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How Accurate are Disaster Loss Data? The Case of U.S. Flood Damage

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Abstract. Policy makers need accurate disaster loss data for decisions about disaster assistance, policy evaluation, and scientific research priorities. But loss estimation is difficult in a disaster situation, and initial loss estimates are seldom evaluated in comparison with actual costs. This paper uses the example of historical flood damage data in the U.S. to evaluate disaster loss data. It evaluates the accuracy of historical flood damage estimates from two federal agencies. The U.S. National Weather Service (NWS) has compiled annual flood loss estimates for each state since 1955. Comparison of the NWS data with similar estimates from five state emergency management agencies reveals substantial disagreement between estimates from different sources. The Federal Emergency Management Agency (FEMA) began in the 1990s to systematically collect damage estimates and cost data associated with its disaster assistance programs. Comparison of early damage estimates with actual expenditures in a California flood disaster reveals large errors in some estimates for individual counties, but no statistically significant tendency to underestimate or overestimate. Positive and negative errors tend to average out and the total damage estimate for the state approximates the final expenditures. Both comparisons indicate that damage estimates for small events or local jurisdictions often are extremely inaccurate. On the other hand, estimates aggregated over large areas or long time periods appear to be reasonably reliable; that is, this study finds that independent estimates for events with losses greater than $500 million disagree by less than 40%. The paper suggests ways of interpreting and using such loss estimates to reduce the likelihood of misinterpretation.

Key words: disaster loss, loss estimation, flood damage, cost estimates

1. Introduction

In the aftermath of every disaster, estimates of economic losses appear related to the disaster. These estimates are repeated and repeated until eventually they take on a semblance of truth. Changnon (1996) relates that in the aftermath of the Great Mississippi Flood of 1993 various agencies and experts presented widely diverging estimates of the costs of the event, differing

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by many billions of dollars. The experience that Changnon documents is common and raises questions about the accuracy of disaster loss estimates. What do they refer to in the first place? Perhaps most importantly, in what ways does having reliable disaster loss data really matter?

Accounting for disaster losses does matter because decision makers use loss information as input to a range of important decisions. Among the most important of these are federal government decisions about the provision of disaster relief assistance, e.g., how much, when, and in what form. Loss estimates provide a sense of urgency and need; and as we have documented elsewhere, federal policy is inconsistent in its use of loss data in making decisions about disaster aid (Downton and Pielke, 2001). Decision makers also use trends and spatial patterns in losses as measures of policy successes and failures and consequently shape thinking about a wide range of policies such as flood insurance and climate policy (NRC, 1999).

Science policy decisions represent a particularly important area for the application of disaster loss data, both to set priorities about what science to fund and to evaluate the contributions of science to real-world outcomes. In a review of federal funding for research and development to prevent disaster losses, prepared for the White House Office of Science and Technology Policy, Meade and Abbott (2003, p. xiii) argue, "Without such data, it is impossible to gauge either the effectiveness of new R&D strategies or their ultimate payoff in terms of losses prevented." Thus, accounting for disaster losses matters a great deal. To the extent that loss information is used in decision making related to disaster assistance, policy evaluation, and science policy, having accurate and reliable data has potential to improve the information base on which such decisions are made.

Accounting for the costs of disasters is inherently complicated for three reasons. First, disasters have direct costs, such as the destruction of a building, but also indirect costs. For example, a community may see property values decrease in years after a disaster and experience a corresponding loss of property tax revenue. Disasters also have direct and indirect benefits, such as when a community receives an infusion of disaster relief funds that pours money into the local economy (cf. Changnon, 1996; Pielke and Pielke, 1997). Second, a disaster's losses are a function of the spatial and temporal scale that the analyst chooses as the focus of a particular loss analysis. For example, federal disaster assistance shifts some of the losses from the local economy to the federal government; and, for more than 100 years the sea wall built after the 1900 Galveston hurricane has provided benefits in lives saved and losses avoided in subsequent storms. For the same event, analysts can develop equally rigorous analyses of losses that differ a great deal (cf. Guimaraes *et al.*, 1993). Finally, many losses (and benefits) associated with a disaster are intangible. For example, widespread damage to agricultural land that results in crop losses can affect commodity prices and thus necessitates a counterfactual argument (i.e., what would commodity prices have been without the event) in order to estimate the economic losses associated with the crops that never went to market. Thus, the true costs of disasters include hidden costs and benefits which are difficult to identify and quantify.

