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RISK ANALYSIS FOR FLOOD MITIGATION ON THE RARITAN

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ABSTRACT: We have developed a framework for flood mitigation risk analysis that applies generally to floods, and have applied it in this study of flood mitigation risk analysis for the Raritan Basin in New Jersey, USA. The framework we have developed involves a conceptual model of the relation among meteorological activity, hydrological models, infrastructure intervention, fine-grained topography, and economic impact. We have developed a hydrological model of the Raritan Basin. We used the calibrated model to compute the reduction in stream gage height (water level) over time as a result of implementing sufficient Green Infrastructure to reduce runoff depth by 1 inch throughout a relevant Watershed Management Area. Three scenarios of sufficient GI implementation and their associated costs were evaluated. In an econometric effort, we have developed a non-linear, threshold-based model that relates the cumulated or integrated amount of river activity above flood level to the FEMA insurance payouts, using historical data on both. This model was tested for four communities, and it achieves excellent predictive behavior against historical data, and can be used to relate the hydrological model results directly to FEMA payout records. Many possible water-related explanatory variables for FEMA insurance payouts were considered, and the most effective was found to be the aggregated quantity of water above flood level during the time directly associated to the flooding event that caused the claims and payouts. We applied this risk mitigation analysis framework to one community, Manville. The estimated cost savings due to the one inch reduction in runoff depth from Green Infrastructure in the region affecting Manville is about 6.1 million US dollars for a 68% reduction in FEMA payouts. Our effort has demonstrated that linking of meteorology, hydrology, non-linear econometric modeling and sophisticated elicitation can provide a very powerful tool for informing and guiding discussion among all stakeholders.

Key Words: Econometric Modeling, FEMA Insurance Payouts, Green Infrastructure, Hydrologic Modeling, Risk Assessment

1. INTRODUCTION

The Raritan River has a history of overflowing its banks and causing substantial damage to nearby townships and boroughs. We have developed a framework for flood mitigation risk analysis that applies generally to floods, and have applied it in this preliminary study of flood mitigation risk analysis for the Raritan Basin.

The framework we have developed involves a conceptual model of the relation among meteorological activity, hydrological models, infrastructure intervention, fine-grained topography, and economic impact. This model can serve as a conceptual foundation for informed communication among stakeholders and a framework for risk analysis of alternative flood mitigation strategies. We have experimented with detailed elaboration of several components of this model, a hydrological model that allows us to relate flood mitigation strategies to water levels, and a nonlinear econometric model that allows us to relate several water-level-related variables to FEMA insurance payouts.

2. RISK ANALYSIS FRAMEWORK

2.1 Overview

Every risk assessment is different and depends on many factors, including availability of data, relevance of different modeling tools, and input from stakeholders. Every risk assessment also depends on simplifying assumptions that make computation feasible or adjust to the lack of all the relevant data. In this project, we have made a variety of simplifying assumptions that we indicate, in order to demonstrate the feasibility of the overall approach.

We have researched alternative approaches to flood risk assessment and gathered as much background information as possible. We have received information from numerous individuals in the U.S. and abroad, and numerous agencies, including New Jersey Department of Environmental Protection, US Department of Homeland Security Risk Management and Analysis, US Army Corps of Engineers, and US Geological Survey. Our multidisciplinary discussions have led us to understand many of the subtleties involved in doing a risk assessment for flooding on the Raritan. We present here a summary of the approach we have developed, discuss the basis for the implementations with which we have experimented, and discuss the kinds of detailed information that full-scale implementation will require.

2.2 Framework for Risk Analysis Modeling

To explain our approach and the issues we have to resolve, let us consider first a diagram (Figure 1), which illustrates the kinds of factors and tools we need to take into account in understanding flood modeling and applying that modeling to a risk assessment.

