Downstream Economic Benefits of Conservation Development

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Abstract: This paper evaluates the downstream hydrologic and economic impacts of development strategies that promote greater on-site storage of storm water. This paper applies a methodology to a specific case study that emphasizes flood risk reduction and drainage infrastructure. The estimates are at a first level of approximation. We use widely accepted simulation models and available data to compare alternative development scenarios for the 0.01 annual probability storm event. For a watershed in a rapidly developing area near Chicago, Ill., reduced downstream flooding with the employment of conservation design practices generates from \$0 to 19,400/ha (\$0–7,800/acre) in downstream property value benefits over all affected areas. For comparison purposes, flood-damage estimation methods generate an average of \$16,800–\$24,200/ha (\$6,700–\$9,700/acres present value reduction in damages for the 0.01 probability flood event alone. The two methods yield conservative, but mutually reinforcing estimates. For infrastructure benefits, considering only downstream road culverts, the use of conservation design techniques upstream avoids \$3.3 million in costs of culvert replacement or upgrades. The sum of the downstream flood mitigation and infrastructure benefits amounts to \$920–1,440/developed hectares (\$380–590/developed acres) following conservation design practices.

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Introduction

Managing storm water is a major challenge in most urban areas. Buildings, roads, and compacted soils reduce absorptive capacity. In suburban areas, 20–50% of the land is impervious to precipitation. In inner cities and commercial zones, imperviousness can exceed 80%. The hydrologic functions of streams change with as little as 5–10% imperviousness, and they change profoundly when imperviousness approaches 25%.

The increased runoff exacerbates flooding and increases conveyance requirements. Less water is left in the soil to recharge aquifers, replenish wells, and maintain base stream flows. Faster runoff increases erosion, scours stream banks, and entrains more sediment, landscape chemicals, petroleum residues, pet wastes, and other anthropogenic detritus. A consequence is surface water quality that is less able to support beneficial uses.

For several decades, detention basins have been the customary prescription for managing storm water. They have received criticism because while they reduce peak flows, they generally increase damaging bank-full flows, and do not contribute to remediation of water quality or groundwater infiltration. More recently, "low impact" or "conservation design" principles use measures such as porous paving, narrower streets, "green" roofs, vegetated swales, and constructed wetlands to maintain a nearly natural water budget and improve water quality (e.g., Arendt 1994; Wilson et al. 1998). Residential conservation development sites typically incorporate more cluster development than conventional development to provide the same gross density of population to land area.

Improved storm water management can produce the following types of downstream benefits: (1) reduced frequency, area, and impact of flooding; (2) less costly public drainage infrastructure; (3) reduced pollution treatment; (4) reduced erosion and sedimentation; (5) improved water quality; (6) improved in-stream biological integrity and aesthetics; and (7) increased groundwater recharge.

While many studies have considered specific physical and biological effects of altered hydrology, there has been no effort to synthesize those elements into an overall benefit measure or to facilitate their transfer by scaling them to local conditions.

Streiner and Loomis (1995, p. 268) group the economic effects of stream corridor enhancement into two categories: (1) reductions in property damages, including residential and public structures, landscaping and parks; and (2) restoration of the natural values of the stream itself, including more stable stream banks, enhanced aquatic habitat through restoration of pool-riffle sequences, and more visually attractive ecosystems. Braden and Johnston (2003) develop a typology of impacts and use benefits transfer techniques to develop estimates of the economic

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significance. Their estimates generally are conditional on property values and local factors. They conclude that the reduction of flood damages and public infrastructure costs of storm water conveyance are usually the most significant sources of change in property value, with most other benefits being case specific, or small.

In this paper, we take the next step toward usefulness by applying the benefits transfer methodology to a specific case study in a suburbanizing watershed in the Chicago, Ill. region. The case study emphasizes the effects of flood risk reduction on property values, and the costs of storm water drainage infrastructure. It combines hydrologic analysis of storm water flows, real estate economics, and financial analysis of public infrastructure. The resulting analysis is dependent on the specific onsite measures used to manage storm water. The estimates are at a first level of approximation and based on generally available data. We use widely accepted simulation models to compare alternative development scenarios.

Approach

Assessment of storm water management benefits would ideally be based on direct observation. However, because conservation design strategies have yet to be employed on a large scale, that is, at watershed scales, it is not possible to draw on monitoring research for assessing downstream effectiveness. Simulation studies are therefore required to provide comparison between two possible future scenarios: development of the watershed with and without the incorporation of conservation design or other measures for on-site storm water retention.

Our hydrologic modeling strategy involves the following steps: (1) perform a flood frequency analysis of the simulated stream flows to estimate the probability of different magnitudes of flood events; (2) compute discharge (flow rates) for reaches in the watershed for the specified flood events; (3) calculate the water surface elevation of the streams; (4) estimate the area of different land uses contained within the flooded extent; (5) use benefits transfer to calculate the economic benefits attributable to the differences in flooded areas; and (6) use engineering costing methods and standard design protocols to estimate savings associated with infrastructure.

