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Dams Sector Consequence-Based Top Screen Pilot Project Results Summary

Final

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prepared by
R.G. Whitfield, T.E. Baldwin, E.K. Hocking, G. Basset, and D. Dickinson
Argonne National Laboratory

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The Dams Sector Consequence-Based Top Screen (CTS) methodology was developed and piloted with the support of the Dams Sector Coordinating Council (SCC), Dams Sector Government Coordinating Council (GCC), the U.S. Department of Homeland Security (the Dams Sector-Specific Agency), and the Critical Infrastructure Partnership Advisory Council. The Dams Sector Top Screen Workgroup, comprising members from the SCC and GCC, took the lead on the CTS but drew on the expertise of the SCC and GCC membership.

The following security partners from the private sector comprise the SCC: Allegheny Energy, Ameren Services Company, American Electric Power, Association of State Dam Safety Officials, AVISTA Utilities, CMS Energy, Dominion Resources, Duke Energy, Exelon Corporation, Hydro-Quebec, National Hydropower Association, National Mining Association (*ex officio*), National Water Resources Association, New York Power Authority, Ontario Power Generation, Pacific Gas and Electric Company, PPL Corporation, Progress Energy, Public Utility District 1 of Chelan County, WA, Scana Corporation, South Carolina Public Service (Santee-Cooper), Southern California Edison, Southern Company Generation, U.S. Society on Dams, and Xcel Energy.

The GCC is composed of the following government security partners: Bonneville Power Administration, Bureau of Reclamation (which also serves as representative for the Bureau of Indian Affairs, National Park Service, Bureau of Land Management, and other Department of the Interior bureaus owning dams), Federal Energy Regulatory Commission, Federal Emergency Management Agency, International Boundary Water Commission, Mine Safety and Health Administration, Natural Resources Conservation Service, Office of Infrastructure Protection of the U.S. Department of Homeland Security, Tennessee Valley Authority, U.S. Army Corps of Engineers, U.S. Coast Guard, Western Power Administration, and State dam safety officials from California, Colorado, Nebraska, New Jersey, Ohio, Pennsylvania, North Carolina, and Washington.

A special note of appreciation is extended to the owners and operators of the 26 dams that participated in the Pacific Northwest Pilot study and to the State dam safety officers who assisted with the State Pilot study.

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EXECUTIVE SUMMARY

The Dams Sector Consequence-Based Top Screen (CTS) was developed in response to Homeland Security Presidential Directive 7 (HSPD-7), which gives the U.S. Department of Homeland Security (DHS) authority to coordinate the overall national effort to enhance the protection of the critical infrastructure and key resources (CIKR) of the United States. Pursuant to Section 18.d, DHS was also given explicit responsibility to coordinate protection activities for the Dams Sector.

The Dams Sector encompasses water retention and water control structures that impound, divert, or control water for a variety of purposes, including water supply, irrigation, hydropower generation, navigation, flood control, storm surge protection, recreation, environmental preservation, sediment control, and hazardous material impoundment. The total number of assets within the Dams Sector is unknown, but the number of dams alone totals more than 82,000 based on the 2007 National Inventory of Dams (NID). Because of the high number of dams and the HSPD-7 requirement to protect the Nation's CIKR, it is advisable to conduct a systematic preliminary consequence-based prioritization of the Dams Sector's assets.

The Dams Sector developed the CTS methodology to quickly identify dam projects whose failure or disruption could trigger significant consequences. The CTS allows the Dams Sector to establish common methods, assumptions, and measures to consistently quantify—across the sector—different types of consequence elements. The consequence elements addressed in the CTS are:

- Impacts on human health and safety caused by inundation of downstream populated areas, industrial areas, and other critical infrastructure assets;
- Economic impacts associated with substantial damage to or disruption of the facility, considering the damage to downstream inundated areas and the financial losses associated with business interruption;
- Direct impact on government capabilities and unavailability of critical services to the military or other critical government services;
- Indirect economic effects associated with the loss of critical functions provided by the facility; and
- Serious collateral damage to assets with strong emotional, symbolic, or iconic value.

The quantification of consequences associated with these elements leads to a sector-wide prioritization framework that facilitates comparison of consequence information within the sector.

The initial phase of the pilot to test the CTS was conducted with the cooperation of 26 dam projects in the Pacific Northwest United States. The pilot was extended to include 22 dam projects from throughout the country to create a more geographically diverse sample.

Pilot participants submitted data on 14 different consequence parameters stemming from three of the consequence elements: human, economic, and mission impacts. The consequence parameters are:

- Total population at risk (PAR)
- PAR 0–3 miles
- PAR 3–7 miles
- PAR 7–15 miles
- PAR 15–60 miles
- Asset replacement cost
- Remediation cost
- Business loss
- Potable water lost
- Water deliveries lost
- Power generation lost
- Flood damage protection lost
- Navigation tonnage lost
- Recreational visits lost

These consequence parameters formed the basis for developing a potential damage index for dam failure—assuming a worst reasonable case scenario. Potentially, a damage index can be calculated for every dam that has been sufficiently characterized; subsequently, the index can be used to identify dams with the highest and the lowest potential damage. A damage index was proposed that is a number scaled from 0 to 100, where 0 means minimal to no potential damage and 100 means maximum potential damage. The estimated damage index for the 48 dam projects in the pilot study indicated that no dams ranked near 100, and five dams had a zero value.

Three different forms of the parameter damage index function (PDIF) were examined in the analysis of the CTS pilot results: linear, nonlinear, and geometric mean (GeoMean).[1] The PDIF incorporated the 14 consequence parameters that form the basis for estimating potential damage from dam failure.

A comparison of the three approaches indicated that the nonlinear and GeoMean forms produced similar results in terms of the total score and overall ranking, based on a total of 48 dams. Damage index values for the linear form are, in general, much higher than those for the other two forms, which is consistent with the fact that the linear consequence PDIF increases at a high rate, as the consequence level increases, compared to the other two forms.

The GeoMean form is tentatively recommended for determining the total score and overall ranking for each dam. The geometric mean appears to be most appropriate because respondents estimated population using ranges that doubled with each progressive category of impact.

It is recommended that further analyses of the three PDIF forms be performed using a larger number of dams to assess whether the above conclusions, which were based on a relatively small sample size, are applicable to the much larger number of dams located in the United States.

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[1] Linear refers to the final plots of a formula; using this method creates a line or linear representation. Nonlinear was chosen because, when the results are plotted, a curve is produced due to the power function within the formula. The geometric mean is relevant any time several quantities multiply together to produce a product. The geometric mean answers the question, "If all the quantities have the same value, what would that value have to be in order to achieve the same product?"

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1 PILOT PROJECT OVERVIEW

1.1 Purpose

Because of the large number of dams and the Homeland Security Presidential Directive 7 (HSPD-7)[2] requirement to protect the Nation's critical infrastructure and key resources (CIKR), it is necessary to conduct a systematic preliminary consequence-based prioritization of assets in the Dams Sector. The Dams Sector Consequence-Based Top Screen (CTS) methodology was developed by the sector to quickly identify those dam projects whose failure or disruption could trigger significant consequences.

This report describes the development of the CTS, its methodology, and the data collection related to a CTS pilot study. Because the function of the CTS is to identify Dams Sector assets with the highest potential consequences, this report focuses on the development of a potential damage index for dam failure. Appendixes A–C provide supporting information; Appendix D contains a list of acronyms used in this report.

1.2 CTS Development

The CTS was developed to initially identify and characterize the subset of high-consequence facilities within the Dams Sector whose failure or disruption could potentially lead to the most severe impacts. A consistent sector-wide approach for estimating the consequences of facility failure or disruption is an essential first step in identifying the sector's critical assets.

The CTS allows the Dams Sector to establish common methods, assumptions, and measures to consistently quantify different types of consequence elements: human health, and direct and indirect economic impacts. The quantification of consequences leads to a sector-wide prioritization framework that facilitates comparison of consequence information within the sector.

The Government Coordinating Council (GCC) and the Sector Coordinating Council (SCC) for the Dams Sector formed a joint GCC/SCC Top Screen Workgroup to monitor, review, and provide input into the development of the CTS methodology. This team, comprised of experts from private industry, State governments, and Federal agencies, served a key role in the development of the screening methodology.

The initial draft of the CTS was tested at three projects in Illinois, Oregon, and Washington in 2007. The main purpose of these tests was to evaluate the practicality and on-site resource requirements of the CTS methodology. On the basis of experiences and lessons learned during these tests, the CTS methodology was modified in discussions with the Dams Sector Top Screen Workgroup. The methodology was then piloted in 2008.

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2 U.S. Department of Homeland Security, 2003, *Critical Infrastructure Identification, Prioritization, and Protection*, Dec. 17. Available at http://www.whitehouse.gov/news/releases/2003/12/20031217-5.html.

The first pilot consisted of 26 dam projects primarily located in the Pacific Northwest United States. The selection of projects that volunteered to participate was a representative cross section of the Dams Sector. This pilot provided a reasonably diverse basis for determining whether the data collection process would be representative across all projects. In response to a request from the Dams Sector Top Screen Workgroup to include a more geographically diverse sample to test the CTS, the pilot was broadened to include 22 dam projects in six States. The States of California, Colorado, Montana, New Jersey, Ohio, and Pennsylvania volunteered to assist in collecting data and providing the information requested.

On the basis of the results of the Pacific Northwest (PNW) Pilot, the CTS information-gathering tool was streamlined for the State Pilot. Additional information on the pilots is presented in Section 2 (Data Collection).

1.3 Consequence-Based Top Screen Methodology

The CTS methodology uses a form-based questionnaire that is completed voluntarily. The questions lead to an estimate of the consequences of the complete failure or partial disruption of the facility in the following areas:

- Impacts on human health and safety caused by inundation of downstream populated areas, industrial areas, and other critical infrastructure assets;
- Economic impacts associated with substantial damage to or disruption of the facility, considering the damage to downstream inundated areas and the financial losses associated with business interruption;
- Direct impact on government capabilities and unavailability of critical services to the military or other critical government services;
- Indirect economic effects associated with the loss of critical functions provided by the facility; and
- Serious collateral damage to assets with strong emotional, symbolic, or iconic value within the impacted area.

To ensure that all respondents use similar assumptions when completing the CTS, the methodology is based on the worst reasonable case scenario that would lead to severe damage to or disruption of the facility. The questions are sufficiently detailed to allow consequence-based facility prioritization but should not require significant time from or resource demands on the respondents.

2 DATA COLLECTION

Upon completion of the PNW Pilot, each question of the CTS was reviewed to determine whether the information requested was appropriately worded and scaled. On the basis of that review, the CTS was streamlined for the participants of the State Pilot.

2.1 Pacific Northwest Pilot

Owners and operators of the projects in the PNW Pilot completed a web-based questionnaire. Each respondent's questionnaire was prepopulated with available National Inventory of Dams (NID)[3] facility-specific information and geographic information system (GIS)-based maps to aid in identifying potentially impacted populations and infrastructure.

The CTS version used in the PNW Pilot corresponded to the items in Form 1, General Information, and Form 2, Consequences Information, as shown in Appendix B, "Forms Used for PNW Pilot." Form 1 requests basic facility, contact, and operational information.

Form 2 consists of tables where respondents selected, from pre-established ranges, estimates applicable to their facility. The tables were used to obtain information on population at risk (PAR), total asset replacement value, total business interruption costs, loss of potable water supply function, annual value of water deliveries, loss of power generation function, average annual damages prevented, annual navigation tonnage, and annual recreational visits. The tables contained follow-on questions requesting specific information, such as population centers served by the facility's potable water supply function, percentage of market share, names of affected water treatment facilities, and reservoir recovery time.

In addition to the tables and related CTS questions, respondents were asked to provide information on which, if any, government capabilities and functions, such as military installations, Federal facilities, and Defense Industrial Base facilities, would be impacted through the dam's worst reasonable case scenario. Respondents were also provided with a list of 16 infrastructure categories (e.g., fossil fuel electric power generation facilities, nuclear electric power generation facilities, major airports, chemical manufacturing plants) and asked to identify which, if any, facilities in those categories would be in the dam's inundation area.

A review of the PNW Pilot revealed that many of the clarifying questions related to the data tables and the infrastructure categories (1) were not completed by many of the respondents or (2) resulted in inconsistent answers, possibly due to misunderstanding of the questions' intent. By comparison, the dropdown tables or checklists were completed and did not appear to be sources of confusion or excessive complexity.

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[3] U.S. Army Corps of Engineers, 2007, *National Inventory of Dams*, Topographic Engineering Center, Oct. Available at http://www.tec.army.mil/fact_sheet/nid.pdf.

2.2 State Pilot

On the basis of experience gained through the PNW Pilot, the State Pilot used only the tables. A streamlined, Excel-based version of the CTS was sent to the State dam safety officers of six States. Appendix C provides the forms used in the State Pilot. Collection of these data was simpler and therefore easier to complete and disseminate. However, key elements of information, such as how PAR or economic determinations were made and the cascading impacts to surrounding infrastructure, were not asked. Therefore, only the tabular information directly compares to the original PNW Pilot data collection.

3 ANALYSIS OF PILOT RESULTS

The comparable consequence data from the PNW and State pilots are shown in Table 1. These include the worst and best levels of consequence for each consequence category. The best consequence has a basis of zero impacts up to the upper range found on the data from the two pilots. The worst consequence is a best estimate of worst-case, Total PAR, and economic and mission impacts. These groupings were used for the consequence analysis and ranking.

Table 1 Potential Consequences of the Failure of a Dam

Consequence Category	Consequence Parameter	Measurement Unit	Worst Level	Best Level
Human	Total PAR	No. of people	>800,000	0–25,000
	PAR 0–3 miles	No. of people	>1,600	0–50
	PAR >3–7 miles	No. of people	>3,200	0–100
	PAR >7–15 miles	No. of people	>6,400	0–200
	PAR >15–60 miles	No. of people	>25,600	0–800
Economic	Replacement cost	$	>3,200 million	0–100 million
	Remediation cost	$	>6,400 million	0–200 million
	Business loss	$	>1,600 million	0–50 million
Mission	Potable water lost	No. of people	>8,000,000	0–250,000
	Water deliveries lost	$	>1,600 million	0–50 million
	Power generation lost	Megawatt(s)	>6,400	0–200
	Flood damages	$/yr	>1,600 million	0–50 million
	Navigation tonnage lost	kton(s)/yr	>96,000	0–3,000
	Recreational visitors lost	No. of people/yr	>4,800,000	0–150,000

3.1 Developing a Potential Damage Index for Dam Failure

The 14 consequence parameters shown in Table 1 form the basis for a potential damage index for dam failure. The damage index is a number scaled from 0 to 100, where 0 denotes minimal to no potential damages and 100 means maximum potential damages. A damage index can be calculated for every dam that has been sufficiently characterized with values for its consequence parameters. Such an index can be used to identify dams with the highest or the lowest potential damage. An obvious use of the damage index is to categorize dams.

The development of a damage index requires weights for aggregating dams consequence parameters. The determination of such weights was based on the scoring of seven subject-matter experts in September 2008. The participants—all familiar with the consequences of a dam failure—provided their expert judgments about the relative seriousness of damages associated with each of the 14 consequence parameters.

A four-step process was used to obtain the judgments of the subject-matter experts. The "weights" assigned by each individual to each consequence were averaged to form an overall weighting for the group.

3.2 Obtaining Judgments by Using a Four-Step Process

The following process was used to encode the judgments of each subject-matter expert in the pilot project:

1. The participants were asked to study the definitions of the 14 consequence parameters. They were advised to pay particular attention to both the least and the most potential damage level for each consequence parameter.

2. They were then asked to choose one consequence category (human, economic, mission) and rank order (i.e., prioritize) the seriousness of all consequence parameters within that category. For example, the human category comprises five consequence parameters: Total PAR, PAR 0–3 miles, PAR >3–7 miles, PAR >7–15 miles, and PAR >15–60 miles. Each participant considered the following thought process:

   a. Imagine a dam having consequences at the highest level for all five consequence parameters (with all other consequence parameters in the other consequence categories set at the *same*—not necessarily the lowest or highest, but all are identical—levels; for simplicity, say that all are at their highest levels). Call this Dam 0.
   b. Imagine five additional dams such that for each dam, one, and only one, consequence parameter is at the lowest level (e.g., Dam 1 is lower for total PAR; Dam 2 is lower for PAR 3). Call these Dams 1–5, respectively.
   c. To complete the ranking of the parameters from most desirable to least desirable, imagine that Dam 0 can be traded for one of Dams 1–5. The dam selected, by

definition, has the most desirable (i.e., least) consequences of all six dams under consideration.

d. Remove the chosen dam from consideration.
e. Repeat step c three more times, each time removing from consideration the dam judged to have the least serious consequences among the dams remaining for consideration.
f. That accomplished, specifies the rank order of the consequence parameters through a process that considers the importance of changes in consequence levels. For the human consequence category, the first dam chosen is judged to have the “most serious” consequences, which means that it is more important to reduce the consequences of its associated consequence parameter than any of the others. Similarly, the dam not chosen when down to the last two is judged to have the least serious consequences, which means that its associated consequence parameter is the “least serious.”
g. Repeat steps 2a–2f for a second consequence category to establish that “within-category” ranking.
h. Repeat steps 2a–2f for the remaining consequence categories to establish their “within-category” ranking.

3. Having established a rank order of each consequence category, participants were then asked to establish a “strength of damage” measure for each consequence parameter in a specific category.
   a. Assign a damage level of 100 to the most serious consequence parameter in a consequence category.
   b. Assign a damage level of ≤ 100 to the next most serious consequence parameter (“ties are allowed” if the levels are considered to be equally damaging; in general, that should not be the case for any of the consequence parameters in the dam damage index considered here). For example, if the damage is considered to be half as serious as the most serious parameter, a damage level of 50 should be assigned.
   c. Repeat step 3b until all parameters within a category have been assigned a value between 0 and 100.
   d. That accomplished, the strength of damage for each parameter within a category is established.
   e. Repeat steps 3a–3d for a second consequence category to establish strengths of damages within that category.
   f. Repeat steps 3a–3d for the last (of the current three) consequence category to establish strengths of damages within that category.

4. Having established strengths of damages within each of the consequence categories, the participants considered the most significant consequence parameter within each category.
   a. As in step 2, determine the rank order of the three consequence parameters, one from each category.
   b. As in step 3, determine the strength of damage of the three consequence parameters, one from each category. The parameter judged to be the most significant should then be assigned a value of 100 (most damaging); the others should be assigned values ≤100. At this stage of the encoding process, ties are more likely to be plausible. If all

three consequence parameters are judged to be equally damaging, each should be assigned a value of 100.

The numerical example in Table 2 illustrates the process described so far. The data in this illustrative table show that, within the human consequence category, PAR 0–3 miles is judged to be the most serious consequence, indicated by the 100 in the "Intra-Category Damage Level" column. In addition, Total PAR is judged to be the least serious, indicated by a value of 20 in the "Intra-Category Damage Level" column. In this example, under economic impact, the remediation cost is judged to be the most serious of the consequence parameters, indicated by the 100 in the Intra-Category Damage Level column.

Potable Water Lost, in the mission consequence category, is judged to be the most serious as indicated by the 100 in the Intra-Category Damage Level column.

It is important to note that the examples shown in this document only represent the views and samples from the internal group of subject-matter experts. A review and scoring completed by Dams Sector experts, combined with a review of end results, are required before final determinations of weights or scores can be determined.

3.3 Calculating the Parameters of a Damage Index

Table 3 is an extension of Table 2. The last two columns show how to calculate the weights to be used in a damage index. An entry for a consequence parameter in the next-to-last column is the product of (1) the intra-category damage level (0–100) determined by considering the relative damage levels of the parameters in a category and (2) the inter-category damage level (0–100) determined by considering the most serious parameters, one each from the three consequence categories. The sum of these 14 inter/intra products—65,000—is listed at the bottom of the table and is used to normalize the individual weights so that they sum to one.

An entry in the last column in Table 3 is the result of dividing a consequence parameter's intra-inter product (in the next-to-last column) by the sum of the 14 intra-inter products. This is the weight in the damage index function. For example, the least important consequence parameter is "Total PAR" with a weight of 0.022. Its intra-category damage level was judged to be 20. The product of this value and the inter-category damage level for the economic category, judged to be 70, is 1,400. The weight then is 1,400/65,000, which is 0.022. Because the sum of the 14 weights is 1, these are said to be normalized weights. (Note that while total PAR has low weight, the PAR at closer distances to a dam has high weights. The PAR within 3 miles of a dam has a weight 0.108).

Table 2 Judgments about the Importance of Potential Consequences of the Failure of a Dam

Consequence Category	Consequence Parameter	Measurement Unit	Worst Level	Best Level	Intra-Category Damage Level	Inter-Category Damage Level
Human	Total PAR	No. of people	>800,000	0–25,000	20	
	PAR 0–3 miles	No. of people	>1,600	0–50	100	100
	PAR >3–7 miles	No. of people	>3,200	0–100	80	
	PAR >7–15 miles	No. of people	>6,400	0–200	60	
	PAR >15–60 miles	No. of people	>25,600	0–800	40	
Economic	Replacement cost	$	>$3,200 million	0–100 million	50	
	Remediation cost	$	>$6,400 million	0–200 million	100	70
	Business loss	$	>$1,600 million	0–50 million	50	
Mission	Potable water lost	No. of people	>8,000,000	0–250,000	100	60
	Water deliveries lost	$	>1,600 million	0–50 million	40	
	Power generation lost	Megawatt(s)	>6,400	0–200	50	
	Flood damages	$/yr	>1,600 million	0–50 million	50	
	Navigation tonnage lost	kton(s)/yr	>96,000	0–3,000	30	
	Recreational visitors lost	No. of people/yr	>4,800,000	0–150,000	10	

Table 3 Calculating the Weights for a Damage Index						
Consequence Parameter Index (*i*)	**Consequence Category**	**Consequence Parameter**	**Intra-Category Damage Level**	**Inter-Category Damage Level**	**Intra*Inter**	**Weight = Intra*Inter/ SUM(Intra*Inter)**
1	Human	Total PAR	20	**70**	1,400	0.022
2		PAR 0–3 miles	100		7,000	0.108
3		PAR >3–7 miles	80		5,600	0.086
4		PAR >7–15 miles	60		4,200	0.065
5		PAR >15–60 miles	40		2,800	0.043
6	Economic	Replacement cost	50		4,000	0.062
7		Remediation cost	100	**80**	8,000	0.123
8		Business loss	50		4,000	0.062
9	Mission	Potable water lost	100	**100**	10,000	0.154
10		Water deliveries lost	40		4,000	0.062
11		Power generation lost	50		5,000	0.077
12		Flood damages	50		5,000	0.077
13		Navigation tonnage lost	30		3,000	0.046
14		Recreational visitors lost	10		1,000	0.015
				Sums	**65,000**	**1.000**

3.3.1 Functional Form of the Damage Index

Recall that a dam is characterized by 14 consequence parameter values, coded on a 7-to-1 scale, where 7 denotes the highest level of potential damage (a range of values) and 1 denotes the lowest level of potential damage (also a range of values). For consequence parameter i, denote the characteristic level for a dam as $p_{i,j}$, where $p_{i,j} = (7, 6, \ldots, 1)$. The relative importance of the seven levels for consequence parameter i is specified by a Parameter Damage Index (PDI) function denoted $\mathrm{PDI}_i(p_{i,j})$, which is described below in Section 3.3.2.

