RECLAMATION
Managing Water in the West

Technical Memorandum Number EC-2009-01

Economic Consequences Methodology for Dam Failure Scenarios

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Security, Safety and Law Enforcement
Denver, Colorado

September 2009

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)* September 2009	**2. REPORT TYPE** Final	**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE Economic Consequences Methodology for Dam Failure Scenarios		**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Dawn Munger		**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bureau of Reclamation Technical Service Center Economics Group (86-68270) Denver, CO 80225-0007		**8. PERFORMING ORGANIZATION REPORT NUMBER** EC-2009-01
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Bureau of Reclamation Denver, CO 80225-0007		**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION / AVAILABILITY STATEMENT
Available from the National Technical Information Service,
Operations Division, 5285 Port Royal Road, Springfield VA 22161

13. SUPPLEMENTARY NOTES
N/A

14. ABSTRACT ***(Maximum 200 words)***
This paper describes a procedure for the evaluation of economic consequences (direct and indirect impacts) that may result from a dam failure or the failure of an asset at a dam.

15. SUBJECT TERMS
Economic Consequences, Dam Failure

16. SECURITY CLASSIFICATION OF: UL			**17. LIMITATION OF ABSTRACT** UL	**18. NUMBER OF PAGES** 53	**19a. NAME OF RESPONSIBLE PERSON** Dawn Munger
a. REPORT UL	**b. ABSTRACT** UL	**c. THIS PAGE** UL			**19b. TELEPHONE NUMBER** *(include area code)* 303-445-2734

MISSION STATEMENTS

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover Photograph: St. Francis Dam following its failure in 1928.

Table of Contents

Page

Acronyms

cfs	cubic feet per second
CGE	Computable General Equilibrium
DHI	Danish Hydraulic Institute
DHS	Department of Homeland Security
EAP	emergency action plan
ECAM	Economic Consequences Assessment Model
EGM	Economic Guidance Memorandum
ESA	Endangered Species Act
ESRI	Environmental Systems Research Institute
EWS	early warning system
FEMA	Federal Emergency Management Agency
FIMA	Federal Insurance and Mitigation Administration
FIT	Flood Information Tool
FY	fiscal year
GDP	Gross Domestic Product
GIS	Geographic Information System
HAZUS-MH	Hazard-United States-Multi-hazard
IMPLAN	Impact Analysis for Planning
I-O	input-output
kWh	kilowatthour
M&I	municipal and industrial
MIG	Minnesota Implan Group
MWh	megawatthour
NED	National Economic Development
NEPA	National Environmental Policy Act
NIBS	National Institute of Building Sciences
NID	National Inventory of Dams
NWS	National Weather Service
OMB	Office of Management and Budget
P&Gs	Principles and Guidelines
PMF	Probable Maximum Flood

Reclamation	Bureau of Reclamation
SDF	sunny day failure
SOD	Safety of Dams
SSLE	Security, Safety, and Law Enforcement
TSC	Technical Service Center
UDV	unit day values
USACE	U.S. Army Corps of Engineers
%	percent

Description

A methodology and tools for estimating direct and indirect economic impacts and related economic consequences that result from dam failure are discussed in this document. This methodology considers the downstream damages to property and infrastructure, losses in project output (benefits), repair/replacement costs, and indirect impacts on the affected regional economy while also addressing the gaps in the Bureau of Reclamation's (Reclamation's) current methodology. A list of definitions related to economic consequences also is contained herein.

Given the potential severity of consequences in terms of human life and property damage that could result from the failure of a Reclamation dam, a methodology has been developed to systematically estimate economic consequences. Reclamation economic analyses must comply with the guidelines provided by the publication commonly referred to as the "Principles and Guidelines (P&Gs),"[1] a publication from the U.S. Water Resources Council.

Probability of failure is not included in the development of economic consequences assessments. Estimating this probability is covered in other methodologies and is essential to understand security risks.