Lack of available data limits the specificity permitted in estimating impacts. The values computed in this paper represent approximate measures of benefits. Assessment is first directed to the existence of benefits, followed by an estimate of the magnitude of benefits.

The Blackberry Creek Watershed west of Chicago, Ill. serves as our case study site. Blackberry Creek drains a 189 km^2 (73 mi^2) watershed in south-central Kane County and north-central Kendall County. It is 52 km (32 mi) long and originates north of the village of Elburn in central Kane County. It drains to the Fox River near Yorkville in Kendall County. Tributaries to Blackberry Creek include Lake Run, East Run, and several unnamed tributaries (Fig. 1).

Blackberry Creek represents an urbanizing watershed. It has been the subject of numerous studies of watershed management and conservation design strategies (Kane County 1996; Blackberry Creek Watershed Committee 1999; CDF 2003). A comprehensive development plan has been prepared for the Kane County portion of the watershed (Kane County 1996). Because of data limitations in Kendall County, only the watershed in Kane County was included in this analysis.

Flood Frequency Analysis

Simulations of discharge from catchments within the watershed used the *Hydrologic Simulation Program—Fortran*, or *HSPF* (USEPA 2001). A recent study (CDF 2003) modeled runoff from catchments using local hydrologic parameters (e.g., infiltration, evapotranspiration, velocity). Parameterization of the model occurred in two different ways to capture the implementation of either conservation design practices or conventional development patterns within the context of the approved plan. The runoff values determined in that study are used as the basis for comparison here. The model formulation used in this study characterizes runoff from catchments in Blackberry Creek based on conventional development at forecasted populations, and conservation development at the same forecasted populations and basic land use arrangement.

Modeling of best management practices was performed using *HSPF* (CDF 2003). Using a two-stage approach, individual best management practices (BMPs) were modeled, followed by an aggregate development scenario. We summarize this approach here. A more complete explanation is given in CDF (2003). The *HSPF* models surface runoff, interflow, and groundwater flow. It models soil moisture in soil layers filled by infiltration and drained by evapotranspiration and gravity. These features permit the characterization of individual BMP performance. For example, green roofs are modeled as a thin, well-drained soil horizon, over a drainage medium modeled as a very porous groundwater layer with a recession constant determined by the media's hydraulic conductivity. In conventional scenarios, vegetated swales used runoff parameters for turf, while in conservation scenarios swales used prairie conditions. Modeling parameters for other BMPs followed similarly. Conventional scenarios assumed standard drainage treatments with storm sewers for commercial and higher density residential development, grass swales for lower density residential and detention throughout (CDF 2003). In addition, to help ensure comparability between the conventional and conservation scenarios, common characteristics include standard 16.2 ha (40 acre) parcels, standard house footprints (but not driveway area), same runoff coefficients for same materials, and detention to the current Kane County allowable release requirement of 0.007 $m^3/s/ha$ (0.1 cfs/acre). For moderate density residential, roof areas were calculated as 278.8 m^2 (3,000 ft^2) for both scenarios. For conventional development, curb, gutter, and storm sewers were assumed to serve the entire template. For conservation development, streets drained to bioswales with 3.35 m (11 ft) infiltration trenches, 0.3 m (12 in.) deep. Runoff from the bioswales, roofs, and lots was directed to vegetated swales [averaging 10.6 m (35 ft) wide] in the backs of the lots (CDF 2003). In agricultural areas, the conservation scenario assumes 10% of the land area is used as prairie filter strips with runoff on the strips calculated as runoff routed from the cultivated areas plus direct precipitation.

In modeling the watershed-scale response, the conservation scenario used as its basis the 2020 Resource Plan published by Kane County (Kane County 1996) and for the conventional scenario existing local municipal plans were used. For both scenarios, existing land uses were retained. This included residential areas within designated agricultural zones. Streams and wetlands were retained under the assumption of Federal and State protection. For the conventional scenario, no additional buffering of streams beyond that specified in the plans were used. For the conservation scenario, in addition to the application of the conservation land use templates, streams were buffered from