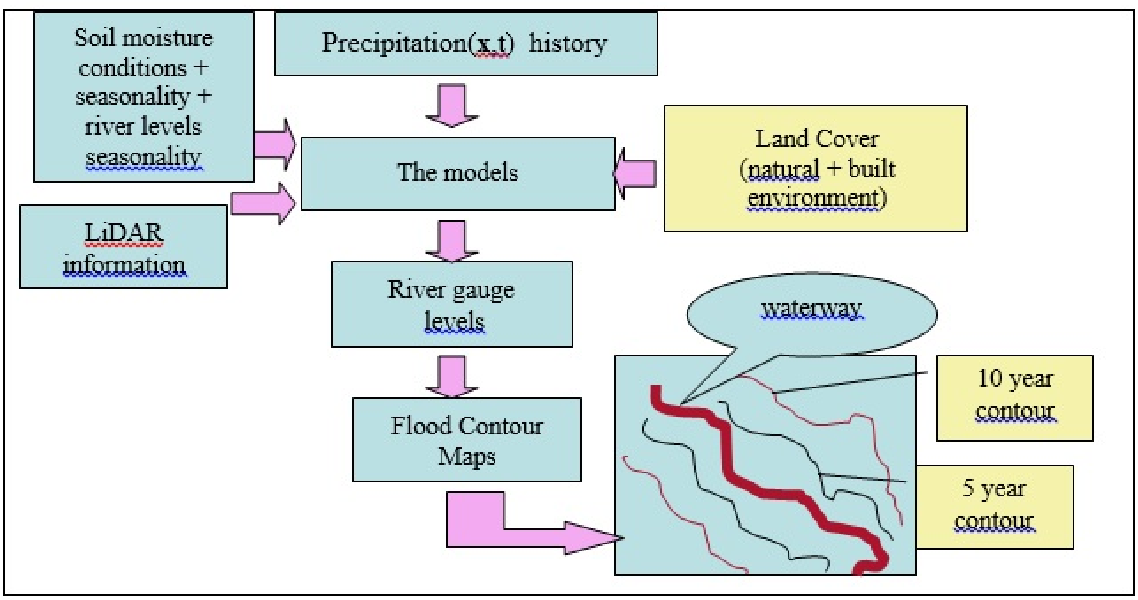

Figure 1: The interaction of nature, models, and controllable activities (shown in yellow)

Engineering models can combine information on rainfall, specified as to time and space, with information on soil moisture conditions, seasonality, and river levels prior to the rain event; the fixed properties of the watershed (not indicated, e.g., topographic information from LiDAR); and the land cover (natural and built environment) to produce flood inundation maps. To obtain the precision needed to specify events that might occur every five or ten years also requires LiDAR information on elevations. We refer to the soil moisture conditions and river levels as “antecedent events” and note that seasonality is important because it affects the ability of the soil to absorb water (due to vegetation cover, freezing, saturation, etc.). (In the simplest case, we might think of four types of soil moisture conditions: dry, “average,” wet, or frozen. Probably it is sufficient to think of four different seasons. In reality, not all of the combinations of soil moisture condition and seasonality are feasible: We won’t have frozen ground in summer.) The land cover/environment is viewed as modifiable (yellow) over the span of a few years. That would in turn move the flood contours. Flood inundation maps can be used for insurance and/or regulatory purposes, for risk assessments, and to communicate complex geology and meteorology to stakeholder groups and thereby facilitate consideration of alternative policies.

2.3 Risk Modeling

The basic outline for how DHS does risk assessment is shown in Figure 2 below, which is taken from a presentation by Dr. Isaac Maya of the CREATE Center at the University of Southern California. It defines “risk” R as a function of threat T, vulnerability V, and consequence C, R = f(T,V,C). Often this is represented as a product, R = T x V x C. Generally the factors T and V are some kinds of probabilities, while C is some measure of loss. In our case, “attack” is interpreted to mean weather event and “success” of the attack is interpreted to mean flooding.