Direct Impacts

In this context, direct impacts are those costs and/or capital expenditures directly made as a result of a flood event. The categories of direct impacts for this analysis are:

- *Dam Benefits Losses* – considered to be the present value of lost benefits not produced by the dam or the replacement cost of services the dam provides
- *Downstream Property Damages* – the costs of the downstream damages produced by the failure event
- *Dam Repair/Replacement Costs* – includes the repair and/or replacement of the onsite assets

[1] U.S. Water Resources Council. *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies*, March 10, 1983.

Dam Benefit Losses

Dam benefit losses are considered to be one of the direct economic costs associated with a particular failure event. According to the P&Gs, the loss of any future benefits is actually a cost of the dam failure. In any economic analysis, after the conceptual framework is established and categories of potential benefits and costs are qualitatively identified, the next step is to quantify those benefits and costs in monetary terms. For a scenario where there is an uncontrolled release of water from the reservoir and the dam can no longer deliver water or power, benefit losses are estimated. Under the P&Gs, this loss or reduction in benefits is considered a National Economic Development (NED) cost.

A brief description of the basis for and methods used to compute losses for the various benefit categories is presented below. The P&Gs are the reference for these categories. In estimating the benefit losses, the costs and benefits to all affected parties from a national perspective should be evaluated. This national stance is referred to as the NED account in the P&Gs. For example, even though flood damage reduction (flood control) may not be a congressionally authorized purpose at a dam, incidental benefits may accrue to the downstream population because of the dam's presence. Every effort is made to capture these additional benefits the dam and reservoir may provide.[2] Benefits are not limited to just the Federal Government and the project beneficiaries; every attempt is made to capture water-related benefits to other entities and measure them within a national framework.

It is necessary to know the reconstruction period or how long water supplies for the various benefit categories will not be delivered to compute losses over that timeframe. The reconstruction schedule can often be estimated by Reclamation's Construction Management Group (86-68170) in the Technical Service Center (TSC). This estimation also may be provided by a construction/engineering individual or organization familiar with dam design and construction.

Prior to benefit losses being calculated, it is also useful to know the amount of water that would be released during an event. This information typically can be found in inundation reports and can be used to determine water deliveries to the various purposes (agriculture, municipal and industrial [M&I], etc.); estimate the reservoir elevations before, during, and after the event; and/or determine the length of time needed to refill the reservoir while resuming benefits to some of its purposes if applicable. Inundation reports typically are performed by water management entities, but the information contained in the inundation report may be obtained from an individual or agency that operates the facility. The reprioritization of water deliveries (i.e., which purposes would first receive water deliveries considering the diminished water supply availability) is not always readily available. Typically, Reclamation's regional offices or the managing

[2] Office of Management and Budget (OMB) does not generally recognize the inclusion of project purposes not specifically authorized in legislation due to financial implications.

entity at the facility can provide some indication of when water deliveries, if any, would resume under various scenarios. In some instances, the political nature of the water deliveries also may be an issue. Sometimes, professional judgment is necessary to define a reasonable scenario.

Agricultural Irrigation Water Supply

Delivery of water for agricultural production is a major purpose of many dams and reservoirs. To estimate the lost benefits from an undelivered supply of irrigation water, the reduction in irrigation water delivered must be estimated as well as the value of the irrigation water.

The amount of undelivered irrigation water can be estimated by using a 3- or 5-year average of recently delivered water for irrigation purposes if the annual amount of delivered irrigation water varies from year to year. The average will help capture the trends in dry and wet water years as well as the trends in deliveries and is a good representation of the amount of irrigation water lost due to the event.