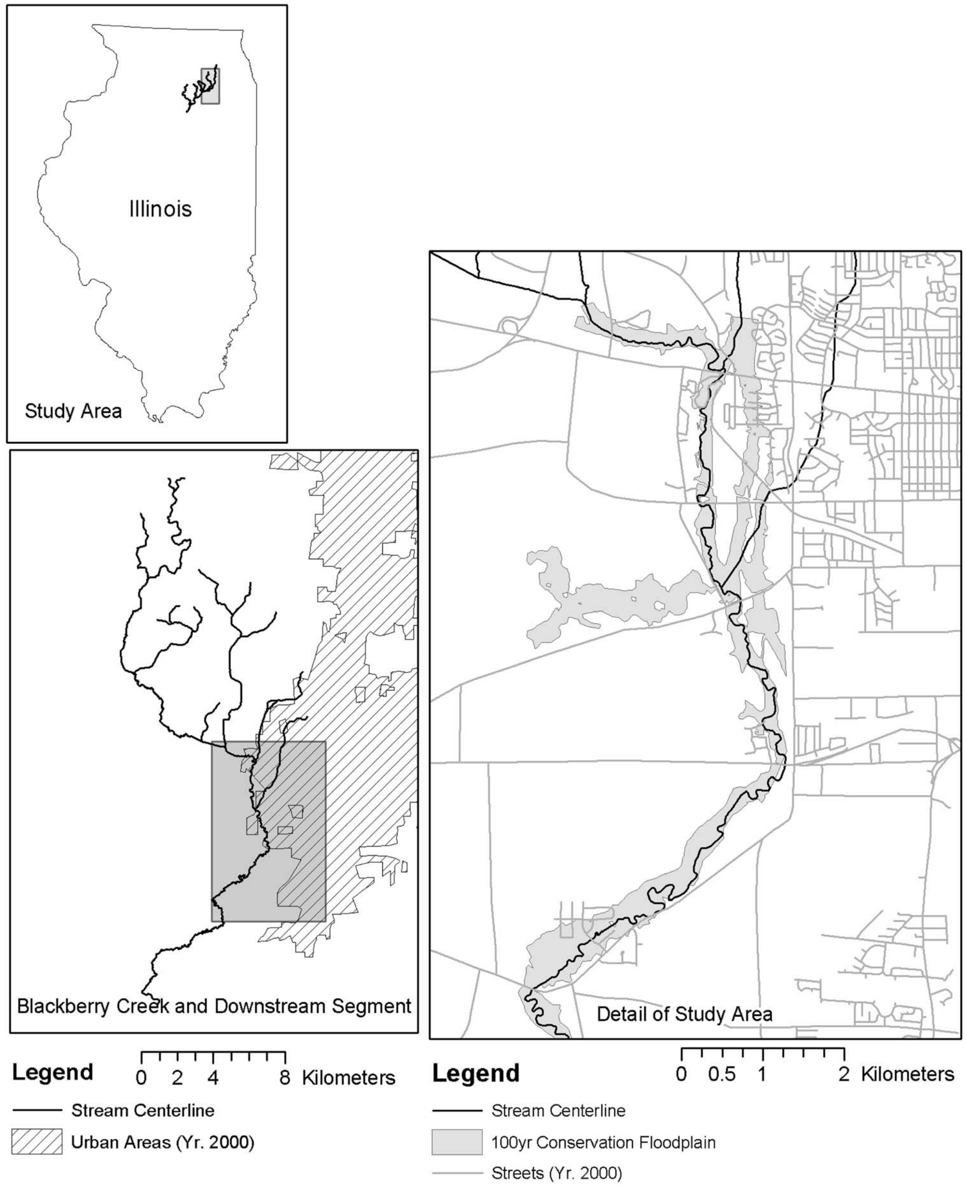

Fig. 1. Blackberry Creek study area

Table 1. Land Use Areas Used in Scenarios

Treatment	Conventional scenario conventional		Conservation scenario			
			Conventional		Conservation	
Land use modeling category	Hectares	(Acres)	Hectares	(Acres)	Hectares	(Acres)
Commercial/transport	1,759	(4,344)	376	(928)	998	(2,464)
Moderate density residential	1,857	(4,585)	1,133	(2,797)	418	(1,031)
Rural residential	1,906	(4,706)	739	(1,824)	1,562	(3,856)
Estate residential	1,999	(4,936)	652	(1,611)	766	(1,891)
Agriculture	3,620	(8,938)	0	(0)	3,190	(7,875)
Water	169	(417)	165	(407)		
Wetland	964	(2,380)	1,136	(2,804)		
Urban grass/park	605	(1,493)	73	(181)		
Natural open space	2,073	(5,119)	3,696	(9,127)		

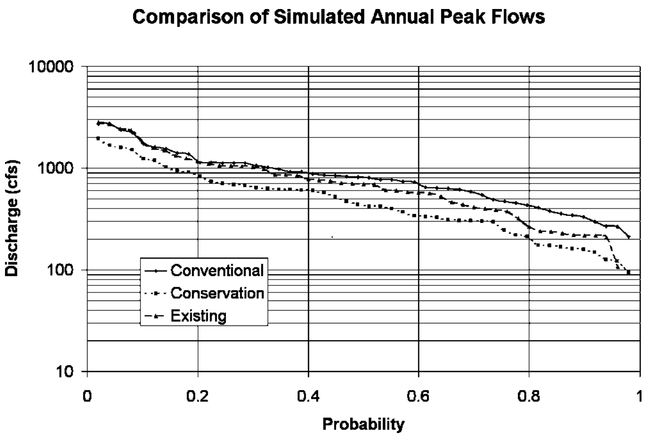

Fig. 2. Probability plot of annual peak flows for Blackberry Creek downstream of Aurora Tributary

