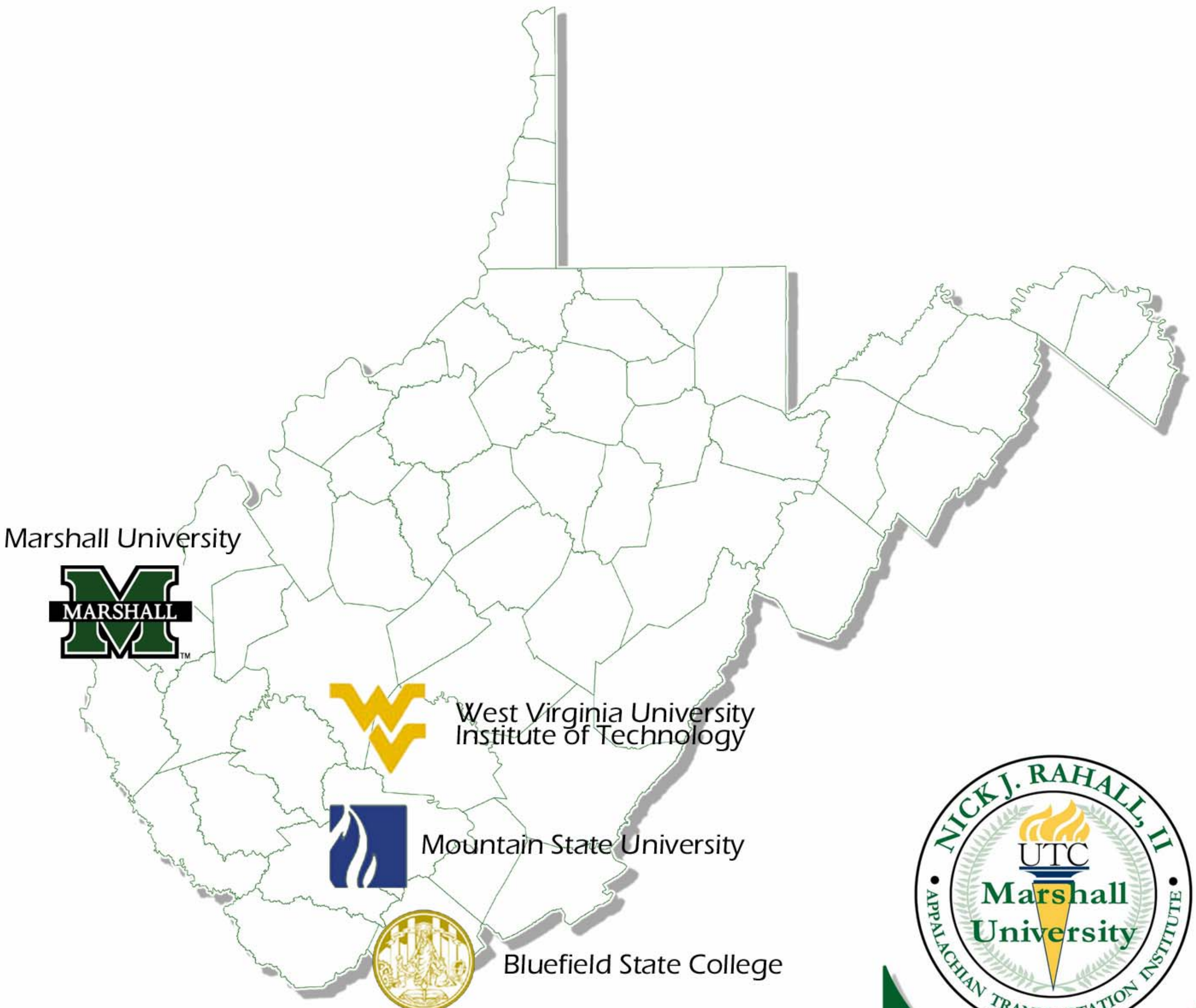
RTI TRP 00-04

Expected Flood Damages to Transportation Infrastructures as a Proportion of Total Event Costs: a Methodological Exploration



NICK J. RAHALL, II
UTC
Marshall University
APPALACHIAN TRANSPORTATION INSTITUTE

Marshall University

West Virginia University Institute of Technology

Mountain State University

Bluefield State College

1. Report No. TRP 00-04	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle TRP 00-04 Expected Flood Damages to Transportation Infrastructures as a Proportion of Total Event Costs: A Methodological Exploration		5. Report Date February 2003
		6. Performing Organization Code
7. Author(s) Dr. Michael Hicks, Dr. Mark Burton		8. Performing Organization Report No.
9. Performing Organization Name and Address Nick J. Rahall II, Appalachian Transportation Institute at Marshall University, 1 John Marshall Drive, Huntington, WV 25755		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTRS-98G-0012
12. Sponsoring Agency Name and Address US Department of Transportation Research and Special Programs Administration 400 7th Street SW Washington, DC 20590-0001		13. Type of Report and Period Covered FINAL
		14. Sponsoring Agency Code USDOT-RSPA
15. Supplementary Notes		

16. Abstract

The Tennessee Valley Authority (TVA) operates a variety of facilities throughout the whole of the Tennessee River watershed through which it affects the flows of both navigable and non-navigable waterways. These flows are influenced in support of a number of activities including, commercial navigation, flood risk mitigation, hydroelectric generation, municipal water supply, recreation, and water quality control.
Within the realm of flood risk mitigation, the TVA routinely must model the effects of water release practices on the likelihood and magnitude of possible flooding in specific geographic areas. Projected flows are translated into pool elevations that must then be used to estimate expected flood damages. Within this process, the TVA has carefully documented the likely damages to residential and commercial properties, as well as their contents. However, damages to transportation infrastructures have traditionally been captured through the application of a scalar value that is, in fact, intended to reflect a number of ancillary flood damages.