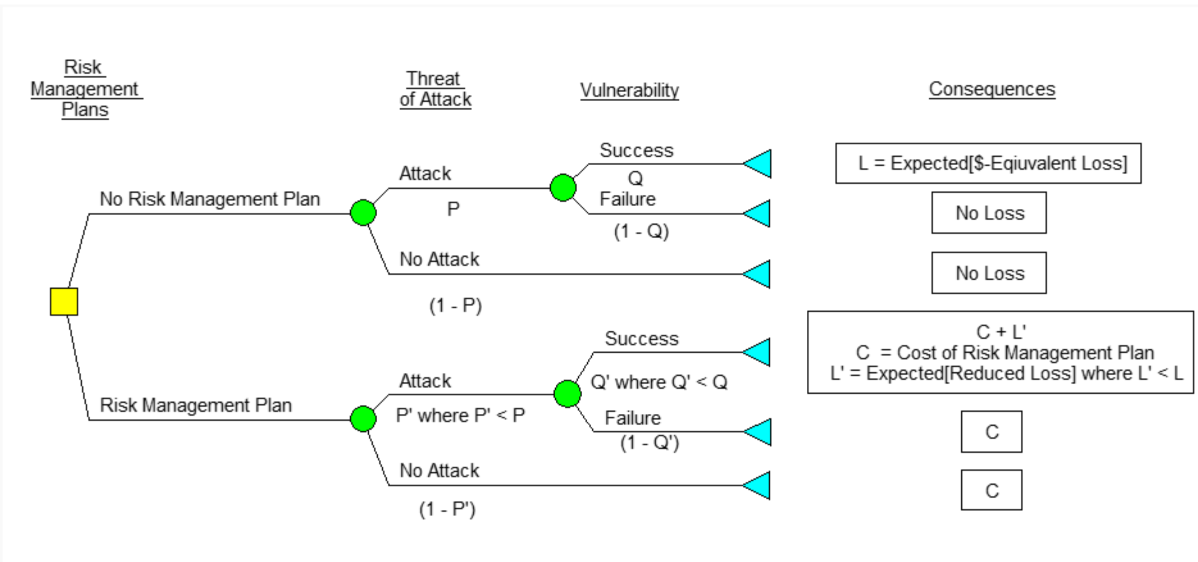

Figure 2. Sketch of the DHS computation of risk. (Isaac Maya, personal communication)

There are two branches to the tree in this figure. The top branch is the “status quo” and the bottom branch involves some mitigation strategy or combination of such strategies. The probability of attack P is the probability that there will be a weather event of the particular kind being considered, and the probability of “success” Q is the conditional probability that such an event, if it does occur, will lead to flooding (the vulnerability) at a site being considered. The consequences could be of various types. In the case of floods, they include loss of life, economic damage to homes and businesses (direct or indirect), and psychological damage. There is an attempt to put each of these types of consequences in terms of dollars. The consequence (cost L) of an attack (flood) is in principle calculated as a weighted sum of the different kinds of costs, in our case of the cost in terms of lives lost, economic damage, and psychological damage. What weights one uses and whether it makes sense to add up these weighted values are issues that will be viewed differently by different stakeholder groups.

3. HYDROLOGICAL MODELING

3.1 Modeling Software

HEC-HMS version 3.5 (http://www.hec.usace.army.mil/software/hec-hms/download.html) was chosen as the modeling software for this project. This is the state-of-the-art version of the software and offers a range of modeling capabilities. An advantage of HEC-HMS 3.5 is that it allows adding and removing components easily as the project develops. It also allows flexibility in switching between modeling methodologies for the different components of the model. In this way, the model can be slowly refined and adjusted according to the objectives set at each stage of the project.

3.2 Data Acquisition and Processing

Manville was chosen as the municipality to be studied in this modeling example. In order to build the hydrologic model, it was necessary to compile precipitation records, discharge records, land use cover maps, and watershed delimitation maps. For purposes of this pilot demonstration of the model, data for the year 2007 was chosen. The choice of Manville and of 2007 as the place and time period to be modeled were based on FEMA payout records which indicate that this year and borough coincide with some of the highest payouts for flooding damage.

ArcGIS Explorer was used as the primary tool for geographic information processing for the system. It allowed us to obtain data on slopes, distances, and coordinates of necessary components within the system. GIS shapefiles and rasters were obtained from the National Geospatial Management Center, the Geospatial Data Gateway, and the New Jersey Department of Environmental Protection Geographic Information Systems webpage.

3.2.1 Watershed delineation

The Raritan watershed comprises approximately 1100 square miles. The Raritan watershed is divided into 3 watershed management areas (WMAs) for administrative purposes, by the New Jersey Department of Environmental Protection (NJDEP). Each of these watershed management areas corresponds to a subbasin within the watershed. WMA 8 (approximately 470 square miles) comprises the Upper Raritan watershed, both the North and South Branches. For this pilot demonstration of methodology for modeling of green infrastructure mitigation strategies, only WMA 8 (and one additional subwatershed from WMA 9) was modeled. WMA 8 is in turn divided into 15 subwatersheds, which were the smallest subdivision used for modeling purposes. One additional subwatershed from WMA 9 was included in the analysis because it contains the Manville stream gage that was used as reference point coordinating the hydrologic and the payout models. Subwatershed delimitation is determined by USGS. Figure 3 below shows the subwatershed delimitation used, where the yellow shaded area corresponds to WMA 08 and the subwatershed marked with a star and the number 16 corresponds to the subwatershed containing the Manville stream gage, which is located in WMA 9.

3.2.2 Precipitation records

Hourly precipitation records for a rain gage located in Somerset Airport within WMA 8 were obtained from the Office of the New Jersey State Climatologist for 2007. Precipitation records for other rain gages, such as Hillsborough and Cream Ridge, were also obtained from this same source.

3.2.3 Discharge records

Fifteen-minute discharge records were downloaded from the USGS Instantaneous Data Archive website for the Manville stream gage. This data was used to perform a rough calibration of the hydrology model. However, further refinement of the model can be performed in the future using multiple stream gages upstream of the Manville gage.