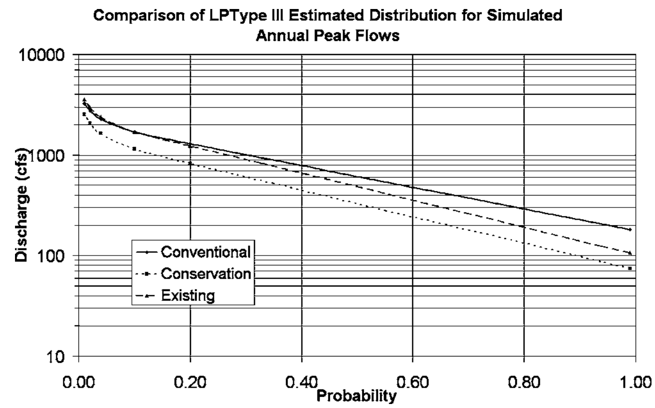

Fig. 3. Log Pearson type III probability plot of annual peak flows for Blackberry Creek downstream of Aurora Tributary

development. Modeled land areas are given in Table 1. To the extent possible within the constraints of the 2020 Resource Plan, the scenarios are development density neutral. In reality, the conservation scenario has 12,742 housing units while the conventional scenario has 14,258 units (10% more). However, differences in the results of the models are attributable to variation in storm water management practices rather than simple variation in land use area, although further research is needed to explore the locational effects of land use.

Flood frequency analysis estimates the probability distribution that fits the highest flow recorded for each year of record (annual peak flow). Running HSPF at an hourly time step for the period of available data (1947–1995) from the nearest recording rainfall gauge at Chicago O'Hare International Airport, Ill. generates a predicted discharge record.

Simulated peak annual flows for the three scenarios are plotted in Fig. 2 using the Weibull plotting positions (Haan et al. 1994). As recommended by *Bulletin 17B* of the Interagency Advisory Committee on Water Data (Haan et al. 1994) we used the Log Pearson III parameter estimation using Chow's formulation (Haan et al. 1994) with the mean and standard deviation of the log of discharge and with frequency factors (adjusting for skewness) taken from *Bulletin 17B*.

The estimation yields predicted discharge rates at different probabilities. Table 2 shows predicted discharge for the outlet of the watershed. Fig. 3 shows a comparison plot of the predicted discharges for the same reach. As would normally be expected, the modeled discharges show an increase in peak discharges throughout the distribution for the conventional development scenario. The conservation scenario, however, results in discharges below not only the conventional but also the existing levels of development. This result reflects precisely the potential impacts of increased storage provided by conservation design practices including permeable paving, green roofs, bioswales, use of native vegetation to increase groundwater infiltration, and evapotranspiration over conventional development types. A possible implication of this is that new development can offset impacts from existing development. It should be recognized however, that in this region, most agricultural lands are subsurface drained, altering its hydrologic response. Because the magnitude of the effects is dependent on the scale of implementation, any analysis must include local and actual development conditions.

Table 2. Discharge Estimates for Blackberry Creek Below Aurora Tributary

	Return period	Discharge (cfs)	Frequency factor	Exceedance probability
Conventional	50	2,754	2.054	0.02
scenario	100	3,261	2.326	0.01
Conservation	50	2,065	2.054	0.02
scenario	100	2,538	2.326	0.01

The U.S. Army Corps of Engineer's Hydrologic Engineering Center River Analysis System (*HEC-RAS*) generates water surface elevations. The *HEC-RAS* is a one-dimensional channel flow simulation model. Given stream cross-section and profile geometry, and boundary conditions of flow, *HEC-RAS* computes hydraulic parameters of discharge, water surface elevation, and velocity, among others. These parameters are calculated at cross sections located along the stream. Estimated discharges for the reaches of Blackberry Creek computed from the *HSPF* simulation become the variable input conditions for the two scenarios modeled in *HEC-RAS*.

To identify the floodplain associated with the modeled events, the cross-sectional surface water elevations are interpolated in a geographic information system using a nearest-neighbor method with hard break lines (forcing no smoothing at the observed locations) to create a triangular irregular network (TIN) of the water surface. Estimation of floodplain extent and depth used available digital elevation models. Kane County data consists of a DEM with 3.0 m (10 ft) horizontal, and 0.60 m (2 ft) vertical accuracy. Because the focus is on downstream impacts, only a 17.4 km (10.8 mi) portion of Blackberry Creek downstream of its major tributaries is examined in the flood analysis (Fig. 1). The impacts of upstream development patterns are progressively diluted downstream as flows from other sources enter the main channel. We then tabulated the land use types and areas falling within the flood risk areas. In the conventional scenario, 704 ha (1,743 acres) of land are subject to flooding while the conservation scenario results in 616 ha (1,525 acres) with a difference of 20 ha (50 acres) of residential property within the analysis area.