Several reports have made the case for policy makers to collect disaster loss data in a rigorous and systematic manner (e.g, NRC, 1999; Heinz Center, 2000; Changnon, 2003; Meade and Abbott, 2003). The National Research Council (NRC, 1999) recommends focusing on direct costs, such as property and crop losses and repairs to public infrastructure, which are most tractable for systematic reporting and quantification. Yet, even when limited to direct costs, loss estimation is difficult in a disaster situation. Using the example of flood damage data in the U.S.A., this paper seeks to illuminate some of the technical issues, ambiguities, and errors associated with collecting and using disaster loss data.

This paper presents results from a comprehensive reanalysis of the U.S.A. flood damage database (Pielke *et al.*, 2002). It proceeds on the premise that many of the lessons learned about flood loss data are applicable in the context of other sources of loss data for a wide range of disasters. It first describes characteristics of the long-term record of flood losses in the U.S.A., which has been kept for nearly 100 years by the National Weather Service. It then compares parts of this record with independent datasets from individual states. Next, using data from the 1998 El Niño flood disaster in California, it compares a set of loss estimates with actual expenditures. Such a comparison provides a rigorous evaluation of the accuracy of initial estimates. To the extent that the process for generating initial estimates in the California case study mirrors that used to estimate losses associated with disasters generally, the case provides some insight as to their accuracy. The paper concludes with lessons and suggestions for appropriate use of flood loss data and disaster data generally.

2. Flood Damage Data in the U.S.A.

The U.S.A. NWS is the only organization that has maintained a long-term and fairly comprehensive record of flood damage throughout the country. According to the NWS, the data are "loss estimates for significant flooding events" (NWS, 2004), providing estimates of "direct damages due to flooding that results from rainfall and/or snowmelt." The data sets exclude ocean floods caused by severe wind or tectonic activity (such as storm surge or tsunami). The estimates are restricted to direct physical damage, including loss of property and crops and costs of repairing damaged infrastructure. The agency has used reasonably consistent procedures and criteria to compile annual damage estimates for each state since 1955, except briefly during

1980–1982 when data compilation temporarily stopped (Downton *et al.*, in press; Pielke *et al.*, 2002).

Since at least 1950, NWS field offices across the U.S.A. have submitted reports on severe storms to NWS headquarters. The reports include descriptions of the storms and their impacts, number of deaths, and estimated damages. After a flood event, staff at NWS headquarters compile and check the damage estimates, requesting additional information if reports are unclear or incomplete. However, field office staff have little or no training in damage estimation and obtain their estimates from diverse sources, such as local officials, insurance agents, or newspapers. Typically, the estimation methods used by their sources are unknown. The NWS usually finalizes its damage estimates within three months after a flood event.

How reliable are such estimates? The answer requires an evaluation of their accuracy and completeness. Assessment of accuracy requires comparison of estimates with actual costs, which often are not known until long after a flood event. Unfortunately, actual loss data are rarely collected in a form that can be compared with estimates made at the time of the flood. Thus, loss estimates become "truth." Fortunately, some data are available that allow for a quantitative evaluation of loss data accuracy.

3. Comparison of Flood Damage Estimates from NWS and Several States

The NWS has published flood damage estimates almost annually since 1933, with annual summaries of damage by state beginning in 1955. For the data reanalysis project, NWS flood damage estimates were gathered from published reports and archives of the NWS Hydrologic Information Center. Primary sources were NWS (1950–1977, passim), and USACE (1983–2001, passim), supplemented by information for 1976–1982 from NWS files and publications. The reanalyzed data and detailed information on their collection are available at http://www.flooddamagedata.org.

To obtain comparable damage estimates from other sources, emergency management agencies in every state were contacted with a request for historical data on flood damage in their state. Five states provided published historical summaries or compiled flood damage estimates from their files, covering at least 20 years, which were based on criteria similar to those used by the NWS. State data sources are listed in Table I. The state reports provide damage estimates for each major flood event, sometimes with two or more events occurring in a given year. To match the annual loss estimates provided by the NWS, the flood losses in each state were summed for each year. The comparison covers a total of 155 years in the 5 states: 44 years each in California and Colorado (1955–1998), 24 years in Michigan (1975–1998), 22 years in Virginia (1977–1998) and 21 years in Wisconsin (1973–1993).

Table I. Sources of state flood damage estimates.