Experience, however, suggests that the proportion of total event damages attributable to transportation infrastructure destruction may vary significantly based on the characteristics of individual floods. Specifically, floods that involve significant flows damage both transportation infrastructures and other structures. However, in the absence of such flows transportation structures are far less likely to be effected even when residential and commercial facilities sustain considerable damage.

The relationship between flood characteristics and damages to transportation infrastructure is also important to residents of West Virginia. Much like the Tennessee River basin the mid-Ohio River basin is comprised of large navigable waterways that are fed by fast flowing mountain streams. Thus, in West Virginia, like Tennessee, it is possible to observe flood conditions with markedly different characteristics. In both locations the possible variations in flows may lead to a wide array of outcomes with regard to transportation infrastructure damages.
Within this context and with the overall aim of improving a priori flood damage assessment, the Rahall Transportation Institute (RTI) and the TVA propose a joint study effort designed to improve the estimation of transportation infrastructure damages as a proportion of total event costs

17. Key Word Damage; Flood; Flooding; Infrastructure; Methodology; Transportation.		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

Expected Flood Damages to Transportation Infrastructures as a Proportion of Total Event Costs: A Methodological Exploration

Rahall Appalachian Transportation Institute
Transportation Research Project 00-04

Prepared for
The Tennessee Valley Authority

February 2003

Mark L. Burton, Ph.D.
Director

Michael J. Hicks, Ph.D.
Director of Research

Center for Business and Economic Research
Marshall University
1 John Marshall Drive
Huntington, West Virginia 25755
304.696.2313
hicksm@marshall.edu

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of exchange. The U.S. Government assumes no liability for the contents or use thereof.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the accuracy of the data presented herein. The contents of this report do not reflect the official views or policies of the West Virginia Department of Transportation. The use of trade names does not signify endorsement by the authors

INTRODUCTION AND MOTIVATION

The Tennessee River's system of locks, dams, and other waterway structures are operated for a variety of purposes including commercial navigation, flood control, hydroelectric generation, municipal water supply and recreation. In order to maximize the overall utility attributable to the system, it is necessary to estimate the benefits that accrue under each operational purpose at varying levels of service, so that where necessary, policy-makers can make sometimes difficult tradeoffs between competing uses of the system.

In some cases, such as navigation or hydroelectric generation, benefits are assessed by comparing river-related service costs to the cost of obtaining the transportation or electricity generation via an alternative source. In other areas, the benefit estimation process is less straightforward. Assessing the benefits attributable to flood control is particularly challenging. Historically, the only method for estimating averted flood damages has involved assessing the value of every structure within the targeted flood plane, then estimating the extent of probable flood damages under various operational scenarios. While providing precise and accurate estimates, the tremendous expense associated with this methodology has meant that it could only be applied in those damage centers with the highest concentration of households and commercial activity.

This method of analysis may now be fundamentally enhanced. US Army Corps of Engineer (Corps) studies of the great floods of 1993 have provided a wealth of data describing the damages that resulted from a variety of different flood events in the upper Mississippi, Missouri, and Illinois River basins between May and August of that year.[1] These damage data, in combination with data describing the existing demographic and economic conditions, provide a significant new opportunity to statistically relate antecedent conditions and flood characteristics in the prediction of flood damages across a variety of damage categories.

---

[1] See US Army Corps of Engineers, North Central Division, *The Great Flood of 1993 Post-Flood Report: Upper Mississippi River and Lower Missouri River Basins*. September 1994 (six volumes).

It is within this context that the Tennessee Valley Authority (TVA) and Marshall University's Rahall Transportation Institute (RTI) have engaged in a study designed to yield a statistical model of flood damages under varying economic, demographic, hydrological and hydraulic conditions. Initially, the study was intended to focus primarily on damages to transportation infrastructure and equipment. However, it soon became apparent that the inclusion of other damage categories would be essential in order to place transportation damages in the proper analytical context. Hence, the study results presented here include estimation techniques for a wide-ranging set of residential and commercial damage groupings.

The data development, statistical techniques, and resulting damage estimations produced within the current study represent a unique and ambitious effort to improve the benefit calculation process. The study team ardently believes that the results presented herein demonstrate the *promise* of this current research course. However, as is often the case, these initial efforts have revealed a number of opportunities to improve and refine both data and estimation procedures.

The remainder of the current document is organized as follows: Section 2 describes the existing economic literature related to the estimation of flood damages. Section 3 provides a general methodology and description of the Corps data. Section 4 contains estimation results and an application of these estimates to the Tennessee River basin. A discussion of potential model and data improvements is provided in Section 5, while the relationship between flood risk and property values is discussed in Section 6. Final conclusions can be found in Section 7.

1. Literature Review

Economic literature has provided only limited basis for empirical models of flood damages useful to this analysis. The most applicable literature relied on economic, demographic and flood characteristics as basis for empirical modeling of damages. As part of this effort to construct damage simulation models the study team modified existing efforts to estimate damages to match data availability and regional variation.