Given $\mathrm{PDI}_i(p_{i,j})$ for $i = (1, 2, \ldots, 14)$, $j = (7, 6, \ldots, 1)$, and the weights, which are denoted w_1, w_2, …, w_{14}, the damage index (DI) for a dam is given by Equation 1:

$$\mathrm{DI} = \sum_{i=1 \text{ to } 14} [w_i * \mathrm{PDI}_i(p_{i,j})], \quad \text{(Eq. 1)}$$

which is the sum of the products of the weight on a consequence parameter w_i and the PDI value for a given dam's characteristic on that consequence parameter p_{ij}.

3.3.2 Plausible Parameter Damage Index Functions

The characteristics of the $\mathrm{PDI}_i(p_i)$ functions describe how damages vary with p_i. This report considers three alternative functional forms. The first form is a linear function of the DI values 7, 6, …, 1:

$$\mathrm{PDI}_i(p_{i,j}) = (j - 1)/(6) * 100. \text{ for } i = (1, 2, \ldots, 14) \text{ and } j = (7, 6, \ldots, 1). \quad \text{(Eq. 2)}$$

This form is referred to as the linear form in that it makes damages a linear function of the $p_{i,j}$ for a specific parameter $_i$. The value of 6 in the denominator of Equation 2 is used to normalize the PDI so that it varies from a minimum of 0 to a maximum of 100. A linear form has been used in many risk-assessment methodologies such as the Strategic Homeland Infrastructure Risk Analysis.

The second form makes damages a nonlinear function of the p_{ij}:

$$\mathrm{PDI}_i(p_{i,j}) = (2^{j-1} - 1)/(2^{7-1} - 1) * 100. \text{ for } i = (1, 2, \ldots, 14) \text{ and } j = (7, 6, \ldots, 1). \quad \text{(Eq. 3)}$$

This form is referred to as the nonlinear form because of the power function in its equation.

The second form has historically been used to determine a damage index for estimating replacement ratios for buildings damaged by major natural phenomena events, such as hurricanes and wildfires. It allows easier comparison of the large numbers used in the consequence parameters.

The value 2^{j-1} means that as j varies over its range of values (7, 6, 5, 4, 3, 2, 1), the associated index varies over a range of values (64, 32, 16, 8, 4, 2, 1), respectively. Among the implications, for example, is that with the linear scale, each unit increase in $p_{i,j}$ leads to a one-unit increase in

PDI_i, whereas with the nonlinear scale, the changes increase geometrically. With the linear scale, a change in p_{ij} from 1 to 2 is the same as from 6 to 7. With the nonlinear scale, however, the latter is much more important because the damage index increases by 32 units.

For both of these forms, $PDI_i(7) = 100$ and $PDI_i(1) = 0$. However, for Form 1, $PDI_i(6) = 5/6 = 0.833$; for Form 2, $PDI_i(6) = (32 – 1)/(64 – 1) = 31/63 = 0.492$. Table 4 lists values for these two forms.

The goal of using the different formulas is to plot the bin values as close to a straight line as possible when the X-axis is a linear scale for a particular parameter. A straight line means that a marginal increase in damage remains constant as the damage value increases. However, it is also important to show or discriminate between most significant potential damage and less significant potential damage.

The differences in the PDI functions are illustrated in Figures 1 through 8. Figure 1 is a graph of Equation 2 in which the X-axis is coded from 7 to 1. It plots as a straight line. Figure 2 is a graph of $PDI_i(p_{i,j})$ in which the X-axis is a linear scale over the actual range of the total PAR consequence parameter. Note the convex-downward shape of the curve.[4] The curve represents a situation where more damage is occurring; however, the value of that increased damage does not increase at the same rate. Figure 3 includes a graph of the step function that corresponds to the PDI for total PAR in Figure 2. Note that the steps lie below or touch the curved line and are entirely above the straight line, except near the upper-left and lower-right corners of the graph. Figure 4 is a graph of Equation 3 and the corresponding step function for the Total PAR. The dashed line is a straight line, and the steps are below or touch the straight line.[5]

Table 4 Consequence Parameter Damage Index Values for Three Functional Forms

Consequence Level	Form 1	Form 2	Form 3
I	**(*i* – 1)/6**	**[2^(*i* – 1) – 1]/(2^6 – 1)**	**Uses GeoMean**
1	0.0	0.0	0.0
2	16.7	1.6	4.4
3	33.3	4.8	8.8
4	50.0	11.1	17.7
5	66.7	23.8	35.4
6	83.3	49.2	70.7
7	100.0	100.0	100.0
	Eq. 2	Eq. 3	Eq. 4

4 This shape implies that marginal increase in damage *decreases* as damage increases, which is not desirable in a public policy environment.

5 The straight line implies that that marginal increase in damage *remains constant* as damage increases, which is highly desirable in a public policy environment.

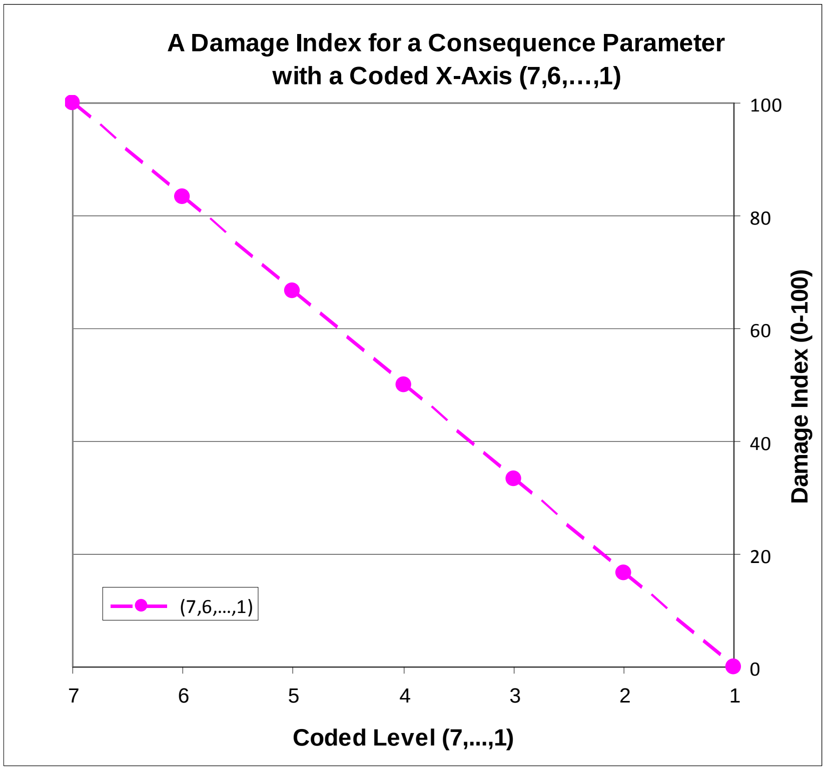

Figure 1 Parameter Damage Index Function (PDIF) Scaled on a Linear Basis Plots as a Straight Line

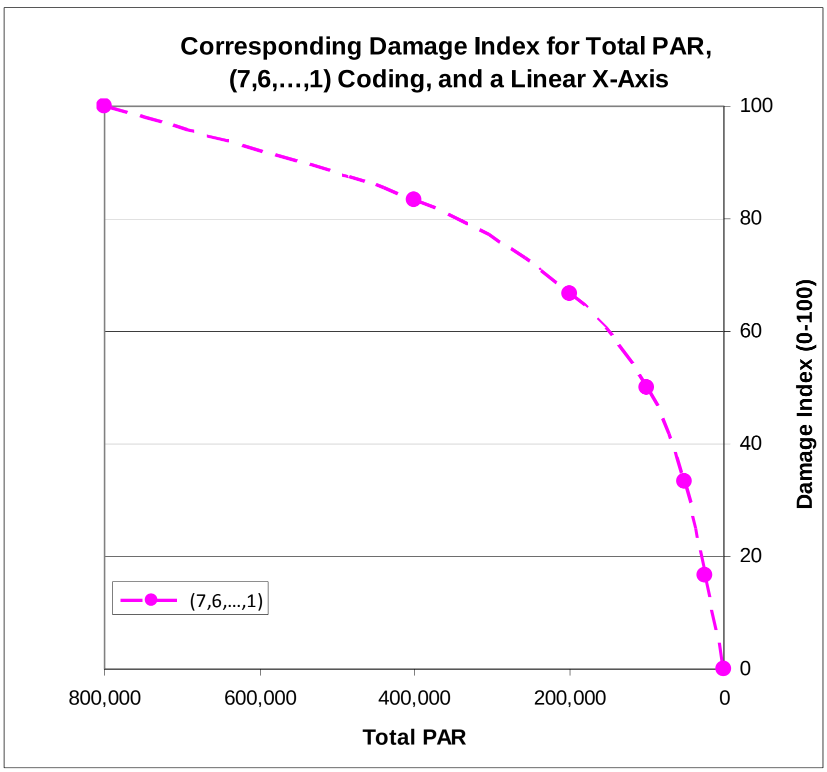

Figure 2 Same Function as Figure 1 Plotted on a Linear Scale for Total PAR (This incorporates the bins or values for PAR used in the CTS pilot.)

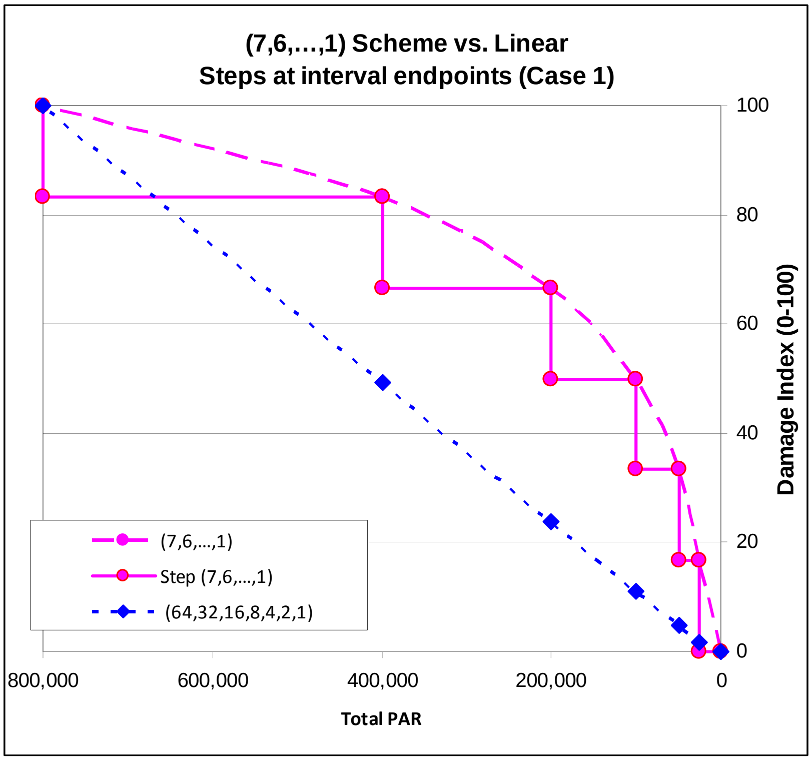

Figure 3 Step Function Corresponding to the PDIF (Notice the PDI increases rapidly as Total PAR increases.)

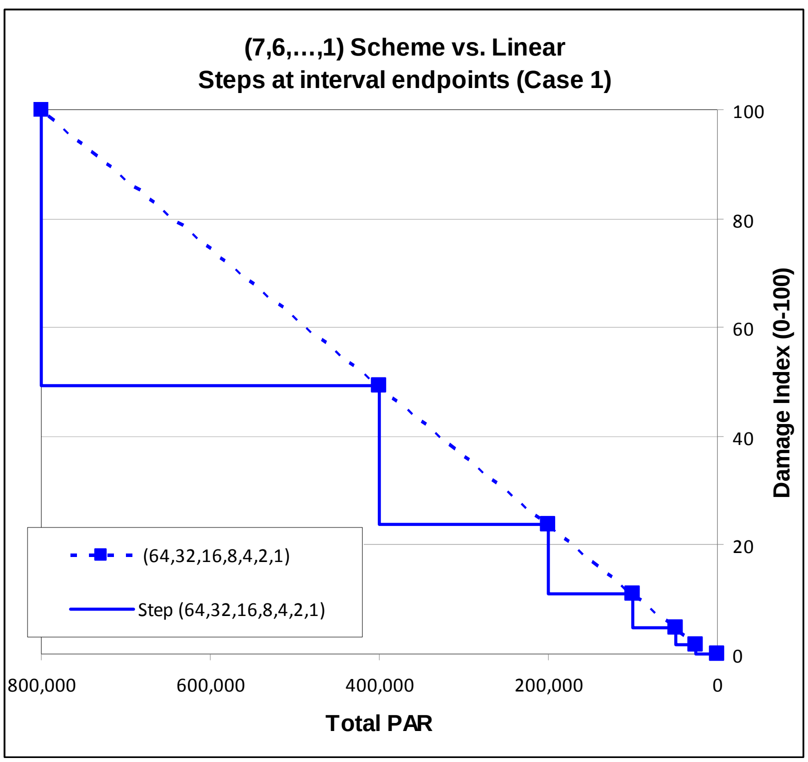

Figure 4 PDIF Scaled on a Linear Basis Plots as a Straight Line on a Nonlinear Scale for Total PAR, with Its Corresponding Step Function

The third form is a variation of Equation 2:

$$\text{PDI}_i(p_{i,j}) = \left(\sqrt{(\text{Lower Bound})_j\,(\text{Upper Bound})_j}\right) / \left(\sqrt{(\text{Lower Bound})_{j=7}\,(\text{Upper Bound})_{j=7}}\right),$$

for $i = (1, 2, \ldots, 14)$ and $j = (7, 6, \ldots, 1)$. (Eq. 4)

Instead of directly using index values, Equation 4 uses the geometric mean of an interval's actual range (i.e., its lower and upper bounds) in a linear function to determine the PDI value for that interval. For example, index value 6 for total PAR corresponds to the range from 400,000 to 800,000. The geometric mean of 400,000 and 800,000 is the square root of their product, which equals 565,685. The corresponding parameter DI value is 565,685/800,000, which is equal to 0.71. Values for Form 3 are also listed in Table 4. Figure 5 is a plot of Form 3, which will be referred to as the "GeoMean" form. Note that each step intersects the straight dashed line and, in a sense, better represents the straight line than Forms 1 and 2 do.

Figure 5 is a representation of the relationship between the linear function and equivalent increase in PDI as the potential damage size increases. This figure shows that damages below 200,000 PAR have a lower PDI. Once 400,000 PAR is reached, there is a more dramatic i in PDI. This may provide for some delineation of relative importance of this particular PDI.

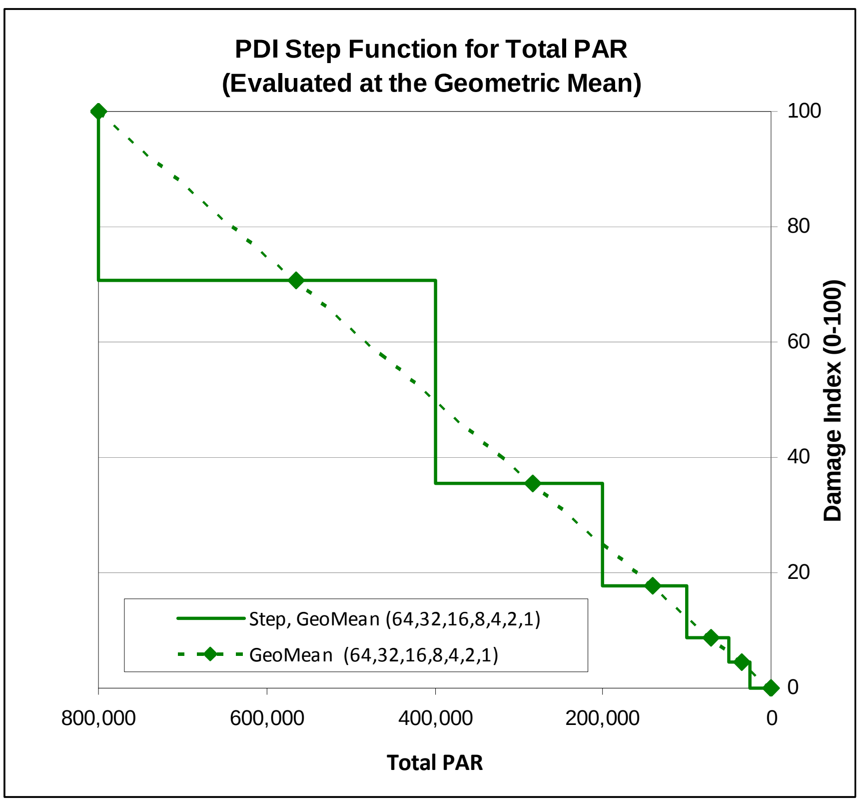

Figure 5 Corresponding Step Function for Same Function with Y Values Determined by the Geometric Mean of Each Interval

Geometric mean is often used for evaluating data that cover several orders of magnitude and sometimes for evaluating ratios, percentages, or other data sets bounded by zero. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. Geometric means are used in many fields, most notably in financial reporting. (When evaluating investment returns and fluctuating interest rates, it is the geometric mean, not the arithmetic mean, that tells what the average financial rate of return would have had to have been over the entire investment period to achieve the end result.)

The general equation for the geometric mean is:

$$\text{Geometric Mean } (GM_y) = (y_1\, y_2\, y_3 \ldots\, y_n)^{(1/n)}, \qquad \text{(Eq. 5)}$$

which converts to a square-root representation for two values (i.e., $1/n = 0.5$).

Figures 6, 7, and 8 illustrate other characteristics of the three forms. Figure 6 is a plot of all three step functions. It clearly shows that the GeoMean form yields a representative step function that lies between that for the other two forms and is therefore representative of the two other forms.

Figure 7 is a plot of Form 1, Form 2 and Form 3 (GeoMean) versus the coded level. With this rescaling of the X-axis, Form 1 is linear and the other two are nonlinear. Clearly, Forms 2 and 3

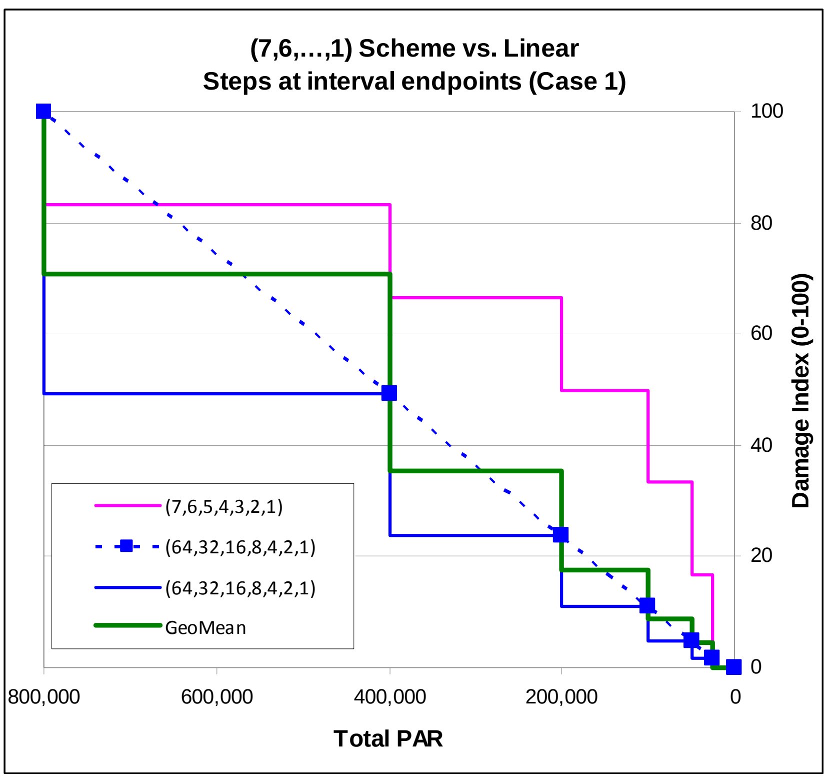

Figure 6 Three Plausible Step Functions for the Total PAR PDIF [Note that the one based on the geometric mean values of each interval most closely approximates the straight line from (800,000; 100) to (0; 0).]

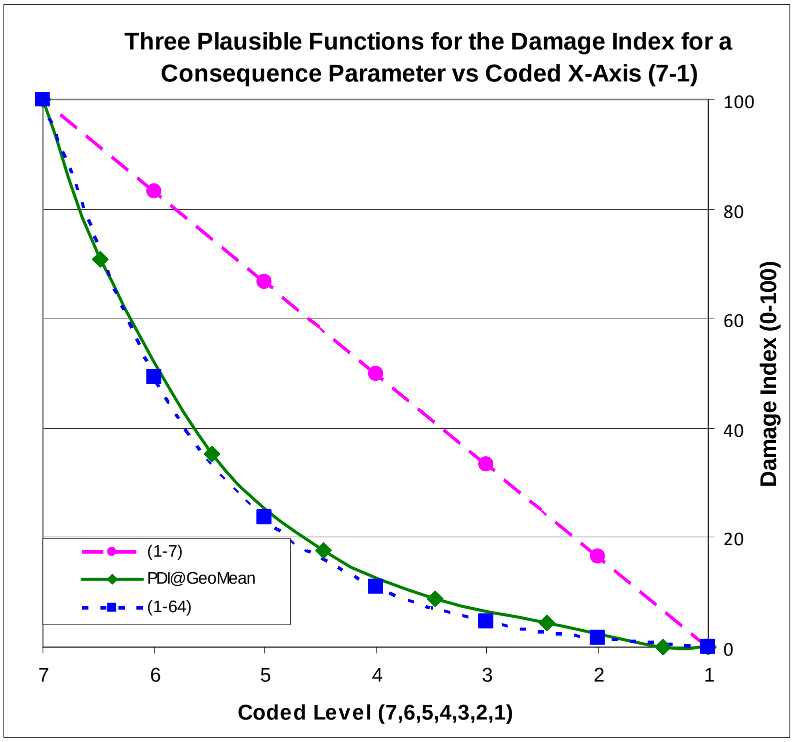

Figure 7 Plots of Leading Edges (as Coding Level Increases) of Each Step for Each of the Three Plausible Total PAR PDIFs Considered (Note that the one based on linear scaling plots as a straight line vs. the coded X-axis.)

are nearly identical, which is expected given that these forms both apply a power-law representation to estimate the PDI.

Figure 8 is a plot of Form 1, Form 2 and Form 3 (GeoMean) form versus a linear scale for total PAR. With this scaling of the X-axis, Form 1 is nonlinear (which is not desirable), and the other two are linear (which is desirable). Also, Forms 2 and 3 appear to be nearly identical.