3.2.4 Land use cover maps

Land use cover maps were obtained from NJ DEP's watershed management areas website.

3.2.5 Topographic contour

The weighted slope of each subbasin was calculated using 20 foot elevation profiles loaded in ArcGIS Explorer over the watershed maps.

Figure 3: Subwatersheds in WMA 8 used for the hydrologic model and the additional watershed included from WMA 9

3.3 Methodology and Parameters

The first step in modeling the watershed was to choose the method to estimate the runoff for each subbasin. The method chosen was the Soil Conservation Service (SCS) curve number (CN) method. This method will allow adjustment of the curve number to represent the modified runoff volume when GI measures are implemented. Using the land use / land cover maps superimposed on the watershed subdivision map, the percentage of land covered by each land use category was determined and tabulated. Given that most of the subwatersheds in the model are located in the highlands or piedmont of New Jersey, a hydrologic soil group D was assumed to be prevalent. The curve number used for each land use type was thus based on soil type D. These values were obtained from hydrology books (Viessman and Lewis, 2003; Bedient et al. 2008) that reproduce them from the original SCS handbook. A composite curve number was obtained for each subbasin by using the land use percentage as a weighting factor. Once the curve number has been obtained, the SCS method is used to estimate the runoff volume by calculating the potential maximum retention and the initial abstraction (the maximum amount of water that the soil will absorb initially). With the runoff volume estimated, the next step is to represent the travel time of this runoff through the watershed. The runoff travel time (lag time) will depend on the area and slope of the watershed and the length of the rivers or streams flowing through the watershed. The method chosen for this modeling component was the SCS unit hydrograph method. The area of the watershed and the length of river through it were measured using ArcGIS explorer.The final component of the subbasin model is the baseflow. The baseflow is the groundwater discharge (Viessman and Lewis, 2003), and can usually be estimated as the low flow in the river before the rain starts. The baseflow for each subbasin was either estimated from available stream gages or, for watersheds without stream gages, interpolated from the available data. The baseflow was assumed to be constant for the modeled period.

3.4 HEC-HMS model components and calibration

With the pertinent GIS shapefiles loaded as background maps, the model was built in HEC-HMS 3.5. The first step was to assign a number to each subbasin and input the gathered and calculated parameters (curve number, lag time, etc.). Ten sections of river/stream (reaches) were defined to simulate the channel flow between subbasins. Flows in the reaches were modeled using the Muskingum method, a common method used for reach routing (Viessman and Lewis, 2003 or Bedient, at al., 2008). Wave travel time through each reach was calculated from available flow data and the cross section of all channels was assumed to be parabolic. The computerized model also includes 5 junctions (where water from the subbasins joins the reaches for modeling purposes) and an outlet defined as the USGS Manville stream gage.

Once the physical model was built, a storm had to be chosen so we could run the model to observe the response of the model to rainfall. Instead of choosing a generic design storm, the Nor'easter storm of 2007, which caused serious flooding in the Manville-Bound Brook area, was chosen. The rainfall data used covered April 11 to April 22, 2007 with a total precipitation of 5.99 inches recorded by the Somerset Airport rain gage. Choosing a specific storm event has the advantage of permitting comparison of the model to actual observed measurements in the stream gages.

A rough calibration of the model was performed. The main goal of the calibration exercise was to try to maintain the total amount of discharge as close as possible between the observed and modeled values. An attempt was made also to have synchrony in the model and observed response time. In some of the locations further upstream, the curves did not match perfectly, but the total amount of water was kept as close as possible to the observed data.

The model was not validated using a separate storm event in this methodology-demonstration project.

Additional details about the modeling can be found from Guo et al. (2012).

3.5 Simulation of Stream Flow Reduction Resulting from Runoff Reduction

The implementation of Green Infrastructure methods would result in reduced runoff. For this modeling exercise, it was assumed that runoff would be reduced by one inch over the entire watershed. In order to simulate this runoff reduction, the curve number corresponding to the reduced runoff was back-calculated. Changing the curve number also changes the lag time and initial abstraction so these values were adjusted accordingly. New curve numbers were calculated for each one of the 16 subbasins that compose the model.

The runoff for the entire watershed under a storm event equal to the 2007 Nor'easter (5.99 inches of rainfall) would decrease from 4.65 inches under the present conditions to 3.65 inches. In terms of discharge, the peak flow would decrease from approximately 30,000 cfs to just under 20,000 cfs.