Agarwal and Roy [1991] provide a model of damage assessments for south Asian flooding using duration of flood in days, number of people affected by flood, per capita income, household types and other data. Krzystofowicz and Davis [1983] employ a similar model with expected number of floods per year, decision (forecast) time, average actual lead time, actual flood crest, probability of the actual crest, maximum possible damage for the reach category (economic variables) among others. These results employed data similar to that of Whipple [1969], in one of the earliest studies. Wind, Nierop, de Blois, and de Kok [1999] provide evidence from the Meuse River that experience with floods mitigates damages in later events. This led the study team to include the number of flood events in its model, a strategy that was empirically rejected in these data. Other issues such as data availability with respect to actual site damages was reviewed in Adams [1993] for flood damages in Africa. This experience was similar to the region analyzed here. Aleseyed, Rephann, and Isserman [1998] evaluated the presence of water development projects on regional income and growth, presenting an endogeneity issue in estimation that was not directly evaluated in the econometric analysis. Ramirez [1988] and other studies evaluated the benefits of mitigation on flood damages. Other research evaluated agricultural damages using river flow and regional crop yields (see Morris and Hess, 1988). Weiner [1996] provides a strong argument for studies of this type. These studies recommend an econometric damages model that we describe in the following section.

2. Methodology and Data

The basic premise that underlies the analysis is that the magnitude of flood damages within specific categories is functionally related to the economic and demographic conditions that were evident prior to the flood, as well as the hydrological and hydraulic characteristics of the event itself. This construct can be represented functionally as:

$M_i = f(\mathbf{D}, \mathbf{E}, \mathbf{F})$

Where:

M_i = The monetary value of flood damages within the i^{th} damage category.

D = A vector of demographic variables including but not limited to total population, age distribution, geographic dispersion.

E = A vector of economic variables, including but not limited to per capita personal income, number of commercial establishments, industrial mix, extent and value of public infrastructures.

F = A vector of variables describing the flood event(s), including but not limited to the maximum stage above flood, the duration of the flood event(s), and the maximum flows associated with the flood event, the length of any period of warning, and prior flood histories.

All data are defined on a county specific basis, so that the value of the damages within each category is the total dollar value for the county in question during 1993.[2] In some cases, specific variables are relevant to only a few damage categories. For example the miles of rail line within a county is a good predictor or rail infrastructure damages, but it is of little value in predicting other damages. Likewise, the annual value of agricultural production is useful in estimating agricultural damages, but is not particularly valuable in estimating other damages. Alternatively, there are more general variables such as population and the number of business establishments that were useful predictors of damages in nearly every damage category. Ultimately, the inclusion or exclusion of specific variables within any given specification was treated as a purely empirical matter. The modeling effort also addressed the size of the damage center by creating three separate models for damage centers.

[2] For those counties that experienced multiple flood events, the countywide value also represents a sum across all events.

Four separate Corps districts collected damage data for a variety of damage categories.[3] These data summarized in Table 3.1 and are provided in full within Appendix A. Demographic and economic data were gathered from a variety of sources. Census data were based on 1990 values. Economic and Demographic data are summarized in Table 3.2

Flood data (summarized in Table 3.3) are from two principal sources – the Corps and the US Geological Survey (USGS). Each entity operates hundreds of monitoring stations or "gauges" within the upper Mississippi, Missouri, and Illinois River basins. The Corps monitors river and stream elevations or "stages", while the USGS monitors flows. From the standpoint of predicting flood damages, the study team saw both measures as potentially valuable. Unfortunately, there appears to be very little coordination between the Corps and the USGS in terms of collecting and correlating hydrological and hydraulic data. In most instances, Corps and USGS gauges on a waterway within a county are not at the same location. Moreover, even when they are co-located, they very often have different site names. As Section 4 suggests, future analytical efforts would greatly benefit from better coordination between the two federal entities.

[3] For a description of data collection methods see US Army Corps of Engineers, North Central Division, (1994) *The Great Flood of 1993 Post-Flood Report: Upper Mississippi River and Lower Missouri River Basins*. September 1994 (six volumes).

Table 3.1

Description of Upper Mississippi, Missouri, and Illinois River Basin Damages

Damage Category	*Number of Counties Reporting Damages*	*Average Value for Counties with Damages*	*Maximum Value for Counties with Damages*	*Total Across All Counties*
Damages to Residential Structures	428	1,303,304	76,538,048	557,814,053
Damages to Residential Contents	371	547,380	57,785,894	203,078,010
Damages to Commercial Structures	335	1,007,813	51,838,939	337,617,315
Damages to Commercial Equipment	245	1,694,620	121,707,659	415,181,822
Commercial Revenue Losses	310	639,585	22,671,163	198,271,402
Damages to Public Structures	321	285,868	9,977,456	91,763,725
Damages to Publicly Owned Equipment	13	99,737	364,038	1,296,586
Cleanup and Restoration of Public Facilities	337	163,090	3,651,401	54,961,414
Damages to Parks and Recreation Facilities	307	65,699	873,788	20,169,651
Damages to Water Control Facilities	242	557,413	27,264,565	134,893,924
Damages to Railroad Properties	99	932,744	9,805,227	92,341,654
Road and Bridge Damage	175	966,270	18,244,352	169,097,286
Damages to Trucking Facilities	7	700,286	2,960,000	4,902,000
Damages to Airports	18	2,294,707	24,400,000	41,304,723
Damages to Navigation Facilities	66	883,616	11,066,000	58,318,655
Sewer System Damages	65	638,694	14,499,463	41,515,081
Damages to Electric Utilities	35	407,967	6,600,000	14,278,851
Other Utility Damages	111	190,588	2,300,000	21,155,224
Crop Damage	408	8,486,155	91,037,500	3,462,351,202
Damages to Farm Buildings	292	951,265	20,300,000	277,769,484