The nonlinear representation of Form 1 in Figure 8 results because each level for a consequence parameter is twice the size of all preceding levels (with the exception of level 2, which is the same size as level 1). Form 2 "undoes" this doubling by introducing the power of 2 in its equation. This results in a linear plot when the X-axis is a linear scale in the natural units of its consequence parameter.

Figure 6 shows a comparison of the linear, nonlinear, and GeoMean plotted using the bin values of total PAR. GeoMean and nonlinear have the best correlation.

Figures 7 and 8 further show the nearly identical relationship between nonlinear and GeoMean. When looking at the bin plots, there is a rather dramatic increase in PDI as the damage increases. Once validated by Dams Sector subject-matter experts and calibrated against a grouping of

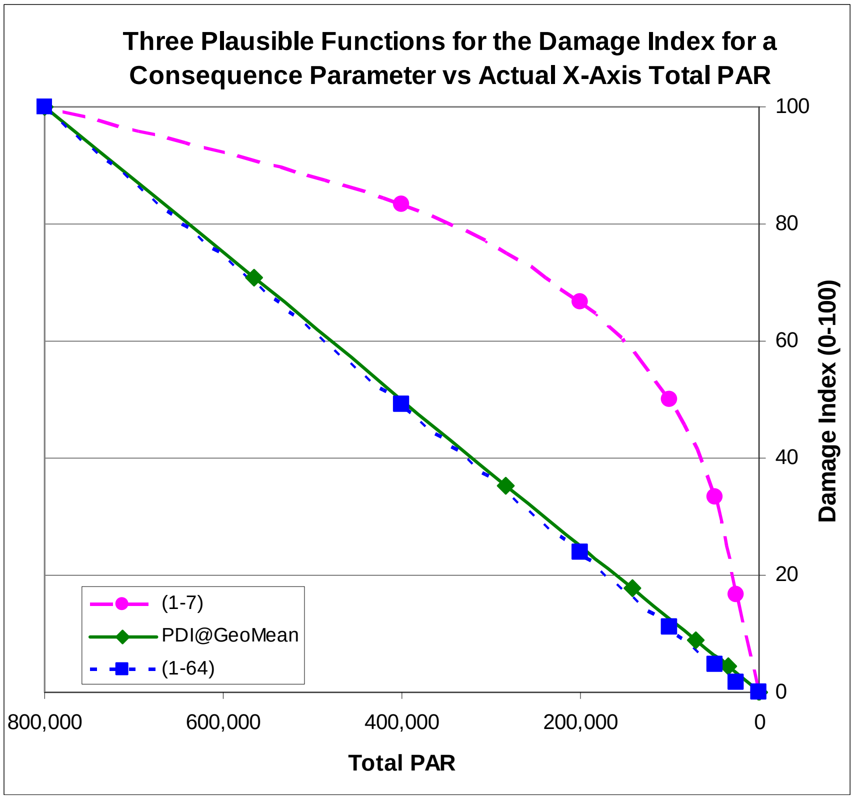

Figure 8 Data of Figure 7 Plotted vs. a Linear Scale for Total PAR (Note that the plot for linear scaling is curved and the others are nearly straight lines and nearly identical.)

actual facilities, GeoMean or nonlinear provide a better opportunity to define the facilities with the more significant overall consequence.

3.4 Results

Results obtained by applying Equation 1, the formula for the damage index, are shown in Figures 9, 10, and 11. The value trade-offs are those for the consolidated judgments of seven participants in a value trade-off exercise. In that exercise, 14 weights for Equation 1 were determined for each participant, and those weights were averaged to form the 14 consolidated weights used here. These three charts help compare the different equations after the weights and values have been applied. It is important to note that these results are preliminary and based on a small sample of dams and the value judgments of seven SMEs. A similar group of Dams Sector experts may provide different value judgments.

Figure 9 is a plot of DI results for 48 dams. The X-axis labels are dam ranks obtained by using the nonlinear (Form 3) form for the consequence PDIFs. Three plots are included, one each of the PDIs described above. The DI values for the linear form (average value of 24.7) are, in general, higher than those for the other two forms (16.0 and 14.1 for the GeoMean and nonlinear forms, respectively; see Table 6). That is consistent with the fact that the linear consequence parameter DI function increases at a higher rate as consequence level increases compared with

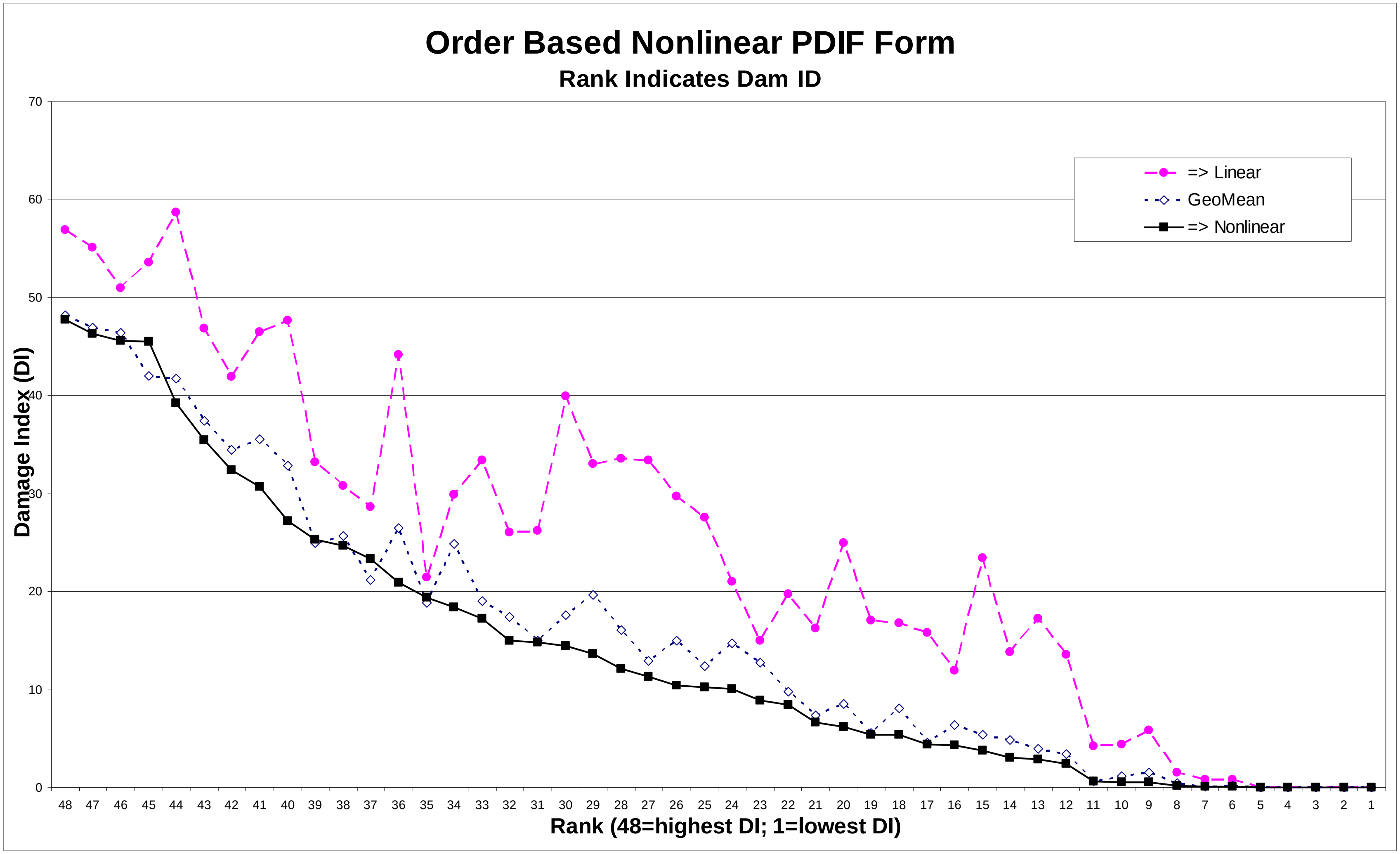

Figure 9 Dam DI Values Are Plotted in Order Using the Nonlinear PDIF Form and Based on the Consolidated Judgments of the Pilot Participants; Rank Uniquely Identifies Dams

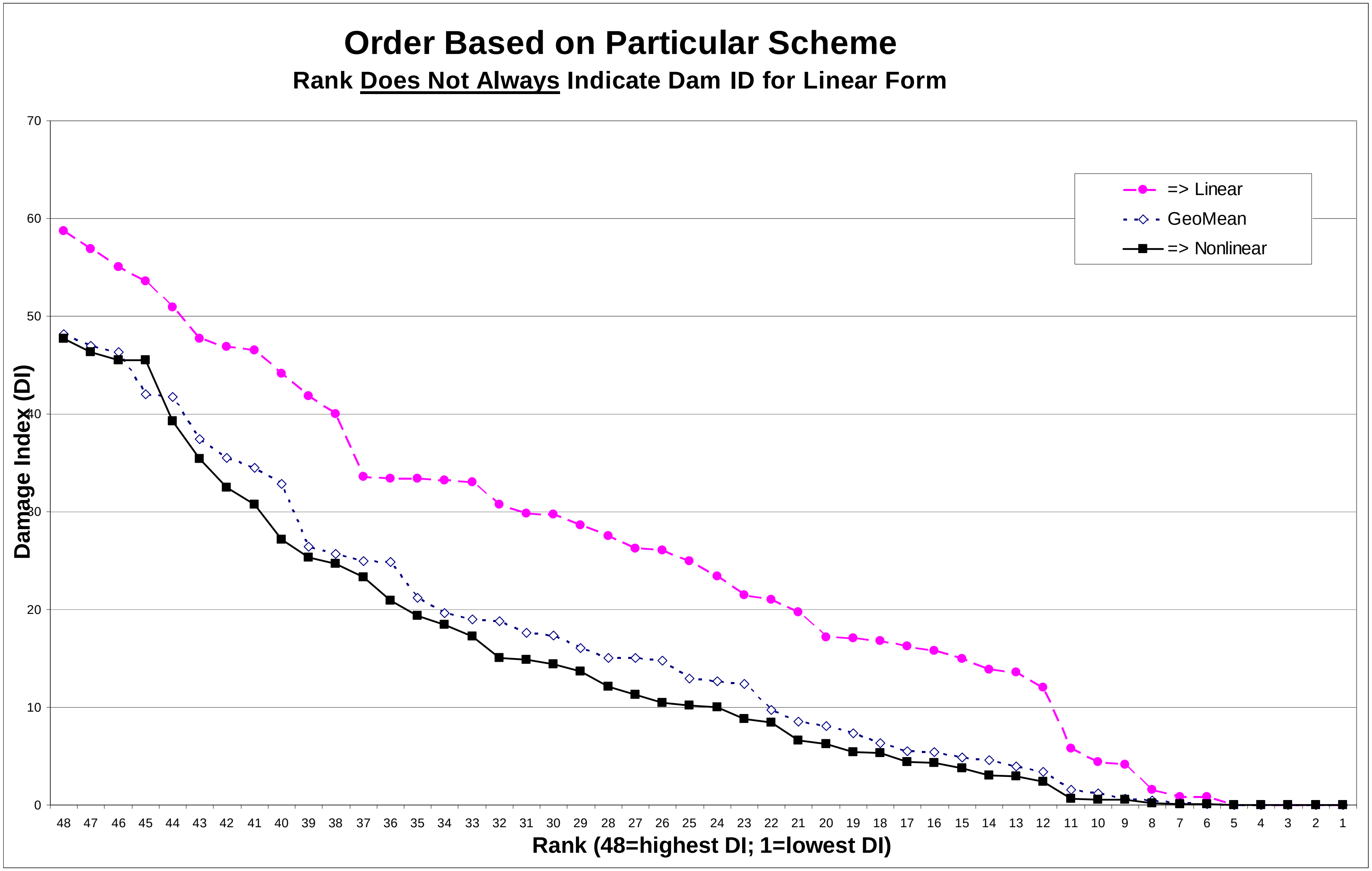

Figure 10 Dam DI Values Are Plotted in Order Resulting from Each Scheme and Based on the Consolidated Judgments of the Pilot Participants

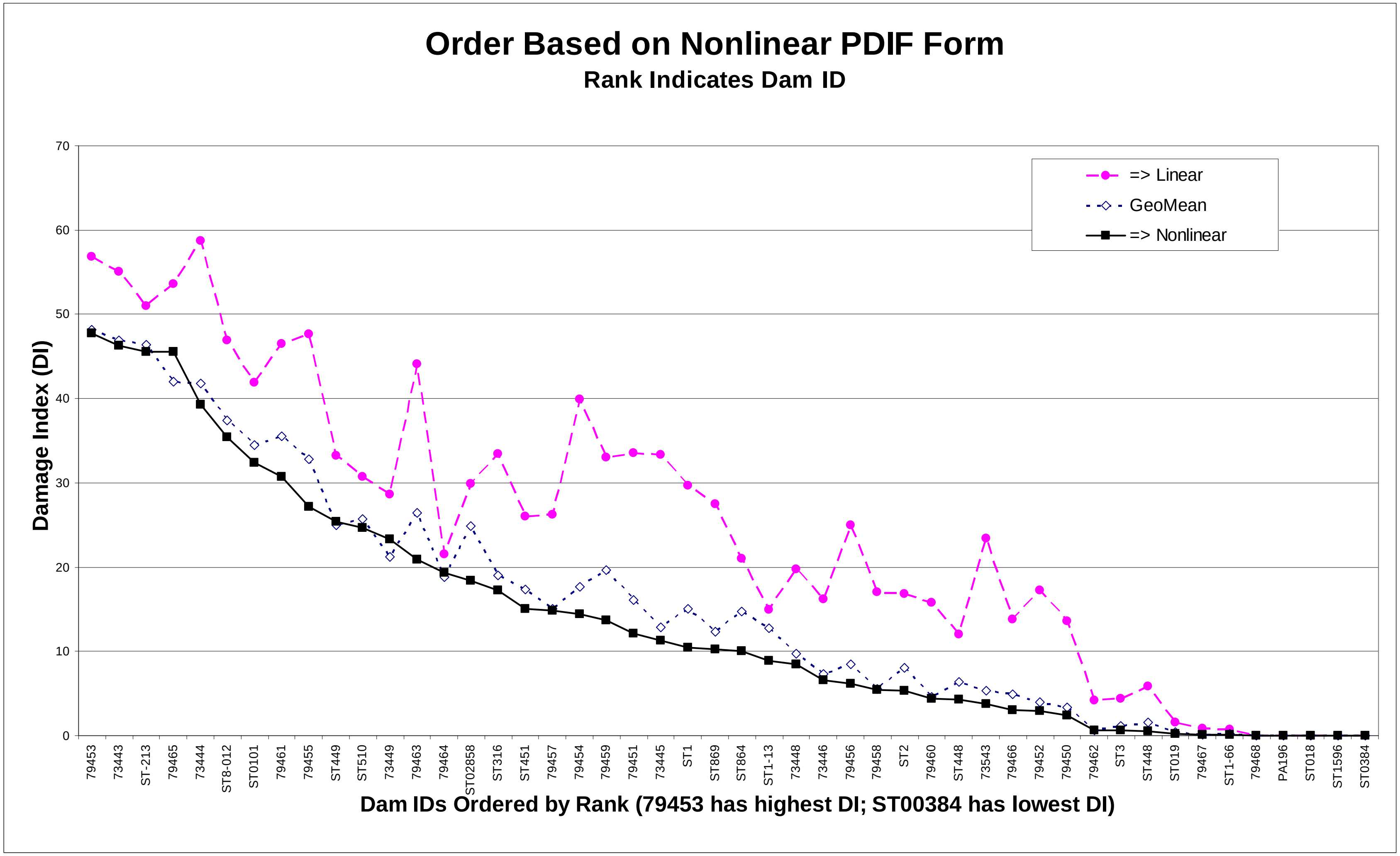

Figure 11 Dam DI Values Are Plotted in Order Using the Nonlinear PDIF Form and Based on the Consolidated Judgments of the Pilot Participants (X-axis = Dam Identification Number)

the other two forms (shown in Figures 1 through 8) because each level for a consequence parameter is twice the size of all preceding levels (with the exception of level 2, which is the same size as level 1). In this plot, a rank of 48 denotes the dam with the highest damage index, and a rank of 1 indicates the dam with the lowest damage index. The significant fact of Figure 9 is the rank or placement of the top ten and top five dams (those with the largest DIs). Regardless of method, the top ten dams are almost the same, although their individual scores and ranks are different. However, there is a larger disparity among the top five dams. Rankings for GeoMean and non-linear methods are similar, but the linear plot shows a very different top five. This implies that using either the GeoMean or non-linear method may provide some indication of possible bin (that is, subsets of facilities with similar relative importance) limits.

While the ranking of dams is similar with the various PDIs, there are some possibly important differences. If the order of the dams is important, Figure 9 indicates that the dam with record number 2 in Table 5 has the highest damage index for the linear form; that dam has the 5th highest damage index according to the two other forms (i.e., 44th rank). The dam with record number 11 in Table 5 has the highest damage index for the nonlinear form as compared with record number 23 for the GeoMean form.

The plot for the nonlinear form in Figure 9 is monotonic decreasing (by definition), meaning that it is always decreasing and never increasing (i.e., remaining constant). If the order of the dams is important it is important to note the nonlinear form appears to distinguish ranking between dams. Departures from the order established by the nonlinear form are indicated by increases in the DI value as you move from left to right on the graph. For example, record 45 has the highest damage index for the GeoMean form; it has the 4th highest damage index for the nonlinear form. Comparison of the nonlinear and GeoMean forms in Table 5 shows that both methods would provide a similar set of dams for the top 10 ranked facilities (although the order of ranking can differ between the two forms) as compared with the linear form.

If establishing specific bins is the goal then Figure 10 shows the same results in a different format: the X-axis is the rank, in decreasing damage index, for each form. Thus, all of the plots are monotonic decreasing. Note that the index does not (necessarily) uniquely identify a dam. Also note that all three forms indicate a zero damage index for the five lowest-ranked dams. In Figure 10, notice the difference of the increase in DI for the linear verses non-linear and GeoMean, especially in the top five or ten dams with the greatest DIs. The GeoMean and non-linear results indicate that there may be a potential bin limit as the DI value begins to flatten out, while the linear plot continues an upward trend. However, remember this is a very small sample size; a larger sample may show different results.

Figure 11 replaces the record numbers in Figure 9 with dam identification numbers. The dams are listed in the rank order obtained by using the nonlinear (Equation 3) form for the consequence PDIFs. Figure 11 requires the most scrutiny by Dams Sector subject-matter experts. With the dams plotted by identification, it is possible to have experts review the rankings and determine if the overall rank makes sense to those who know the most about dams. Using either GeoMean or the nonlinear equation, the math indicates which dams may be significant and shows there may be a reasonable bin cut-off above a PDI of 40. But this only represents the projects in the pilot and the internal subject-matter experts.

All three approaches may have value. The Top screen tool may be utilized to:
1. Identify possible groupings and explain how they are grouped.
2. A more thoughtful look at some dams may be warranted for dams that seem controversial (i.e., ranking differs significantly across the methods).

Further review and analysis and project scrutiny are required by Dams Sector experts to validate the results.

Tabular results for dam DI values shown in the above-cited figures are listed in Table 5. The records are listed in order of decreasing DI values according to the nonlinear form. The highest total scores are similar for the nonlinear (47.7) and GeoMean (48.2) forms, but less than for the linear form (57.1).

Statistics for the results in Table 5 are listed in Table 6. The average values are similar for both the nonlinear and GeoMean forms (14.1 versus 16.0) compared with the linear form (24.7); comparison of the average to the maximum values for the three forms shows that the distribution of values is skewed toward the lower end, in agreement with the concave behavior of the plots in Figure 9. As expected, the average of the linear form is greater than the other two forms, indicating the effect of very high values, which are dampened by the other two approaches. The standard deviations for all three forms are relatively high in comparison with the average values, indicating that many data points are far from the average with a wide spread between the values in the data set. This sign is encouraging for all three forms because it shows that the DI values are not bunched together, which enhances the possibility of identifying bins.

Table 7 displays the absolute value of the rank differences compared with the linear form. There is a much higher difference in ranking between the linear form and the two other forms. As an example, the dam with record number 22 is ranked 23rd for the linear form, compared with 34th for the nonlinear form and 32nd for the GeoMean form. There is a much higher degree of consistency in ranking between the nonlinear and GeoMean forms with a maximum difference of 4 for the dam with record number 17.

Statistics for the results in Table 7 are listed in Table 8. The standard deviation relative to the average value is similar for both data sets, although the standard deviation is much smaller than the maximum deviation. This fact indicates that the difference in ranking between the three forms is not large, and the ranking would be similar between the three approaches on an overall basis.

Figure 11 displays the absolute value of rank differences compared with the nonlinear form, based on the information in Table 6. As shown in Table 6, there is a greater degree of disagreement in ranking between the linear and nonlinear forms as compared to the nonlinear and GeoMean forms.

Table 5 Damage Index Results for 48 Dams Using Three Functional Forms for the Consequence Parameter Damage Index Functions						
Record No.	Linear		Nonlinear		GeoMean	
	Total Score	Rank	Total Score	Rank	Total Score	Rank
11	56.9	46	47.7	48	48.2	47
1	55.1	45	46.3	47	46.9	46
33	50.9	44	45.5	46	46.4	45
23	57.1	47	45.5	45	48.2	48
2	58.7	48	39.2	44	41.8	44
42	46.9	42	35.4	43	37.4	43
46	41.9	39	32.4	42	34.5	41
19	46.5	41	30.7	41	35.5	42
6	35.0	37	27.2	40	27.6	39
13	47.7	43	25.3	39	32.9	40
27	33.2	33	24.7	38	25.0	36
32	30.8	31	23.3	37	25.7	37
34	34.9	36	20.9	36	23.6	34
21	44.1	40	19.3	35	26.4	38
22	21.5	23	18.4	34	18.8	32
47	29.9	30	17.2	33	24.9	35
28	26.1	26	15.0	32	17.4	30
15	26.2	27	14.8	31	15.0	28
12	40.0	38	14.4	30	17.6	31
17	33.0	32	13.6	29	19.7	33
9	33.6	35	12.1	28	16.0	29
3	33.4	34	11.3	27	12.9	25
37	29.7	29	10.4	26	15.0	27
29	27.5	28	10.2	25	12.4	23
35	21.0	22	10.0	24	14.7	26
40	15.0	15	8.8	23	12.7	24
5	19.7	21	8.4	22	9.7	22
4	16.2	17	6.6	21	7.3	19
14	24.9	25	6.2	20	8.5	21
16	17.0	19	5.4	19	5.5	17
38	16.8	18	5.4	18	8.1	20
18	15.8	16	4.4	17	4.6	14
36	12.0	12	4.3	16	6.4	18
7	23.4	24	3.8	15	5.4	16
24	13.8	14	3.1	14	4.9	15
10	17.2	20	2.9	13	3.9	13
8	13.6	13	2.4	12	3.4	12
20	4.2	9	0.6	11	0.6	9

Table 5 Damage Index Results for 48 Dams Using Three Functional Forms for the Consequence Parameter Damage Index Functions

Record No.	Linear		Nonlinear		GeoMean	
	Total Score	Rank	Total Score	Rank	Total Score	Rank
39	4.4	10	0.6	10	1.2	10
30	5.8	11	0.6	9	1.5	11
43	1.6	8	0.2	8	0.4	8
25	0.8	7	0.1	7	0.1	6
41	0.8	6	0.1	6	0.2	7
26	0.0	1	0.0	1	0.0	1
31	0.0	1	0.0	1	0.0	1
44	0.0	1	0.0	1	0.0	1
45	0.0	1	0.0	1	0.0	1
48	0.0	1	0.0	1	0.0	1

Table 6 Statistics Associated with the Values in Table 5

Statistical Parameter	Linear	Nonlinear	GeoMean
Average	24.7	14.1	16.0
Standard deviation	17.7	14.3	14.9
Minimum	0	0	0
Maximum	58.7	47.7	48.2

Table 7 Absolute Value of Rank Differences vs. the Nonlinear Form					
Record No.[a]	Abs(Nonlinear-Linear)	Abs(Nonlinear-GeoMean)	Record No.[a]	Abs(Nonlinear-Linear)	Abs(Nonlinear-GeoMean)
11	2	1	35	2	2
1	2	1	40	8	1
33	2	1	5	1	0
23	2	3	4	4	2
2	4	0	14	5	1
42	1	0	16	0	2
46	3	1	38	0	2
19	0	1	18	1	3
6	3	1	36	4	2
13	4	1	7	9	1
27	5	2	24	0	1
32	6	0	10	7	0
34	0	2	8	1	0
21	5	3	20	2	2
22	11	2	39	0	0
47	3	2	30	2	2
28	6	2	43	0	0
15	4	3	25	0	1
12	8	1	41	0	1
17	3	4	26	0	0
9	7	1	31	0	0
3	7	2	44	0	0
37	3	1	45	0	0
29	3	2	48	0	0

[a] The rows are in decreasing order of the DI values obtained by the nonlinear form; the highest DI value is at the top of the table; the lowest DI value is at the bottom of the table.

