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ANATOMY OF AN URBAN FLOOD

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Abstract

Due to the scarcity of land for development in urban areas, more and more land which was once open space with trees and ground cover is being developed into residential and commercial properties. This phenomenon is having a deleterious effect on existing properties and storm drainage systems. The development is changing the character of urban hydrology.

Development is reducing the tree canopy and larger residential and commercial buildings are increasing the percentage of land area impervious to run-off. These two major factors have adversely impacted urban hydrology. They have increased the amount of runoff to be handled by existing storm-water drainage systems and because of this the existing infrastructure has become inadequate to handle normal storm runoff. In the case of unusual rainfall the results are catastrophic. The inability to carry off excessive rainfall results in serious flooding.

This paper takes the reader through the thought processes involved in the investigation, analysis and design of alternative solutions for the remediation of an urban flood that resulted in substantial monetary loss (over $50k) and the loss of priceless personal family heir-looms to one urban family. This "Anatomy" of an Urban Flood briefly discusses the many facets involved in arriving at an acceptable engineering solution, including the engineering (hydrologic and hydraulic) considerations, the social, economic, political and legal aspects of the problem. The primary focus of the paper is on an innovative approach to assigning value to the intangibles associated with the problem.

Introduction

What investment can or should an individual home owner make to protect his/her property against the ravages of flood damage? What are the benefits to be derived from various solutions to solve the problem of urban runoff? How do we assign a monetary value to the loss of personal items with little or no intrinsic value but priceless in the eye of the owner? What is the value of alleviating the apprehension caused by the fear of future damage due to the potential of flooding?

This paper will explore potential answers to these questions through the "Anatomy of an Urban Flood." Civil Engineering students and faculty at UDC were engaged in the study of an actual urban flood (located in Somerset, MD, a suburb of Washington, DC) resulting in significant property damage. The analysis of the flood and the consideration of potential options for remediation against future flooding were investigated by the students and faculty.

An integral aspect of the problem was the engineering economy study of possible solutions. In that study, the cost of remediation was to be borne by the home owner and the apprehension caused by concern over flooding created a situation that requires new and innovative means of evaluating the economy of this engineering problem. Most significant was the need to develop a means of assigning monetary values for intangible benefits such as comfort and the confidence of there being adequate protection against future flooding.

Brief hydrologic and hydraulic background

Integral to a solution for the mitigation of future flooding is the determination of the potential rainwater to be handled. A detailed hydrological study of the site was carried out resulting in an estimate of the volume of water that needs to be diverted from the property to prevent future flooding. Only the results necessary for the economic analysis are included in this paper.

Due to the inability of the current storm drainage system (SDS) serving the property, approximately 16,000 gallons of storm water accumulated in front of the garage resulting in flooding of the basement, garage and the area in front of the garage. A critical component of the existing storm drainage system is a 10-inch drain pipe from the area in front of the garage leading to a 24-inch storm sewer located in the street as shown in Figure 1. The hydraulic analysis of this pipe indicated that a maximum flow of approximately 660 gallons/min could be discharged by the pipe (Ref. 1).

The drainage area feeding the 24-inch storm sewer is about 60 acres. While this is an older community, more recent development has resulted in larger homes with more than normal paved surface areas. Based on these conditions, approximately 56% of the surface area is judged to be impervious. Using this data it was estimated that in one hour approximately 1-inch of storm water falling on 34 acres of land had to be discharged by the 24-inch storm sewer. A storm of this intensity has a return period of 25 years. This was approximately 735,000 gallons of water.

The existing 24-inch storm sewer was designed to carry approximately 12,000 gallons/min or 720,000 gallons of water in one hour. The storm drain on the property under study entered directly into the initial inlet of the storm drain. The inability of the storm sewer to carry away the volume of water created by the storm was the primary reason for the accumulation of water and eventual flooding of garage and basement. These figures are approximations to confirm the basis of occurrence of the flood.

Assessment of intangibles

This problem has many facets. Included are legal issues resulting from inappropriate drainage of water from the neighboring properties. The storm drain is public property and the local political jurisdiction was involved, but the solution to the problem would be owner funded. This fact made the problem more than just a routine engineering project. For this paper the authors are focusing on one interesting and challenging aspect of the benefit/cost analysis of the problem.