Table 3.2
Economic and Demographic Characteristics

	County Average	*Maximum*	*Minimum*
Population	36,430	994,640	1,220
Area (Sq. Miles)	669	2,576	62
Population per Sq. Mile	83	6,377	1
Per Capita Income	15,643	26,935	7,933
Number of Residence	15,044	401,839	583
Number of Business	925	29,574	20
Population of Largest City	16,137	441,574	218

Note: All Values are from 1990 except "Population of Largest City" which is from 2000.

Table 3.3
Sample Flood Characteristics

State	*Average Number of Flood Events*	*Average of Ft Above Flood Stage*	*Average of Max Flow*
Illinois	4.9	11.36	25,504
Iowa	3.6	7.63	31,231
Missouri	4.5	12.52	50,311

Note: Flooding occurred in a number of other mid-western states. However, the data developed within the current context only supports the development of summary statistics for the three hardest hit states.

3. Estimation Results and a Tennessee Basin Application

Three distinct models were created for small, medium and large damage centers (as estimated by the Tennessee Valley Authority). Small damage centers suffered damages of less than $20 million, medium from $20 to $50 million and large centers greater than $50 million. This permitted us to ameliorate, in part, the impact of non-linearities in damages. Tables 4.1 through 4.3 summarize the model specifications coefficient estimates used to estimate the damages within 15 distinct damage categories. All coefficient estimates are based on ordinary least squares or non-linear least squares regressions. All were corrected for heteroscedasticity using White's [1980] heteroscedasticity invariant variance-covariance matrix.

Generally, county populations or population densities, the number of business establishments, and the maximum number of feet above flood stage were reliable predictors of flood damages. Somewhat surprisingly, the maximum flow and flood duration were not. The result with respect to flows likely owes to the fact that flows are measured within the normal course of the waterway, not in flooded areas. The quality of overall model fit varies widely between damage categories. Clearly, in some instances the estimated models explain a sufficient amount of observed variations to afford a high degree of confidence. Just as clearly, however, for other damage categories, this conclusion does not hold.

Perhaps the best test of the overall system's reliability is a comparison of model values to damage estimates prepared under the traditional survey methodology. Accordingly, the model was used to predict damage estimates for 10 of the 11 TVA damage centers where survey data are available. The comparison is presented in Table 3.2. Within the data from the upper Mississippi, mean value for the maximum elevation above flood stage is 10.6 feet. Thus, the best comparison between the TVA data and the model generate estimates is at that elevation. In some cases, however, the survey-generated TVA damage curves did not allow for a comparison at that precise elevation, so the nearest elevation was used.

In five of 11 cases, the TVA data validated the model generated damage estimates. In an equal number of damage centers, the model-generated estimates were significantly higher than those produced through the survey method – so much so that they must be judged as unreliable. A closer examination of the damages centers where the model fails yields some important clues as to how the modeled system may be made to perform better. Equations for most damage categories include variables that capture the amount of residential and / or commercial activity within each county. Generally, these measures are good proxies for the amount of residential and commercial activity that is at risk during a flood event. However, where a disproportionate amount of activity is within a county's boundaries, but outside the flood plane(s), the modeled system of damage estimation tends to overestimate the degree of flood damage. This is precisely the case for three of the TVA damage centers where the model failed to produce reliable results. Specifically, Knoxville, Clinton, and Elizabethton contain small flood plane areas relative to the amount of economic and residential activity within the respective counties (Knox, Anderson, and Carter).[4]

[4] In the case of Knox and Anderson Counties, the error is traceable to the disproportionately high amount of residential and commercial activity that lies outside the flood plane. In the case of Carter county, the error is due to the steep terrain that measurably limits the size of the flood plane.

Table 4.1: Large Damage Centers Estimated Model Coefficients

	c	BUS01	RES01	pcincome	POP/ AREAINSQ	hwymile	Pop	FTABOVE	COMSTRD	RESSTRD	Res100	ELECREV	Adj-R^2
Commercial Structure	927513.4	4180.078	-185.7553								-187.599		0.81
Commercial Equipment	-3419527	1350.922							2.067087		-318.9444		0.65
Residential Structure Damages									1.47998		-175.3708		0.71
Residential Contents	-1267154		-226.0791				118.9452			0.374149	-171.9938		0.92
Commercial Revenues	1712696	341.4776		-143.6377	2680.036				0.342306		-79.33487		0.94
Electricity Damages	-197441.7								-0.038892	0.117491			0.81
Electricity revenues										0.014329	-1.247492	-0.095582	0.31
Truck Damages	49707.51						8.052025	-12549.92			-50.10565		0.96
Mission Damages	437773.5												0.00
Highway Damages	462332.8					41697.05							0.36
Sewer Damages									0.254656				0.56
Water Damages								45507.7					0.08
Rail Damages Damages									0.16116	0.16116			0.68
Emergency Damages	226633.9						1.422861		0.07187				0.19
Federal Building Damages									0.550773				0.26
Airport Damages									0.100549				0.14