The value of irrigation water can be estimated using any one of the following approaches:

a) Benefit losses in this category are measured as the difference in net farm income "with" the dam failure event versus "without" the event. These losses are sometimes developed from detailed farm budgets that depict returns and expenses for representative crops in the project area. Care must be taken to ignore any sunk farm investment costs in the farm income calculation that are not recoverable, such as irrigation development costs. In an NED analysis, expenditures made in the past are not relevant for current decisionmaking. In the event that a farm budget net income estimation already been completed for a previous study, it should be used. However, time and budget constraints often do not allow for this in-depth type of estimation procedure.

b) An alternative approach to estimating a value for lost agricultural benefits is to use a "shadow value" or opportunity cost for water. This value typically is more readily available than net farm income. When available, this value can be multiplied by the amount of acre-feet of irrigation water lost annually.

c) The most readily available and cost and time saving value available is the market value of water. This is the dollar value that water is leased and/or sold for in the region based on recent market transactions. This information typically can be found in publications such as *Water Strategist* (http://www.waterstrategist.com/).

d) The P&Gs provide yet another approach to valuing the loss of irrigation water. This method involves determining the value of agricultural land with and without a water supply—the difference being the irrigation benefit value. Again, this would require more detailed information than typically is available.

M&I Water Supply

Municipal and industrial water supplies are delivered to cities, towns, industries, and other entities for various purposes such as drinking water, lawn application, and cooling water. To estimate the lost benefits from an undelivered supply of M&I water, the amount of water undelivered for M&I purposes must be estimated as well as the value of the M&I water.

The amount of undelivered water can be estimated by using a 3- or 5-year average of recently delivered water to M&I purposes if the annual amount of delivered M&I water varies from year to year. The average will help capture the trends in deliveries and is a good representation of the amount of M&I water lost due to the event.

To estimate the value of the M&I water, several approaches may be utilized:

a) In areas where there is an active wholesale water market in which project or nonproject irrigation water supply is leased or permanently sold to municipal water providers, transfer prices can be used as a measure of the value that M&I users ascribe to the water. In the P&Gs, this measure of benefits is called "willingness to pay." When valuing a project M&I water supply that might be lost due to a failure scenario, it is important to use prices from sales that reflect a water supply of the same quality and dependability. In addition, adjustments for transportation costs are necessary if prices used reflect water that is not at the same physical location as the project water supply. The value per acre-ft is then multiplied by the annual amount of M&I water lost under the failure scenario.

b) If there is not an active water market in the project area to use for the M&I benefit analysis, then the least cost of the most likely alternative to develop a new supply in lieu of the affected project water supply can be used to approximate benefits. For example, such an alternative might be development of a groundwater well field or construction of a new dam and reservoir. As with the use of market prices, it is necessary to ensure that the benefit value the alternative will provide is based on water of the same quality, quantity, timing of deliveries, and location as the project supply. However, the length of time to construct a new M&I water supply project can be more lengthy, costly, or both than repairing or replacing the failed facility.

Power Generation

To estimate the lost benefits from power generation, the amount of power that would not be generated under the failure scenario must be estimated as well as the value of the power generation.

The amount of power generation lost can be estimated by using a 3- or 5-year average of recently generated power by the facility since the annual amount of power generated typically varies from year to year. The average will help capture the trends in generation and is a good representation of the amount of power generation lost due to the event.

The value of the power generated can be estimated using different approaches:

a) Power values can be difficult to predict due to increasing natural gas prices, inflation, market volatility, and other factors. Wholesale market prices can be used for determining lost project power benefits and are available through entities such as Dow Jones, Bonneville Power Administration, and the California Independent System Operator. These prices usually are expressed in mills per kilowatthour or dollars per megawatthour. In some markets, prices are distinguished between power that is generated during the peak use period of the day or off-peak, as well as power that is firm or nonfirm, which is a measure of reliability. The power prices used need to match the characteristics of the power lost as closely as possible. As a worst-case scenario, firm, peak prices may be used. These prices then are multiplied by the amount of net generation lost as a result of the event and any subsequent generation lost during the reconstruction process.

b) Similar to M&I benefits, if wholesale market prices are not available or do not match the attributes of the power generated at the dam being evaluated, lost power benefits can be approximated using the avoided costs of constructing an alternative thermal generation plant, usually a coal or gas-fired facility.