When performing a benefit/cost analysis for an engineering project the determination of cost is usually straightforward. However, determining the monetary value of benefits is quite varied and oftentimes difficult.

The history of determining a monetary benefit from engineering improvements dates back to 1930's. For example, the benefit derived from the construction of a dam to provide flood control can be easily identified in monetary terms (value of property and goods lost due to flooding). When a dam is constructed for flood control there are incremental aspects of the project, such as means for hydro-electric power generation and recreational facilities on the impounded lake. The determination of the monetary value of the hydro-electric power is rather straightforward, but monetary quantification of the benefit derived from the inclusion of the recreational facilities is not so easy. Over time, numerous public engineering agencies have developed means for assigning a monetary value to intangible benefits.

The value of a day of rest and relaxation at a lake (Ref. 2) and the value of time saved due to the alleviation of road congestion (Ref. 3) are two examples for which means of assigning monetary value have been developed. Virtually all of the applications today have been applied to large public engineering works. For this study it became necessary to assign a monetary value to the intangible benefits to be derived from the investment in flood protection for a single family home.

In large public projects a higher level of risk is tolerated because the cost of further reduction of the risk is greater than the cost incurred by accepting a lower level of risk. However, for an individual the risk must approach zero. In contrast to large publicly funded projects the cost to an individual for a small project is significantly more critical. The dilemma regarding the intangible benefits for the home owner are:

1- The quantification of the intangibles
2- The assignment of a monetary value to the reduction of anxiety
3- The determination of a monetary value for personal effects

Quantification of the reduction of anxiety / stress

In an effort to express in monetary terms the benefit resulting from a reduction in personal anxiety and stress the following rationale was used. The apprehension on the part of home owner over the possibility of future flooding was estimated in the following way.

As our team (CE faculty and students) worked on a solution to prevent future flooding frequent communication (primarily by e-mail) was maintained with the home owner. It became apparent that the concern on the part of the home owner over a similar event occurring in the future was significant. From this observation we inferred that a substantial amount of time was being spent by the home owner on this problem. We then speculated that a means of establishing a measure that could be expressed in monetary terms for the stress and anxiety being caused by this problem would provide us with a means of quantifying the "benefit" that would result from the elimination or reduction in this stress/anxiety. We observed initially that as much as 10% of one's productive time was consumed over concern for the problem. In retrospect through an analysis of extensive e-mail communications this concern reduced exponentially to an insignificant level over about three months as shown in Figure 2.

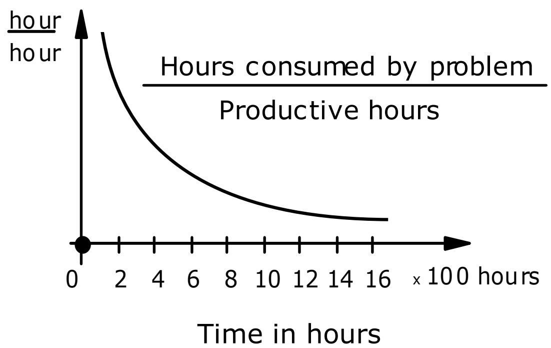


Figure 2

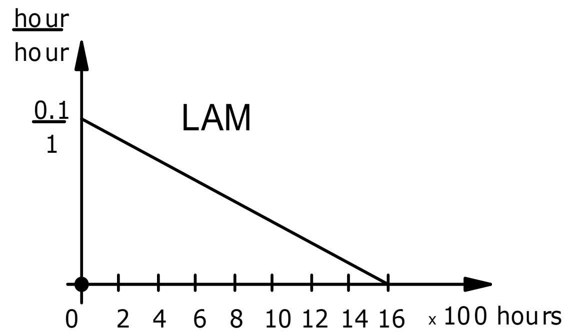


Figure 3

To facilitate the use of this exponential relationship in computation a linear approximation was developed (Linear Anxiety Model-LAM). The maximum value of time consumed by the flood problem expressed as a ratio was set at 0.1/1 hour/hour. The consumption of time was set to zero at 1600 hours. And a linear relationship, y = -m x + n was established. The LAM is shown in Figure 3.