Table 8 Statistics for Rank Differences Shown in Table 7		
Statistical Parameter	Abs(Nonlinear-Linear)	Abs(Nonlinear-GeoMean)
Average	2.9	1.3
Standard deviation	2.8	1.0
Minimum	0	0
Maximum	11	4

3.5 Conclusions

Three different forms of the PDIF were considered: linear, nonlinear, and geometric mean (GeoMean). The PDIF incorporated the 14 consequence parameters that form the basis for estimating potential damage from dam failure.

A damage index was proposed. The damage index is a number scaled from 0 to 100, where 0 denotes minimal to no potential damage, and 100 means maximum potential damage. The estimated damage index for a sample of 48 dams indicated that no dams ranked near 100, and 5 dams had a 0 value.

A comparison of the three approaches indicates a similar—though not identical—ranking of the dams. The nonlinear and GeoMean forms produced very similar results in terms of the total score and overall ranking, based on a total of 48 dams. DI values for the linear form are, in general, much higher than those for the other two forms consistent with the fact that the linear consequence PDIF increases at a high rate as consequence level increases compared to the other two forms.

The GeoMean form is tentatively recommended for determining the total score and overall ranking for each dam. GeoMean appears to be most appropriate because respondents estimated population by using ranges that doubled with each progressive category of impact.

The current process starts all bins at zero, and they increase to some value. In the data collection, facilities that have a zero score or value are combined with facilities that have some value of more than 1. It is suggested that a new bin of Zero, Not Applicable, or Does Not Apply be added to the tables to minimize the loss of data or merging of unlike data.

It is recommended that further analyses of the three PDIF forms be performed using a larger number of dams with different dam functions (hydroelectric generation, flood control, commerce) located throughout the United States to ensure a representative sample of the 82,000 total dams.

4 GENERAL IMPACT RESULTS

The human, economic, and mission impact results from the tables used in both pilots are provided in Appendix A, “Summary of Results.” These results are confined to the pilot studies and cannot be generalized to all dams in the United States.

The questions designed to elicit information on infrastructure that could be impacted through a worst reasonable scenario (i.e., direct impact on government capabilities and unavailability of critical services to the military, indirect effects associated with the loss of critical functions provided by the facility and collateral damage to assets with strong emotional, symbolic, or iconic value) were only asked of the participants of the PNW Pilot.

The following sections describe the types of impacts assessed in the pilots.

4.1 Human Impact

For the CTS methodology, the PAR is the total estimated number of humans occupying a permanent residence, commercial building, or recreational area in the potential zone of inundation represented by the dam break.[6] The PAR does not represent the expected loss of life; rather, it is the number of residents impacted by a possible flood scenario from dam failure as a result of an adversarial attack. The number of expected deaths from a dam break may be significantly less than the PAR and depends on many factors, including time of warning, depth of flooding, and velocity of flood wave. The CTS methodology requires an estimated value for the total PAR within the flood inundation zone.

4.2 Economic Impact

Pilot respondents estimated the economic consequences and impacts on the basis of expert judgment and prior case histories of dam failure incidents assuming a worst reasonable case scenario. Such a scenario may differ from the one that causes the greatest impact on human health and safety and often, but not always, represents a total dam system failure.

The highest value property losses may not necessarily correspond to the maximum number of buildings and equipment. For example, a central control building or a switchgear room at a dam is likely to have a much higher replacement cost value than a maintenance shop or warehouse. Respondents were instructed to assume that pertinent structures of value located within the downstream inundation zone had been damaged or destroyed (total destruction was to be assumed when there was doubt) and to estimate economic losses in U.S. dollars.

All 48 facilities answered three economic impact questions related to total asset replacement value, total remediation cost, and total business interruption cost. Respondents to the PNW Pilot were also asked for remarks related to the cost estimates. Respondents to the State Pilot were not asked to describe the basis upon which they estimated the economic impact. Similar to PAR, the estimates of economic impact were obtained by multiplying the number of dams by the geometric mean for each range of the indicators used by the respondents to estimate economic impact.

4.3 Mission Impact

The failure or disruption of a facility can severely impact essential services or critical functions that affect population centers, industrial areas, agricultural regions, flood-protected areas, or inland navigation systems. The CTS methodology incorporates the potential impacts that a successful adversarial attack could have on the loss of the following:

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6 A dam break means that the capability of the dam to impound water has been partially or totally lost, resulting in an uncontrolled release of water.

- Potable water supply
- Water delivery
- Power generation function
- Flood damage protection
- Inland navigation
- Recreation

5 SUMMARY

The sample was sufficiently large or diverse to determine whether the "bin" ranges (e.g., PAR, economic impact) were appropriate. However, it can be determined that the error induced by using bins instead of actual raw numbers is relatively small. It is almost always preferable to use an actual value versus a bin to ensure more accurate and smooth results. It is possible that using bins rather than raw numbers could affect the final "bin" of a given asset, particularly if a facility is at the extreme of a given bin. Without the raw number, it is possible that the facility could be overvalued or undervalued for that particular category. Depending on the category, it could impact the overall results.

When using information binned by a power function (e.g., 1–10, 10–100, 100–1,000), the use of the geometric mean is the preferred "mean" statistic. The arithmetic mean works well for bins that are equal in width (e.g., 0–10, 10–20). There may be room for a combination of both types of data collection in the CTS process. A larger sample size is needed to determine whether the changes are appropriate and effective.

The CTS questions that request information on the characteristics of the asset were generally effective. However, some of the questions designed to elicit information on infrastructure that could be impacted through a worst reasonable scenario were less effective, particularly those related to psychological effects. This inefficiency in data gathering can be resolved through greater use of GIS analysis to ascertain an initial idea of dependency and interdependency, followed with on-site visits and validation to refine the information and clarify the dependency and interdependency.

APPENDIX A:
SUMMARY OF RESULTS

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APPENDIX A: SUMMARY OF RESULTS

This appendix contains descriptions of the responses of the 48 pilot participants to the human impact, economic impact, and impact on critical functions tables depicted in Appendix B. The analysis of results is limited to the responses of the 48 participants.

Each of the 14 consequence parameters for which the subject-matter expert pilot project participants provided data were first broken down into seven bins, and the projects were sorted into these bins. For this summary, the bins have been characterized throughout this appendix by using estimates of the PAR, economic consequences, and impact on government capabilities and disruption of critical functions. These estimates are obtained by multiplying the geometric mean of the range by the number of projects in that category. Where the pilot project subject-matter expert respondents indicated that a consequence parameter "does not apply," their project was not included in the overall consequence estimate for that parameter.

Total Population at Risk and Population at Risk by Distance

For the CTS methodology, the PAR is the total estimated number of humans occupying a permanent residence, commercial building, or recreational area in the potential zone of inundation represented by the dam break.[7] The PAR does not represent the expected loss of life; rather, it indicates the number of residents impacted by a possible flood scenario from dam failure as a result of an adversarial attack. The number of expected deaths from a dam break may be significantly less than the PAR and depends on many factors, including time of warning, depth of flooding, and velocity of flood wave. The CTS methodology requires an estimated value for the total PAR within the flood inundation zone.

All 48 facilities provided data on population at risk. Typically, the PAR was determined by the facilities by using either existing data or the geographic information system (GIS) tools provided for this study. Five projects in the PNW Pilot used inundation maps dated from 1981 to 1997 where there could be substantial population change from those years to the present, which would affect the PAR. These same five projects also based the PAR on census data ranging from 1990 to 2006. The remaining 21 projects did not indicate what the PAR was based on. Respondents to the State Pilot were not asked to indicate what the PAR estimate was based on.

Figures A.1–A.5 and Tables A.1–A.5 show the breakdown of total PAR and the PAR for each distance used in the CTS. The PAR for each bin is estimated by multiplying the number of projects by the geometric mean of the population range for each. The geometric mean was used because respondents estimated population using ranges that doubled with each progressive category of impact.

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7 A dam break means that the capability of the dam to impound water has been partially or totally lost, resulting in an uncontrolled release of water.

Total Population at Risk

Figure A.1 and Table A.1 summarize the tabulations of responses to total population occupying the inundation zones out to 60 miles. Most of the projects included in the pilot studies have a population of less than 25,000 persons occupying permanent residences, commercial buildings, and recreational areas within the inundation zone considered for the worst reasonable case scenario. Forty-two (87 percent) of the projects would impact fewer than 100,000 occupants out to 60 miles, and none include more than 200,000 persons in the total inundation zone. Nevertheless, it is worth noting that the 100,001–200,000 range (bin 4) accounts for nearly 849,000 occupants or more than half (56 percent) of the total estimated PAR for all of the 48 projects.[8] The 50,001–100,000 range (bin 3) accounts for an additional 424,000 occupants or 28 percent of the total estimated PAR.

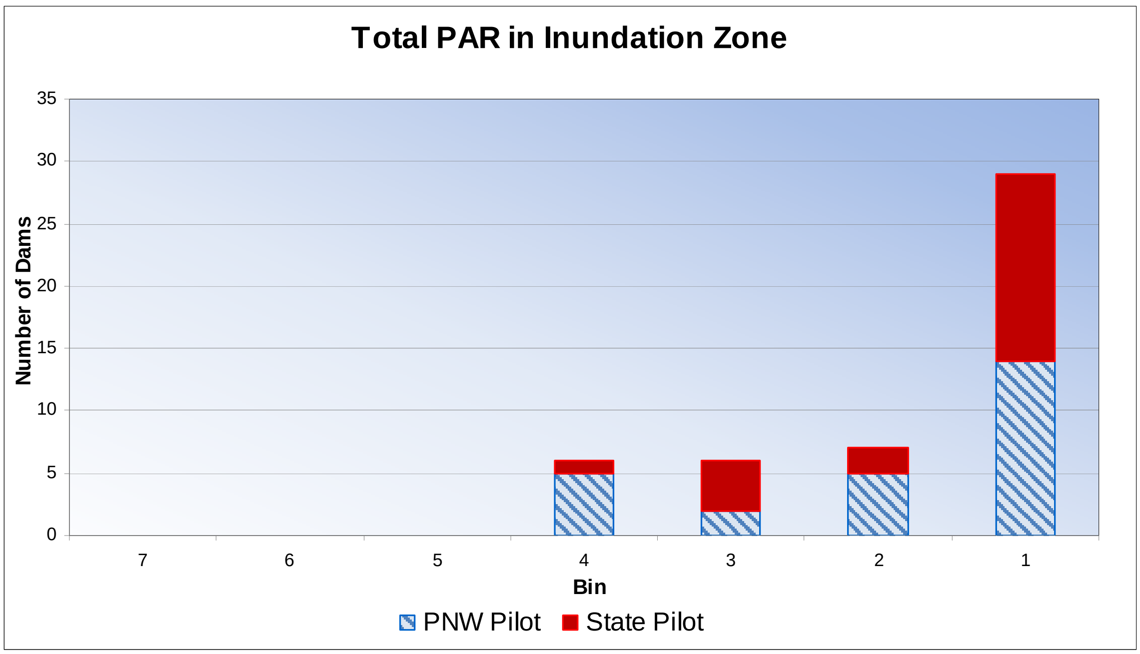

Figure A.1 Total PAR in Inundation Zone

8 In this and all subsequent sections of this appendix, the estimated number (in this case, PAR in bin 4) is obtained by multiplying the geometric mean of the range by the number of projects in that category (e.g., 141,422 × 6 = 848,532 rounded to the nearest 1,000).

Table A.1 Total PAR in Inundation Zone					
	Population		Projects		
Bin	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	800,001 +	800,000	0	0	0
6	400,001–800,000	565,686	0	0	0
5	200,001–400,000	282,843	0	0	0
4	100,001–200,000	141,422	5	1	6
3	50,001–100,000	70,711	2	4	6
2	25,001–50,000	35,356	5	2	7
1	0–25,000	158	14	15	29
Total			**26**	**22**	**48**

Population at Risk 0–3 Miles

Figure A.2 and Table A.2 summarize the estimates of population occupancy for the 0- to 3-mile inundation zone. Except for the smallest (0–50 occupants) and largest (>1,600 occupants) population range categories, the projects in the pilot studies are fairly evenly distributed with respect to population consequences out to 3 miles. Twenty-seven (56 percent) of the projects have fewer than 200 persons occupying permanent residences, commercial buildings, and recreational areas within the 3-mile inundation zone assumed in the worst reasonable case scenario. Fourteen or nearly 30 percent have more than 800 persons occupying the 3-mile inundation zone, and nine of these (nearly 20 percent of the total) have more than 1,600 occupants. The two highest population ranges (> 800 occupants) account for just over 20,000 estimated occupants or 80 percent of the total estimated PAR within 3 miles of all 48 projects. The 0- to 3-mile distance from a dam is especially important because catastrophic failure would represent a travel time of 0 to 15 minutes.

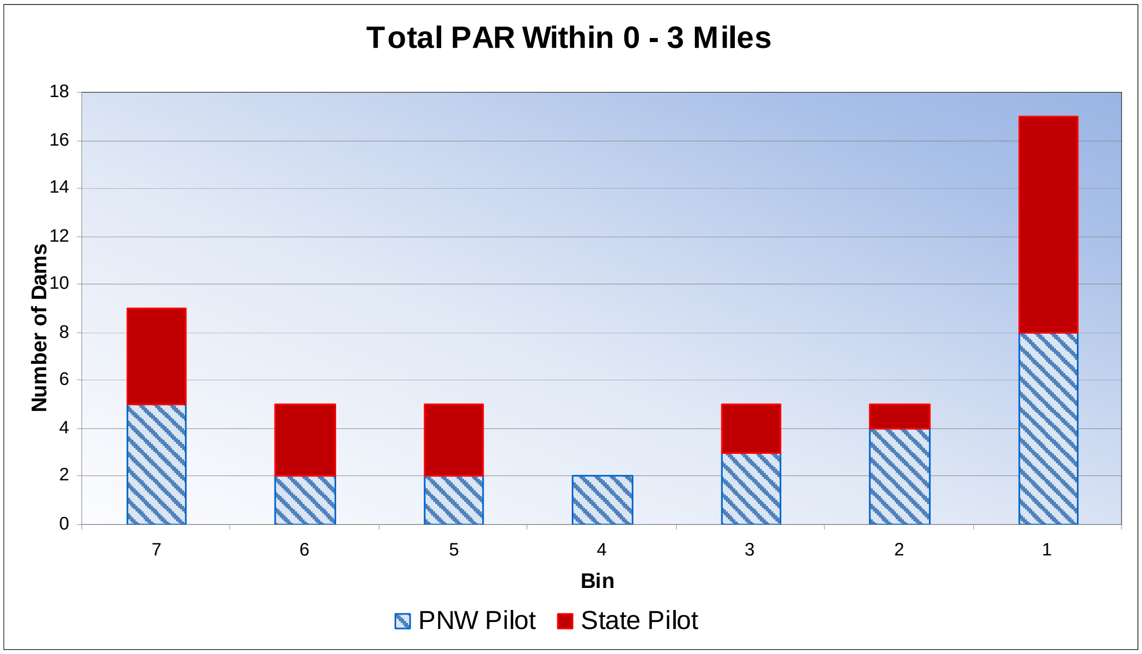

Figure A.2 Total PAR within 0–3 Miles

Table A.2 Total PAR within 0–3 Miles

Bin	Population		Projects		
	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	1,601 +	1,600	5	4	9
6	801–1,600	1,132	2	3	5
5	401–800	566	2	3	5
4	201–400	284	2	0	2
3	101–200	142	3	2	5
2	51–100	71	4	1	5
1	0–50	7	8	9	17
Total			**26**	**22**	**48**

Population at Risk 3–7 Miles

Figure A.3 and Table A.3 summarize estimated population occupancy within the 3- to 7-mile range of the inundation zone. Nineteen (40 percent) of the 48 pilot study projects have 100 or fewer occupants, and more than half (27 projects) have fewer than 400 people. The total estimated PAR increases with increased distance from the projects that were considered, and 14 (nearly 30 percent of the projects included in the pilot) have 1,600 or more occupants and 5 (10 percent) have 3,200 or more. Although the lower ranges with fewer than 1,600 occupants account for more than 70 percent of the projects in the pilot studies, the largest ranges (bins 6 and 7; with more than 1,600 occupants) account for 84 percent of the total estimated population in the 3- to 7-mile zone, which represents approximately 15 to 30 minutes of travel time.

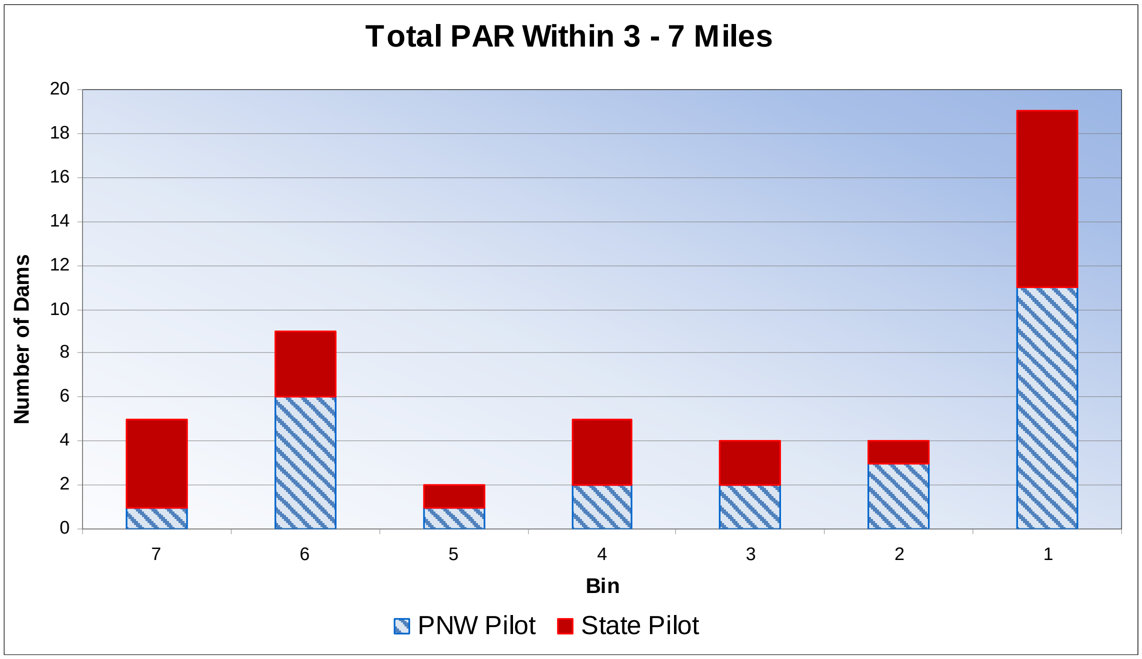

Figure A.3 Total PAR within 3–7 Miles

Table A.3 Total PAR within 3–7 Miles

Bin	Population		Projects		
	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	3,200 +	3,200	1	4	5
6	1,601–3,200	2,263	6	3	9
5	801–1,600	1,132	1	1	2
4	401–800	566	2	3	5
3	201–400	284	2	2	4
2	101–200	142	3	1	4
1	0–100	10	11	8	19
Total			**26**	**22**	**48**

Population at Risk 7–15 Miles

Figure A.4 and Table A.4 show that within the 7- to 15-mile zone, 28 (nearly 60 percent) of the pilot projects have fewer than 400 occupants. Thirty-five projects (73 percent) have fewer than 3,200 occupants in this zone, and the remaining 13 (27 percent) have more than 3,200 occupants. Most projects included in the pilot studies have small occupant populations in the 7- to 15-mile zone. However, the 13 projects in the two highest ranges (bins 6 and 7, with 3,200 or more occupants) account for 85 percent of the total estimated population (more than 70,000 of the total 82,500 estimated occupants) in that zone. At nearly 5,400 occupants per project, this is not an insignificant consequence because water is estimated to flow from the toe of the dam to the 15-mile limit in 30 to 60 minutes.

