation, planning, or development that are not specifically listed in storm-water budgets. The magnitude of these costs is thus a first-order estimate of what the region is spending, and how it is spending it, on measures to reduce storm-water-related damage. Based on these values and various jurisdictions' budgets, typical management costs are on the order of $100/capita/year, exclusive of the episodic damage that is also incurred during loosely defined "large storms."

A specific example from an individual jurisdiction demonstrates both the magnitude of the existing local government management costs and their self-assessed shortfalls. The most recent, systematic assessment of local storm-water-management needs in the region was conducted by Snohomish County (population 606,024) for its 155 km^2 of unincorporated urban growth areas within this county, a study that itself cost $12.3 million ($23/capita) to conduct (Snohomish County 2005). That study inventoried the drainage system, identified present and potential drainage and surface water issues, and developed a list of 220 recommended projects with a total project cost of $87 million (or about $144/capita). As of late 2005, 1/6 of the aggregate dollar value of these projects had been completed or cancelled, leaving an estimated $71 million ($117/capita) still to be addressed.

Private-sector costs for storm-water-management facilities were not specifically documented for this study, but available information suggests that they can be substantial (though varying dramatically by age, nature, and location). The most commonly compiled private-sector costs are associated with required storm-water mitigations measures for new residential development; compliance with current regulations in the region have been estimated at around $10,000 per new house by local trade groups (e.g., Master Builders Association; http://www.mba-ks.com). These costs are not readily translated into per capita expenses for the region as a whole, but they suggest an additional dimension to the cost of "storm-water-management programs" that is not readily acquired by our research approach.

Table 5. Examples of Puget Sound Storm-Water Management and Damage Costs

Jurisdiction	Costs
City of Kirkland (population 45,054[a])	For the past 11 years, the City of Kirkland's surface water utility reduced major flooding, documented surface water systems, and implemented a program prioritizing responses to flooding "hot spots" (City of Kirkland 2005). It emphasizes reduction of drainage problems through routine maintenance that requires an annual budget of $1.5 million ($33.29/capita/year).
Pierce County (population 700,820)	Pierce County spent capital improvement costs of $2.8 million annually ($4.00/capita/person) over the past 15 years to implement flood-control measures exclusive of the cost of maintenance (Hans Hunger, personal communication, February 13, 2006).
Kitsap County (population 231,969)	In this County, 50–60% of the Public Works Storm-Water Management budget ($4.6 million or $19.83/capita/year) is allocated to inspection and maintenance of storm-water management infrastructure (Dave Dickson, personal communication, February 7, 2006; FCS Group Inc. 2005). As part of this expenditure, storm-water management staff for Kitsap County must respond to as many as 400 drainage problems per year, reflecting the large amount of time and effort demanded by such issues during periods of heavy rains.

[a]Population of jurisdictions from *U.S. Census 2000* (U.S. Census Bureau 2001).

Costs of Storm-Water Damage

We found that both the literature review and interviews tended to divide the common impacts of storm-water runoff in the Puget Sound region into four categories: flooding and property damage, water-quality degradation, destruction of estuarine and freshwater habitat, and natural resource losses. Each is explored in turn below.

Flooding and Direct Damage to Property

The direct impact of storm water on property is perhaps the most prominent, overt expression of the "cost" of urban runoff. Damage and financial losses, the expense of storm-water facilities, and the cost of complying with and administering regulatory programs designed to reduce these problems are all apparent. Anecdotal information and case studies, however, can only demonstrate the general magnitude of damage from urban flooding. In part, this is because flooding is a natural occurrence, although particularly common in areas of urban development and demonstrably exacerbated by insufficient or poorly maintained storm water and drainage facilities (Booth 1991; Booth and Jackson 1997; MacRae 1997). Examples of flooding and drainage costs are displayed in Table 5.

The direct cost of mitigating flooding and drainage issues due to storm water thus range from $4 to $36 per capita/year for these jurisdictions. These costs reflect the capital improvement and maintenance costs associated with flooding and drainage. Comparisons of capital improvement project budgets among various-sized jurisdictions indicate that flooding and drainage costs used much of the overall funding.