Estimation of Economic Impact

Flood Effects on Property Values

In this section and the next, we apply two different approaches to determine the downstream flood mitigation benefits of storm water retention. The first approach uses benefits transfer techniques as suggested by Braden and Johnston (2003). The second applies flood damage formula-based approaches used by the U.S. Army Corps of Engineers (USACE 1996; USWRC 1983). In both cases, we confine the analysis to the 0.01 annual probability flood event. This is the cutoff for land to be included in the National Flood Insurance Program. While additional land is subject to flooding from more extreme events, our analysis essentially assumes that such flooding has no economic significance. This imparts a downward bias in the economic estimates. At the same time, we make assumptions that should offset this bias, at least in part. In the first case, we assume that the land remaining in the 100 year floodplain is subject to a reduction in the extent and height of higher-frequency events, thereby reducing the costs, but by a lesser amount than land removed from flood risk below the 0.01 probability event. In the second case, we compute damages only for the 0.01 probability event and neglect damages that might accompany lesser events. In all cases, we view this as a very conservative approach to estimating benefits as mentioned earlier.

Braden and Johnston (2003) concluded that residential propertie exposed to flooding are discounted in the market by an average of 2–5%, and 0–2% for properties subject to reduced flooding. To apply this observation to our case study, we need to know, first, how many acres would be in the 100 year floodplain with conventional development upstream but outside it with conservation development and the number of acres subject to flooding in both scenarios. Second, we need to know the market values of those properties.

U.S. Census Bureau data provide localized estimates of property value. Data from the 2000 Census Summary File 3 for Median Owner Occupied Housing (H085001) are available at the block group level. Census data reflect regional differences within a county, although not differences between individual properties. They are also self reported, which may impart bias, and they reflect medians rather than mean values, which means that they generally under-represent aggregate housing value. For our study site, the area-weighted median housing value was $175,600 per unit for homes in the census block groups within the flood risk areas. Using an average density of 5.5 units/ha (2.2 units/acres), the difference in flooded residential area between the conservation and conventional scenarios would have an aggregate housing value of $967,600/ha ($391,600/acres) or a total of $19,580,000. Applying the 2–5% approximation from Braden and Johnston (2003), the conservation scenario generates $391,600–979,000 in total benefits ($19,400–48,400/ha, $7,800–19,600/acres, $3,500–8,800/unit) for the area that would be added to the floodplain if conventional rather than conservation design practices are applied upstream. For properties remaining in the floodplain but subject to reduced damages, we apply the 0–2% approximations from Braden and Johnston (2003), resulting in an additional benefit of $0–19,400/ha ($0–7,800/acres, or $0–3,500/unit), or a total of $0–1,509,500 for 78 ha (192 acres). Therefore, the total benefit based on Census data is $391,600–$2,488,500 over the downstream reach study area.

The development scenario used in this analysis envisions the development of approximately 4,050 additional hectares (10,000 acres) by the year 2020. The downstream reach flood mitigation benefits discussed above are equivalent to between $100 and $620 per developed ha ($40 and $250/developed acres) based on Census median housing value and the reduction in flood risk.

Flood Damage Estimation

An alternative method to estimate flood reduction benefits is to calculate the change in flood damage to structures and contents based on stage-damage curves following procedures used by the U.S. Army Corps of Engineers (1994). These estimates are cost based rather than value based, making them theoretically less desirable than property value differentials as a basis for estimates (Braden and Johnston 2003), but have pragmatic advantages of stability and transparency.

Stage damage curves are ideally developed in situ using data collected from historic flood events. Davis et al. (2003) developed broadly applicable relationships based on surveys of approximately 1,000 homes in various geographic regions within the United States. They considered several variables, such as depth, duration, warning lead time, and building material, but found depth of inundation to be the only significant predictor of damage. This suggests that estimating structure and content damages based on modeled flood depths is an appropriate and adequate method. Damage equals the present value of expected costs based on flood depth at a particular location. We estimate flood depth from the surface water elevations produced by our hydrologic models and apply the stage damage curves described by Davis et al. (2003). Because the stage damage curves are derived for different building types, we estimate damages using both one- and two-story homes with no basement. We further use the previously identified average market value of $967,634/ha ($391,600/acres), based on census data.

For the conventional development scenario, the modeled flood depths range from 0 to 3.0 m (0 to 10 ft) over the 97.7 ha (242 acres) of residential property within the floodplain. For the conservation scenario, modeling resulted in flood depths of 0–2.7 m (0–9 ft) over 77.5 ha (192 acres) of residential property. We compute flood damage as the representative value of flooded residential property multiplied by percent loss using the depth–damage relations given by Davis et al. (2003). The difference in flood damage between the conventional and conservation scenarios equals the difference in total expected damage from the conventional scenario and the total expected damage from the conservation scenario.

The 100 year (0.01/year probability) flood event, the cutoff event for the National Flood Insurance Program, provides illustrative results. For the conventional development scenario, structural flood damages for two-story homes are $20,948,000 while content damage is $12,174,000 or a total estimated damage of $31,122,000. The annual expected value of total damage is $331,220. At a 5% real rate of interest, the expected present value is $6,624,000 data (Table 3) or $67,800/ha ($27,100/acres. For one-story residences, the expected present value is $9,752,000 ($99,800/ha, $39,900/acres) (Table 4).