State	Years covered	Sources	Description of information used
California	1950–1998	Montane (1999)	Damage estimates for disasters that involved flood, heavy rainfall, or severe storms
Colorado	1864–1998	McLaughlin Water Engineers, Ltd. (1998)	Damage estimates for all major floods
Michigan	1975–1998	Michigan Department of State Police (1999)	Damage estimates for floods that received a presidential disaster declaration or a gubernatorial declaration
Virginia	1977–1999	Michael Cline, Virginia Department of Emergency Services, personal communication (2000)	Damage estimates for presidentially-declared flood disasters
Wisconsin	1973–1993	FEMA (1993) Wisconsin Department of Natural Resources (1993)	Damage estimates for all major floods

The state estimates are subject to the same types of error as the NWS estimates; therefore, neither dataset is assumed *a priori* to be more accurate. The comparison between the datasets focuses on large discrepancies in order to understand how estimates of the same event vary and also to determine whether some floods are overlooked. In the following analysis, all loss estimates are reported in inflation-adjusted 1995 dollars, using implicit GDP price deflators from the U.S. Department of Commerce, Bureau of Economic Analysis.

The NWS discontinued compilation of flood damage data during 1980–1982, restarting in 1983. Several years later, NWS staff attempted to fill the data gap by developing damage estimates from available information, but estimates during that period are particularly unreliable. For example, an NWS estimate of $806 million flood damage in Michigan in 1981 is contradicted by the state's flood report (Michigan Department of State Police, 1999), which lists eight floods since 1975 and describes the 1986 flood as the most damaging with losses of about $400 million, but makes no mention of a flood in 1981. Such errors cast doubt on the reliability of NWS estimates for 1980–1982, so that period has been excluded from the reanalyzed data sets.

As an example of the differences between NWS and state estimates, Figure 1 shows estimated California flood damage during 1983–1998 for the years in which at least one damage estimate was greater than $50 million. Comparison of the estimates in 1995 and 1997 illustrates the problem of

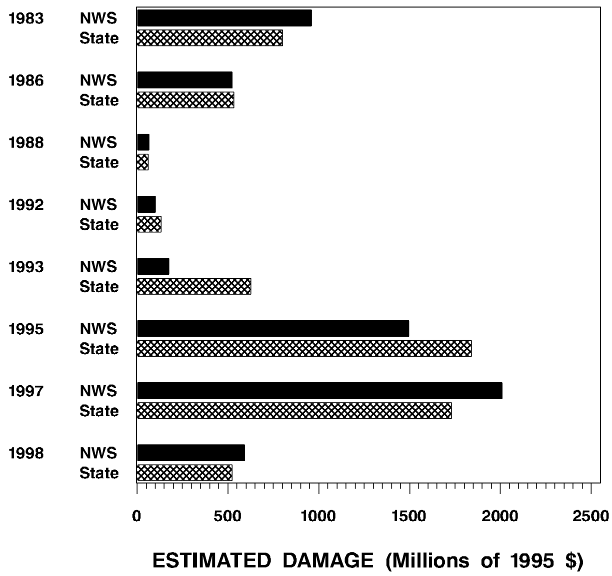

Figure 1. California flood damage, 1983–1998, estimated by the NWS and the state.

using these data to compare individual floods: The NWS estimates indicate that damage was greater in 1997 than in 1995, while the state estimates suggest the opposite conclusion.

The state reports typically focus on severe floods, so generally they do not include years of relatively low flood loss. State damage estimates are missing in 91 of the 155 data-years, and are less than $5 million in only 6 cases. Therefore, years with estimates below $5 million are classified here as "low-damage" and the comparison of damage estimates is considered to be most meaningful above that level. The threshold for reporting appears to be somewhat higher in California, where the lowest reported loss is $15 million. In contrast, the NWS estimates are collected every year so low-damage floods are typically included.

NWS damage estimates are low or missing in 84 of the 155 data-years. The state reports agree, with damage either low or missing, in 78 (93%) of the 84 cases. But two floods involving substantial damage are overlooked entirely by the NWS: California reports flood losses of $50 million in 1979 and $15 million in 1984, while the NWS does not mention any flood losses in California in those years. In four other cases, states claim moderate losses when the NWS estimate is very low: Colorado 1969 and 1983 ($20 and $24 million, respectively), California 1972 ($29 million), and Virginia 1998 ($13 million).

Figure 2 shows the cases that have estimates from both the NWS and the state. Logarithmic scales are used to highlight proportional differences in the estimates. The solid diagonal line represents perfect agreement. Data points