Degradation of Water Quality

Interviewed representatives from most jurisdictions identified water quality as the most "significant" problem resulting from storm-water runoff in their area. However, many interviewees felt that water-quality issues are often ignored because local officials and citizens are more immediately concerned about flooding and related drainage problems.

The costs identified in this study that are directly associated with water bodies degraded by pollution are primarily those associated with cleaning polluted surface-water bodies and protecting such resources from future or additional contamination. Degradation of water quality, however, is also a factor in a host of ecological problems. Poor water quality is implicated in many environmental studies of diseased aquatic organisms nationwide, with causal linkages commonly suggestive but not generally proven.

Although Puget Sound is the ultimate recipient of polluted water, the consequences of degraded water quality begin in upstream water bodies and drinking-water supplies. Threats to their quality can create an immediate public health risk and necessitate significant financial outlays. For example, Lake Whatcom, a major water supply in the Puget Sound region that provides water for approximately 86,000 Whatcom County residents (Cusimano et al. 2002) is being threatened by previously permitted urban development that surrounds this body of water. The water supply is impaired due to problems with Dieldrin, dissolved oxygen, mercury, PCBs, and phosphorus (Washington State Department of Ecology 2005a) caused primarily by land use changes and storm water, with minor contributions from wastewater discharges and illegal dumping. The county in which this water supply is located is spending about $800,000 ($7.37/capita/year) in constructing water-quality treatment retrofits in 2006 alone, such as swales and vaults, to improve the water quality of this drinking supply (Kirk Christensen, personal communication, June 12, 2006). It has also cost the nearby City of Bellingham (population 67,171) $400,000 per year ($6.11/capita/year) to construct and maintain similar water-quality treatment retrofits; their overall capital expenditure is nearly $900,000 as of 2006 (William Reilly, personal communication, February 6, 2006).

Even where drinking-water supplies are not directly affected, degradation of the water quality of streams and rivers is a primary concern of storm-water managers and public works directors. About 60% of Puget Sound lowland streams are listed as "impaired," a ratio for Washington State second only to the Columbia Basin (Butkus 2002). Although little systematic data are available to prove direct linkages, this concern is based on strong associations: ". . . water-quality standards are frequently exceeded in urban storm-water runoff. Where that runoff makes up the bulk of the flow in a lowland stream, violations are highly likely" (Ed O'Brien, Washington State Department of Ecology, personal communication, May 31, 2006).

Local examples of direct water-quality mitigation costs are abundant. Seattle's Thornton Creek (30 km^2 watershed area; watershed population around 75,000) is on the Washington State Department of Ecology's 303(d) list for impaired waters due to fecal coliform, temperature, and dissolved oxygen (Washington State Department of Ecology 2005b). In order to improve water quality, the local utility is installing water-quality swales and sediment basins to treat storm water from a 670-acre urban subbasin that enters Thornton Creek. The state offered the utility $7.0 million ($12.37/capita) for this project (Washington State Department of Ecology 2005c), which would partly treat less than 10 percent of the total watershed area. The state also offered the utility $1 million ($1.87/capita) in funding to implement disinfection by ultraviolet light in three of Seattle's urbanized creeks (Thornton, Pipers, and Longfellow Creeks) to reduce fecal coliform levels.

Loss of Estuarine and Freshwater Habitat

Direct costs of habitat damage are difficult to assign, because the "value" of habitat is rarely measured in strictly economic terms. More commonly, the damage is reflected in the response of the organisms that depend on that habitat (e.g., "loss of fish"), but the specific contribution of habitat loss to that overall change has engendered more than 2 decades of debate and is unlikely to be resolved any time soon. Economic costs can more readily be assigned on the basis of remedial programs; as with those programs targeting degraded water quality, however, they are surely reversing only a scant fraction of the actual damage that is occurring, and in many instances there is little evidence that the expenditures are making any actual difference at all [e.g., Maxted and Shaver (1997); Horner et al. (1997)]. Despite these shortcomings, the amounts being spent are quite substantial.