Comparable calculations for the conservation design scenario lead to estimated structural damages of $23,725,000 and content damages of $13,213,000 or a total of $36,937,000. The expected present value of damages is $7,387,000 ($75,500/ha, $30,200/acres) for one-story housing (Table 5). For two-story residences, the expected present value of damages is estimated at $4,979,000 ($50,900/ha, $20,400/acres) (see Table 6).

Therefore, using the stage-damage approach, the upstream conservation measures produce an expected present value of downstream flood benefit for the 0.01 annual probability event ranges from $1,040,000 to $1,526,000 in structural damages and $605,600–838,000 in content damages. The combined value is

Table 3. Estimated Flood Damage Benefits for Two Story Residences: Conventional Scenario

Flood depth (m)	Estimated structural damage		Estimated content damage		Flooded (hectares)	Total damages		
	Damage (%)	/hectare ($)	Damage (%)	/hectare ($)		Structural ($)	Content ($)	Total ($)
0–0.3	9.30	89,990	5.00	48,382	21.9	1,968,803	1,058,496	3,027,300
0.3–0.6	15.20	147,080	8.70	84,184	15.5	2,286,773	1,308,877	3,595,650
0.6–0.9	20.90	202,235	12.20	118,051	18.1	3,659,476	2,136,154	5,795,630
0.9–1.2	26.30	254,488	15.50	149,983	14.9	3,791,061	2,234,276	6,025,337
1.2–1.5	31.40	303,837	18.50	179,012	13.8	4,203,629	2,476,660	6,680,290
1.5–1.8	36.20	350,283	21.30	206,106	8.8	3,086,125	1,815,869	4,901,994
1.8–2.1	40.70	393,827	23.90	231,264	2.6	1,019,969	598,950	1,618,918
2.1–2.4	44.90	434,468	26.30	254,488	1.7	751,539	440,211	1,191,750
2.4–2.7	48.80	472,205	28.40	274,808	0.3	125,257	72,895	198,152
2.7–3.0	52.40	507,040	30.30	293,193	0.1	55,104	31,863	86,967
				Total	97.8	20,947,736	12,174,251	33,121,988
Property value per hectare		Property value per acre			Expected value			331,220
$ 967,634		$391,601			Present value (@5%)			6,624,398
					PV/hectare			67,764

$16,800–$24,200/ha ($6,700–$9,700/acre) for one- and two-story housing, respectively, or $274–394 per developed hectares ($110–158 per developed acres).

Because it is based on the 0.01 annual probability storm event alone, rather than the entire distribution of events (USACE 1996), the flood damage calculation produces a lower-bound estimate. In practice, sampled events are sometimes used (USACE 2000). While desirable, a full risk-based estimation was beyond the scope of a methodology aiming for a first approximation of benefits. Notwithstanding this obvious limitation, the resulting aggregate estimate of downstream benefits is within the range of the benefits transfer calculation based on property values. The area-normalized values are comparable across examples. Both methods yield conservative approximations that exclude damages from lower-frequency, higher-intensity storm events.

Infrastructure Benefits

Complete estimation of downstream infrastructure benefits would entail the assessment of differences in the number, size, or type of any conveyance, flood control, or channel modifications between the conservation and conventional scenarios. Effects are highly site specific. To illustrate the principles of infrastructure estimation and to provide a conservative, first-order estimate of the potential benefits, we consider the design requirements for storm water conveyance through roadway culverts along Blackberry Creek and compare the costs associated with the different channel flow rates resulting from the conventional and conservation design scenarios.

Computation of culvert sizes and costs includes parameters of channel discharge (flow rates), culvert type, critical depth, and

Table 4. Estimated Flood Damage Benefits for One Story Residences: Conventional Scenario

Flood depth (m)	Estimated structural damage		Estimated content damage		Flooded (hectares)	Total damages		
	Damage (%)	/hectare ($)	Damage (%)	/hectare ($)		Structural ($)	Content ($)	Total ($)
0–0.3	13.40	129,663	8.10	78,378	21.9	2,836,771	1,714,764	4,551,535
0.3–0.6	23.30	225,459	13.30	128,695	15.5	3,505,383	2,000,927	5,506,310
0.6–0.9	32.10	310,610	17.90	173,206	18.1	5,620,535	3,134,193	8,754,728
0.9–1.2	40.10	388,021	22.00	212,879	14.9	5,780,287	3,171,230	8,951,517
1.2–1.5	47.10	455,755	25.70	248,682	13.8	6,305,444	3,440,550	9,745,994
1.5–1.8	53.20	514,781	28.80	278,679	8.8	4,535,410	2,455,260	6,990,670
1.8–2.1	58.60	567,033	31.50	304,805	2.6	1,468,554	789,411	2,257,965
2.1–2.4	63.20	611,545	33.80	327,060	1.7	1,057,846	565,747	1,623,592
2.4–2.7	67.20	650,250	35.70	345,445	0.3	172,484	91,632	264,117
2.7–3.0	70.50	682,182	37.20	359,960	0.1	74,138	39,119	113,257
				Total	97.8	31,356,852	17,402,832	48,759,684
Property value per hectare		Property value per acre				Expected value		487,597
$ 967,634		$391,601				Present value (@5%)		9,751,937
						PV/hectare		99,757