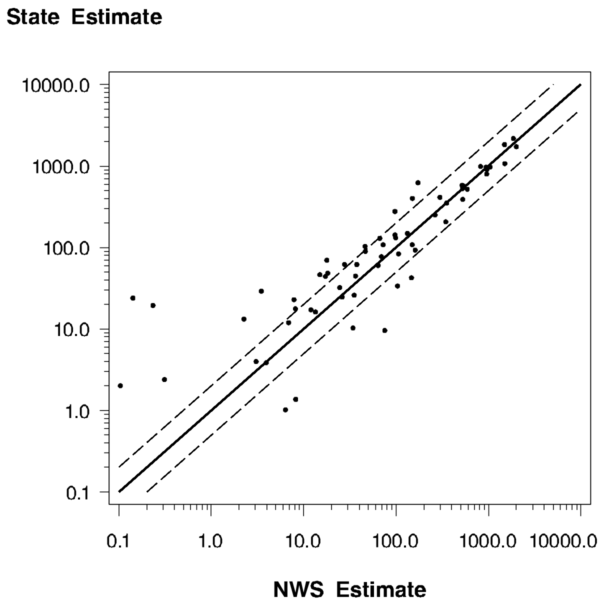

Figure 2. Comparison of NWS and state flood damage estimates in five states, in millions of 1995 dollars.

outside the two dashed lines are cases in which the estimates differ by more than a factor of two. Seventeen cases are above the upper dashed line, representing state estimates more than twice as large as the NWS estimate. Six cases are below the lower dashed line, with NWS estimates more than twice as large as the state estimate.

The closest agreement between state and NWS estimates occurs in floods involving major damage (over $500 million). At the other extreme, the largest proportional disagreements (cases farthest outside the dashed lines) occur when both sources indicate that flood damage was low or moderate (under $50 million).

From the standpoint of the NWS estimates, when the NWS damage estimate is:

(1) moderate ($5–50 million), then 55% of state estimates differ by a factor of 2 or more;
(2) high ($50–500 million), then 30% of state estimates differ by a factor of 2 or more;
(3) major (over $500 million), then none of the differences exceed a factor of 1.4.

There are several plausible explanations why agreement might improve as total damage increases. First, the crisis of a major flood spurs studies by numerous agencies. Collection of damage information is more likely to be systematic and complete in a major flood than in a smaller one. Second, agencies are more likely to share information about major floods (which may lead to increased agreement, but does not necessarily guarantee greater accuracy). In smaller floods, on the other hand, collection of damage information is likely to be haphazard and there is less interest in checking and correcting early damage estimates. Third, the damage in large floods is aggregated from many individual damage estimates so that random errors tend to cancel out (Pielke *et al.*, 2002). Small floods involve less aggregation and, hence, relatively larger proportional errors. Finally, different estimates may reflect different temporal and spatial scales, so there is no guarantee of apples to apples comparison.

4. Comparison of Damage Estimates with Actual Costs

Until recently, even in serious disasters, actual (however actual is defined) total damage costs were not systematically compiled by any government agency. Thus, there was no way of checking the accuracy, or even the reasonableness, of most damage estimates.

In recent years, however, the Federal Emergency Management Agency (FEMA) has systematically collected cost data for the programs it administers, which of course represent only a fraction of a disaster's total costs. Such data allow for a comparison of initial estimates with final expenditures in a manner that sheds some light on disaster costs more generally. Beginning in 1992, FEMA instituted a computerized system for recording and tracking applications for federal assistance in presidentially declared disasters. State and county governments have gradually developed the capabilities to link to this system. The damage estimates submitted by local officials to FEMA represent the best available early estimates under disaster conditions. A team visits each damage site to view the extent of losses and make preliminary estimates. Thus, in some disasters and some jurisdictions, it is now possible to systematically compare early damage estimates with actual costs.

Data from FEMA's Public Assistance Program are similar to NWS damage estimates, in that most of the losses involve physical damage to property. Public assistance covers damage to public facilities such as roads and bridges, schools, government buildings, and nonprofit agencies. To better understand the errors that might be expected in NWS damage estimates, records from the FEMA Public Assistance Program are used to compare damage estimates with actual costs in a California flood disaster. The FEMA data were obtained from Michael Sabbaghian, Deputy Public Assistance Officer, California Office of Emergency Services (OES).

In the aftermath of a natural disaster, damage information is assembled in the following stages, according to guidelines established by FEMA (M. Sabbaghian, personal communication 8/30/00, 7/29/04; FEMA, 1998).

(1) *Initial Damage Estimate* (IDE). Shortly after a disaster has occurred, local officials provide estimates of physical damage based on early reports and descriptions, without necessarily visiting the damage sites. At this time, some areas may be inaccessible and there is little accurate information available.

(2) *Preliminary Damage Assessment* (PDA). Several days later, a team including local, state, and FEMA officials visits the damage sites. They do a "windshield estimate," perhaps viewing the sites from a car window or walking around. The PDA is generally more accurate than the IDE because, by this time, local officials have a better idea of the damage level and state or FEMA officials can eliminate ineligible estimates. The PDA estimates are used to decide whether federal assistance is needed. If so, they are submitted to FEMA as part of the governor's request for a presidential disaster declaration.