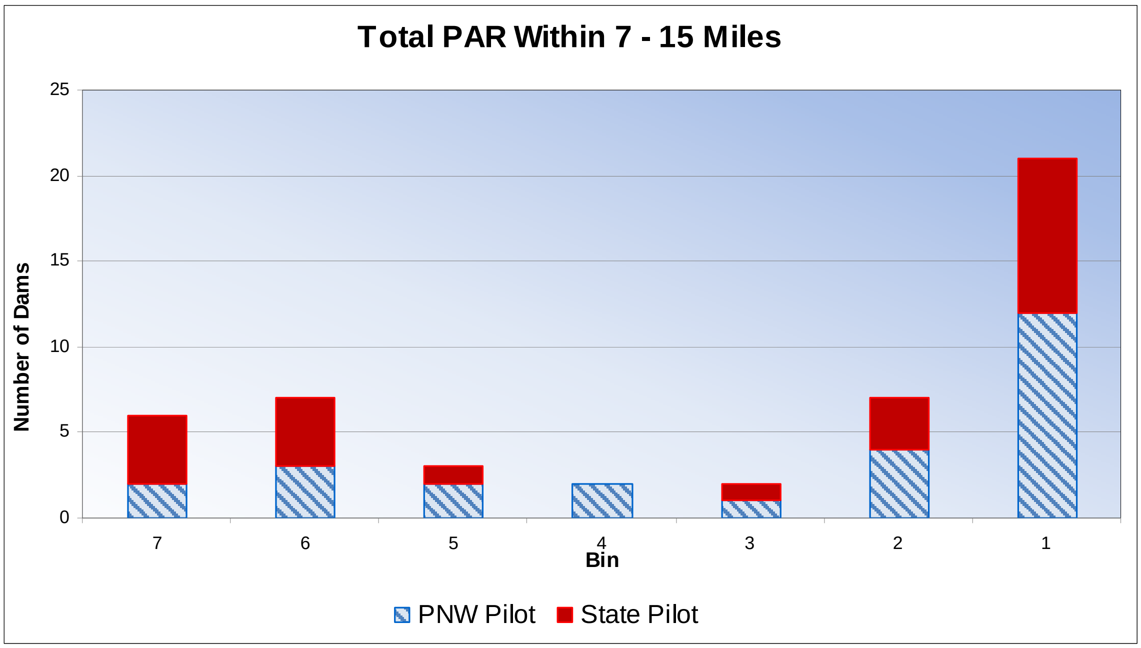

Figure A.4 Total PAR within 7–15 Miles

Table A.4 Total PAR within 7–15 Miles					
	Population		Projects		
Bin	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	6,400 +	6,400	2	4	6
6	3201–6400	4,526	3	4	7
5	1,601–3,200	2,263	2	1	3
4	801–1,600	1,132	2	0	2
3	401–800	566	1	1	2
2	201–400	284	4	3	7
1	0–200	14	12	9	21
Total			**26**	**22**	**48**

Population at Risk 15–60 Miles

As shown in Figure A.5 and Table A.5, the human health and safety consequences for the 15- to 60-mile zone follows a pattern similar to that of the 7- to 15-mile zone, except that over the larger area, the estimated total population is more than three times greater (280,000 estimated occupants compared with 82,500) over all 48 projects considered in the pilot studies. Twenty-seven (nearly 60 percent) of the projects have fewer than 1,600 occupants. Thirty-seven projects (77 percent) have fewer than 6,400 occupants, and the remaining 11 (23 percent) have more than 6,400 occupants. The 11 projects in the three highest ranges (occupant populations greater than 6,400) account for nearly 84 percent of the total estimated population (over 233,500 occupants) in the 15- to 60-mile zone, or more than 21,000 occupants per project. Flow from the toe of the dam to this zone has been estimated in excess of 30 to 60 minutes.

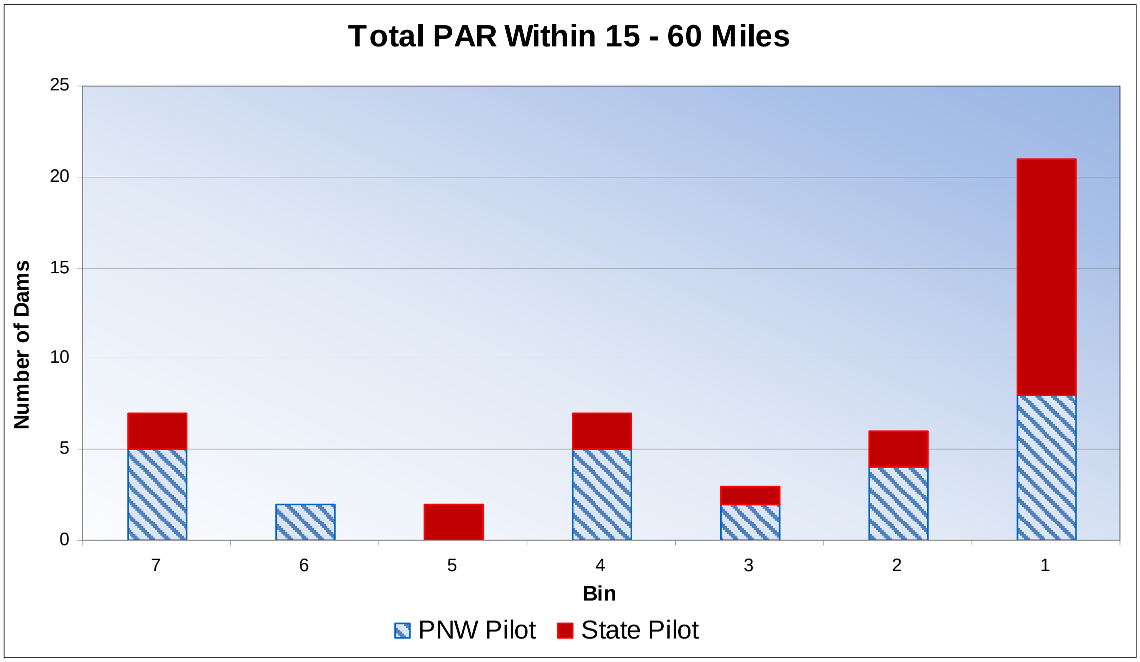

Figure A.5 Total PAR within 15–60 Miles

Table A.5 Total PAR within 15–60 Miles

Bin	Population		Projects		
	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	25,600 +	25,600	5	2	7
6	12,801–25,600	18,103	2	0	2
5	6,401–12,800	9,052	0	2	2
4	3,201–6,400	4,526	5	2	7
3	1,601–3,200	2,263	2	1	3
2	801–1,600	1,132	4	2	6
1	0–800	28	8	13	21
Total			**26**	**22**	**48**

Economic Impacts

The economic consequences and impacts presented below were estimated by the pilot study respondents on the basis of expert judgment and prior case histories of dam failure incidents assuming a worst reasonable case scenario. Such a scenario may differ from the one that causes the greatest impact on human health and safety and often, but not always, represents a total dam system failure.

The highest value property losses may not necessarily correspond to the maximum number of buildings and equipment. For example, a central control building or a switchgear room at a dam is likely to have a much higher replacement cost value than a maintenance shop or warehouse. Respondents were instructed to assume that pertinent structures of value located within the downstream inundation zone were damaged or destroyed (total destruction was to be assumed when there was doubt) and to estimate economic losses in U.S. dollars.

All 48 facilities answered three economic impact questions regarding the total asset replacement value, total remediation cost, and total business interruption cost. Respondents in the PNW Pilot were also asked for remarks related to the cost estimates. Similar to the PAR, the economic impact results were obtained by multiplying the number of dams by the geometric mean for each range of the indicators used by the respondents to estimate economic impact.

Asset Replacement Value

Asset replacement costs were defined as applying to site equipment, units, or other on-site property that was damaged beyond repair and would need to be replaced in order to restore the original functionality of the equipment or units to the design productivity level. “Unit(s) or asset(s)” were defined as any person, environment, facility, material, information, business reputation, or activity that had a positive value to an owner/operator. This value was estimated regardless of whether the owner planned to rebuild or not. The decision to rebuild is not a consideration for this estimate because the benefits of the dam have been lost to the Nation or region. In any event, a cost-benefit analysis would be performed to determine the economics of rebuilding.

The economic value to repair or replace the damaged or destroyed facility and its equipment, plus the economic value of on-site products destroyed, if any, were estimated in U.S. dollars. For this estimate, the replacement value of the dam property and on-site products involved were used. Because of the volatility of market values, respondents were asked not to use them for the asset replacement estimate. As with the health effects, the adversarial attack scenario that yields the highest costs was to be used as the basis for the estimate.

Respondents in the PNW Pilot study generally estimated asset replacement cost on the basis of construction costs or the cost of labor and concrete procurement and placement adjusted to current year costs. Respondents in the State Pilot were not asked to indicate the basis for their asset replacement estimate.

Figure A.6 and Table A.6 show the replacement costs for the 48 facilities obtained from the PNW and State Pilot studies. Just over half of the projects (52 percent) are in the lowest impact category, and 40 (83 percent) result in replacement costs of less than $800 million. There are a few high-consequence dams. The three projects in the highest impact category account for 40 percent of the nearly $24 billion replacement cost estimated for all 48 projects, and the 8 projects in the three highest categories account for an estimated $17.5 billion (nearly 75 percent) of the total replacement costs for the 48 dams considered in the pilot studies.

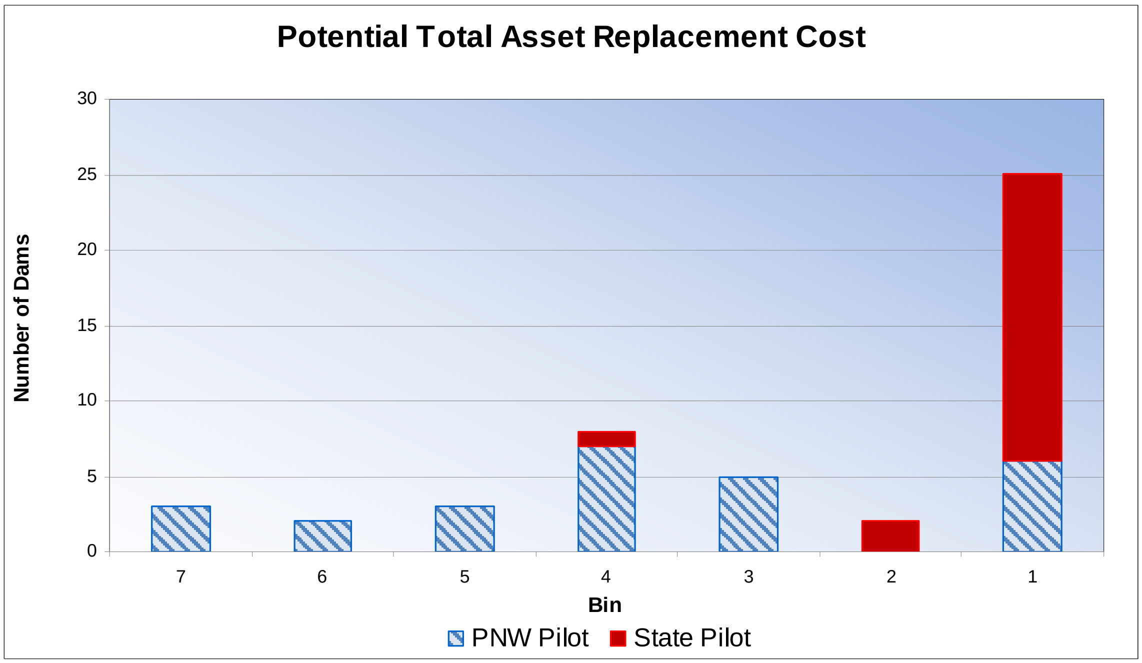

Figure A.6 Potential Total Asset Replacement Cost

Table A.6 Potential Total Asset Replacement Cost					
	Cost ($)		Projects		
Bin	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	3,200,000,001 +	3,200,000,000	3	0	3
6	1,600,000,001–3,200,000,000	2,262,741,701	2	0	2
5	800,000,001–1,600,000,000	1,131,370,851	3	0	3
4	400,000,001–800,000,000	565,685,426	7	1	8
3	200,000,001–400,000,000	282,842,713	5	0	5
2	100,000,001–200,000,000	141,421,357	0	2	2
1	0–100,000,000	$10,000	6	19	25
Total			**26**	**22**	**48**

Asset Remediation Costs

Remediation costs included estimated restoration/repair of on-site and off-site property damage and/or the environmental restoration costs. In preparing their estimates, respondents were directed to exclude emergency response (search and rescue) costs and indirect costs such as lawsuits, increased insurance costs, or higher financing/borrowing as remediation costs.

The remediation cost estimates therefore include only those off-site (downstream) costs related to direct property damage and environmental restoration, as well as repair (not replacement) of on-site property. The costs to remediate collateral damage beyond the dam include the following:

- Costs to repair or replace downstream property affected by the inundation area (public property, as well as residential and commercial property);
- Costs to remediate and restore the environmental effects caused by the failure scenario, including release of contaminants and cascading downstream failures; and
- Costs associated with the financial write-off of the facility and/or other indirect remediation costs, not already accounted for above, such as costs for temporary constructed facilities, rented/leased facilities, safety/security measures provided for public protection, etc.

Respondents were not to include any liability costs associated with damage to other property or the environment, including fines imposed by regulators.

Respondents to the PNW Pilot listed several formulas for estimating remediation costs: economic consequence assessments, $100,000 per PAR for damages, doubling of the estimated replacement cost, and total asset replacement value plus 20 percent. Several respondents simply listed the names of the communities that would be impacted as the basis for their response; others indicated their estimate was a guess. The State Pilot respondents were not asked to explain the basis of their remediation cost estimate.

Figure A.7 and Table A.7 show the remediation cost binning for the 48 facilities in the Pilot and State surveys.

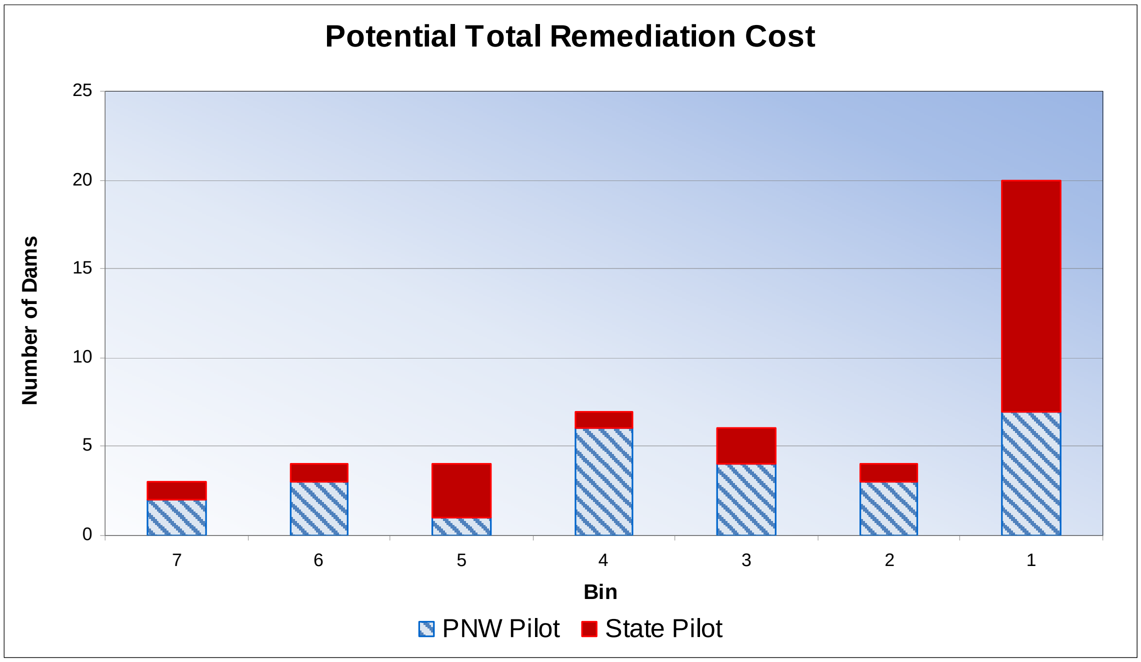

Figure A.7 Potential Total Remediation Cost

A small number of dams have the potential to create situations with very high remediation costs. Thirty (63 percent) of the 48 dams in the pilot studies are estimated to have remediation costs under $800 million. The remaining 18 (37 percent) projects with remediation costs estimated to be in excess of $800 million account for $54 billion (92 percent) of the total cost of $58.9 billion estimated to remediate all 48 projects. While only seven dams (15 percent of the total projects considered) are in the two highest impact categories where remediation costs are estimated to be in excess of $3.2 billion, these large projects account for nearly $37 billion (63 percent) of the total remediation cost of all 48 dams included in the pilot studies. The three projects in the highest impact category account for $19.2 billion, nearly 33 percent of the total remediation cost.

Table A.7 Potential Total Remediation Cost					
	Cost ($)		Projects		
Bin	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	6,400,000,001 +	6,400,000,000	2	1	3
6	3,200,000,001–6,400,000,000	4,525,483,400	3	1	4
5	1,600,000,001–3,200,000,000	2,262,741,701	1	3	4
4	800,000,001–1,600,000,000	1,131,370,851	6	1	7
3	400,000,001–800,000,000	565,685,426	4	2	6
2	200,000,001–400,000,000	282,842,713	3	1	4
1	0–200,000,000	4,472	7	13	20
Total			**26**	**22**	**48**

Business Interruption Costs

Business interruption costs include the total estimated value of the benefits not being produced over a 1-year period during which the dam or affected companies are unable to operate. These costs were to be estimated by using either the insured value of lost business or other data available from the owner/operator. In estimating these business interruption costs, respondents were instructed not to consider costs to suppliers, customers, or other secondary business interruptions. The following costs were to be considered as business interruption costs:

- Direct costs of lost business based on the value of the benefits provided per unit time and the amount of time the facility could not produce them, not to exceed 12 months, and

- Costs represented by the lost market share.

To overcome the restriction on many private owners/operators of disclosing financial information, respondents reporting on the lost revenue from electric power generation could use an “average annual generation figure” estimated value of $60 per megawatt-hour (estimated in 2008 U.S. dollars).

The business interruption cost estimates appeared to be more substantive than those offered for total remediation estimates. Many of the estimates made by the PNW Pilot respondents were based on the total annual power generation multiplied by $60 per megawatt-hour, estimates of annual power sales, or a consequence assessment. Several respondents indicated their estimate was a guess or listed the names of impacted communities. The State Pilot respondents were not asked to reveal the basis for their business interruption costs.

Figure A.8 and Table A.8 depict the business interruption cost binning for the 48 facilities in the PNW and State Pilots. Once again, a few dams have the potential to experience high business interruption impacts. The three projects (only 6 percent of the total) in the highest impact category account for more than 28 percent of the total estimated potential business interruption costs. Eight dams in the two highest impact categories, where business interruption costs are estimated to be in excess of $800 million per facility, account for $10.4 billion (62 percent) of the total potential $16.8 billion business interruption costs estimated for all of the 48 dams included in the pilot studies. Seven additional dam projects with individual estimated interruption costs under $800 million account for an additional $4 billion (24 percent) of the total estimate. Thirty-three (69 percent) of the 48 dams in the pilot studies are estimated to have potential business interruption costs under $400 million. The estimated $2.4 billion total business interruption cost for these is less than 15 percent of the $16.8 billion estimated for all 48 projects.

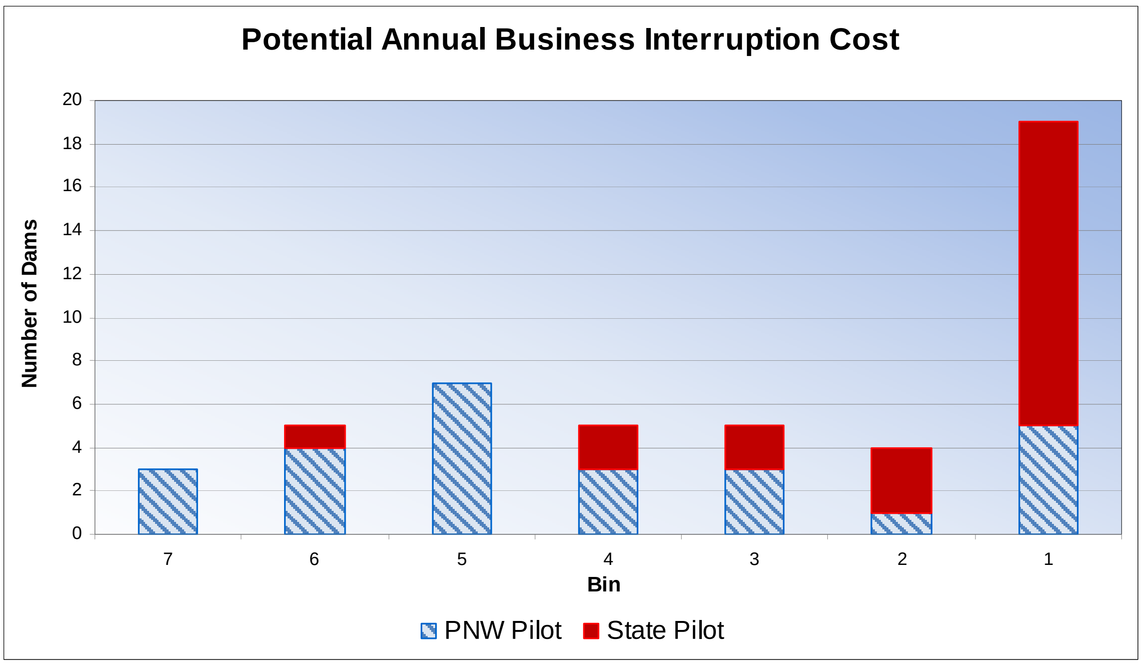

Figure A.8 Potential Annual Business Interruption Cost

Table A.8 Potential Annual Business Interruption Cost					
	Cost ($)		Projects		
Bin	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	1,600,000,001 +	1,600,000,000	3	0	3
6	800,000,001–1,600,000,000	1,131,370,851	4	1	5
5	400,000,001–800,000,000	565,685,426	7	0	7
4	200,000,001–400,000,000	282,842,713	3	2	5
3	100,000,001–200,000,000	141,421,357	3	2	5
2	50,000,001–100,000,000	70,710,679	1	3	4
1	0–50,000,000	7,071	5	14	19
Total			**26**	**22**	**48**

Impact on Government Capabilities and Disruption of Critical Functions

The failure or disruption of a facility may severely impact essential services or critical functions that affect populated centers, industrial areas, agricultural regions, flood protected areas, or inland navigation systems. The CTS methodology incorporates the potential impacts that a successful adversarial attack could have on the following:

- Loss of potable water supply;
- Loss of water delivery and critical irrigation impacts;
- Critical power generation impacts;
- Critical flood damage protection impacts;
- Critical inland navigation impacts; and
- Critical recreation impacts.

Loss of Potable Water Supply

Respondents were asked to estimate the size of the population potentially impacted by the loss of potable water associated with their dam. Nine of the PNW Pilot respondents and four State respondents answered that this consideration "does not apply" to their project. Figure A.9 and Table A.9 summarize estimates for the 35 projects that provided data. A few individual projects have the potential for significant consequences. Two projects serve populations of 8 million or more (accounting for 16 million or about 73 percent of the total served by these projects), and a third project serves between 2 million and 4 million (accounting for an additional 2.8 million and over 85 percent of the combined total served). The 29 projects providing potable water to populations of 500,000 or fewer serve less than 2 percent of the total estimated population served.