C = Constant Intercept Term
BUS01 = Number of Business Establishments
RES01 = Number of Residences
POPDEN = Population Density per Sq. Mile
POPULTN = County Population
ELECREV = Electricity Revenue Damabges
FTABOVE = Maximum Feet Above Flood Stage for Flood Events
COMSTRD = Magnitude of Damages to Commercial Structures
RESSTRD = Magnitude of Damages to Residential Structures
INCOME = Per Capita Personal Income
HWYMILE = The Number of Highway Miles within the County
RES100 =The number of residential structures (100 year flood plain)

Table 4.2:
Medium Damage Centers Estimated Model Coefficients

	C	BUS01	POP/ AREAINSQ	hwymile	Pop	pcincome	COMSTRD	resstrd	RES100	ELECREV	Adj-R^2
Commercial Structure	4558120	399.891									**0.24**
Commercial Equipment							0.563894				**0.82**
Residential Structure Damages							1.784678		833.5212		**0.43**
Residential Contents					5.43402			0.59808			**0.82**
Commercial Revenues	1712696	341.478	2680.036			-143.6377	0.342306		-79.33487		**0.94**
Electricity Damages	-197441.7						-0.038892	0.11749			**0.81**
Electricity revenues								0.01433	-1.247492	-0.095582	**0.31**
Truck Damages	49707.51				8.05203	-12549.92			-50.10565		**0.96**
Mission Damages	437773.5										**0.00**
Highway Damages	462332.8			41697.05							**0.36**
Sewer Damages							0.254656				**0.56**
Water Damages						45507.7					**0.08**
Rail Damages								0.16116			**0.68**
Emergency Damages	226633.9				1.42286		0.07187				**0.19**
Federal Building Damages							0.550773				**0.26**

C	= Constant Intercept Term	FTABOVE	= Maximum Feet Above Flood Stage for Flood Events
BUS01	= Number of Business Establishments	COMSTRD	= Magnitude of Damages to Commercial Structures
RES01	= Number of Residences	RESSTRD	= Magnitude of Damages to Residential Structures
POPDEN	= Population Density per Sq. Mile	INCOME	= Per Capita Personal Income
POPULTN	= County Population	HWYMILE	= The Number of Highway Miles within the County
ELECREV	= Electricity Revenue Damabges	RES100	=The number of residential structures (100 year flood plain)

Table 4.3: Small Damage Centers Estimated Model Coefficients

	C	BUS01	pcincome	POP/AREAINSQ	hymile	Pop	Ftabove	COMSTRD	resstrd	res100	ELECREV	
Commercial Structure										11448.03		**NA/No C**
Commercial Equipment								0.563894				**NA/ No C**
Residential Structure Damages								1.04909		686.6194		**0.35**
Residential Contents								0.722967		-7368.068		**0.82**
Commercial Revenues	2E+06	341.478	-143.638	2680.04				0.342306		-79.33487		**0.94**
Electricity Damages	-2E+05							-0.038892	0.1175			**0.81**
Electricity revenues									0.0143	-1.247492	-0.09558	**0.31**
Truck Damages	49708					8.052	-12549.9			-50.10565		**0.96**
Mission Damages	4E+05											**0.00**
Highway Damages	5E+05				41697							**0.36**
Sewer Damages								0.254656				**0.56**
Water Damages							45507.7					**0.08**
Rail Damages Damages								0.16116				**0.68**
Emergency Damages	2E+05					1.4229		0.07187				**0.19**
Federal Building Damages	5E+05							0.060136				**0.02**

C	= Constant Intercept Term	FTABOVE	= Maximum Feet Above Flood Stage for Flood Events
BUS01	= Number of Business Establishments	COMSTRD	= Magnitude of Damages to Commercial Structures
RES01	= Number of Residences	RESSTRD	= Magnitude of Damages to Residential Structures
POPDEN	= Population Density per Sq. Mile	INCOME	= Per Capita Personal Income
POPULTN	= County Population	HWYMILE	= The Number of Highway Miles within the County
ELECREV	= Electricity Revenue Damabges	RES100	=The number of residential structures (100 year flood plain)

Table 4.4
Tennessee River Basin Comparative Damage Estimates: Full Model

Damage Center	Difference	CBER		TVA	Percent Diff
Clinton	$7,560,967	$7,910,967	(4.67 ft)	$350,000	91.53%
Chattanooga	$13,984,288	$84,284,288	(10.5 ft)	$70,300,000	9.05%
Cooperhill	$9,311,552	$9,365,952	(10 ft)	$54,400	98.85%
Decatur	$10,424,375	$31,732,277	(5.18 ft)	$21,307,902	19.65%
Elizabethton	$12,682,742	$12,832,068	(10 ft)	$149,326	97.70%
Fayetteville	-$8,483,160	$25,816,840	(11.8 ft)	$34,300,000	-14.11%
Kingsport	$12,041,195	$33,741,195	(11.7 ft)	$21,700,000	21.72%
Knoxville	$17,660,233	$22,550,233	(11.2 ft)	$4,890,000	74.68%
Lenoir City	-$4,062,570	$39,849,180	(14.3 ft)	$43,911,750	-4.85%
Savannah	$25,567,119	$25,676,119	(11.6 ft)	$109,000	99.15%
South Pittsburg	$9,123,386	$25,623,386	(10 ft)	$16,500,000	21.66%
Total	**$105,810,127**	**$319,382,505**		**$213,572,378**	**19.85%**

The current TVA methodology measures only the value of damages to residential and commercial structures and their contents. To account for damages to public infrastructure such as roadways, utilities, and rail lines, TVA scales survey results to 120 percent of their estimated levels. This is viewed (appropriately) as a conservative method of estimating additional damages that cannot be easily captured under the survey method employed by TVA. In order to assess the efficacy of this approach we conducted a second set of estimation in which we simulated flood damage impacts only to commercial and residential structures. Through this approach we may potentially evaluate the efficacy of the 20% scalar of damages. Results appear in Table 4.5.