(3) *Damage Survey Report* (DSR). Once the president has issued a disaster declaration, applicants submit requests for public assistance with detailed worksheets estimating the cost of repairs. FEMA or the state perform inspections (physical surveys) for each large project and "verify documentation on a portion of the small projects" (FEMA, 1998). The DSR is used to obligate federal and state disaster assistance funds. The DSR obligations change as bids are received to accomplish the repair work, and computer records are updated accordingly.

(4) *Actual Cost*. When all projects are completed, the DSR is closed and final costs are totalled. For large disasters, closure might not occur until 4–5 years after the disaster event.

Descriptions of the NWS procedures for obtaining flood damage estimates suggest that often the estimates are qualitatively similar to the IDE and certainly no better than the PDA. Indeed, NWS field offices obtain some of their estimates from FEMA's survey teams. Only in the largest floods (notably, the widespread flooding of the upper Mississippi basin in 1993) have extensive efforts been made to update the damage estimates over an extended period (Changnon, 1996). Therefore, to estimate the errors in early damage estimates that can be expected under good conditions (that is, from officials who have systematically viewed the damage), FEMA records from a California flood disaster serve as a case study.

California's winter climate can be strongly influenced by the "El Niño" phenomenon, a warming of the eastern equatorial Pacific Ocean that occurs irregularly at intervals of 2–7 years, with varying intensity. In the summer and fall of 1997, meteorologists reported that a particularly strong El Niño was developing in the Pacific. They predicted intense rainstorms in California in the coming winter, comparable to the "devastating deluges" in the El Niño of 1982–1983 (Malnic, 1997). Public meetings and intensive publicity inspired widespread efforts to clean flood channels, repair roofs, and shore up hillsides in anticipation of an especially stormy winter (Malnic, 1998; Pielke, 2000). The predicted severe weather materialized in February 1998, when a series of Pacific storms drenched California for three weeks, leading to widespread flooding.

The president declared a major disaster in 41 counties, designated the "1998 California El Niño disaster" (FEMA-1203-DR). Table II shows the IDE and PDA estimates for each county under the public assistance program. It also shows the funds that had been obligated in the FEMA database as of December 1, 2003. Although the DSR has not been closed (i.e., finalized) at the time of this writing, many of the applications are closed and nearly all remaining costs have been obligated; therefore these figures can be treated as the "actual costs." Closeout of this disaster is expected to occur in 2005 (M. Sabbaghian, personal communication, 12/22/03).

The bottom line of Table II shows that total public assistance costs in the state were approximately $341 million. The PDA underestimated the total costs by $43 million, or 13% (Figure 3a). Because no IDE was provided for several counties, the total IDE of $240 million should be compared with the total actual cost of $303 million from the matching 33 table entries. On that basis, the IDE underestimated total costs by about $63 million, or 21% (Figure 3b).

Estimates for smaller units (individual counties and the "state agencies" category) are much less accurate, however. Actual costs in each case are less than $50 million. Yet, errors in the IDE range from −$39 million in the state agencies category to +$20 million in Colusa County. Errors in the PDA range from −$32 million in the state agencies category to +$24 million in San Bernardino County. The bar graphs for several counties in Figure 4 give a sense of the proportional errors in both IDE and PDA.

Figure 5 shows scatterplots of (a) the PDA vs. actual costs and (b) the IDE vs. actual costs. Again, logarithmic scales are used, and data points outside of the two dashed lines are cases in which the estimate differs from the actual costs by more than a factor of two. Clearly the IDE is less accurate than the PDA: the points are much more scattered. (Correlations between the logs of estimates and actual costs are $r = 0.88$ for the PDA and 0.46 for the IDE.)

Since the IDE are based on rather superficial damage descriptions, it is not surprising that large errors are the norm: Over half of the IDEs (19 out of 33) are off by at least a factor of 2, and 12 of them are off by more than a factor of 4. In proportion to the actual costs, some IDE errors are enormous: underestimated by a factor of 216 in Santa Barbara County and overestimated by a factor of 24 in Tehama County. (Note that in those two counties

Table II. California 1998 El Niño disaster: estimated and actual public assistance costs, in thousands of current dollars.