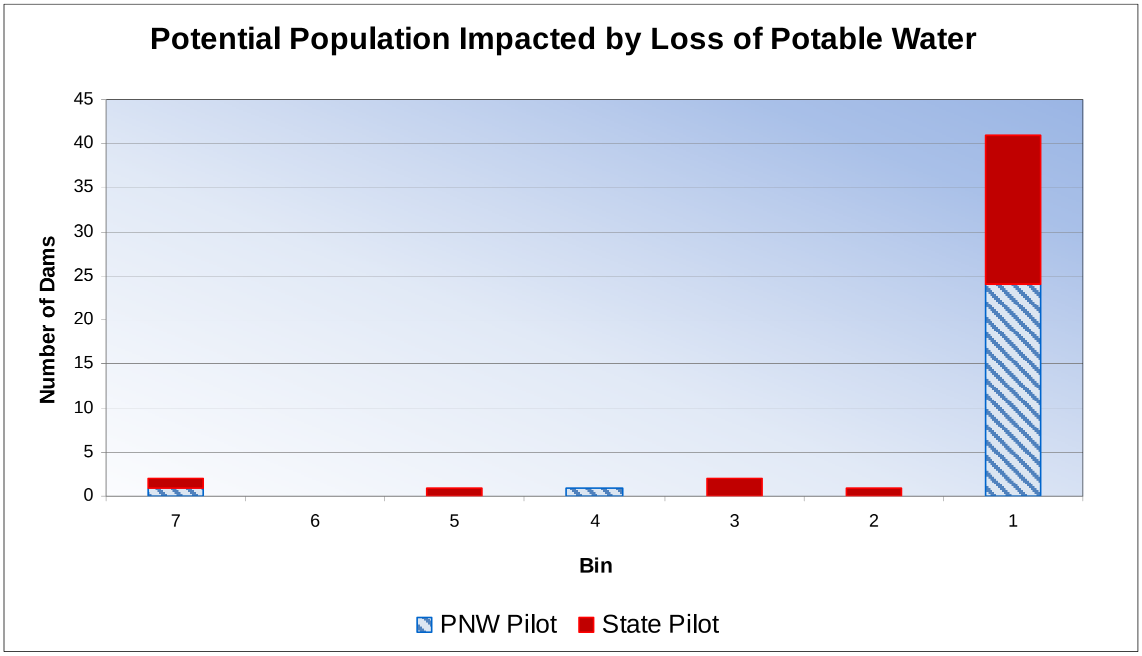

Figure A.9 Potential Population Impacted by Loss of Potable Water

Table A.9 Potential Population Impacted by Loss of Potable Water

Bin	Population		Projects		
	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	8,000,001 +	8,000,000	1	1	2
6	4,000,001–8,000,000	5,656,855	0	0	0
5	2,000,001–4,000,000	2,828,428	0	1	1
4	1,000,001–2,000,000	1,414,214	1	0	1
3	500,001–1,000,000	707,107	0	2	2
2	250,001–500,000	353,554	0	1	1
1	0–250,000	500	15	13	28
Total			**17**	**18**	**35**

Loss of Water Delivery and Critical Irrigation Impacts

Pilot respondents were asked to estimate the value of lost water deliveries associated with loss of their dam. Eleven of the initial PNW respondents and one State respondent answered that this consideration "does not apply" to their project. Figure A.10 and Table A.10 summarize the estimates for the 36 projects that provided data. Again, a few individual projects have the potential for significant consequences. Two projects have estimated consequences of $1.6 billion or more, and an additional three have an estimated loss impact of between $800 million and $1.6 billion. Together, these top five projects account for an estimated $6.6 billion of lost water delivery value—approximately 80 percent of the total $8.3 billion potential. The seven projects that would result in lost water deliveries in excess of $4 billion account for a total of $7.7 billion or more than 93 percent of the total estimated value of lost water deliveries. The 29 projects with estimated lost value of $400 million or less account for approximately $566 million or less than 7 percent of the potential total lost delivery value.

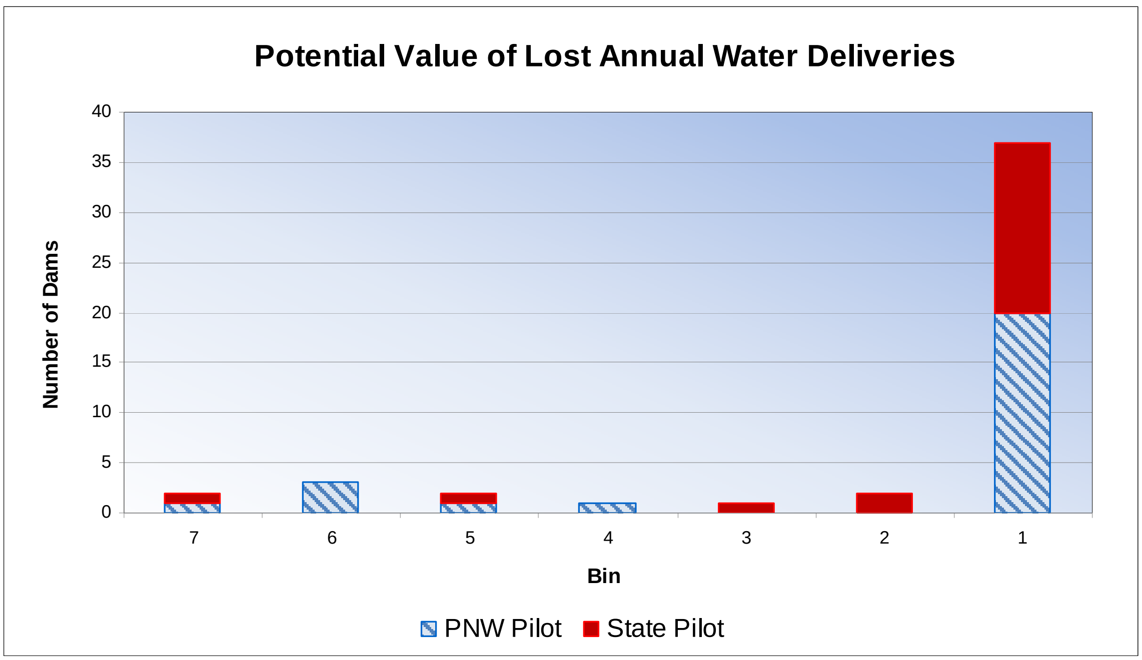

Figure A.10 Potential Value of Lost Annual Water Deliveries

Table A.10 Potential Value of Lost Annual Water Deliveries					
	Cost ($/yr)		Projects		
Bin	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	1,600,000,001 +	1,600,000,000	1	1	2
6	800,000,001–1,600,000,000	1,131,370,851	3	0	3
5	400,000,001–800,000,000	565,685,426	1	1	2
4	200,000,001–400,000,000	282,842,713	1	0	1
3	100,000,001–200,000,000	141,421,357	0	1	1
2	50,000,001–100,000,000	70,710,679	0	2	2
1	0–50,000,000	7,071	9	16	25
Total			**15**	**21**	**36**

Critical Power Generation Impacts

Figure A.11 and Table A.11 show the potential for lost electricity-generating capacity from the 38 facilities in the Pilot that generate hydropower. Although 10 of the State Pilot respondents answered that their dams do not generate power, this null option was not available to the PNW respondents. In validating the data, it became clear that some of the PNW projects included in the lowest category (0–200 MW) are not power generators. Although this fact does not significantly alter the consideration of consequences described below, all projects must be distinguished as to whether they are power generators or not, and the lowest range should be anchored at 1 MW.

Again, a few individual projects have the potential for significant consequences. Two projects with generating capacity of 6,400 MW or greater have a combined estimated capacity of 12.8 gigawatts (GW), accounting for more than 50 percent of the total 24.5-GW capacity of the 38 projects included in the analysis. Together, the 12 projects with generating capacity in excess of 400 MW, account for 24 GW or 98 percent of the generating capacity among all 38 projects analyzed. The 26 projects with estimated generating capacity of 200 MW or less account for about 370 MW—approximately 2 percent of the total generating capacity of all 38 projects.

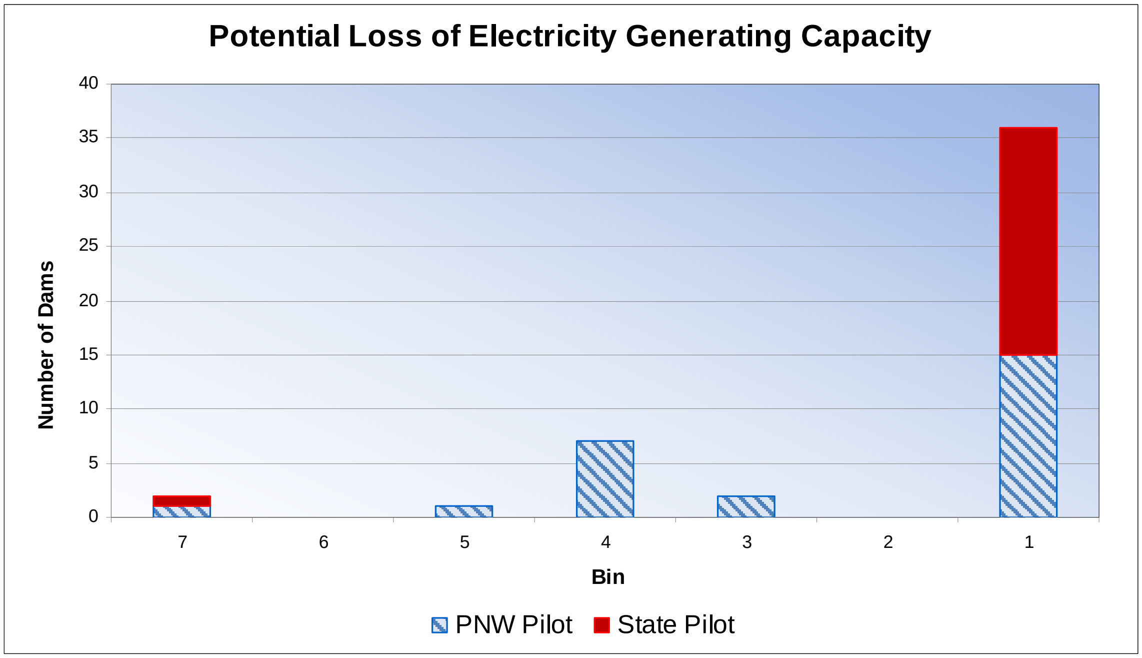

Figure A.11 Potential Loss of Electricity Generating Capacity

Table A.11 Potential Loss of Electricity Generating Capacity

Bin	Capacity (MW)		Projects		
	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	6,401 +	6,400	1	1	2
6	3,201–6,400	4,526	0	0	0
5	1,601–3,200	2,263	1	0	1
4	801–1,600	1,132	7	0	7
3	401–800	566	2	0	2
2	201–400	284	0	0	0
1	0–200	14	15	11	26
Total			**26**	**12**	**38**

Critical Flood Damage Protection Impacts

Respondents whose projects are authorized flood control projects were asked to estimate the value of average annual flood damages prevented by their dam. Ten of the PNW projects are authorized flood control projects. It is unknown how many of the State dams are flood control projects, but they were given the option to respond “does not apply.” Figure A.12 and Table A.12 summarize the estimates of potential flood damages prevented by the 39 projects. Thirty-five of the projects (90 percent) estimate that they each prevent less than $100 million in damages, accounting for a total value of $283 million or about 17 percent of the total estimated value of $1.7 billion. Four projects prevent damages in the range from $200 million to $800 million, for a total of $1.4 billion (83 percent of the total $1.7 billion); an average of approximately $353 million per project. No flood control projects were estimated to result in preventing damages in excess of $800 million.

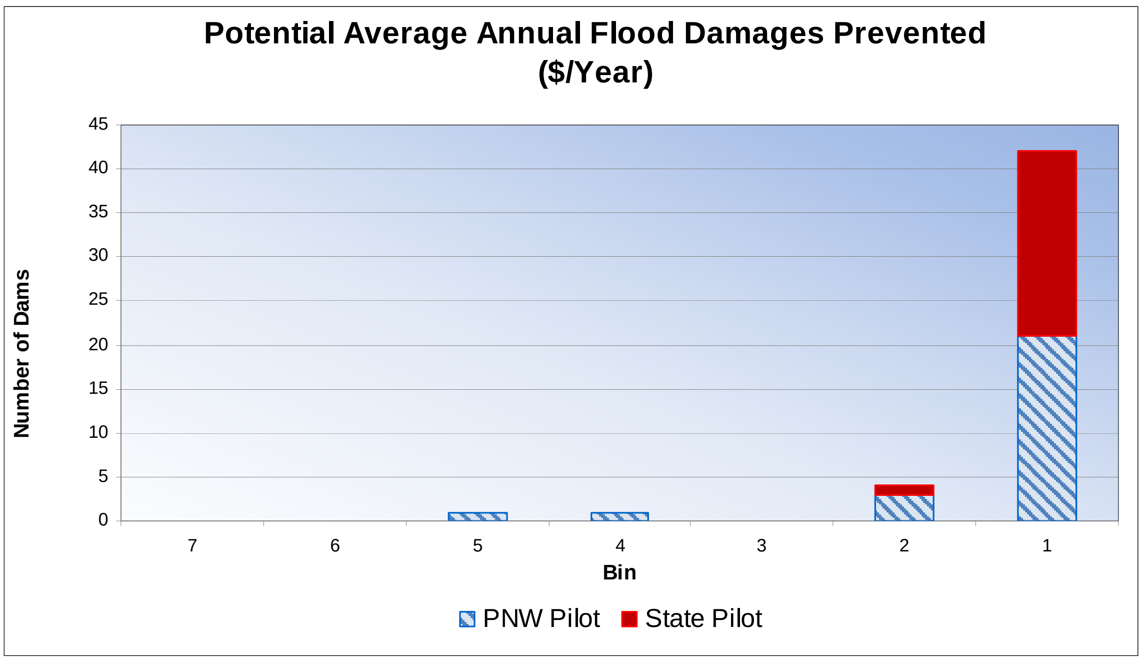

Figure A.12 Potential Annual Flood Damages Prevented ($/yr)

Table A.12 Potential Annual Flood Damages Prevented					
	Cost ($/yr)		Projects		
Bin	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	1,600,000,001 +	1,600,000,000	0	0	0
6	800,000,001–1,600,000,000	1,131,370,851	0	0	0
5	400,000,001–800,000,000	565,685,426	1	0	1
4	200,000,001–400,000,000	282,842,713	3	0	3
3	100,000,001–200,000,000	141,421,357	0	0	0
2	50,000,001–100,000,000	70,710,679	3	1	4
1	0–50,000,000	7,071	19	12	31
Total			**26**	**13**	**39**

Critical Inland Navigation Impacts

Figure A.13 and Table A.13 summarize the estimates of navigation benefits lost in kilotons of cargo not transported over the 12 projects designated as navigable. Two of the PNW projects and 10 of the State projects were so classified. The results indicate that this is not a discriminating factor; considering that 10 (83 percent) of the facilities place themselves in the less than 3,000-kiloton range, accounting for 550 kilotons and approximately 3 percent of the total 17,500 kilotons for the 12 navigable projects. The remaining 97 percent or approximately 17,000 kilotons is accounted for by the two navigable projects in the 6,000- to 12,000-kiloton range.

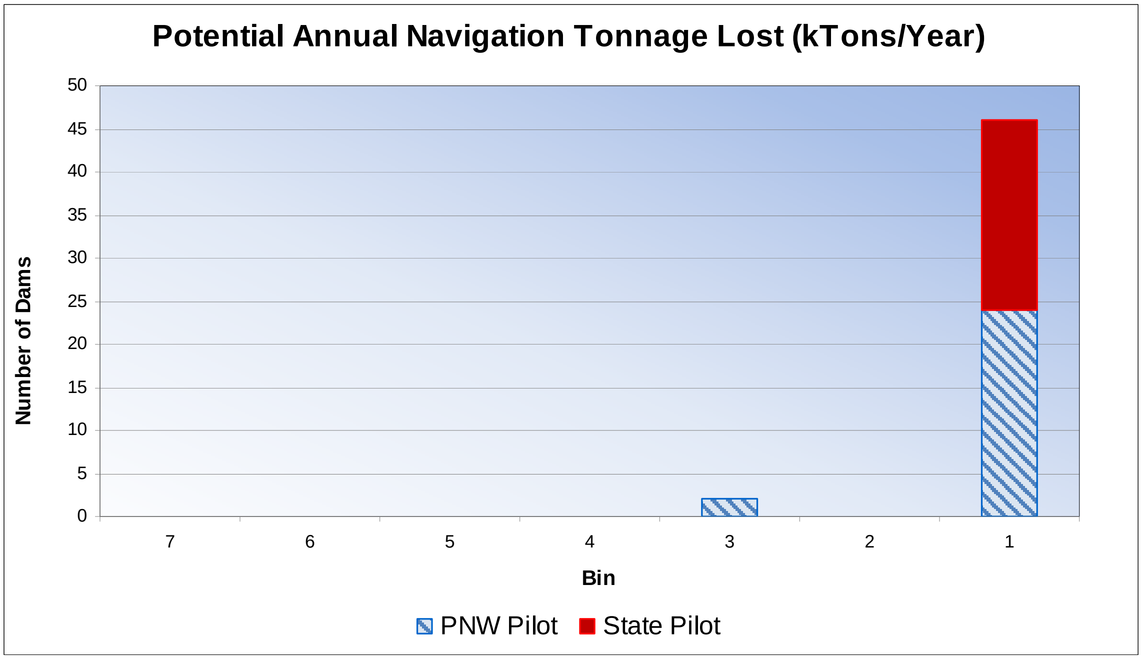

Figure A.13 Potential Annual Navigation Tonnage Lost (kton/yr)

Table A.13 Potential Annual Navigation Tonnage Lost

Bin	Navigation Tonnage Lost (kton/yr)		Projects		
	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	96,000 +	96,000	0	0	0
6	48,001–96,000	67,883	0	0	0
5	24,001–48,000	33,942	0	0	0
4	12,001–24,000	16,971	0	0	0
3	6,001–12,000	8,486	2	0	2
2	3,001–6,000	4,243	0	0	0
1	0–3,000	55	0	10	10
Total			**2**	**10**	**12**

Critical Recreation Impacts

Pilot respondents were asked to estimate the number of recreational visits to the project area that could be lost if their facility was destroyed by the worst reasonable case scenario. These estimates are summarized in Figure A.14 and Table A.14. Again, a few projects produce the greatest consequences. The single project estimated to have 4.8 million visits annually accounts for 30 percent of the total 16 million visitors to all 48 projects. The 12 projects with 300,000 to 2.4 million visits account for 9.3 million or 58 percent of the total annual visits to all 48 projects for an average of 778,000 annual visits. Thirty-five of the projects (73 percent of the total) estimate that they have less than 300,000 visitors annually, accounting for a total of 1.9 million visits or about 12 percent of the total estimated 16 million visits to all 48 project areas.

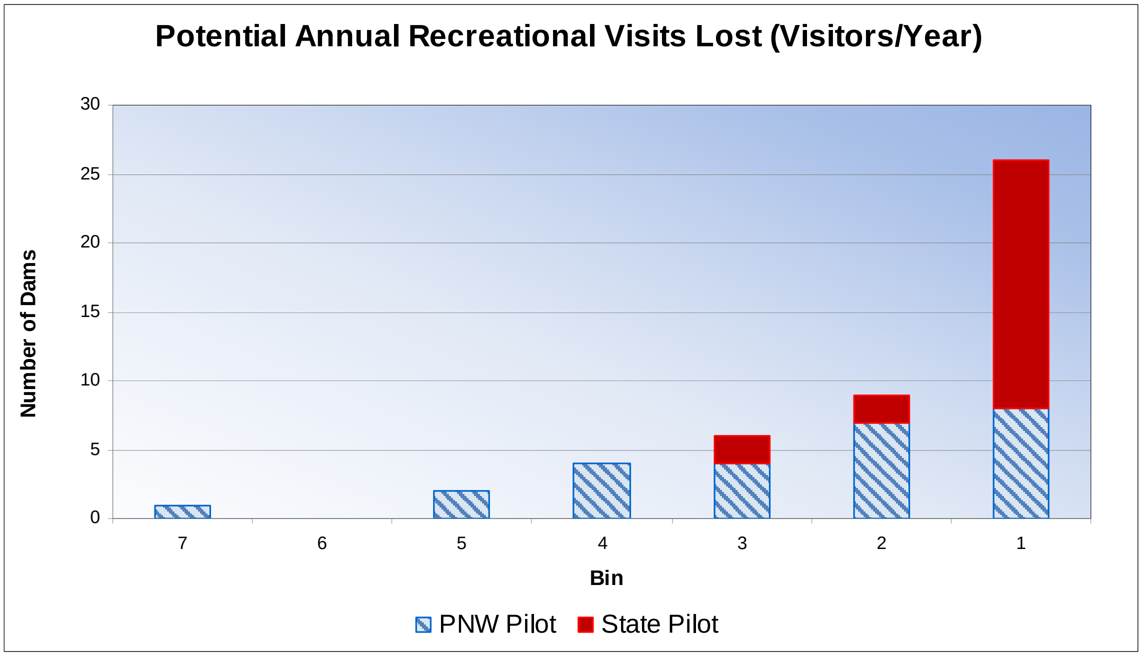

Figure A.14 Potential Annual Recreational Visits Lost (Visitors/yr)

Table A.14 Potential Annual Recreational Visits Lost

Bin	Recreational Visits (visitors/yr)		Projects		
	Range	Geometric Mean of the Range	PNW Pilot	State Pilot	Total
7	4,800,001 +	4,800,000	1	0	1
6	2,400,001–4,800,000	3,394,113	0	0	0
5	1,200,001–2,400,000	1,697,057	2	0	2
4	600,001–1,200,000	848,529	4	0	4
3	300,001–600,000	424,265	4	2	6
2	150,001–300,000	212,133	7	2	9
1	0–150,000	387	8	18	26
Total			**26**	**22**	**48**

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APPENDIX B:
FORMS USED FOR PNW PILOT

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APPENDIX B: FORMS USED FOR PNW PILOT

Form 1 – General Information

Form 1 collects general information for the facility under review. In many cases, this form will be provided to the facility pre-populated with data from the National Inventory of Dams (NID). If your facility's NID data is not accurate, please input the appropriate changes in Form 1 and indicate the need for changes here.