In general, habitat conditions in urban streams and creeks are significantly degraded. Although some jurisdictions do not have the funds or staff to document habitat degradation, such damage is ubiquitous with urban development and is almost certainly occurring throughout western Washington, whether quantified or not. By one estimate (Bernhardt et al. 2005), $1 billion per year is currently being spent nationwide in the name of stream restoration, and a significant fraction of that outlay is contributed by the Pacific Northwest in general and the Puget Sound region in particular. An even greater cost is the loss of biological resources, a cost that is compounded by expenditures on ineffectual projects (Frissell and Nawa 1992; Booth 2005).

In the Puget Sound region, examples of restoring damaged salmon habitat are commonplace. In King County, an estimated cost of $570,000 ($0.33/capita) was spent on habitat restoration efforts for three urban creeks (Maplewood, Patterson, and Taylor Creeks) to enhance fish habitat (Salmon Recovery Board 2006). The example illustrates the magnitude being spent on stream restoration in urban areas that have been most impacted by storm water.

The cleanup of the Thea Foss Waterway, an inlet of Commencement Bay adjacent to downtown Tacoma, provides a particularly challenging and costly example. This Superfund site contains highly contaminated sediments; extreme habitat destruction, water pollution, and ecological losses have occurred here. The dredging of contaminated sediment was completed in 2006 for an estimate final cost of $97 million ($41.76/capita), with storm water identified as one of the several main sources of pollutants (City of Tacoma 2006a; Shauna Hansen, personal communication, July 28, 2006).

Beyond the dredging of historic contamination, current steps are being taken by the city to reduce the effects of storm-water contamination in the contributing watershed. In 2005 alone, these efforts cost the City of Tacoma's Surface Water Management Division $26 million ($137.71/capita/year), which accounts for 52% of its total budget for storm water (City of Tacoma 2006a). Based on 2001–2005 storm-water monitoring, various storm-water contaminant loads were reduced by 40–80% since the late 1990s, but sediment and water samples collected in the public storm mains upstream of the storm-water outfalls that discharge to Thea Foss Waterway between 1997 and the present have found a continuing runoff contribution of mercury, polycylic aromatic hydrocarbons (PAHs), phthalates, heavy oil, and diesel (City of Tacoma 2006b).

Natural Resource Losses and Other "Costs" of Urban Storm Water

The majority of this report presents examples of incurred costs (i.e., dollars spent) and lost economic value that have resulted from our present levels of urban development and its associated storm-water management. The interviewees, however, commonly articulated other costs that do not translate readily into economic terms, or that cannot be assigned unequivocally and solely to urban runoff. The dollar value of a degraded fishery, for example, is only one dimension of what has been lost; the related social, cultural, ecological, and quality-of-life changes are far more difficult to quantify. Furthermore, those losses are strongly correlated with urban development but are probably not caused exclusively by urban runoff—overharvest, competition from invasive species, and physical alteration of habitat may also be factors. Thus an attempt to assign a purely economic, "storm-water-based" cost would not be entirely correct, and it would also overstep the information provided by respondents that form the basis of this study.

These unquantified "losses," caused in whole or part by urban runoff, include some of the most widely recognized examples of what the region has lost due to urban development. The most prominent of these losses is the local collapse of aquatic ecosystems, but degradation is also expressed by the reduced recreational value of polluted waters and the lost opportunity cost of damages that, once imposed, are difficult to reverse no matter how heroic the efforts. We have no examples from this region where high fecal coliform counts in urban waters have been reversed over time, and so continued population growth in the Puget Sound region will inexorably result in a growing number of kilometers of freshwater streams and marine coastline that suffer irrevocable losses from just this one pollutant, most commonly expressed as closures to shellfishing and other recreational activities. This, in turn, results not only in quantified costs but also in less tangible reductions in consumer confidence and the region's quality of life.