Table 5. Estimated Flood Damage Benefits for Two-Story Residences: Conservation Scenario

Flood depth (m)	Estimated structural damage		Estimated content damage		Flooded (hectares)	Total damages		
	Damage (%)	/hectare ($)	Damage (%)	/hectare ($)		Structural ($)	Content ($)	Combined ($)
0–0.3	9.30	89,990	5.00	48,382	14.9	1,336,819	718,720	2,055,539
0.3–0.6	15.20	147,080	8.70	84,184	17.5	2,581,161	1,477,375	4,058,536
0.6–0.9	20.90	202,235	12.20	118,051	15.8	3,202,038	1,869,132	5,071,170
0.9–1.2	26.30	254,488	15.50	149,983	12.4	3,165,638	1,865,680	5,031,317
1.2–1.5	31.40	303,837	18.50	179,012	11.3	3,430,725	2,021,287	5,452,011
1.5–1.8	36.20	350,283	21.30	206,106	3.1	1,098,723	646,486	1,745,209
1.8–2.1	40.70	393,827	23.90	231,264	1.9	745,610	437,840	1,183,450
2.1–2.4	44.90	434,468	26.30	254,488	0.3	131,428	76,983	208,411
2.4–2.7	48.80	472,205	28.40	274,808	0.1	56,503	32,883	89,386
2.7–3.0	52.40	507,040	30.30	293,193	0.0	—	—	—
					77.4	15,748,644	9,146,386	24,895,030
Property value per hectare		Property value per acre				Annual expected value		248,950
$967,634		$391,601				Present value (@5%)		4,979,006
						PV/hectare		50,910

allowable backwater head. To compute pipe size requirements, we use Federal Highway Department design specifications (FHA 1985).

Within our study area, bridges comprise all stream crossings in the downstream reaches of Blackberry Creek. The design of bridge structures is complex due to issues of traffic management and aesthetics that range well beyond conveyance considerations that are the focus of this study. Therefore, we analyze differences in culvert costs as the purest way to represent differences in the costs of water conveyance. We sample existing culverts from throughout the basin to represent the effects. The flow impacts of the two development scenarios are not uniformly cumulative, so this approach should capture the variation in effect throughout the basin. In all cases, the culverts are downstream of modeled catchments.

The benefits attributable to infrastructure stem from avoided costs of infrastructure due to the reduced peak discharges in the conservation scenario (resulting, generally, in smaller culverts). Because several interacting variables affect the design and therefore construction costs of culverts, we fix all design variables other than size. The baseline for comparison is the conservation flow simulation with existing culvert infrastructure. For the sampled culverts, we use the existing type, size, and other parameters. Because the conservation scenario generally results in discharges below those of the existing conditions, it is likely that existing infrastructure is oversized for that scenario. Thus, the results should be viewed as a conservative estimate of benefits, rather than an absolute difference between conservation and conventional development where new infrastructure would be provided for both scenarios. Our approach represents a developing watershed that has at least basic infrastructure already in place.

The costs of infrastructure equal the construction costs for materials and labor for the culvert and its installation (Illinois Heavy Construction Cost Data for 2003). Related costs, such as those for excavation and grading, and related road construction, are not included due to the site-specific nature of these factors. Land

Table 6. Estimated Flood Damage Benefits for One Story Residences: Conservation Scenario

Flood depth (m)	Estimated structural damage		Estimated content damage		Flooded (hectares)	Total damages		
	Damage (%)	/hectare ($)	Damage (%)	/hectare ($)		Structural ($)	Content ($)	Combined ($)
0–0.3	13.40	129,663	8.10	78,378	14.9	1,926,169	1,164,326	3,090,495
0.3–0.6	23.30	225,459	13.30	128,695	17.5	3,956,648	2,258,516	6,215,164
0.6–0.9	32.10	310,610	17.90	173,206	15.8	4,917,963	2,742,415	7,660,378
0.9–1.2	40.10	388,021	22.00	212,879	12.4	4,826,695	2,648,062	7,474,756
1.2–1.5	47.10	455,755	25.70	248,682	11.3	5,146,087	2,807,950	7,954,036
1.5–1.8	53.20	514,781	28.80	278,679	3.1	1,614,697	874,122	2,488,819
1.8–2.1	58.60	567,033	31.50	304,805	1.9	1,073,532	577,069	1,650,601
2.1–2.4	63.20	611,545	33.80	327,060	0.3	184,994	98,937	283,931
2.4–2.7	67.20	650,250	35.70	345,445	0.1	77,808	41,335	119,143
2.7–3.0	70.50	682,182	37.20	359,960	0.0	—	—	—
				Total	77.4	23,724,593	13,212,732	36,937,325
Property value per hectare		Property value per acre				Annual expected Value		369,373
$967,634		$391,601				Present value (@5%)		7,387,465
						PV/hectare		75,536