3.6 From Hydrologic Modeling to Flood Risk Management

In the context of flood risk management, hydrologic modeling can be used to estimate the risk of flood that the different scenarios pose. Building on the Department of Homeland Security's (DHS) methodology for risk assessment as described in Section 2, hydrologic modeling can be used to produce a parameter of vulnerability. Based on the DHS methodology, Figure 4 shows a proposed method to assess risk using the information obtained from hydrologic modeling. In this case, Risk (R) would be defined as a function of threat (T), vulnerability (V), and Consequences (C), where T is measured by the probability of a certain type of storm occurring (e.g. a 10-year storm has a 10% chance of occurring on any given year), V is measured in terms of the water level above flood stage (obtained by hydrologic modeling of the different design storms), and consequences C are measured in terms of the losses, which could be directly identified with FEMA payouts or might include other economic and human components.

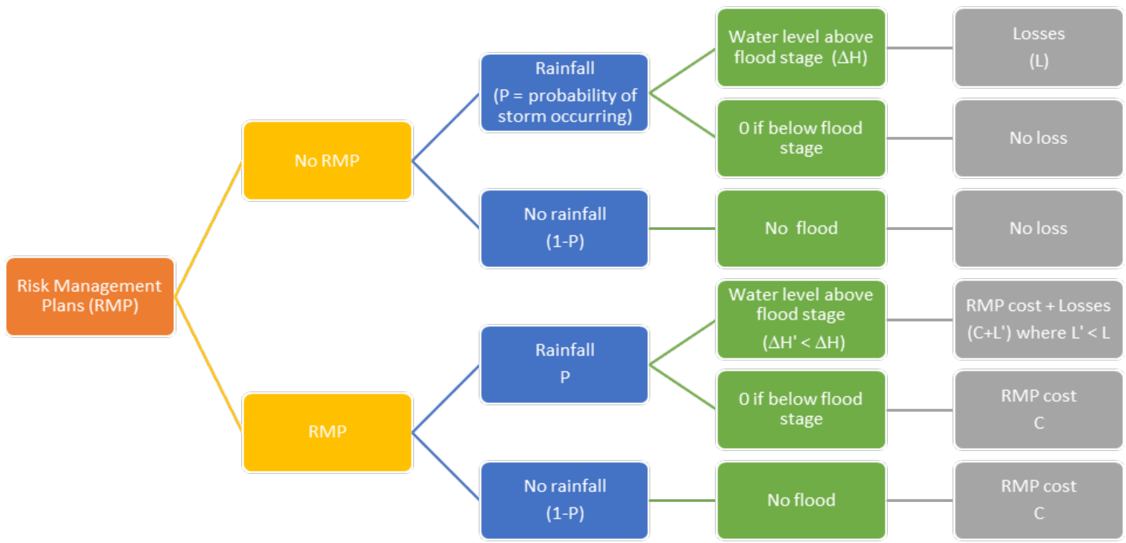

Figure 4: Sketch of proposed risk computation based on modified DHS risk diagram

For the mitigation strategies (Risk Mitigation Plans: RMP - corresponding to the lower half of the diagram), the threat does not change but the vulnerability and consequences do. The new water level above flood stage used to calculate the new risk is obtained from the simulation run using Green Infrastructure measures (or modeling any other mitigation measures that could be used). The consequences are directly related to the height above flood stage and can thus be linked to the hydrologic model.

For the height above flood stage, it is necessary to use the rating curve for the Manville station to convert from flow, the output of the computer model, to height. The flood stage for the Manville station is 14 feet according to the USGS website, so the level above flood stage is simply calculated by subtracting 14 feet from the height obtained using the rating curve.

4. RUNOFF REDUCTION BY GREEN INFRASTRUCTURE

Runoff can be reduced by implementing Green Infrastructure techniques such as rain barrels, rain gardens, pervious pavements, vegetative swales, green roofs, etc. Green Infrastructure is still a fairly new mitigation strategy and there is very little published data regarding cost of implementation. Given that quantifying the costs of the different GI techniques was not the primary goal of this study, cost estimates were obtained using the Center for Neighborhood Technology's (CNT) Green Values National Stormwater Management Calculator (Center for Neighborhood Technology, 2012).

Three GI scenarios were chosen and for each the cost was estimated using the Green Values National Stormwater Management Calculator. All of the scenarios were adjusted to remove one inch of runoff. It was assumed that the type of soil, land cover use, etc. is homogeneous throughout the watershed being modeled. The first scenario includes a combination of permeable pavement, bioswales, rain gardens, and cisterns. Table 1 shows the capital and maintenance cost associated with this scenario as calculated by the CNT's tool. The other two scenarios can be found from Guo etc. (2012). Applying GI to the entire Raritan watershed would cost between 6 and 19 billions of dollars based on the estimated capital and maintenance costs per acre.