Caution should be exercised not to use current power rates instead of the economic value or prices for power. Power rates can be as little as one-half of the actual power values[3] and are not appropriate for use in this type of analysis.

For both M&I benefits and power benefits, use of prices is generally limited to wholesale market prices rather than retail rates consumers actually pay. That is because water and power are essentially wholesaled to entities who layer on costs before the product reaches the consumer. Using retail rates to value wholesale

[3] U.S. Geological Survey. Southwest Biological Science Center. *The State of the Colorado River Ecosystem in Grand Canyon: A Report of the Grand Canyon Monitoring and Research Center 1991-2004*. USGS Circular 1282.

power would involve removing these layered costs, which can be quite cumbersome.

Recreation

To estimate the lost benefits from recreation visitation, the number of recreation visits lost under the failure scenario must be estimated as well as the value of the recreation, whether in general or by specific recreation activity. Reservoirs behind a dam typically provide public recreation for a variety of activities, which can be very significant in economic value.

Several approaches can be utilized as indicated below:

a) As contained in the P&Gs, the standard measure for recreation benefits is the amount that visitors would be willing to pay, over and above what they actually do pay, to recreate at the site. This amount is known as "consumer surplus" and usually is expressed on a dollar-per-day or per trip basis. There are several highly technical and time-consuming methodologies used to estimate consumer surplus at a particular site. Sometimes, site-specific values may be available and should be used when they can be obtained. Fortunately, a large number of studies have already been performed for recreation sites and activities across the United States which can be used to approximate benefits at reservoirs with similar activities, amenities, and characteristics (economists typically call this procedure "benefits transfer"). This value per trip or visit is multiplied by the number of lost recreational trips or visits associated with the failure event. When recreation visitation is available by type of activity (i.e., fishing, boating, camping, picnicking, etc.), lost visitation for each activity is multiplied by the value for those specific activities to obtain an estimate of lost recreation benefits.

b) The U.S. Army Corps of Engineers (USACE) also suggest the use of published unit day values (UDV) to estimate a value of a recreation visit which is also a measure of consumer surplus. The UDV method for estimating recreation benefits relies on expert or informed opinion and judgment to approximate the average willingness to pay of users. USACE's Engineer Regulation (ER 1105-2-100) in their *Planning Guidance* provides guidelines for assigning points and their conversion to dollar value for evaluating recreation. When the UDV method is used for economic evaluations, planners select a specific value from the range of values provided annually by USACE, in Economic Guidance Memorandum (EGM) 06-03, "Unit Day Values for Recreation." The selected value is used to estimate annual use over the project life, in the context of both the with- and without-project framework. The difference between the with- and without-project conditions provides the estimate of recreation benefits. The UDV method relies on informed judgment and is an acceptable method to approximate average willingness to pay for federally funded projects.

The number of visitors to a recreation area typically is available or can be determined by the managing entity through vehicle counters, manual samples, entrance fees, permits and registration, or a combination of some or all of these methods. The amount of lost visitation can be estimated by using a 3- or 5-year average of recent visitation to the recreation area since the annual amount of visitation typically varies from year to year. The average will help capture the trends in dry and wet water years and is a good representation of the amount of visitation lost due to the event.

In computing recreation benefits lost at a reservoir, it is assumed that current visitors simply would not substitute another nearby reservoir or recreation site for their recreation activity. In assessing the possibility of substitution, it is important to look at the congestion (carrying capacity) of alternate sites as well as whether those sites offer the same type and quality of activities as the original site.

These same methodologies are used to compute lost benefits for river recreation downstream from a reservoir. User-day information, such as number of anglers, rafters, kayakers, etc., is not as readily available as reservoir visitation data; but some State fish and game agencies collect it. Sometimes, a "special" study may have been previously conducted if the area is heavily used for river recreation purposes.