☐ Updated NID Data   Data Field(s) No.: ____________________________

1. Basic Facility Information
1. Dam Name: *Official name of the dam.*
2. Other Dam Names: *Other names (i.e., reservoir name) of the dam in common use.*
3. Dam Former Name: *Any previous reservoir or dam name(s), if changed.*
4. State or Federal Agency ID: *Official State or Agency identification number for the dam.*
5. NID ID Number: *Official NID identification number for the dam.*
6. Longitude: *Longitude at dam centerline as a single value in decimal degrees.*
7. Latitude: *Latitude at dam centerline as a single value in decimal degrees.*
8. Section, Township, Range Location: *Section, Township, and Range Location on the state database.*
9. County: *Name of the county in which the dam is located.*
10. River or Stream: *Official name of the river or stream on which the dam is built.*
11. Owner Name: *Name of the dam owner.*
12. Owner Type: *Type of owner (F: Federal, S: State, L: Local Government, U: Public Utility, P: Private).*
13. Dam Designer: *Name of the principal firm(s) or agency accomplishing design of dam and major appurtenant operating features, and major modifications.*

14. Non-Federal Dam on Federal Property: *Code indicating whether this dam is a non-Federal dam located on Federal property (Y/N).*
15. Dam Type: *Type of dam, list all applicable codes (RE: Earth, ER: Rockfill, PG: Gravity, CB: Buttress, VA: Arch, MV: Multi-Arch, CN: Concrete, MS: Masonry, ST: Stone, TC: Timber Crib, RC: Roller-Compacted Concrete, OT: Other).*
16. Core: *Position, type of watertight member, and certainty (Position – F: Upstream Facing, H: Homogeneous Dam, I: Core, X: Unlisted/Unknown; Type – A: Bituminous Concrete, C: Concrete, E: Earth, M: Metal, P: Plastic, X: Unlisted/Unknown; Certainty – K: Known, Z: Estimated).*
17. Foundation: *Material upon which dam is founded, and certainty (Foundation – R: Rock, RS: Rock and Soil, S: Soil, U: Unlisted/Unknown: Certainty – K: Known, Z: Estimated).*
18. Purposes: *Purposes for which the reservoir is used, list all applicable codes (I: Irrigation, H: Hydroelectric, C: Flood Control and Storm Water Management, N: Navigation, S: Water Supply, R: Recreation, P: Fire Protection, Stock, or Small Farm Pond, F: Fish and Wildlife Pond, D: Debris Control, T: Tailings, O: Other)*
19. Year Completed: *Year when the original main dam structure was completed.*
20. Year Modified: *Year when major modifications or rehabilitation of dam or major control structures were completed, and type of modification (S: Structural, F: Foundation, M: Mechanical, E: Seismic, H: Hydraulic, O: Other).*
21. Dam Length (Feet): *Length of the dam, defined as the length along the top of the dam. This also includes the spillway, powerplant, navigation lock, fish pass, etc., where these form part of the length of the dam. If detached from the dam, these structures should not be included.*
22. Dam Height (Feet): *Height of the dam, defined as the vertical distance between the lowest point on the crest of the dam and the lowest point in the original streambed.*
23. Structural Height (Feet): *Structural height of the dam, defined as the vertical distance from the lowest point of the excavated foundation to the top of the dam.*
24. Hydraulic Height (Feet): *Hydraulic height of the dam, defined as the vertical difference between the maximum controllable water level and the lowest point in the original streambed.*
25. Maximum Discharge (Cubic Feet Per Second): *Spillway discharge capacity when the reservoir is at its maximum designed water surface elevation.*

26. Maximum Storage (Acre-Feet): *Maximum storage, defined as the total storage space in a reservoir below the maximum attainable water surface elevation, including any surcharge storage*.
27. Normal Storage (Acre-Feet): *Normal storage, defined as the total storage space in a reservoir below the normal retention level, including dead and inactive storage and excluding any flood control or surcharge storage.*
28. Surface Area (Acres): *Surface area of the impoundment at its normal retention level.*
29. Drainage Area (Square Miles): *Area that drains to a particular point (in this case, the dam) on a river or stream.*
30. Downstream Hazard Potential: *Potential hazard to the downstream area resulting from failure or misoperation of the dam (L: Low, S: Significant, H: High, U: Undetermined).* [9]
31. Emergency Action Plan: *Code indicating whether this dam has an Emergency Action Plan (EAP) developed by the dam owner (Y/N).*
32. Inspection Date: *Date of the most recent inspection of the dam.*
33. Inspection Frequency (Years): *Scheduled frequency interval for periodic inspections.*
34. State Regulated Dam: *Code indicating whether this dam is "State Regulated" under the National Dam Safety Program Act (Y/N).*
35. State Regulatory Agency: *Name of the primary state agency with regulatory or approval authority over the dam.*
36. Spillway Type: *Type of spillway (C: Controlled, U: Uncontrolled, N: None).*

[9] Interagency Committee on Dam Safety, 2004, *Federal Guidelines for Dam Safety: Hazard Potential Classification System for Dams (FEMA 333)*, Federal Emergency Management Agency, U.S. Department of Homeland Security, Washington, D.C., Jan., pp. 5–6.

Low Hazard Potential

Dams assigned the low hazard potential classification are those where failure or misoperation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the owner's property.

Significant Hazard Potential

Dams assigned the significant hazard potential classification are those dams where failure or misoperation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns. Significant hazard potential classification dams are often located in predominantly rural or agricultural areas but could be located in areas with population and significant infrastructure.

High Hazard Potential

Dams assigned the high hazard potential classification are those where failure or misoperation results will probably cause loss of human life.

37. Spillway Width (Feet): *Width of the spillway available for discharge when the reservoir is at its maximum designed water surface elevation.*
38. Outlet Gates: *Codes describing the type of spillway and controlled outlet gates, if any (X: None, U: Uncontrolled, T: Tainter/Radial, L: Vertical Lift, R: Roller, B: Bascule, D: Drum, N: Needle, F: Flap, S: Slide/Sluice Gate, V: Valve, O: Other).*
39. Volume of Dam (Cubic Yards): *Volume occupied by the materials used in the dam structure. Portions of powerhouse, locks, and spillways are included only if they are an integral part of the dam and required for structural stability.*
40. Number of Locks: *Number of existing navigation locks for the dam.*
41. Length of Locks (Feet): *Length of the primary navigation lock.*
42. Lock Width (Feet): *Width of the primary navigation lock.*
43. Federal Agency Involvement in Funding: *Federal agency involved in funding of the dam.*
44. Federal Agency Involvement in Design: *Federal agency involved in the design of the dam.*
45. Federal Agency Involvement in Construction: *Federal agency involved in the construction of the dam.*
46. Federal Agency Involvement in Regulatory: *Federal agency involved in the regulation of the dam.*
47. Federal Agency Involvement in Inspection: *Federal agency involved in the inspection of the dam.*
48. Federal Agency Involvement in Operation: *Federal agency involved in the operation of the dam.*
49. Federal Agency Owner: *Federal agency that partly or wholly owns the dam.*
50. Federal Agency Involvement – Other: *Federal agency involved in other aspects of the dam.*

2. Contact Information

1. Facility Contact(s) – Individual(s) designated as project manager(s) and qualified to answer questions about project characteristics and its different operations:

   a. Name: *Name(s) plus title(s) or job classification(s) of the person(s) designated as project manager(s).*

   b. Address: *Address(es) for the person(s) designated as the project manager(s). This should be the address at which they regularly receive business mail. (Include street, city, state, and zip code information, including the 4-digit extension if applicable. Use local road and street designations, not post office or rural box numbers, if possible.).*

   c. Phone Number: *Phone number(s) for the person(s) designated as project manager(s), including area code information (include office and mobile numbers, if possible).*

   d. E-mail: *E-mail address(es) for the person(s) designated as project manager(s).*

2. Facility Emergency Contact(s) – Individual(s) designated as primary contact(s) at the facility in the event of an emergency. If appropriate, include other required primary contacts in other levels within the organization that need to be included in potential notifications:

   a. Name: *Name(s) plus title(s) or job classification(s) of the person(s) designated as the 24 hour emergency contact.*

   b. Address: *Address(es) for the person(s) designated as the 24 hour emergency contact. This should be the address at which they regularly receive business mail. (Include street, city, state, and zip code information, including the 4-digit extension if applicable. Use local road and street designations, not post office or rural box numbers, if possible.).*

   c. Phone Number: *Phone number(s) for the person(s) designated as the 24 hour emergency contact, including area code information (include office and mobile numbers, if possible).*

   d. E-mail: *E-mail address(es) for the person(s) designated as the 24 hour emergency contact.*

3. State Dam Safety Agency Point of Contact (POC) (if applicable): a. Name: *Name(s) plus title(s) or job classification(s) for the person(s) identified as State Regulatory Agency representative(s).* b. Address: *Address(es) for the person(s) identified as State Regulatory Agency representative(s) (include street, city, state, and zip code, including the 4-digit extension, if applicable).* c. Phone Number: *Phone number(s) for the person(s) identified as State Regulatory Agency representative(s), including area code (include office and mobile numbers, if possible).* d. E-mail: *E-mail address(es) for the person(s) identified as State Regulatory Agency representative(s).*
4. Federal Regulatory Agency POC (if applicable): a. Name: *Name(s) plus title(s) or job classification(s) for the person(s) identified as Federal Regulatory Agency representative(s).* b. Address: *Address(es) for the person(s) identified as Federal Regulatory Agency representative(s) (include street, city, state, and zip code, including the 4-digit extension, if applicable).* c. Phone Number: *Phone number(s) for the person(s) identified as Federal Regulatory Agency representative(s), including area code (include office and mobile numbers, if possible).* d. E-mail: *E-mail address(es) for the person(s) identified as Federal Regulatory Agency representative(s).*
5. Local/State Primary Response Organizations: a. Name: *Name(s) of responsible organizations.* b. Address: *Address(es) for the responsible organizations.* c. Phone Number: *Phone number(s) for the responsible organizations.* d. E-mail: *E-mail address(es) for the responsible organizations.*

3. Operational Information

1. Reservoir. *Please provide the pertinent information below.*

   a. Vertical Datum Convention used:

   b. Streambed Elevation (feet):

   c. 10% Exceedance Duration Pool Elevation[10] (feet):

   d. Maximum Operating Pool Elevation (feet):

   e. Minimum Operating Pool Elevation (feet):

   f. Historical Maximum Pool Elevation:

   g. Date of Maximum Pool Elevation: *(MM/DD/YYYY)*

2. Impounding Structure. *Please provide the pertinent information below.*

   a. Crest Width (feet):

   b. Crest Elevation (feet):

   If applicable:

   c. Upstream Embankment Slope: *(H:1V)*

   d. Downstream Embankment Slope: *(H:1V)*

   e. Upstream Slope Protection Type: *(Riprap, ACB, RCC, etc.)*

   f. Downstream Slope Protection Type: *(Riprap, ACB, RCC, etc.)*

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[10] The 10 percent Exceedance Duration Pool Elevation is based on the period of record daily average elevation for the project (see Appendix A). Additional guidance can be found in Section 2-2 of the USACE publication, EM 1110-2-1415, *Hydrologic Frequency Analysis*. The publication is available at: http://www.usace.army.mil/publications//eng-manuals/em1110-2-1415/toc.htm

3. Spillway. *Please provide the pertinent information below.* a. Spillway Crest Elevation (feet): Gate Type: *(U: Uncontrolled, T: Tainter/Radial, L: Vertical Lift, R: Roller, B: Bascule, D: Drum, N: Needle, F: Flap, S: Slide/Sluice Gate, V: Valve)* b. Number of Gates: c. Gate Bottom Elevation (feet): *If different from Spillway Crest Elevation.* d. Gate Height (feet): e. Gate Width (feet):
4. Staffed/Unstaffed Facility. Indicate whether the facility is staffed or unstaffed and mainly subject to remote monitoring/operation. a. Staffed 24/7: *Indicate if the facility is staffed on a 24/7 basis (Y/N).* b. Staffed during Normal Operational Hours: *Indicate if the facility is staffed during normal operational hours only (Y/N).* c. Unstaffed: *Indicate if the facility is unstaffed on a regular basis (Y/N).* d. Remote Monitoring: *Indicate if the facility is subject to remote monitoring (Y/N).* e. Remote Operations: *Indicate if the facility is subject to remote operation (Y/N).*

5. Was a Security Risk Assessment conducted for the facility? (Y/N)

If yes, please provide the following information on the most recent risk assessment:

a. Date of most recent Risk Assessment? *(MM/DD/YYYY)*

b. Name of Methodology Used: *(Name)*

c. Short Description: *Provide a short description of the methodology or approach used for the most recent risk assessment conducted on the facility.*

d. Did It Include a Physical Vulnerability Assessment? *(Y/N)*

e. Did It Include a Cyber Vulnerability Assessment? *(Y/N)*

f. Did It Include a Physical Threat Assessment? *(Y/N)*

g. Did It Include a Cyber Threat Assessment? *(Y/N)*

h. Did It Include a Physical Consequence Assessment? *(Y/N)*

i. Did It Include a Cyber Consequence Assessment? *(Y/N)*

Form 2 – Consequence Information

1. Human Impact

1.a Provide an approximated estimate for the total "Population at Risk" (PAR)—that population occupying permanent residences, commercial buildings, and recreational areas within the inundation zone at the time of failure associated with the worst reasonable case scenario—by selecting the appropriate range from the table below.

Table 1 Total PAR in Inundation Zone

Range	Rating	Check Appropriate Box Below
800,001 +	6	☐
400,001 – 800,000	5	☐
200,001 – 400,000	4	☐
100,001 – 200,000	3	☐
50,001 – 100,000	2	☐
25,001 – 50,000	1	☐
0 – 25,000	0	☐

For facilities with a rating of 3 or above, please provide the name(s) of any towns/cities/counties located TOTALLY or PARTIALLY within the inundation zone.

Table 2 Populated Areas Potentially Affected

City/Town	County	State/Province

For facilities with a rating of 3 or above, please provide information on how the PAR was determined:

Inundation Maps: *(Y/N)* – Date of Inundation Study: *(MM/DD/YYYY)*
Census Data: *(Y/N)* – Date of Census: *(MM/DD/YYYY)*
Professional Judgment: *(Y/N)*

Additional Remarks:

1.b (i) Provide an approximated estimate for the "Population at Risk" within 0 and 3 miles[11] from the facility occupying permanent residences, commercial buildings, and recreational areas located within the inundation area associated with the worst reasonable case scenario by selecting the appropriate range from the table below.

Table 3 Total PAR within 0 and 3 miles

Range	Rating	Check Appropriate Box Below
1,601 +	6	☐
801 – 1,600	5	☐
401 – 800	4	☐
201 – 400	3	☐
101 – 200	2	☐
51 – 100	1	☐
0 – 50	0	☐

Additional Remarks:

1.b (ii) Provide an approximated estimate for the "Population at Risk" within 3 and 7 miles[12] from the facility occupying permanent residences, commercial buildings, and recreational areas located within the inundation area associated with the worst reasonable case scenario by selecting the appropriate range from the table below.

Table 4 Total PAR within 3 and 7 miles

Range	Rating	Check Appropriate Box Below
3,201 +	6	☐
1,601 – 3,200	5	☐
801 – 1,600	4	☐
401 – 800	3	☐
201 – 400	2	☐
101 – 200	1	☐
0 – 100	0	☐

Additional Remarks:

[11] This distance approximately represents a travel time of 0–15 minutes.
[12] This distance approximately represents a travel time of 15–30 minutes.

1.b (iii) Provide an approximated estimate for the "Population at Risk" within 7 and 15 miles[13] from the facility occupying permanent residences, commercial buildings, and recreational areas located within the inundation area associated with the worst reasonable case scenario by selecting the appropriate range from the table below.

Table 5 Total PAR within 7 and 15 miles		
Range	**Rating**	**Check Appropriate Box Below**
6,401 +	6	☐
3,201 – 6,400	5	☐
1,601 – 3,200	4	☐
801 – 1,600	3	☐
401 – 800	2	☐
201 – 400	1	☐
0 – 200	0	☐

Additional Remarks:

1.b (iv) Provide an approximated estimate for the "Population at Risk" within 15 and 60 miles[14] from the facility occupying permanent residences, commercial buildings, and recreational areas located within the inundation area associated with the worst reasonable case scenario by selecting the appropriate range from the table below.

Table 6 Total PAR within 15 and 60 miles		
Range	**Rating**	**Check Appropriate Box Below**
25,601 +	6	☐
12,801 – 25,600	5	☐
6,401 – 12,800	4	☐
3,201 – 6,400	3	☐
1,601 – 3,200	2	☐
801 – 1,600	1	☐
0 – 800	0	☐

Additional Remarks:

[13] This distance approximately represents a travel time of 30 – 60 minutes.
[14] This distance approximately represents a travel time that could exceed 30 – 60 minutes.

2. Economic Impact

2.a Assuming a reasonable worst case scenario affecting the most valuable, or largest economic unit(s) or asset(s) of the facility, provide an approximated estimate for the corresponding total "Asset Replacement Value" by selecting the appropriate range from the table below.

Table 7 Total Asset Replacement Value

Range	Rating	Check Appropriate Box Below
$3,200,000,001 +	6	☐
$1,600,000,001 – $3,200,000,000	5	☐
$800,000,001 – $1,600,000,000	4	☐
$400,000,001 – $800,000,000	3	☐
$200,000,001 – $400,000,000	2	☐
$100,000,001 – $200,000,000	1	☐
$0 – $100,000,000	0	☐

Description: *Please provide a short description of how the Total Asset Replacement Value was estimated.*

2.b Assuming a reasonable worst case scenario affecting the most valuable, or largest economic unit(s) or asset(s) of the facility provide an approximated estimate for the corresponding Total Remediation Cost by selecting the appropriate range from the table below.

Table 8 Total Remediation Cost

Range	Rating	Check Appropriate Box Below
$6,400,000,001 +	6	☐
$3,200,000,001 – $6,400,000,000	5	☐
$1,600,000,001 – $3,200,000,000	4	☐
$800,000,001 – $1,600,000,000	3	☐
$400,000,001 – $800,000,000	2	☐
$200,000,001 – $400,000,000	1	☐
$0 – $200,000,000	0	☐

Description: *Please provide a short description of how the Total Remediation Cost was estimated.*

2.c Assuming a reasonable worst case scenario affecting the most valuable, or largest economic unit(s) or asset(s) of the facility, provide an approximated estimate for the corresponding "Business Interruption Cost" over a period of 12 months by selecting the appropriate range from the table below.

Table 9 Total Business Interruption Cost (12 Months)

Range	Rating	Check Appropriate Box Below
$1,600,000,001 +	6	☐
$800,000,001 – $1,600,000,000	5	☐
$400,000,001 – $800,000,000	4	☐
$200,000,001 – $400,000,000	3	☐
$100,000,001 – $200,000,000	2	☐
$50,000,001 – $100,000,000	1	☐
$0 – $50,000,000	0	☐

Description: *Please provide a short description of how the annual Total Business Interruption Cost was estimated.*

3. Impact on Government Capabilities & Critical Functions	
3.a	<u>Based on the information available</u>, indicate if the inundation area associated with a worst reasonable case failure scenario could affect the operations of the following infrastructure categories with potentially significant national security and government functionality impacts: Military Installations *(Yes/No/Unknown)* Federal Facilities *(Y/N/U)* Federal Research Centers *(Y/N/U)* Defense Industrial Base Facilities[15] *(Y/N/U)* If any of the above were answered "yes," provide the name(s) of the facility. Name: ________________________________
3.b	Does the facility directly provide mission essential services such as electricity and water supply to military installations or government facilities? *(Y/N)* If "yes," identify the military or government facilities for which the facility directly provides mission essential services. Name of military/government facility: ______________________________________

[15] Defense Industrial Base (DIB) facilities include the private facilities with capabilities to research and develop, produce, deliver, and maintain military weapon systems, subsystems, components, or parts to meet military requirements necessary to fulfill the National Military Strategy.

3.c Based on the information available, indicate if the inundation area associated with a worst reasonable case failure scenario could affect the operations of the following infrastructure categories with potentially significant regional infrastructure impacts:

Fossil Fuel Electric Power Generation Facilities *(Y/N/U)*
Nuclear Electric Power Generation Facilities *(Y/N/U)*
Petroleum Processing, Storage, and Transport Facilities *(Y/N/U)*
Major Electricity Transmission and Distribution Facilities *(Y/N/U)*
Natural Gas Processing, Storage, and Transport Facilities *(Y/N/U)*
Major Highways, Bridges, and Tunnels *(Y/N/U)*
Major Airports *(Y/N/U)*
Ports and Freight/Passenger Terminals *(Y/N/U)*
Inland Waterways *(Y/N/U)*
Major Wired, Wireless, and/or Satellite Telecommunication Facilities *(Y/N/U)*
Major Financial and Commercial Data Processing Centers *(Y/N/U)*
Downstream Dams, Locks, and/or Levees *(Y/N/U)*
Chemical Manufacturing Plants *(Y/N/U)*
Hazardous Material Warehousing and Process/Storage Facilities *(Y/N/U)*
Special Nuclear Material Storage *(Y/N/U)*
Waste Water Facilities *(Y/N/U)*

If any of the above were answered “yes,” please provide the name(s) of the infrastructure assets that prompted an affirmative response.

Name: ________________________________

3.d Assuming the worst reasonable case scenario, provide an approximated estimate for the potential impact associated with loss of potable water supply function by selecting the appropriate range from the table below.

Table 10 Loss of Potable Water Supply Function (Total Population Served)		
Range	**Rating**	**Check Appropriate Box Below**
8,000,001 +	6	☐
4,000,001 – 8,000,000	5	☐
2,000,001 – 4,000,000	4	☐
1,000,001 – 2,000,000	3	☐
500,001 – 1,000,000	2	☐
250,001 – 500,000	1	☐
0 – 250,000	0	☐
Does Not Apply	N/A	☐

For facilities with a rating of 1 or above, provide the name(s) of the population center(s) whose drinking water is provided by the facility and, if possible, provide an approximated estimate for the corresponding market share.

Population Center: ____

Market Share:

- ☐ 0% – 33%;
- ☐ 34% – 64%;
- ☐ 65% – 100%

For facilities with a rating of 2 or above, indicate the name(s) of the corresponding water treatment plants served by the facility and, whenever appropriate, identify the corresponding aqueducts or water conveyance systems.

Water Treatment Facility(ies): ___________________________________

Aqueduct(s) or Canal System(s) served: ____________________________

For facilities with a rating of 2 or above, provide the estimated Recovery Time to refill the reservoir sufficiently to provide a functioning potable water system to restore normal supply to the population center(s) listed above.

Recovery Time: *(Number of Months)*

3.e Assuming the worst reasonable case scenario, provide an approximated estimate for the potential impact associated with loss of water deliveries by selecting the appropriate range from the table below.

Table 11 Annual Value of Water Deliveries

Range	Rating	Check Appropriate Box Below
$1,600,000,001 +	6	☐
$800,000,001 – $1,600,000,000	5	☐
$400,000,001 – $800,000,000	4	☐
$200,000,001 – $400,000,000	3	☐
$100,000,001 – $200,000,000	2	☐
$50,000,001 – $100,000,000	1	☐
$0 – $50,000,000	0	☐
Does Not Apply	N/A	☐

For facilities with a rating of 1 or above, describe the agricultural markets or regions served by the facility and, if possible, provide an approximated estimate for the corresponding market share.

Agricultural Market or Region: ____

Market Share:

- ☐ 0% – 33%;
- ☐ 34% – 64%;
- ☐ 65% – 100%

For facilities with a rating of 2 or above, and if applicable, identify the corresponding aqueduct(s) or water conveyance system(s).

Aqueduct(s) or Canal System(s) served: __________________________________

For facilities with a rating of 2 or above, provide the estimated Recovery Time to refill the reservoir sufficiently to restore the normal level of annual water deliveries provided by the facility.

Recovery Time: *(Number of Months)*

3.f Assuming the worst reasonable case scenario, provide an approximated estimate for the potential impact associated with loss of power generation function by selecting the appropriate range from the table below.