Table 7. Summary Capital Costs for Culverts

Culvert	Shape	Material	Headwall type	Length (m)	Difference (benefit) ($)
1	Ellip	Metal	a	19.5	1,006.51
2	Box	Concrete	b	4.9	1,079.00
3	Box	Concrete	b	16.8	12,027.60
4	Box	Concrete	c	70.1	302,070.45
5	CMP	Metal	d	6.1	429.00
6	CMP	Metal	d	20.7	16,787.16
7	CPC	Concrete	a	6.9	4,138.08
8	Ellip	Metal	a	11.0	3,248.18
9	Box	Concrete	b	21.3	28,541.40
10	CPC	Concrete	a	94.5	52,284.18
11	CMP	Metal	d	12.2	5,627.60
12	CPC	Concrete	a	20.7	29,980.83
			Average benefit		38,101.67
			Average benefit (without No. 4)		17,568.29

[a]Square headwall.

[b]Wingwall flared 30–75°.

[c]Tapered inlet throat.

[d]Pipe projecting from fill.

Notes: Cost sources: box culvert material costs from the Rio Valley Pipe Company. (labor and equipment assumed as 40% of material costs); corrugated metal pipe (CMP), concrete pipe culvert (CPC) and headwall costs from 2003 Illinois heavy construction costs.

acquisition, easements, legal, design, and other costs are equal between the scenarios. We also assume that maintenance and project lifetimes are equal. Interest on capital costs is not considered.

We considered 12 culvert designs representing a range of flow conditions and culvert types. In some cases, multiple culverts are required to meet the design flows. In all cases, the conventional scenario resulted in larger culvert requirements. The difference between the costs of the conventional solution and the conservation solution range from $430 for a small corrugated metal culvert in a small tributary to $302,000 for a long concrete box culvert on a tributary of Blackberry Creek (Table 7). The average difference between scenarios was $38,100 per culvert. In the Blackberry Creek watershed, there are presently 87 culverts. Using the average cost, the total benefit due to smaller required drainage culverts in the basin is $3,315,000. With 4,050 ha (10,000 acres) of new development in the scenarios for the whole watershed, the downstream benefit is equivalent to $820 per developed hectare ($340/developed acre).

As noted before, these estimates apply only to existing infrastructure, which is presently oversized relative to the conservation scenario. In the case of new development, which is not factored in these estimates, the difference in the size and number of culverts, and therefore benefits, would be greater.

Conclusions

Using benefits transfer methods as outlined by Braden and Johnston (2003), conservation design practices in a suburban Chicago, Ill. watershed generate estimated total benefits based on increased downstream property values of $391,600–2,488,500 due to reduced flooding. These values range between 0.4 and 2.5% of the value of affected properties, depending whether or not they remain in the 0.01 annual probability flood zone. These effects amount to between $100 and $620 per upstream developed hectares ($40–250 per developed acres). In comparison, using flood-damage estimation methods, conservation design practices generate an average of $16,800–24,200 per hectares ($6,700–9,700 per acres) present value reduction in damage for the 100 year (0.01 annual probability) flood event. This amounts to 1.7–2.5% of the average property value throughout the floodplain area and $274–394 per upstream developed hectares ($110–158 per developed acres). The former methodology is value based while the latter is cost based. The fact that they produce comparable estimates provides some assurance of reasonableness. However, the property value method accounts for lesser flood events while the damage method does not. Neither accounts for the economic effects of greater than 0.01 annual probability events.

In addition to property value benefits, infrastructure design requirements are assessed. Benefits in avoided costs for culverts totaled $3,315,000 or $820 per upstream developed hectares ($340/acres). These estimates are limited to existing culvert structures. The savings attributable to fewer and smaller new installations as development progresses are not included. Here again, our estimates of benefits are conservative.

The case study provides an application of a methodology for assessing economic benefits. It uses widely available data, and standard practices to examine the direction and magnitude of off-site benefits. To improve the accuracy of the results, several additional steps could be included. Benefits could be integrated across the probability distribution of flood events instead of the single, large magnitude event (0.01 probability) used here for consistency with flood insurance policy. More accurate base property values may be obtained from parcel level data from sale transactions or assessors' data. However, variation in property characteristics could offset any potential improvement. Application of the methodology at multiple scales of urban development and in different watersheds would provide useful additional information on the range of potential benefits from flood reduction. Additional specific study on property value changes due to different development practices would also improve the estimates based on related conditions used in this study. Potential benefits not considered directly in this analysis are water quality benefits, aquifer recharge benefits, or habitat values.

An increase in downstream storm water related costs are often assumed a necessary outcome of urbanization. The results reported here provide perspective on the extent to which conservation design of residential developments can manage these costs. The results indicate that implementation of upstream conservation design practices should have substantial off-site benefits in addition to any on-site economic benefits. A remaining research opportunity is to compare these benefits to the incremental cost of conservation design practices.

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