Assigning monetary value to mementos

There is no monetary value that may be objectively placed on the lost of personal mementos and heirlooms. To arrive at a monetary value to be used in a benefit cost analysis of an engineering solution to problem the following rationale was adopted.

In this study the objects lost were irreplaceable family mementos that were stored in the basement of a 3-story single family house. To avoid the risk of future loss of such objects stored in the basement the homeowner decided that he would move those objects of greatest value to locations not in the basement and cease storing any material in the space that had been inundated by the flood water. This meant the loss of space to the homeowner. Either by a necessity to displace objects in the primary living space to accommodate things to be relocated from the basement (family china) and by using storage shelves such that no destructible items, such as files, would be stored below the elevation of the recent flood water. It is our assumption that a solution addressing future flooding that would provide a level of confidence for the home owner such that the lost storage space in the basement could be used for the family mementos and heirlooms could be considered a benefit in the benefit-cost analysis of potential engineering solutions.

The average market value of the home in question is approximately \$900,000. The foot print is approximately 600 sq. ft. The usable space in the house was categorized into three classes:

1- Garage space (≈ 300 sq. ft.). Value Factor = 1

2- Basement (unfinished space ≈ 300 sq. ft.). Value Factor = 2
3- Prime living space (two floors ≈ 1200 sq. ft.). Value Factor = 3

The relative value of these spaces was considered by assigning a Value Factor (VF) or weight to each of the classes of space "1","2", and "3" respectively. This resulted in a unit value of $200 /sq. ft See Table 1. For cost-benefit analysis the weighted value for each space was determined to be $ 200 / sq. ft. for the garage, $ 400 / sq. ft. for the basement and $ 600 / sq. ft. for the prime living area (1st and 2nd floors).

Unit value computation:

Category	Area ft^2	VF	(VF)x Area	(WV)	Total
	(1)	(2)	(3)	(4)	(5)
			(1)x(2)	(2)x $200/ft^2	(1)x(4)
Garage	300	1	300	$200	$60,000
Basement	300	2	600	$400	$120,000
Prime Living	1200	3	3600	$600	$720,000
Total	1800		4500		$900,000

Table 1

- VF = Value Factor, WV = Weighted Value of Space ($ / sq. ft.)
- Market value of the house = $ 900,000
- Average value per square ft. = $ 900,000 / 1800 = $ 500 sq. ft. (Col.5Total / Col.1)
- Unit value (weighted) = $ 900,000 / 4,500 sq ft = $ 200 / sq. ft. (Col.5 Total / Col.3 Total)

Alternative solutions considered to mitigate future flooding

Alternative one: New additional storm drain from backyard

The first alternative considered was to divert the majority of runoff inundating the property from the neighboring properties from the west to a new drainage system connected directly to the storm sewer. The estimated cost of constructing a new 12-inch drainage pipe to the storm sewer was about $35,200. While this option would alleviate the problem of future flooding it would take up to a year to install and if the storm sewer backs up (as it had in the current flooding), no benefit would be obtained since flooding would still occur. Reduction of risk of anxiety for this alternative was minimal. When the homeowner understood the problem of flooding was due to the backup from the storm sewer it became obvious that this solution provided virtually no benefit in terms of reduced anxiety against future flooding. Therefore this option was no longer considered. **lternative two:** New additional storm drain from backyard with overflow provisions and a check-valve on the existing system.

For the second alternative a 10-inch drainage pipe with two (2) intermediate drop inlets located at the points where the pipe would change direction and slope with an overflow system that would permit water to drain out on to the street in the event of a back-up in the storm sewer, see Figure 1. This option would permit any backup in the storm sewer to overflow into the street and recycle to the storm sewer instead of the backyard. See Figure 2. This option included the installation of a check-valve on the existing 10-inch pipe which would prevent accumulation of water in front of the garage area. The estimated cost of constructing a new 10-inch drainage pipe to the storm sewer was about $30,500.