County	Actual cost (by 12/1/03)	IDE estimate	Proportion of actual	PDA estimate	Proportion of actual
State agencies	46,384	7,129	0.15	14,497	0.31
Alameda	18,737	12,971	0.69	8,176	0.44
Amador	268	235	0.88	176	0.66
Butte	1,442	665	0.46	706	0.49
Calaveras	136	–	–	162	1.19
Colusa	4,810	25,000	5.20	1,829	0.38
Contra Costa	6,030	3,885	0.64	4,760	0.79
Del Norte	280	–	–	461	1.65
Fresno	1,764	820	0.46	1,052	0.60
Glenn	3,966	21,250	5.36	9,884	2.49
Humboldt	7,783	1,049	0.13	1,753	0.23
Kern	12,558	–	–	10,306	0.82
Lake	2,149	1,395	0.65	3,044	1.42
Los Angeles	33,420	5,660	0.17	35,516	1.06
Marin	6,940	3,319	0.48	5,447	0.78
Mendocino	3,506	4,259	1.21	3,846	1.10
Merced	2,398	490	0.20	734	0.31
Monterey	25,505	20,181	0.79	11,822	0.46
Napa	460	720	1.57	448	0.97
Orange	13,204	3,992	0.30	16,720	1.27
Riverside	3,180	–	–	5,964	1.88
Sacramento	3,374	–	–	3,066	0.91
San Benito	6,726	26,870	3.99	10,595	1.58
San Bernardino	6,776	–	–	30,429	4.49
San Diego	6,563	–	–	9,180	1.40
San Francisco	4,162	12,300	2.96	3,703	0.89
San Joaquin	2,659	655	0.25	3,155	1.19
San Luis Obispo	3,976	772	0.19	4,915	1.24
San Mateo	21,909	16,110	0.74	26,328	1.20
Santa Barbara	16,219	75	0.00	12,954	0.80
Santa Clara	14,324	9,846	0.69	13,310	0.93
Santa Cruz	14,064	13,673	0.97	6,320	0.45
Solano	3,400	3,628	1.07	8,564	2.52
Sonoma	10,516	11,180	1.06	4,127	0.39
Stanislaus	2,189	–	–	909	0.42
Sutter	1,305	1,582	1.21	758	0.58
Tehama	822	20,000	24.33	616	0.75
Trinity	1,044	1,970	1.89	975	0.93

Table II. Continued.

County	Actual cost (by 12/1/03)	IDE estimate	Proportion of actual	PDA estimate	Proportion of actual
Tulare	2,205	–	–	919	0.42
Ventura	21,769	3,302	0.15	14,350	0.66
Yolo	939	4,321	4.60	4,484	4.78
Yuba	727	196	0.27	249	0.34
Total	340,588	239,500	0.79*	297,204	0.87

* Proportion of actual cost ($303 million) of cases with an IDE.

the PDA estimate is a great improvement.) In general, the Preliminary Damage Assessments are somewhat better than the IDEs, yet over one-third (16 out of 42) are off by at least a factor of 2 and 3 of them are off by more than a factor of 4.

A systematic tendency to *underestimate* damages might be expected if some types of damage cannot be observed without careful inspection. On the other hand, the forecasts of unusually severe storms might predispose observers to *overestimate* damages in this particular disaster. A statistical paired-comparison test is used to check for systematic bias in these early damage estimates.

The distribution of each of the variables, IDE, PDA, and actual cost, approximates a log normal distribution. (That is, the logarithms of the variables are approximately normally distributed, based on the Shapiro–Wilk test.) Therefore, let

$$E_i = \log(e_i) \text{ and } A_i = \log(a_i),$$

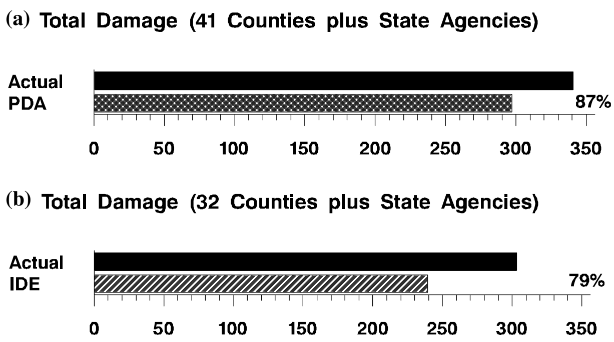

Figure 3. Actual statewide public assistance expenditures in the 1998 California El Niño disaster with (a) the PDA estimate, and (b) the IDE estimate (which excludes nine counties), in millions of current dollars.