Loss of Fish

Urban storm water is a critical element in the decline in urban salmon but it is not the sole cause, because the cumulative effect of the wide variety of human activities in urban basins profoundly influences urban streams and their biota (Booth et al. 2004). The effects of individual storm-water pollutants on fish species have been studied in the Puget Sound region, but even the strong causal (and detrimental) linkages that can be documented do not easily translate into discrete costs. Some of the unquantifiable consequences of storm-water runoff on fish species, however, are suggested by the following examples:

1. High death rates of prespawning salmon have been discovered in Puget Sound lowland streams since the 1990s. It is estimated that 20–90% of spawning Coho salmon in the fall have been affected, with storm-water runoff from nonpoint sources the as-yet unconfirmed but most probable source (National Oceanic and Atmospheric Administration 2006).
2. Coho salmon suffer from increased lethargy and decreased feeding and swimming rates when exposed to *Chlorpyrifos* (Sandahl et al. 2005), a common insecticide found in surface waters of the Puget Sound basin (Bortleson and Ebbert 2000). A study of streams in King County detected pesticides, including *Chlorpyrifos*, more frequently and at higher concentrations during storm events than at normal base flow (Frans 2004).

Table 6. Summary of Puget Sound Storm-Water Management and Damage Costs

Impact	Types of costs	Reported costs
Costs of storm-water management	Expense of storm-water regulatory compliance	NPDES Phase 1 Jurisdictions in the Puget Sound region spent over $138 million (an average of $36/capita/year) to meet the 1995 NPDES permit requirements.
	Storm-water capital improvement plan expenditures	Capital improvement plan costs ranged from $120,000 to $20 million per year ($6 to $127/capita/year) in the Puget Sound region with the division of program area spending varying.
Costs of storm-water damage		
Flooding and property damage	Drainage maintenance and flood control	Drainage maintenance and flood control costs three jurisdictions $1.5 million to $4.6 million annually ($4 to $33 per capita/year).
Degradation of water quality	Clean-up of polluted water supplies	Improving the water quality of a single watershed due to a single contaminant has reported costs as much as $1 million ($1.87/capita).
	Protecting water supplies from additional contamination	Treatment costs for storm-water discharge by various Puget Sound jurisdictions range from $400,000 to $7 million.
Loss of estuarine and freshwater habitat	Habitat restoration and protection efforts	Individual restoration projects associated with storm-water discharges have cost individual Puget Sound jurisdictions $570,000 to as much as $100 million.

3. Coho salmon are affected by copper exposure, a common constituent of storm-water runoff, which inhibits their olfactory system and is vital for recognition of predators and kin and reproduction (Baldwin et al. 2003).
4. The risks of English sole developing liver lesions increase with exposure to PAHs, especially in urban areas where sediment PAH concentrations are the highest (Puget Sound Water Quality Action Team 2002). Storm water is suspected to be a significant source of PAH contamination at these sites.

Although damages such as these do not have a direct dollar value attached to them or have yet to be solely and conclusively linked to storm-water runoff, they must be part of any evaluation of the consequences of urban development in the Puget Sound region because their effects are so widespread.

Discussion

The results of this study illustrate the magnitude and distribution of storm-water program expenditures in the Puget Sound region. A summary of the monetary costs of storm-water management and damage is displayed in Table 6. Much of the public costs of storm-water management are focused on flooding and drainage problems, while the economic resources devoted to water quality and the degradation of habitat vary among jurisdictions but are almost everywhere much lower. Annual budgets of storm-water programs in the Puget Sound region range from thousands to millions of dollars per year within a single jurisdiction; per capita costs are in the tens to hundreds of dollars for each individual element that can be readily quantified. In aggregate, current expenditures and self-identified programmatic needs likely exceed $1 billion for the region over the next decade.

While storm-water management is costly, these examples from the Puget Sound region suggest that the damages resulting from storm-water runoff can be even more expensive. The costs of storm-water damages explored in this study, namely, flooding and property damage, degradation of water quality, loss of estuarine and freshwater habitat, and loss of natural resources, reveal that potential benefits (in the form of cost avoidance) should be far greater than the expenditures on storm-water management. Additional noneconomic benefits of social, cultural, and environmental value can also accrue if mitigation and restoration programs can be successful.