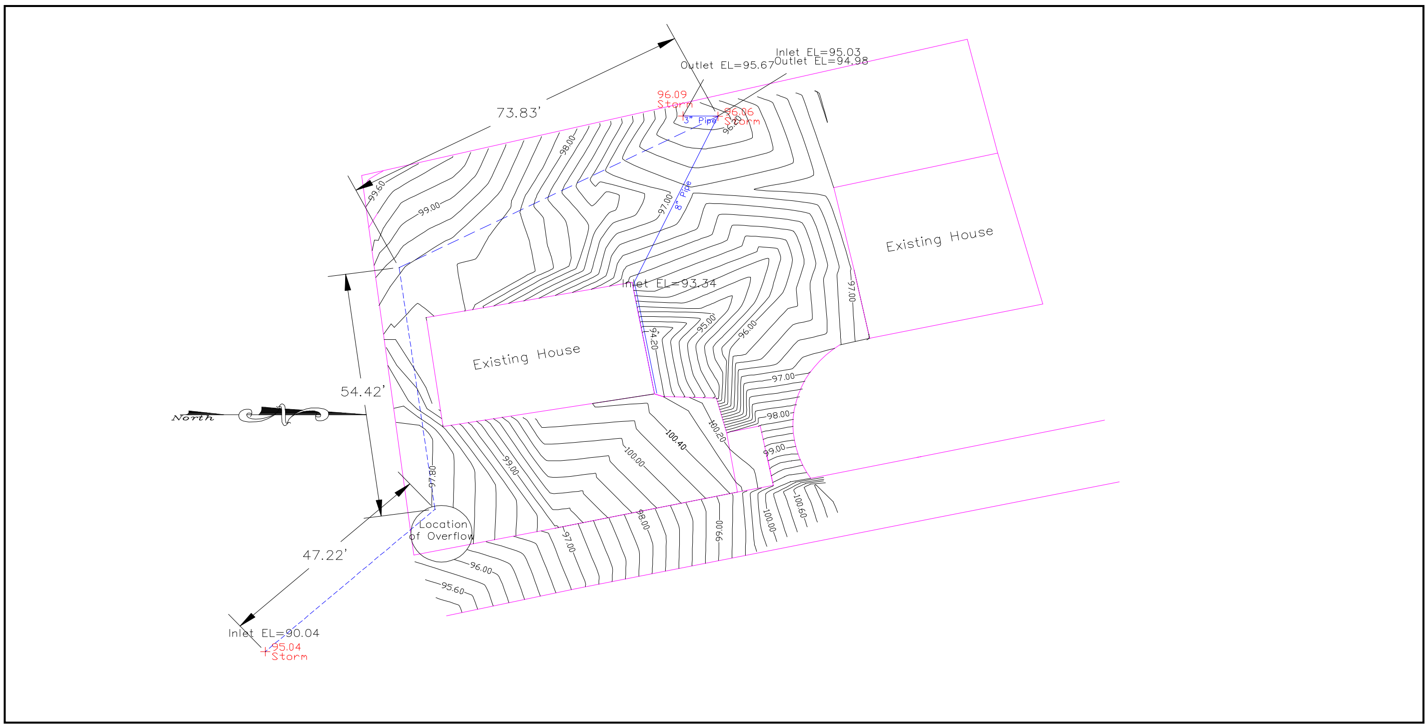
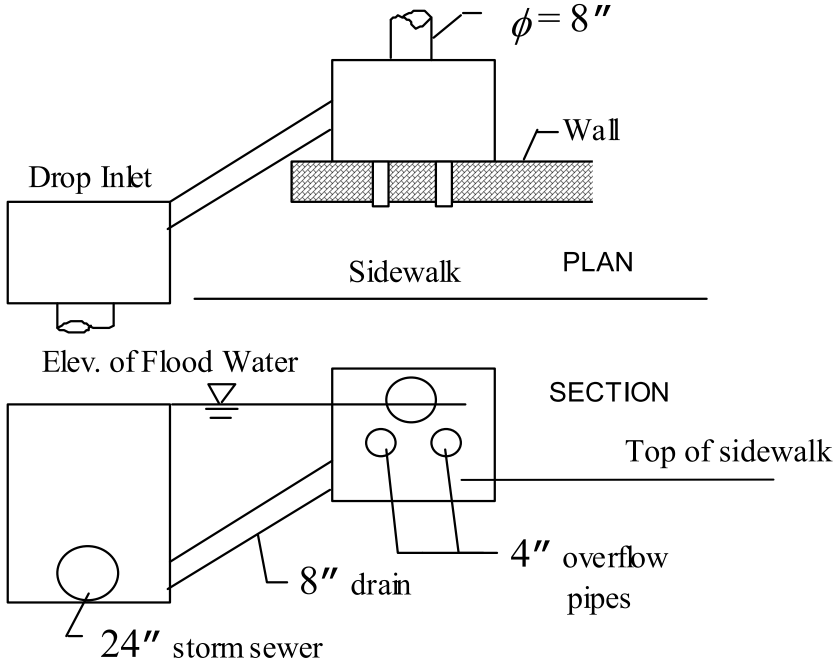