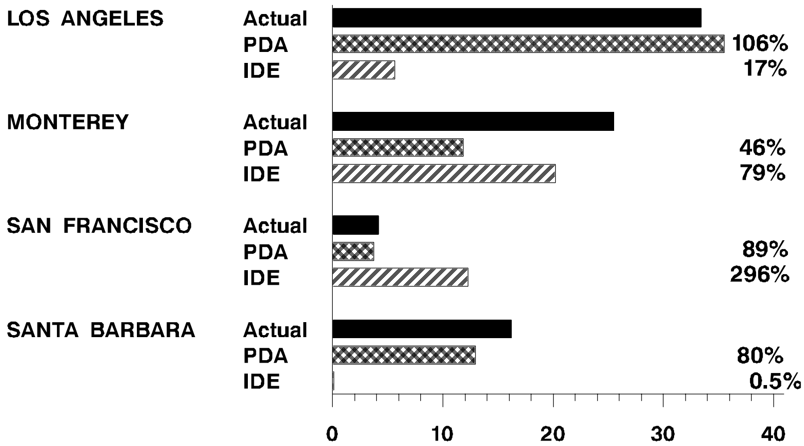

Figure 4. Actual public assistance expenditures in selected counties, with the PDA and IDE estimates, in millions of current dollars.

where e_i = estimated damage, and a_i = actual cost. The IDE and PDA estimates can be compared with actual costs by using paired *t*-tests to test the null hypothesis

$$H_0\text{: mean}(E_i - A_i) = 0.$$

The results of the two tests are shown in Table III. For the IDE, $t = -1.44$ (with 32 degrees of freedom), and for the PDA, $t = -1.52$ (with 41 degrees of freedom), neither of which is statistically significant at a 95% confidence level. Though there appears to be a tendency to underestimate the amount of damage, the bias is not statistically significant. Furthermore, large under- and overestimates occur with similar frequency and magnitudes (Figure 5), so there is no evidence that the forecasts and warnings led to overestimates of damage.

In summary, this case study suggests that positive and negative estimation errors tend to average out when estimates are highly aggregated in a large flood event. With total damage of $340 million statewide, underestimation by only 13% in the case of the PDA would be acceptable for many purposes.

However, this case study also indicates that in smaller flood events (under $50 million damage), which involve substantially less aggregation, the estimation errors can be extremely large. Although there was no evidence of systematic bias, over half of the PDA estimates were in error by more than a factor of 1.5; and over half of the IDEs were in error by more than a factor of 2 (with many off by more than a factor of 4). The population of some California counties exceeds that of many small states. So estimation errors in the larger counties indicate error levels to be expected in damage estimates for some entire states. For example, Figure 4 and Table II show that in Los

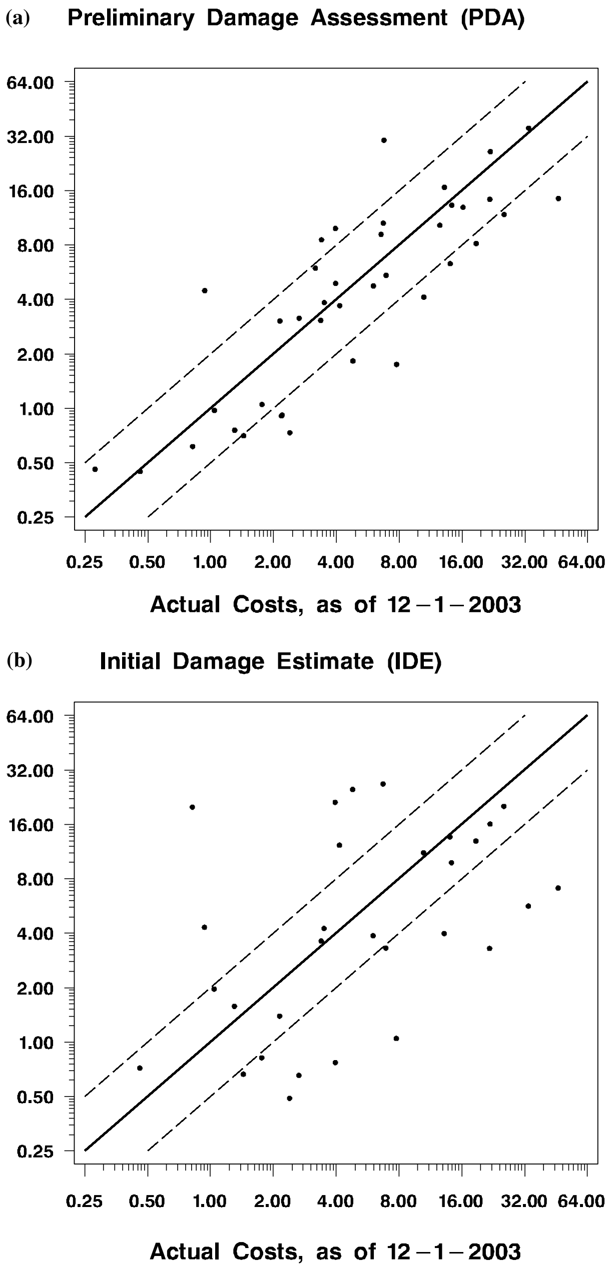

Figure 5. Comparison of actual public assistance expenditures for all counties with (a) the PDA estimate, and (b) the IDE estimate, in millions of current dollars.