Table 1. Costs per acre associated with scenario 1 - combining several green infrastructure techniques

Green Infrastructure Technique	Area (ft2)	Capital Cost ($)	Annual Maintenance ($)	
Permeable pavement	3,000	$ 19,020	$ 570	
Swales in parking lot	400	$ 8,000	$ 50	
Roadside swales	800	$ 16,000	$ 100	
Rain gardens	600	$ 7,200	$ 205	
Downspout disconnect	-	$ 70	-	
Cisterns (500 gallons)	-	$ 725	$ 35	
TOTAL	**4,800**	**$ 51,015**	**$ 960**	

5. WATER FLOWS AND FEMA–PAYOUTS: LINEAR AND NON-LINEAR MODELS

5.1 Overview

Our risk analysis of flood mitigation in the Raritan Basin relates rainfall in the Basin to river gage levels and relates river gage levels to the costs of repair and remediation. This section addresses the latter linkage, using data from the boroughs/townships of Bound Brook, Manville, Branchburg and Middlesex about gage levels and insurance payouts. As noted earlier, we seek explanatory variables defined in terms of water levels from which insurance payouts can be derived. The payout data can be represented as residential, non-residential, or both, and we seek explanation of each of these three categories of payout data. Also, there are situations in which the cost could rise exponentially with water level, which is modeled by plotting the logarithm of the FEMA payout against the explanatory variable.

Our results show that a single explanatory variable we call Aggregate Feet over Flood Stage (Single Event), or AFEET (Single), consistently shows high correlation between water flow and FEMA payouts over all the towns we have studied and independent of whether we measure payout in terms of residential, non-residential, or both, or whether we measure payout or logarithm of payout. Our results also show that a piecewise linear regression model is consistently the model that produces the best fit with this variable. There are cases where other explanatory variables or regression models give better fits, but usually the improvement is negligible in comparison to the results when the AFEET (Single) is used with the piecewise linear regression model. In most cases, the fits are over 90% under the criterion known as R^2, the coefficient of determination. R^2 is used with regression equations (more generally statistical models) that predict future outcomes on the basis of other related information. It is the proportion of variability in a data set that is accounted for by the statistical model and provides a measure of how well future outcomes are likely to be predicted by the model. Even in the worst case, the model for Middlesex, the fits are in the 75% to 85% range.

5.2 Data, Variables, and Models

5.2.1 Data

Three gage stations were used in this study and were linked to four adjacent townships/boroughs. Table 2 shows the gage number and township which each gage site corresponds with.

Table 2. Gages and Townships. (Data downloaded from U.S. Geological Survey: http://www.usgs.gov/)

Gage	Town
USGS 01400500 Raritan River at Manville NJ	Manville Township
USGS 01400000 North Branch Raritan River NJ	Branchburg Borough
USGS 01403060 Raritan River below Calco Dam at Bound Brook NJ	Bound Brook
USGS 01403060 Raritan River below Calco Dam at Bound Brook NJ	Middlesex Borough

5.2.2 Explanatory Variables - Annual maxima

From the downloaded data, the annual maximum gage height for each gage can be read off directly. Similarly, the annual maximum discharge (the volume rate of water flow that is transported through a cross-sectional area) was taken from the U.S. Geological Survey hourly data. These single numbers, the annual maxima, are a very crude, but directly available measure of the peak water flow at the (presumed) most destructive event of the year. These numbers can be used in a conventional econometric analysis as the independent or explanatory variable.

5.2.3 Integrated Variables and Engineering Considerations

Consideration of the way in which water damages property suggests that a variable that captures, with more precision, the amount of water that flows onto and into the properties, might be more effective. With this in mind, we define two new variables, “Aggregate Feet over Flood Stage,” (AFEET), and “Aggregate Flow” (AFLOW). The variable AFEET is formally defined as the integral over a flood event of the positive part of the gage level minus the flood level:

$$AFEET = \int_{start(E)}^{end(E)} [g(t) - f]_{+} dt$$

Here, E is an event, t is time, g(t) is gage level at time t, and f is flood level. This can be represented graphically as shown in Figures 5 and 6 below.

In practice, it is not obvious how to define the beginning and end of an event. Our method, which is a variant of Lebesgue integration for a rapidly fluctuating variable, used sorting of the data to simplify the integration, which becomes a sum over the largest values. The hourly gage height data for an entire year was sorted in descending order, and the accumulated feet above flood stage for each specific gage was accumulated over a target range. We explored two different methods to represent this variable, which measures water buildup over time. The first method (Figure 6) is equivalent to assuming that there was only one event per year, which caused the damages that were linked to the FEMA payouts. Thus, this explanatory variable was calculated by only taking the aggregate feet over flood stage for the first event that produced the highest gage height values. This variable is what we have called AFEET (Single) or Aggregate Feet over Flood Stage (Single Event).