Table 4.5
Tennessee River Basin Comparative Damage Estimates: Structures

	Difference	CBER		TVA	Percent Difference
Clinton	-$92,770	198,897	(4.67 ft)	$291,667	-18.91%
Chattanooga	-$6,508,936	52,074,397	(10.5 ft)	$58,583,333	-5.88%
Cooperhill	$4,012,164	4,057,497	(10 ft)	$45,333	97.79%
Decatur	$2,852,385	20,608,970	(5.18 ft)	$17,756,585	7.43%
Elizabethton	$3,893,280	4,017,718	(10 ft)	$124,438	93.99%
Fayetteville	-$12,103,722	16,479,612	(11.8 ft)	$28,583,333	-26.86%
Kingsport	$1,898,641	19,981,975	(11.7 ft)	$18,083,333	4.99%
Knoxville	$3,483,083	7,558,083	(11.2 ft)	$4,075,000	29.94%
Lenoir City	-$18,570,347	18,022,779	(14.3 ft)	$36,593,125	-34.00%
Savannah	$7,467,250	7,558,083	(11.6 ft)	$90,833	97.62%
South Pittsburg	-$6,191,917	7,558,083	(10 ft)	$13,750,000	-29.06%
TOTAL	**-$19,860,888**	**$158,116,094**		**$177,976,982**	**-5.91%**

The current research suggests that the 20% scalar may be significantly underestimating the magnitude of these additional damages. A review of the results presented in Table 4.1 must lead one to conclude that the modeled estimates are not sufficiently reliable to support any conclusion in most infrastructure damage categories. There is simply too much unexplained variation However, the summary statistics presented in Table 2.1, in and of themselves, are strong evidence that the TVA scalar is too low. The 1993 flood damages to structures and contents totaled more than $1.5 billion. Corresponding damages to public infrastructures totaled more than $0.9 billion. Thus, in the upper Mississippi, Missouri, and Illinois River basins the relevant scalar was more than 0.6, triple the value used by TVA.[5] While there may be economic, demographic, or topological variations that partially explain variations in damages between the Tennessee River basin and the mid-west, it seems unlikely they of this magnitude.[6] In addition, the difference between total damage calculations in Table 3.2 and 3.3 suggest that a scalar in the range of 40% to 50% may be more appropriate. This figure would still present a conservative estimate of additional damages and yet be lower than that applied on the Upper Mississippi which was derived from actual damage experience.

[5] Crop damages and damages to agricultural structures are excluded from this calculation.

[6] There is no documentation as to the original source of the 20% scalar that has been in use for many years. However, it is worth noting that the magnitude and value of public infrastructure relative to regional population has grown considerably within the Tennessee River basin over the past several decades, so that at one point in time, the 20% value may well have been valid.

The ultimate aim of the current methodology is to provide a system for estimating flood damages that can be substituted for traditional survey methods, at least in some settings. The results presented here suggest that this aim may well be achievable, but that further model refinements are required if modeled flood damage estimates are to have the necessary degree of reliability. Thus the next section is devoted to outlining how greater reliability can be attained.

4. Potential Model Improvements

The most promising avenues for refining the current methodology relate to improving the quality of the supporting data. First, there are almost certainly opportunities to add to the current database by improving the way in which stage and flow data are matched to specific geographic locations. As noted in Section 2, the Corps and USGS data are generally incompatible, so that it was necessary to hand-match these data. In doing so, there were almost certainly errors and omissions that could be corrected in subsequent efforts. Policy-makers may also wish to consider compelling these entities to integrate data collection efforts to the extent possible.

Second, the data could be expanded to include information describing flood histories within each of the effected counties. The Corps damage data reflects annual summaries for 1993, so that it is impossible to identify how earlier flood events impacted the magnitude of the damages sustained in later floods. However, with sufficient time and resources, it should be possible to quantify the flood history of each county within the region. Supplementing the data in this fashion would allow the analysis to determine whether past experiences with flood events helps communities to mitigate damages during future occurrences.

Similarly, while advance warning may or may not make it possible to reduce damages to structures, it almost certainly should improve the ability to protect contents. The current analysis does not include any measure of warning times, yet these warning times varied from a minimum of a few hours on tributaries to a maximum of several days on the lower reaches of the upper Mississippi. Again, it should be possible to quantify average countywide warning times for inclusion within the analysis.

Finally, the greatest opportunity for improvement likely lies in potential to more accurately represent each county's exposure to flooding. The current analysis increases this exposure linearly based on water elevation and the magnitude of population and economic activity. There are, at least, three reasons why this representation is suboptimal. First, the existence of variations in terrain within flooded areas leads to non-linearities in the area of the flood with each incremental increase in water elevation. Second, if the flooding were the result of a breach in a levy or floodwall, so that floodwaters are dispersed from a single location, the increase in flooded acreage associated with an incremental increase in water elevation would also be non-linear. Finally, as Knox and Anderson Counties aptly demonstrate, if the terrain is such that large segments of the population and related commercial activity are naturally protected from flood events within the county, the degree of exposure (and resulting damage) is measurably lower.