Figure 1



Schematic drawing of overflow

Figure 2

Alternative three: Alternative two with the addition of a small sump pump. (A solution using a sump pump system as the sole means of eliminating potential flooding in front of the garage was significantly more costly. The size of the pump would incur significant operating cost and in the event of a power failure would be rendered useless. Therefore it was not considered a viable solution).

The installation of a sump pump for an incremental cost of \$5,500 would alleviate anxiety and stress immediately (the sump pump installation would not handle the volume of water that could be expected to accumulate in front of the garage due to a serious storm, its presence provided a significant "security blanket" for the home owner). The incremental cost of the sump pump was significantly less than the incremental benefits attributed to its presence.

Summary of benefit / cost analyses

Alternative one: Potential benefits due to this option were insignificant. This alternative would only reduce the ponding of water in the backyard. Should the storm sewer again back up, the area in front of the garage would again be inundated.

$$B/C = (<1) / (\$35{,}200) \approx 0 \qquad (I)$$

B = Benefit
C = Cost

Alternative two: The homeowner lost priceless family heirlooms and records in addition to two relatively new cars (valued at \$48,000) in the garage and destroyed by the flood water. To estimate the value of the loss of storage space in the basement for one year until the new system is installed, a cost of $2,400 is assumed as the cost of one year of rental of public storage. When the new drainage system is installed, anxiety over flooding is essentially eliminated. Using the weighted value of basement space of $ 400 /sq. ft. and a capital recovery factor of 6% for an infinite period of recovery a value of $ 24 /sq. ft. of recovered space was used as a measure of "benefit" represented by recovered use of the basement for storage. 6% was chosen as a reasonable value to reflect the value of money with time. Traditionally this might be the current home mortgage rate. In the Washington, DC area the home mortgage rate is quite varied, so 6% was accepted for this problem. Assuming 75 % of the basement area used for storage, $5,400 (0.75 x 300 x 24) was used as the benefit due to recovery of storage space.

Analogously, the value assigned as a benefit for recovery of confident use of the garage for parking is $3,600 (1.0 x 300 sq. ft x 0.06 x $200). The long term benefits from the new drainage system and provisions to accommodate potential back up of water (check valve and over-flow system) were established by estimating the increased value of property due to the new system. It is our assumption that by providing the improved drainage system the market value of the house is increased by 3%. In that this represents a current market improvement in the value of the house, its present worth of $27,000 (0.03 x $900,000) is used as an immediate benefit.

Under normal market conditions it would be reasonable to reduce the market value of the home due to the potential for flooding. However, in the area in which the home is located (a very upscale suburb of Washington, DC) there actually would be no reduction in the market value of the house. The "lost" is only the beneficial use of the space that is at risk (basement and garage).

By providing a degree of confidence in the ability to use this space there is a real increase in the market value of the house (in other words, the current value of the house reflected the risk of flooding. The elimination of the risk increased the market value of the house).

Total benefits = $5,400 + $3,660 + $27,000 = $36,000 (II)

B / C = $36,000 / ($32,500 + $2,400) = $36,000 / 34,900 = 1.03

Alternative three: Alternative two with the addition of a small sump pump

An incremental benefit / cost analysis was made to see if the immediate installation of a small sump pump proved to be beneficial. The benefit of the sump pump would be an immediate reduction of anxiety and concern over flooding of the garage and basement. As indicated previously, a total sump pump solution was not feasible. A small pump with battery backup in the event of a power failure, while inadequate to solve the problem, would address smaller excessive rainfall.

In the incremental benefit/cost analysis the following data were used:

1- The cost of the sump pump installation = $5,500
2- The benefit is the reduction in apprehension over potential flooding and peace of mind established by the presence of the pump (security blanket).