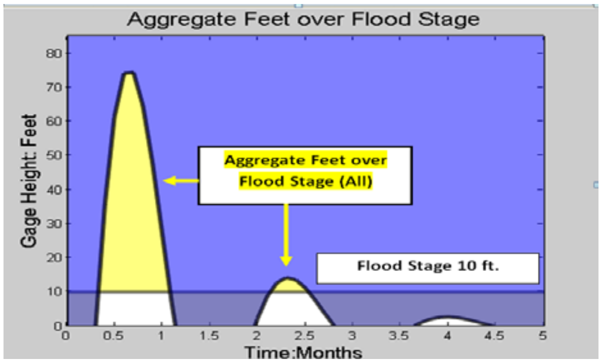

Figure 5. The accumulation of water over flood stage, across the entire year (AFEET All)

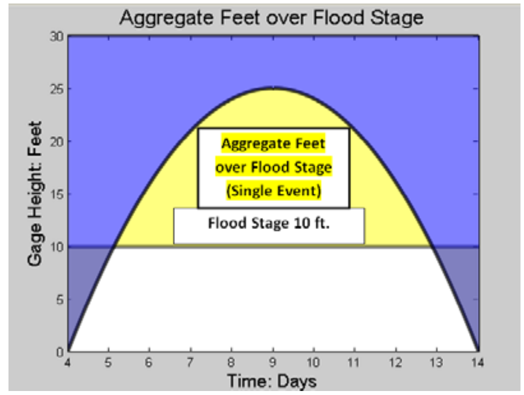

Figure 6. The accumulation of water over flood stage for a single event. (AFEET Single)

An alternative version posits that FEMA payouts are linked to the annual accumulation of all feet above flood stage. Thus, this explanatory variable was calculated by taking all aggregate feet over flood stage over the whole of each year. This variable is named AFEET (All) or Aggregate Feet over Flood Stage (All) (Figure 5).

Still another explanatory variable that we have found useful is called AFLOW or Aggregate Flow. AFLOW is based on the discharge rate, d(t) and is given by:

$$AFLOW = \int_{start(E)}^{end(E)} D(t)dt$$

Here D(t) is the discharge rate as a function of time and we think of the event as beginning when the discharge exceeds flood level and ending when it returns to the flood level. AFLOW seeks to measure the total rate of water flowing through a cross-sectional area during the peak period of a storm or event. This variable captures the aggregate values of discharge for times when the gage height is greater than flood stage and is taken into account for a single event. The calculation was performed by arranging the annual hourly gage height and discharge data in descending order sorted based on gage height. Then the sum of all discharge values that corresponded to gage height values over flood stage was taken to calculate the Aggregate Discharge over Flood Stage Variable. Figure 7 and Figure 8 plot the graph of payout (combining both residential and non-residential) vs. AFEET and payout vs. AFLOW. These plots show the potential benefit of switching to such an engineering-based selection of explanatory variables. We should expect that the more intuitively sensible a variable is, the better it can do at explaining puzzling data. The "aggregate over flood variables" are both an effort to capture the fact that it is only excess water that does the damage. However, "Aggregate feet over flood" (Figure 7) is a somewhat abstract measure, which considers that two feet of water above flood level is, roughly speaking, twice as harmful as one foot of water above flood level. On the other hand, the "discharge rate" figures make use of an estimated shape of the riverbed to convert these heights into volumes of water. Therefore, if we use the "aggregate discharge over flood" as an explanatory variable (Figure 8), we are actually using the product of a rate at which water flows by the time unit, summed over a period of time. In other words, the explanatory variable is now an amount of water. As we see by comparing Figure 8 and Figure 7, this removes the poor fit that we see in Figure 7. We see that there is a clear association between having "more water over the dam," so to speak, and having a higher FEMA payout. The low payout associated with a high aggregate FEET over flood did not have a high payout, leading to the poor fit in Figure 7. But it also did not have a high aggregate FLOW, as shown in Figure 8, where the fit is correspondingly better.