Flood Damage Reduction

Dams and reservoirs often provide flood damage reduction benefits, either through reservation of specific reservoir space to store a flood or incidentally through operation of the reservoir to meet other project purposes. These benefits are computed as downstream damages prevented—"with" the reservoir versus "without" it—and usually are relevant for floods with recurrence levels of 100 years or less. Measurement of benefits can be complicated and time-consuming; but in many cases, USACE has developed damage curves allowing staff to fairly easily estimate historical damages prevented over a given period.[4] In these cases, the average damages prevented, indexed to current dollars, can be used as an estimate of future annual benefits.

For reservoirs without damage curves, flood damage reduction benefits generally are not computed because of the level of effort required and that these benefits are typically much less than other affected project benefits.

[4] See *Planning - Risk Analysis for Flood Damage Reduction Studies*, http://140.194.76.129/publications/eng-regs/er1105-2-101/toc.htm.

Fish and Wildlife

To estimate the lost benefits of water reserved for fish and wildlife purposes, the amount of water unavailable for fish and wildlife purposes must be estimated as well as the value of the water. Flows from reservoirs may be legally allocated to instream flows for fish and wildlife or their habitat. This is usually for compliance under the National Environmental Policy Act (NEPA) or Endangered Species Act (ESA). Only water provided for fish and wildlife improvement would be considered a project benefit.

Unless there is a specific value tied to these or similar environmental flows via a contingent valuation or similar type of willingness to pay study, the market value of replacement water is multiplied by the annual acre-feet of water lost to this purpose to arrive at lost fish and wildlife benefits.

Often, reservoir fisheries provide benefits and can be included under the Recreation or Fish and Wildlife benefits category, but not both. To avoid double-counting, caution should be exercised to include the reservoir fishery and/or downstream fishery in only one benefit category. If the fishing component can be carved from the recreation visitation, then it can be included under the Fish and Wildlife benefits category. However, it is often difficult to separate out fishing because it can become intertwined with other recreation activities such as boating.

Treaty Water Supply

To estimate the lost benefits of water reserved for interstate or international purposes not already accounted for in the categories above, the amount of undelivered water must be estimated as well as the value of the water. Typically, it is not known exactly where or how water is used after it crosses the United States border. There are possible political and/or legal ramifications from not delivering treaty water. However, in such emergency cases, the United States may not be held liable due to the extenuating circumstances surrounding the event.

If there is a specific dollar value tied to treaty water, it should be used. In other instances, the market value of purchased water from an irrigation or M&I water supply used to meet delivery of the treaty water multiplied by the amount of undelivered supply is used as the estimated cost.

Indian Water Rights

When water has been allocated to tribal purposes under a settlement or compact, its use is included under irrigation or M&I water supply, depending on how the Tribe uses its allocation. In most cases, valuation of benefits would be based on the amount of water provided and how the water is used by the tribe.

Discount Rate and Period of Analysis

Annual costs are converted to present worth values over the period of time the benefits are lost or the period the dam is out of commission. A real interest rate (one adjusted for inflation) is used. This rate is the real interest rate recommended by the Office of Management and Budget.[5] This rate varies by the maturity time period of the Treasury notes and bonds, typically, between 2.5 and 3.0 percent for 3- and 20-year notes, respectively.

The P&Gs prescribe using the Plan Formulation and Evaluation Rate as the discount rate (4.875 percent for fiscal year [FY] 2008). This is a nominal (market) rate that assumes no inflation. Since these studies are not considered "implementation" studies or "feasibility" studies, for which the P&Gs apply to and advise the use of this market rate, a real interest rate as described above is used.

The time period benefits will be lost or the dam is out of commission depends upon the scenario. Reclamation's Construction Management Group in the TSC is tasked with calculating the timeframe for facility reconstruction based on specific assumptions. The region or area office typically estimates the time it will take to refill the reservoir depending on the specific assumptions of the scenario (e.g., deliveries during the refill period). These estimations also may be provided by a construction/engineering individual or organization familiar with dam design and construction.