Table III. Paired *t*-tests comparing the IDE and PDA estimates with actual costs.

Comparison	*N*	Mean	S.E	*t*	Probability
IDE vs. Actual	33	−0.380	0.263	−1.444	0.159
PDA vs. Actual	42	−0.163	0.107	−1.524	0.135

Angeles County, with a 1990 population of 8.9 million and larger than 42 of the 50 states, the IDE underestimated actual costs by 83%.

Given the methods used by NWS field offices to obtain flood damage estimates, NWS estimates are unlikely to be significantly different in quality than the IDEs examined here. Thus, when an annual flood damage estimate for a state is less than about $50 million, one should not expect the NWS estimate to depict actual losses accurately. Similar estimates across different types of disasters and made by other agencies and experts are likely to be of comparible accuracy to the IDEs and PDAs examined here.

From the above results, it can be concluded that aggregation of many damage estimates in floods involving high levels of damage (in this case, $340 million in 1998 dollars) can provide reasonably good estimates of total damage. However, estimates at a low level of aggregation ($50 million or less) often are in error by factors of 2 or more. Users of such small estimates should exercise caution. Certainly, direct comparisons of individual estimates are likely to mislead.

5. Conclusion: Cautions and Suggestions for Use of Flood Damage Estimates

The state-NWS and FEMA data comparisons demonstrate the following issues that users should be aware of when interpreting the U.S. flood damage database and other similar estimates of disaster loss.

- Individual damage estimates for small events or for local jurisdictions within a larger flood area tend to be extremely inaccurate.
- Disasters causing moderate damage are occasionally omitted, or their damage greatly underestimated.
- Damage estimates become proportionally more accurate at higher levels of aggregation. Thus, estimates summed over large geographic areas or many years can be considered reasonably reliable (that is, independent estimates over $500 million disagreed by less than 40%, as shown in Section 3).

The reanalyzed NWS flood damage data, available at http://www.flooddamagedata.org, provide damage estimates at the national level during 1926–2003 and for each state during 1955–2003. Despite their defects, these are the best available historical estimates having nationwide coverage (Downton *et al.*, 2005). At the national level, this analysis suggests that the annual damage totals are reasonably reliable because they are sums of estimates from many flood events. However, annual damage estimates for individual states or counties are likely to be much less reliable.

Downton *et al.*, (2005) give examples of how the estimates can be misleading and describe five factors that users should consider in interpreting damage estimates for states or smaller jurisdictions:

- The lack of a damage estimate does not necessarily imply zero damage, because reporting of damages in small flood events is inconsistent. To determine the frequency of damaging floods in a state or region, establish a threshold below which estimates often go unrecorded and report the frequency of floods that exceed the threshold.
- To reduce the impact of estimation errors at the state level (especially in regions where damage estimates tend to be low), aggregate estimates over space or time. To compare damage between years, one can aggregate state damage estimates over multi-state regions. To compare damage between states or regions, one can aggregate the estimates over many years and compare the sums. Even when the estimates are highly aggregated, be aware that some of the variability is caused by estimation errors, and interpret the results accordingly.
- When comparing flood damage between regions or time periods, consider the effect of differences in population, wealth, geographic area, or incidence of extreme weather events during the period of study (e.g., Pielke and Downton, 2000).
- When comparing individual floods, do not rely exclusively on damage estimates. Look for qualitative descriptions of the nature and impacts of the damage.
- Different agencies use different definitions of "flood" and "flood damage". Check for incompatibilities before combining damage estimates from different sources.

Disaster costs are growing in the United States and around the world largely because of increasing societal vulnerability to disasters. In this context, understanding the problems posed by disasters and their losses, as well as consideration of policy alternatives in response, requires a solid basis of information to inform decision making.

As calls for collecting such information accumulate, decision makers must also begin paying attention to the challenges that would be posed by a commitment to collecting and archiving disaster data. More work is needed to understand the challenges of implementing a centralized resource for disaster loss information. The analysis in this paper provides a contribution to such understanding. Clearly defined protocols and procedures for data collection will not only help to create a comprehensive and accurate database, but will also facilitate the use of disaster data in policy decisions related to disaster assistance, policy evaluation, and science policies.

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