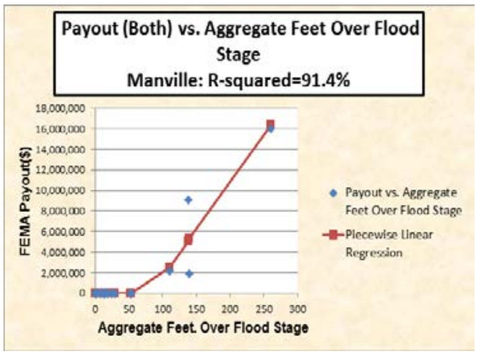

Figure 7. Payout versus aggregate FEET over flood stage (AFEET) for Manville. Note the two poorly fit points at the highest value of AFEET.

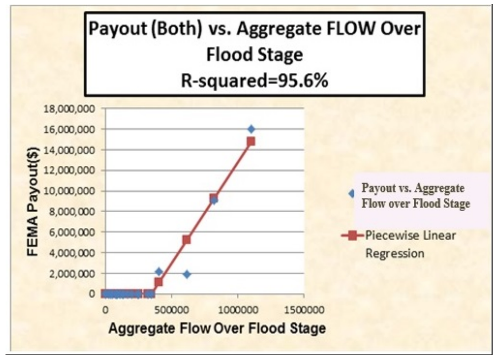

Figure 8. Payout versus aggregate FLOW for Manville. Note that one of the poorly fit points is now on the curve, and the other has moved (to the left) much closer to it.

5.2.4 Regression Models

We have fit the data points using three different models: linear regression, polynomial of degree two (quadratic model) and a piecewise linear (PWL) regression. These define the dependent variable as a function of the independent (explanatory) variable, as follows (respectively):

$$y_{lin}(x) = a + bx$$

$$y_{quad}(x) = a + bx + cx^2$$

$$y_{PWL}(x) = \begin{cases} 0 & x < x_{threshold} \\ a(x - x_{threshold}) & x \geq x_{threshold} \end{cases}$$

Additional details and sample calculations can be found from Guo et al. (2012).

5.3 Cost Savings Resulting from Runoff Reduction

Based on our models (the hydrologic model and the econometric model), the estimated cost savings due to the one inch reduction in runoff depth from Green Infrastructure in the region affecting the Manville Gage Station is about $6.1M, for a 68% reduction in FEMA payouts, which are estimated at $8.9M without the mitigation. Presumably there are comparable benefits for other regions that are flooded in the Raritan Basin. The long-term flood damage reduction benefits should be added up spatially across the entire watershed and a portion of the downstream watershed and over the lifetime of the Green Infrastructure. There are also other flood-related costs in addition to the FEMA payouts that should be accounted for. The total benefit could conceivably add up to 100 times the benefit for one single town over one single event (so perhaps $600M) – though detailed analysis would be needed to establish the figure.

6. CONCLUSIONS AND RECOMMENDATIONS

This pilot analysis demonstrates that it is possible to “connect the dots” of meteorology, hydrology, and economic modeling to estimate the savings, in recovery expense, attributable to mitigation strategies for flooding events in the Raritan watershed. The calculation for the impact of Green Infrastructure suggests that with present estimated costs and benefits, alternative methods may be more cost effective purely as flood mitigation strategies. However, this preliminary conclusion is based on a very limited analysis that surely underestimates both the flood-related costs saved and the other benefits derived from GI. The innovative methodology we have outlined and the component parts of that methodology that are tested here are more important than this or any specific conclusion. This methodology will, in principle, allow for the comparison of alternative mitigation strategies from a cost-benefit, risk reduction, point of view.

This project has laid out a framework for flood mitigation risk analysis and explored in depth two components of the analysis. As noted above, every risk analysis is invariably based on simplifying assumptions, e.g., to make computation feasible or to allow for the limitations on available data. Here, we make some recommendations about key elements that are needed to move our risk analysis to the next level.

We need to calculate the probability P of different kinds of weather events (the threats). Note that climate change will likely affect the value of P, but we do not know how to calculate modified P, distinct from the historical record, with any degree of confidence. We also need to improve upon quantifying the probability Qi (the vulnerability) that a flood of category i occurs. The alternative is to run the hydrological model on a continuous basis for many seasons and years, rather than on a single event. Our work has been limited to the costs of floods (the consequences) as they are measured by FEMA flood insurance payouts. In the case of floods, consequences also include loss of life, economic damage to homes and businesses (direct or indirect), and psychological damage. More sophisticated risk analysis needs to put each of these types of consequences in terms of dollars. A key issue is the extent to which statistics for estimating the needed parameters are available, and the extent to which one needs to use elicitations to estimate them. This is particularly true, for example, in deriving the weights that would be used to make a weighted sum of the scale values of different consequences. We have only done the analysis for one sample mitigation strategy. A full risk assessment would want to look not at individual mitigation strategies but at “portfolios” of mitigation strategies.

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