Table 12 Loss of Power Generation Function		
Installed Capacity [MW] Range	**Rating**	**Check Appropriate Box Below**
6,401 +	6	☐
3,201 – 6,400	5	☐
1,601 – 3,200	4	☐
801 – 1,600	3	☐
401 – 800	2	☐
201 – 400	1	☐
0 – 200	0	☐

For facilities with a rating of 2 or above, provide the installed generating capacity (MW), the name(s) of key customer(s) potentially impacted, and an estimate of worst reasonable potential impacts on the grid.

Impacted Critical and Key Customer(s): ___________________________________

Estimated Impact on Regional Grid:

☐ HIGH *(Severe to catastrophic impact)*
☐ MEDIUM *(Moderate to significant impact)*
☐ LOW *(Negligible to minor impact)*

For facilities with a rating of 2 or above, provide the estimated Recovery Time to replace generating units if they are destroyed or severely damaged.

Recovery Time: *(Number of Months)*

3.g Is the facility authorized as a Flood Control Project? *(Y/N)*

For facilities authorized as a flood control project, provide an approximated estimate of the value of average annual flood damages prevented by selecting the appropriate range from the table below.

Table 13 Average Annual Damages Prevented ($/Year)		
Range	**Rating**	**Check Appropriate Box Below**
$1,600,000,001 +	6	☐
$800,000,001 – $1,600,000,000	5	☐
$400,000,001 – $800,000,000	4	☐
$200,000,001 – $400,000,000	3	☐
$100,000,001 – $200,000,000	2	☐
$50,000,001 – $100,000,000	1	☐
$0 – $50,000,000	0	☐

For facilities with a rating of 3 or above, provide the name(s) of the population center(s) and/or local area(s) protected by the facility:

Population center(s) and/or local area(s): ________________________________

Additional Remarks:

3.h Assuming the worst reasonable case scenario, provide an approximated estimate for the value of the navigation benefits that could be lost by selecting the appropriate range from the table below.

Table 14 Annual Navigation Tonnage (kton/yr)		
Range	**Rating**	**Check Appropriate Box Below**
96,000 +	6	☐
48,001 – 96,000	5	☐
24,001 – 48,000	4	☐
12,001 – 24,000	3	☐
6,001 – 12,000	2	☐
3,001 – 6,000	1	☐
0 – 3,000	0	☐
Does Not Apply	N/A	☐

For facilities with a rating of 2 or above, provide the name(s) of impacted waterway(s), and provide a description of the main commodities (e.g., coal, petroleum, chemicals, crude materials, manufactured goods, food and farm, manufactured equipment) in each direction.

Impacted Waterway(s): ____

Main Commodity(ies) (Upbound): __________________________________

Main Commodity(ies) (Downbound): ________________________________

For facilities with a rating of 2 or above, provide the estimated Recovery Time to replace or repair lock gates if they are destroyed or severely damaged.

Recovery Time: *(Number of Months)*

3.i Assuming the worst reasonable case scenario, provide an approximated estimate for the number of recreational visits to the project area that could be lost by selecting the appropriate range from the table below.

Table 15 Annual Recreational Visits (visitor/yr)

Range	Rating	Check Appropriate Box Below
4,800,001 +	6	☐
2,400,001 – 4,800,000	5	☐
1,200,001 – 2,400,000	4	☐
600,001 – 1,200,000	3	☐
300,001 – 600,000	2	☐
150,001 – 300,000	1	☐
0 – 150,000	0	☐

Additional Remarks:

4. Impact on Public Confidence

4.a Assuming the worst reasonable case scenario, estimate the severity of the potential psychological effects and behavior changes.

☐ HIGH *(Severe impacts such as massive evacuations and permanent relocations; widespread looting and civil unrest; loss of confidence in government; sustained effects on financial markets; disruption of important social functions for a sustained period of time, etc.)*

☐ MEDIUM *(Significant impacts such as mass evacuations and temporary relocations; temporary impacts on financial markets; loss of nonessential social functions for a sustained period of time, etc.)*

☐ LOW *(Minor impacts such as limited evacuations; impact on nonessential social functions in a small geographical area, etc.)*

4.b Describe any highly recognized iconic/symbolic assets or highly populated temporary events (Super Bowl, NASCAR, etc.) that could be directly affected by the worst reasonable case scenario.

Iconic/Symbolic Asset or Event: ________________________________

4.c Describe any high profile entities (school age children, National or State government officials, high profile corporations, etc.) that could be directly affected by the worst reasonable case scenario.

High Profile Entities: ____

5. Miscellaneous Information

Name of Person Completing CTS:

Position/Title:

Phone:

E-mail:

Date:

APPENDIX C:
FORMS USED FOR STATE PILOT

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APPENDIX C: FORMS USED FOR STATE PILOT

In response to a request from the Dams Sector Top Screen Workgroup to include a more geographically diverse sample to test the CTS methodology, the PNW Pilot was expanded to include 22 dam projects in six States. The States of California, Colorado, Montana, New Jersey, Ohio, and Pennsylvania volunteered to assist in the data collection and provided the information requested.

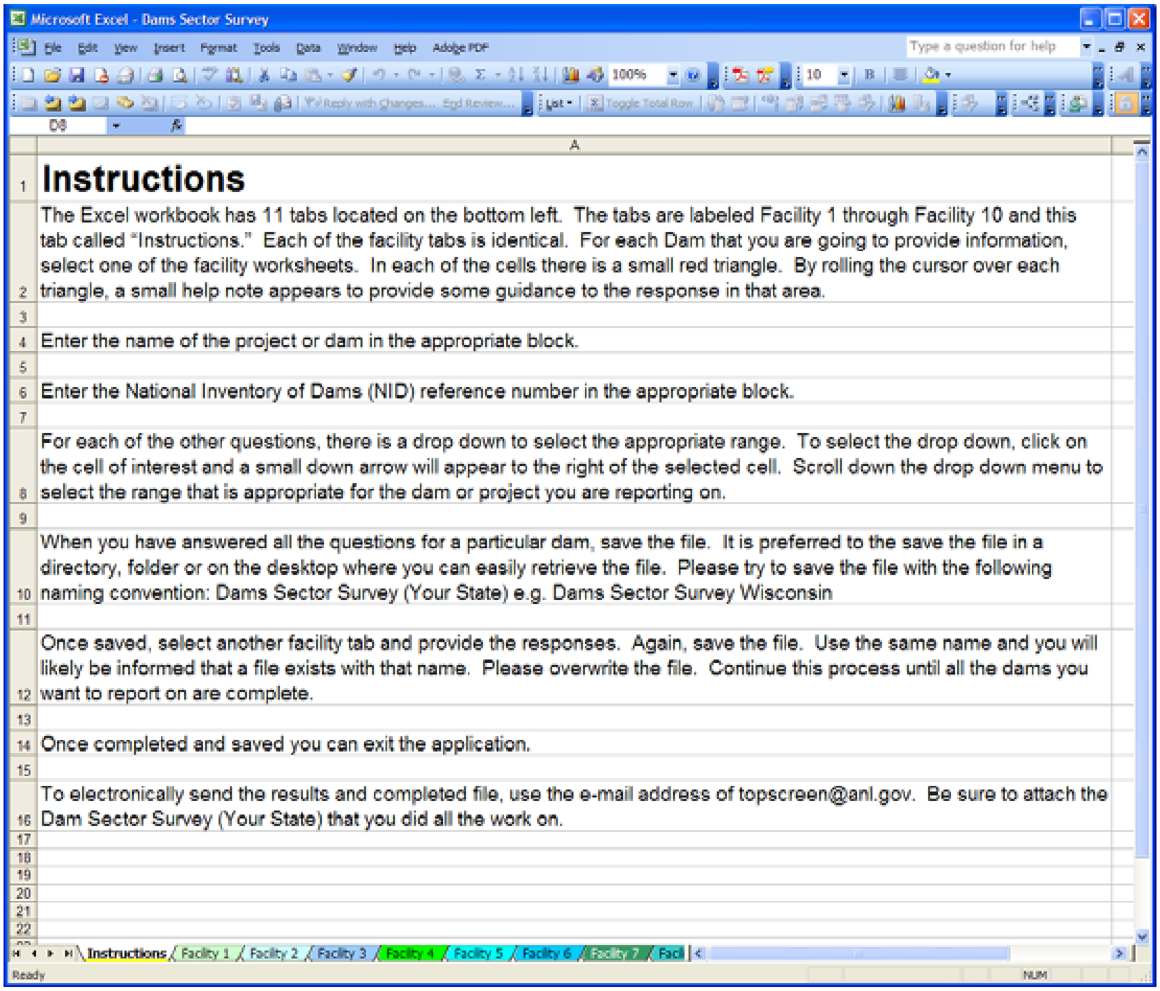
On the basis of experience gained through the PNW Pilot, the State Pilot used the tables but not the entire questionnaire used in the PNW Pilot. A streamlined, Excel-based version of the CTS and a modified version of the CTS methodology document were provided to the participants to help them understand the intent of the information sought through the tables. This version was sent via e-mail to the State dam safety officers of six States. This appendix provides screen shots, which show the form and instructions associated with this pilot.

An instruction page was included to provide guidance on how to complete the form and how to submit the information (see Figure C.1).

Comments or “Help” boxes were added to the spreadsheet for instruction on each main element of the tables (see Figure C.2).

Drop-down boxes were provided for “bin” selection. The participants were asked for the name of the project and the National Inventory of Dams (NID) number. No other identifying or contact information was requested. Figures C.3 and C.4 provide screen shots of drop-down boxes.

Collection of these data was simpler and therefore easier to complete and disseminate than with the full CTS tool. However, key elements of information, such as how population at risk (PAR) or economic determinations were made and the cascading impacts to surrounding infrastructure, were not asked. Therefore, only the tabular information directly compares to the original PNW Pilot data collection. The results of the State Pilot are shown in Appendix A, combined, when possible, with the PNW Pilot project.



Instructions

The Excel workbook has 11 tabs located on the bottom left. The tabs are labeled Facility 1 through Facility 10 and this tab called "Instructions." Each of the facility tabs is identical. For each Dam that you are going to provide information, select one of the facility worksheets. In each of the cells there is a small red triangle. By rolling the cursor over each triangle, a small help note appears to provide some guidance to the response in that area.

Enter the name of the project or dam in the appropriate block.

Enter the National Inventory of Dams (NID) reference number in the appropriate block.

For each of the other questions, there is a drop down to select the appropriate range. To select the drop down, click on the cell of interest and a small down arrow will appear to the right of the selected cell. Scroll down the drop down menu to select the range that is appropriate for the dam or project you are reporting on.

When you have answered all the questions for a particular dam, save the file. It is preferred to the save the file in a directory, folder or on the desktop where you can easily retrieve the file. Please try to save the file with the following naming convention: Dams Sector Survey (Your State) e.g. Dams Sector Survey Wisconsin

Once saved, select another facility tab and provide the responses. Again, save the file. Use the same name and you will likely be informed that a file exists with that name. Please overwrite the file. Continue this process until all the dams you want to report on are complete.

Once completed and saved you can exit the application.

To electronically send the results and completed file, use the e-mail address of topscreen@anl.gov. Be sure to attach the Dam Sector Survey (Your State) that you did all the work on.

Figure C.1 Instructions for Pilot Study Questionnaire

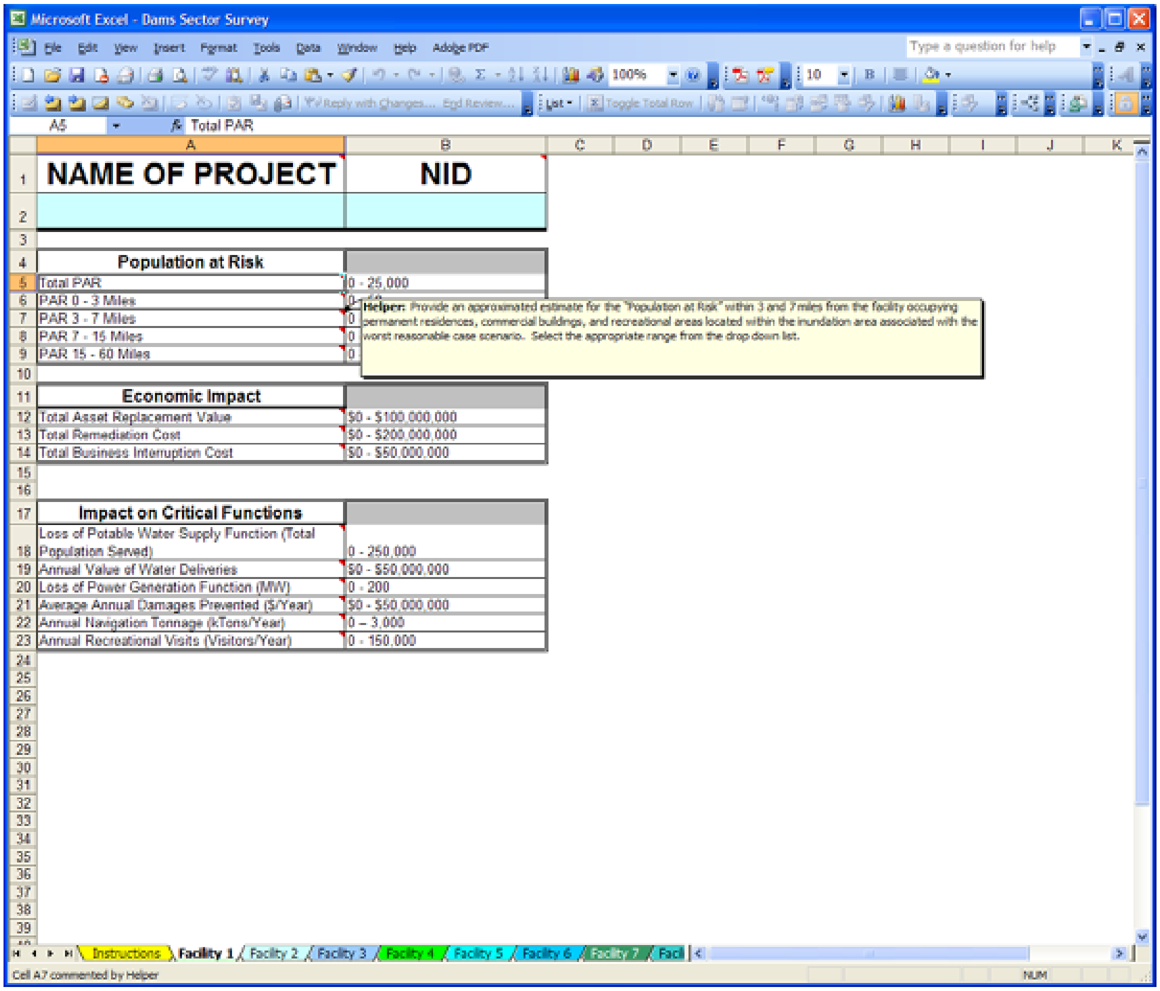


Figure C.2 Drop-Down Box Showing "Helper"

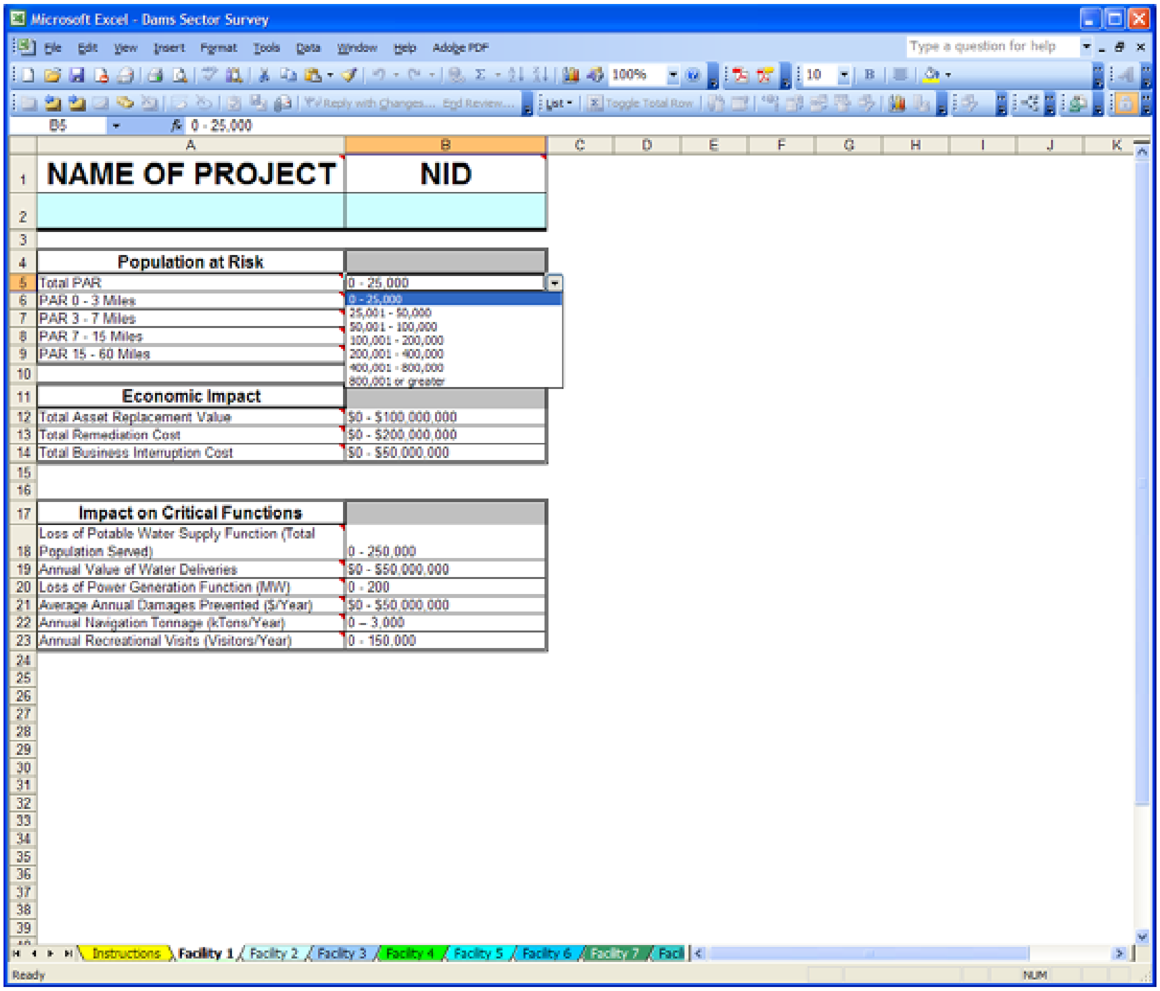


Figure C.3 Screen Shot Showing Drop-Down Box with Choices for Population at Risk Categories

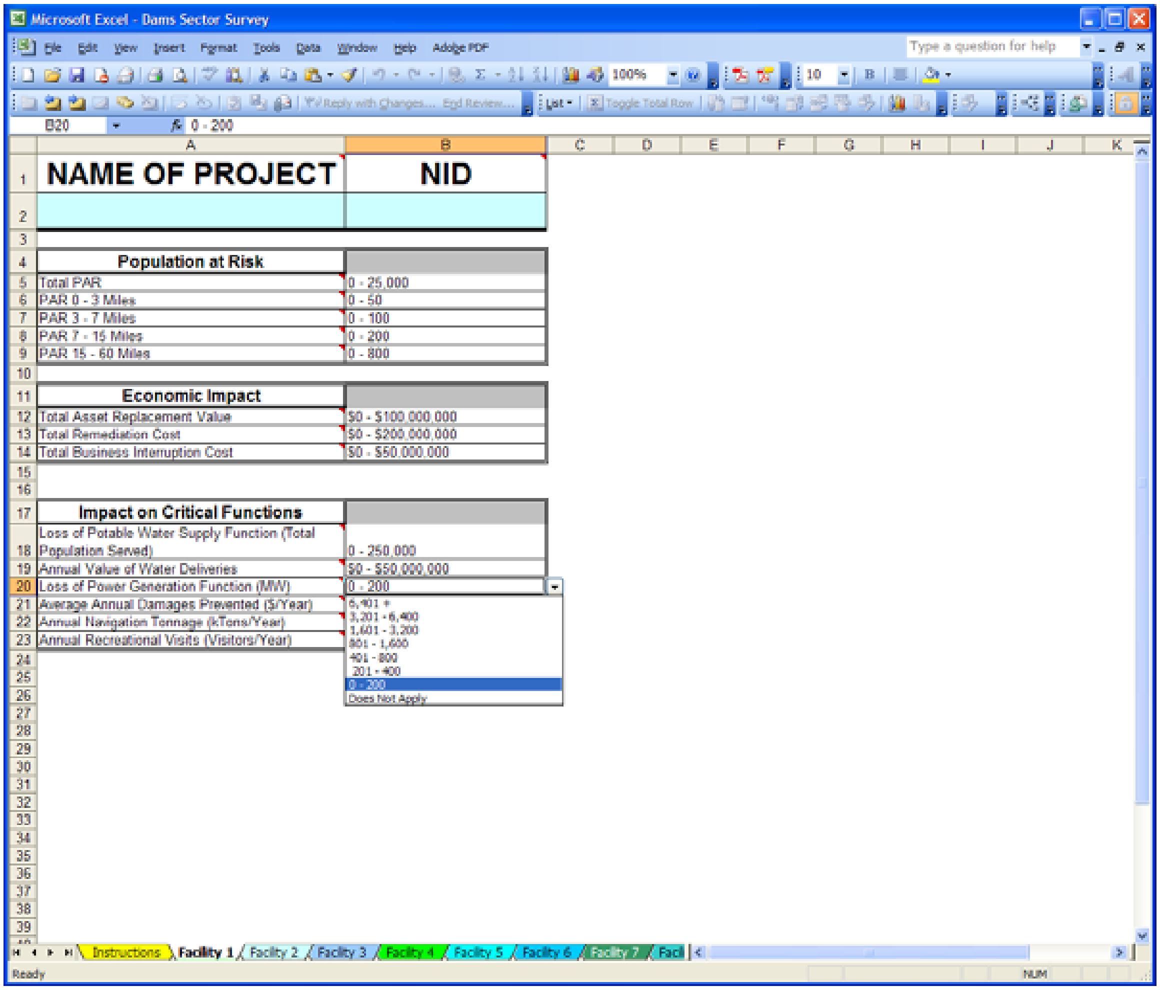


Figure C.4 Screen Shot Showing Drop-Down Box with Loss of Power Function Selections

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APPENDIX D: NOTATION

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APPENDIX D: NOTATION

CIKR	critical infrastructure and key resources
CTS	Consequence-Based Top Screen
DHS	U.S. Department of Homeland Security
DI	damage index
GCC	Government Coordinating Council
GeoMean	geometric mean
GIS	geographic information system
GW	gigawatt(s)
HAZMAT	hazardous materials
HSPD-7	Homeland Security Presidential Directive 7
MW	megawatt(s)
NID	National Inventory of Dams
PAR	population at risk
PDI	parameter damage index
PDIF	Parameter Damage Index Function
PNW	Pacific Northwest (Pilot)
POC	point of contact
R&D	research and development
SCC	Sector Coordinating Council
USACE	U.S. Army Corps of Engineers

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Decision and Information Sciences Division
Argonne National Laboratory
9700 South Cass Avenue, Bldg. 900
Argonne, IL 60439-4867

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