Reconstruction time, in addition to refill time, is the time period used to convert annual costs (or lost benefits) to present worth values. The length of time water deliveries are not able to be made may vary by project purpose. For example, deliveries to M&I may be able to occur a year or two after the reconstruction period, but deliveries to agriculture may be restricted until the reservoir refills to an appropriate level enabling diversions to take place. Similarly, recreation access may be minimal during refill period, and river fisheries may take longer to recover requiring recreation to have a longer discount period than other resources.

Downstream Property Damage Estimates

Downstream property damages include the replacement costs of residential, commercial, and industrial property as well as infrastructure such as roads, bridges, railroads, and utility lines. To begin the assessment of property damages that result from flooding, an inundation map for the scenario must be obtained. Typically, a "sunny day" failure (SDF) map is used. An SDF is an unexpected failure that is the preferable scenario used to evaluate inundation damages from an unanticipated event.

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[5] OMB Circular No. A-94. January 2008.

Prior to 2008, damages were computed in a different manner than post-2008 studies. The inundation maps were used by Reclamation's Remote Sensing and Geographic Information Group so that they, in turn, could provide inundation reports developed by utilizing a computerized geographic information system (GIS). This GIS data contained the level of detail needed for the inundation area being analyzed. The GIS Group analyzed the inundation data and produced a "flood report" that identified the location and types of infrastructure that would be inundated by the event. Types of infrastructure listed included homes, businesses, essential facilities such as hospitals, fire stations, and police stations, airports, roads, railroads, canals, bridges, other dams, electric transmission lines, etc.

For the purpose of pre-2008 damage assessments, it was assumed that all infrastructure within the inundation boundary was a total loss. This assumption is reasonable considering the potential for high flood water velocities from a dam failure near the stream channel. Also, floods of this nature carry large amounts of debris that compound the destructive force of the flood waters. This method may have overstated damages and, therefore, was determined not to be the best or most accurate method to determine downstream property damages given the recent availability of more advanced tools. This especially was true for property and infrastructure located away from the river channel and on the fringe of the flood inundation boundary.

The economic standard for property valuation is replacement costs and not market value. Downstream property damages include the replacement costs of residential, commercial, and industrial property as well as infrastructure such as roads, bridges, railroads, and utility lines. Property replacement costs were derived using publically available building construction cost software (myestimator.com), and infrastructure damages are generally based on unit cost data collected from local transportation and utility entities.[6] Total replacement value was estimated by multiplying the average replacement cost per structure by the number of structures.

A brief summary of the methodology previously employed by Reclamation to estimate downstream damages for Safety of Dams and Security, Safety, and Law Enforcement (SSLE) Programs is outlined below.

- A polygon outlining the maximum extent of the dam failure inundation is obtained and used as a 'clipping' outline.

- The most current infrastructure, business, housing, census, and agriculture data are assembled for the counties affected. These data are imported into Environmental Systems Research Institute (ESRI) ArcGIS.

[4] For more detail, please consult *Estimating Economic Consequences from Dam Failure in the Safety of Dams Program*, Economics Group, Technical Service Center, September 2000.

- GIS geoprocessing functions are performed on the various data features. This produces amounts, counts, and areas of the various features involved in the flood boundary.

- Any data not in a spatial database format are interpreted onscreen and recorded.

- A summary spreadsheet is created for the various data themes.

- Reclamation economists use the summary of features in the flood boundary as one of their data sources to estimate the potential downstream damages to property and infrastructure. No percent of damages incurred information from the flood is available using this methodology. All infrastructure inundated is considered a total loss. The information produced is binary in nature; the features are either in or not in the flood boundary.

Reclamation is now employing a more standardized method of computing downstream damages. The flood inundation boundaries are still utilized using GIS technologies but now incorporate HAZUS software developed by Federal Emergency Management Agency (FEMA) under contract with the National Institute of Building Sciences (NIBS). HAZUS is a nationally applicable standardized methodology and risk assessment software program for analyzing potential losses from floods, hurricane winds, and earthquakes.