There is a feasible two-tiered approach for supplementing currently available data to better reflect exposure to flood related damages. Both involve the further application of Geographic Information Systems (GIS). The first step in the process would be to calculate the maximum acreage flooded during the 1993 floods in each affected county. This variable would reflect the nonlinearities noted above and should, therefore, more accurately measure the extent of the flooding (as opposed to feet above flood stage). Note, however, that to apply the model to areas where floods have not occurred would require estimating flood acreage at various levels of water elevation.

The second step in providing a better measure of flood risk exposure would require the same GIS application as described above. However, flood acreage data would be combined with Census block level population data to estimate the residential and commercial populations at risk under various flood scenarios.

Finally, though we believe that these approaches represent an effective and cost efficient improvement in flood damage estimates they are not a substitute for the site specific census of structures currently undertaken by the TVA. The current practice of surveying a region's structures and estimating damages from visual inspection of the location likely provides the best estimates of flood damages short of an actual flooding event. However this method is so resource intensive that it will likely be applied only to a limited number of damages centers. The continuation of this method is useful for a variety of reasons, not the least of which is that it provides a beneficial calibration of the models described in this document.

5. Flood Risks and Property Values

Economic theory suggests that changing the probability of flooding in a specific area can convey benefits or impose costs regardless of whether or not flooding actually occurs simply by altering property values. To confirm this potential outcome, the study team contacted professional appraisers in the Chattanooga area. The consensus is that exposure to flood risk does affect property values, so that changing the probability of flooding could increase or decrease property values. However, there is no formulaic treatment of flood risk in the appraisal process. Instead, appraised values are entirely driven by property comparisons, so that the appraised value of a property where there is a risk of flooding is impacted by the extent to which flood risk has affected transactions for similar properties.

6. Concluding Remarks

The current analysis was undertaken with the general aim of using existing flood data and resulting flood damage estimates to predict the damages to transportation infrastructures that might be expected in the wake of future flood events. However, early in the analytical process, the study team elected to broaden the scope of the analysis to include all damage categories for which adequate data are available. Estimation results were compared to survey-generated flood damage estimates provided by the Tennessee Valley Authority. The comparisons suggest that, in some settings, the new methodology produces reliable results. In other instances, the modeled estimates significantly exceeded survey-based values. By carefully examining those damage centers where the deviations between survey and modeled values is the greatest, the study team has identified probable corrective actions that should significantly improve the accuracy of the modeled outcomes.

On a related matter, the TVA currently uses a scalar of 20% to reflect the damages that extend beyond structural value and the value of structure contents. While the model results neither support nor refute the magnitude of the scalar, a relatively careful examination of the raw 1993 damage data from the upper Mississippi, Missouri, and Illinois River basins suggest that the actual ratio of "other" damages to residential and commercial damages may be 0.6 or higher. Thus, current TVA estimates of the benefits from flood control may be measurably understated.

In terms of further analysis, there are reasons to further pursue the methodology developed herein and there are, likewise, reasons to abandon it. To the positive, the results presented here demonstrate that it *may* be possible to refine the model estimation techniques, so that they produce reliable estimates in most settings. However, the data from the 1993 floods stand as the only known source of broad cross-sectional damage estimates. To the extent that these data are, in any way, unreliable, all subsequent analytical efforts will be suspect. In any case, resulting model parameters will likely become dated, this in a setting where there is little opportunity to re-estimate these parameters.

7. REFERENCES

Adams, W. M. **(1993)**. Development's Deaf Ear: Downstream Users and Water Releases From the Bakolori Dam, Nigeria. *World Development*. Vol. 21, No. 9, 1405-1416.

Aleseyed, Mostafa; Rephann, Terance; Isserman, Andrew **(1998).** The Local Effects of Large Dam Reservoirs: US Experience, 1975- 1995. *Review of Urban and Rural Development Studies.* Vol. 10, No. 2, 91-108.

Arnell, Nigel W.; Gabriele, Salvatore **(1998).** The Performance of the Two-component Extreme Value Distribution in Regional Flood Frequency Analysis. *Water Resources Research.* Vol. 24, No. 6, 879-887.

Batabyal, Amitrajeet A **(2001).** On flood occurrence and the provision of safe drinking water in developing countries. *Applied Economics Letters*. Vol. 8, No. 12, 751-754.

Browne, Mark J.; Hoyt, Robert E. **(2000).** The Demand for Flood Insurance: Empirical Evidence. *Journal of Risk and Uncertainty*. Vol. 20, No. 3, 291-306.

Bruce, James B. **(1978).** Public Opinion on Flood Recovery Policy Issues in Matewan, West Virginia: Report of a Survey for the Matewan Town Council.

Driscoll, Paul; Dietz, Brian; Alwang, Jeffrey **(1994).** Welfare Analysis When Budget Constraints Are Nonlinear: The Case of Flood Hazard Reduction. *Journal of Environmental Economics and Management*. Vol. 26, No. 2, 181-199.

Gram, Soeren **(2001).** Analysis: Economic valuation of special forest products: an assessment of methodological shortcomings. *Ecological Economics*. Vol. 36, No. 1, 109-117.