In combination, these studies suggest four main recommendations for improving the effectiveness of storm-water-management programs. First, given the large amounts of money being spent on storm-water management and related damage reduction, expenditures need to be evaluated for their relative effectiveness in addressing the most critical problems. In some cases, the programmatic component that receives the greatest funding may not be the greatest problem, and the efforts may not be particularly successful. Monitoring before, during, and after project implementation can provide information to assess and improve project outcomes. Currently, this information is almost entirely absent—we can tally costs and we can estimate the magnitude of economic (and noneconomic) losses, but we have no basis to determine whether the costs of the former are actually offsetting the losses from the latter.

Second, storm-water programs should acknowledge and dedicate more resources to mitigating ecological and social impacts, such as habitat and estuarine damage, water quality degradation, and the loss of natural resources. While flooding and drainage problems may be among the most visible impacts of storm water, and typically receive the greatest funding, the cumulative and often hidden impacts of others are nonetheless significant. This broader range of impacts warrants more legislative and community awareness. Citizens frequently recognize (and most frequently complain about) flooding and drainage, but they commonly have little awareness of the longer-term ecological and social impacts of storm water, which typically receive much less funding but may carry equivalent (or greater) long-term costs. These generally unappreciated impacts include effects on human health, quality of life, and provision of ecological services. Monetizing environmental impacts through an integrated cost-benefit analysis in a socioeconomic context (i.e., to assess citizens' willingness to pay to prevent air and water pollution) may produce outcomes that vary greatly from a standard cost-benefit analysis that does not consider environmental impacts (Feng and Wang 2007). Therefore, translating these environmental and social impacts into monetary terms may improve the public's awareness of storm water's consequences.

Third, our results stress the importance of preventive measures that are typically much less expensive than the cost of treatment or restoration after storm-water damage occurs. This assessment for the Puget Sound region suggests some of the difficulties, and attendant costs, in reversing storm-water damage. Other studies also support the implementation of preventive measures by showing the inability of restoration and remediation efforts to reverse natural resource damages and losses, especially in urban areas, and thus the importance of avoidance (Frissell and Nawa 1992; Horner et al. 1997; Karr and Rossano 2001; Morley and Karr 2002; Booth et al. 2004). Additionally, others have successfully demonstrated that the preservation of natural drainageways within communities have added benefits such as creating open spaces and wildlife habitat for citizens to enjoy (Galuzzi and Pflaum 1996). The preservation of pristine areas and healthy habitats, acquiring or otherwise limiting development in flood-prone areas, and prioritizing projects according to the potential for success are just some of the few examples identified by the interviewees that may be implemented by storm-water managers and programs.

Fourth, storm-water programs as a whole will require greater attention and dedication of resources if they are ever to achieve success. Storm-water problems tend to be neglected and underfunded compared to other public works programs, such as transportation or wastewater. Among all public works programs in Washington State, storm-water programs had nearly the lowest amount of funding and the largest reported funding gap. Public education on the need for storm-water mitigation, and the benefits of effective storm-water management, could motivate the public and officials to increase efforts and investments in storm-water programs. A recent study of urban infrastructure determined that citizens were more willing to pay for services if they were aware of operation and maintenance issues, and they had a more integral part in the decision-making process (Sohail et al. 2005).

Conclusions

This assessment of storm-water costs and benefits in the Puget Sound region provides multiple examples of storm-water mitigation and storm-water-related damage. Although the impacts described in this study are not a comprehensive list of all the effects of storm-water runoff, this study does provide representative categories and an approach to assess cumulative costs that can be applied to storm-water programs across the nation. While documented expenditures in the name of urban storm-water management are substantial, the hidden costs of untreated problems may be even greater.

The planning community has experienced difficulty in allocating limited funds to mitigate the various categories of storm-water damage. By examining the resulting damage of storm-water runoff, comparing it to the expenditures within programmatic components, evaluating the success of those management efforts, and prioritizing projects according to potential for success, planners and storm-water managers should be able to develop programs that are both socially supported and more demonstrably cost effective. Additionally, implementing preventative storm-water measures in the planning stages of development projects, such as preserving pristine areas and natural drainage areas, and restricting development in flood-prone areas, may be the most effective means of mitigating and avoiding storm-water consequences.

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