The benefit of the sump pump is virtually all derived from the reduction in anxiety and concern over flooding during the interim period until the more permanent drainage solution is completed. This benefit was estimated using the Linear Anxiety Model (LAM). The ordinate of the Linear Anxiety Model is lost productivity due to anxiety and stress expressed in hour/hour. The abscissa is calendar hours.

It is estimated that at the beginning of the concern over the conditions resulting from the flood 10% of productive time was consumed dealing with the flood.

For a professional person (the homeowner is a medical researcher) we used 16 hours as the normal number of potential productive hours per day and 100 days (approximately 3 months) as the point in time at which concern over the problem would have for all practical purposes reduced to zero. The point at which the decision to install a sump pump resulting in reduction in anxiety was a little over a month from the time of the flood. Therefore we established 600 hours as the point at which we could assume anxiety had been reduced to a minimum. For medical professionals we selected $200 / hour as a normative rate for the value of time.

There will be arguments questioning the "literal" benefit of assigning a monetary value to the elimination or reduction of the anxiety on the part of the home owner. Just as assigning value to time saved by the improved road conditions, this is just a means of trying to quantify the reduction of anxiety. Additionally a research professional actually does not "loose" time but his/her total time can be managed more effectively.

True also the sump pump is only a "stop" gap measure, but it does accomplish a significant reduction in the inefficient use of the home owner's time addressing this problem.

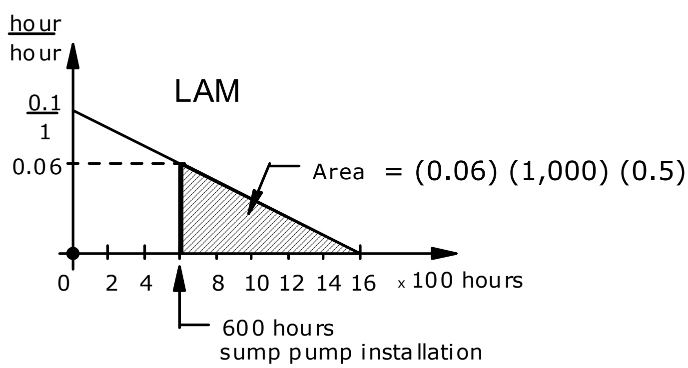


Figure 3

Area x ($200/hr) = (0.06).(1000).(1/2).($200/hr) = $6,000

ΔB / ΔC = $6,000 / $5,500 = 1.09 (III)

ΔB = Incremental benefit

ΔC = Incremental cost

This provided a economic basis for the justification of immediate installation of the sump pump system.

Conclusion

This study started out as a routine problem of how to eliminate the flooding of a basement of a residential structure due to a serious storm. In the investigation of the cause of the flooding and the consideration of alternative solutions, the assignment of "value" to personal anxiety and stress caused by the flood and the assignment of monetary value to priceless personal heirlooms and records lost in the flood became an ancillary project of interest. The solution of the hydraulic and hydrologic engineering aspects of the problem were straightforward and traditional.

It was the consideration of the intangible benefits, resulting to the homeowner that motivated this paper. While assigning a monetary value to intangible benefits of large public projects has been done, to our knowledge no attempt has been made to do this for private residential work. This study is an initial reporting of our efforts to address the assignment of monetary value to the reduction of anxiety and stress as a benefit. In addition, an initial effort to assign a monetary value to the loss of family heirlooms and personal records has been made. This is a work in progress. The authors plan to refine this concept further so that it might be a basis for considering these concepts in the benefit-cost analysis of engineering projects.

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Selected Photos of Site

Photo 1

Photo 2

Photo 3

Photo 4

Photo 1 Looking south into garage. Water level was above the height of the tire at the left of the door opening.

Photo 2 Looking west, toward the back yard in the area in which the new drain pipe will be installed.

Photo 3 View from front of the house. The sump pump outlet is located in middle of the wall in the foreground of the picture. (See Photo 4)

Photo 4 View of the sump pump. The vertical pipe is the discharge to the street (outlet of pipe is shown in Photo 3). The case in the lower left of the picture is the battery for a small back-up pump which operates in the event of a power failure.