Green, Gareth P.; O'Connor, John P. **(2001).** Water Banking and Restoration of Endangered Species Habitat: An Application to the Snake River. *Contemporary Economic Policy*. Vol. 19, No. 2, 225-237.

Hammitt, James K.; Liu, Jin-Tan; Liu, Jin-Long **(2001).** Contingent valuation of a Taiwanese wetland. *Environment and Development Economics*. Vol. 6, No. 2, 259-268.

Harrison, David M.; Smersh, Greg T.; Schwartz, Jr.; Arthur L. **(2001).** Environmental Determinants of Housing Prices: The Impact of Flood Zone Status. *Journal of Real Estate Research.* Vol. 21, No. 1-2, 3-20.

Holway, James M.; Burby, Raymond J. **(1990).** The Effects of Floodplain Development Controls on Residential Land Values. *Land Economics*. Vol. 66, No. 3, 259-271.

Karlinger, M. R.; Attanasi, E.D. **(1980).** Flood Risks and the Willingness to Purchase Flood Insurance. *Water Resources Research*. Vol. 16, No. 4.

Kunreuther, Howard; Miller, Louis **(1985).** Interactive Computer Modeling for Policy Analysis: The Flood Hazard Problem. *Water Resource Research*. Vol. 21, No. 2.

Kunreuther, Howard; Sheaffer, John R. **(1970).** An Economically Meaningful and Workable System for Calculating Flood Insurance Rates. *Water Resources Research*. Vol. 6, No. 2.

Lachman, Steven Frederic **(2001).** Should Municipalities be Liabl for Development-Related Flooding? *Natural Resources Journal*. Vol. 41.

MacDonald, Don N.; Murdoch, James C.; White, Harry L. **(1987).** Uncertain Hazards, Insurance and Consumer Choice: Evidence from Housing Markets. *Land Economics*. Vol. 63, No. 4, 39-49.

MacDonald, Don N.; White, Harry L.**(1990).** Flood Hazard Pricing and Insurance Premium Differentials: Evidence From the Housing Market. *Journal of Risk Management*. Vol. 57, No. 4, 654-663.

Mustafa, Daanish **(1998).** Structural Causes of Vulnerability to Flood Hazard in Pakistan. *Economic Geography*. Vol. 74, 289-305.

Niewiadomska-Szynkiewicz, Ewa; Malinowski, Krysztof; Karbowski, Andrzej **(1996).** Predictive methods for real-time control of flood operation of a multireservoir system: Methodology and comparative study. *Water Resources Research*. Vol. 32, No. 9, 2885-2895.

del Ninno, Carlo; Dorosh, Paul A. **(2001).** Averting a food crisis: private imports and public targeted distribution in Bangladesh after the 1998 flood. *Agricultural Economics*. Vol. 25, 337-346.

Paul, Bimal Kanti **(1995).** Farmer's Response the Flood Action Plan (FAP) of Bangladesh: An Empirical Study. *World Development*. Vol. 23, No. 2.

Ramirez, Jorge; Adamowicz, Wiktor L.; Easter, Wiliam K.; Graham-Tomasi, Theodore **(1988).** Ex Post Analysis of Flood Control: Benefit-Cost Analysis and the Value of Information. *Water Resources Research*. Vol. 24, No. 8, 1397-1405.

Reiss, R.D.; Thomas, M. **(2002).** Statistical Analysis of Extreme Values. *MSOR Connections*. Vol. 2, No. 2.

Salazar, Joanna Gail **(2000).** Damming the Child of the Ocean: The three Gorges Project. *Journal of Environment and Development*. Vol. 9, No. 2, 160-174.

Shabman, Leonard; Stephenson, Kurt **(1992).** The Possibility of Community-wide Flood Control Benefits: Evidence From Voting Behavior in a Bond Referendum. *Water Resource Research*. Vol. 28, No. 4, 959-964.

Shabman, Leonard; Stephenson, Kurt (1996). Searching for the Correct Benefit Estimate: Empirical Evidence for an Alternative Perspective. *Land Economics*. Vol. 72, No. 4, 443-449.

Shilling, James D.; Sirmans, C. F.; Benjamin, John D. **(1989).** Flood Insurance, Wealth Redistribution, and Urban Property Values. *Journal of Urban Economics*. Vol. 26, No. 1, 43-53.

Tasker, Gary D.; Moss, Marshall E. **(1979).** Analysis of Arizona Flood Data Network for Regional Information. *Water Resources Research*. Vol. 15, No. 6.

Theiler, Donald F. **(1969).** Effects of Flood Protection on Land Use in the Coon Creek, Wisconsin, Watershed. *Water Resources Research*. Vol. 5, No. 6.

Topping, Audrey R**. (1995).** Ecological Roulette: Damming the Yangtze. *Foreign Affairs*. Vol. 75, No. 5, 132-146.

US Army Corps of Engineers, North Central Division, **(1994)** *The Great Flood of 1993 Post-Flood Report: Upper Mississippi River and Lower Missouri River Basins*. September 1994 (six volumes).

White, Halbert **(1980)** "A Heteroskedasticity-Consistent Covariance Matrix and a Direct Test for Heteroskedasticity," *Econometrica*, 48, 817–838.

Wiener, John D. **(1996).** Research opportunities in search of federal flood policy. *Policy Sciences*. Vol. 29, 321-344.

Young, Robert A. **(1996).** Measuring Economic Benefits for Water Investments and Policies. *Technical Paper, no. 338. Washington, D.C.: World Bank*