FEMA HAZUS-MH software provides the ability to determine damages resulting from a dam failure based on flood depth and extent.[7] The HAZUS-MH flood model includes over 700 depth-damage functions that relate water depth to structure and content percent damage. The damage functions include buildings, essential facilities, transportation systems, utility systems, agricultural products, and vehicles. Depth-damage curves are compiled from a variety of sources including the Federal Insurance and Mitigation Administration (FIMA), USACE, and the USACE Institute for Water Resources. Functions have been compiled for the USACE Chicago, Galveston, New Orleans, New York, Philadelphia, St. Paul, and Wilmington Districts.

HAZUS-MH offers the ability to perform analysis at three levels. A level 1 analysis with the HAZUS Flood Model is the simplest analysis requiring little, if any, expert input. The model is run from the provided default inventory data. This level is used for determining possible mitigation sites to potentially reduce damage losses. It also is useful for preparing emergency response and recovery plans for various flood scenarios studied. Level 1 can be used to run rapid loss estimates following an actual event due to its ease of use. Loss estimates will be

[7] HAZUS disclaimer states that "There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between modeled results contained in this report and the actual social and economic losses following a specific Flood."

crude and are most appropriate for regional levels. Level 1 analysis should not be used for dam failures. The default hydraulic data is not appropriate for dam failure scenarios.

Level 2 HAZUS-MH analysis appears to be the target level that should be performed when estimating the downstream damages from a dam failure. To achieve the desired level 2 analysis, supplemental data from alternate sources must be imported into the HAZUS-MH model. This requires additional effort and expertise on the part of the HAZUS user. HAZUS-MH databases have specific schema requirements that must be met. Once the data are formatted and imported, the HAZUS-MH program performs the analysis relatively rapidly given the proper computer hardware.

Level 2 analysis may be used when a level 1 study highlights an area where a more accurate flood damage/loss estimate is warranted. More extensive inventory data is gathered, and greater effort is required by the user. Input from hydraulic/hydrology models is used to determine flood elevations. This is especially true in the case of dam failure studies. Unlike the broad regional default damage curves used in level 1 analysis, the user will tailor the functions based on specific flood depth and velocity. As more complete inventory data is provided, the quality of the results will improve. The user at this level will modify and add to the site specific inventories. At level 2, a separate but related software package is used to update default inventories—possibly from assessor data, other infrastructure databases, or import user defined site specific data.

Level 3 analysis builds on level 2 and likely would include detailed building specific information. More information from the external hydraulic models, such as MIKE 21 or HEC-RAS, would be used. Level 3 analysis requires detailed engineering data about individual buildings that is not economically feasible for the large inundation areas involved in a dam failure.

Some of the inventory data that also may be inundated and damaged is not yet dealt with in the HAZUS-MH Flood Model. Linear features such as roads and canals are examples of features not dealt with by HAZUS-MH. Additionally, some transportation and energy facilities are not analyzed in the flood model. All these types of facilities must, therefore, be accounted for manually.

A summary of the methodology now employed for dam failure damage estimates using HAZUS-MH is presented rather than a step-by-step explanation of the process. The *HAZUS-MH User Manual* is a 355-page working document that details the mechanics of using the software.

- Define study region based on the dam failure inundation boundary. Select of all of the counties and U.S. Census blocks that are affected by the dam failure.

- Run the Flood Information Tool (FIT); this is an ArcGIS extension that processes user supplied flood boundaries into the format required by the HAZUS-MH flood model. FIT requires the digital elevation for the study area, the flood boundary polygon, and a set of cross sections attributed to flood elevations.

- Alternatively, if a flood depth grid is available, the FIT process can be bypassed.

- Review HAZUS-MH provided default inventory data.

- Collect additional data (always needed) and integrate (format) into HAZUS-MH. This step is a large part of the effort, as mentioned in the *HAZUS-MH User Manual* and earlier in this report.

- Ground truth the spatial locations of structures and flood depth/extent using the most current aerial imagery. Determine which hazard profiles and damage functions will be used for the scenario.

- Run HAZUS-MH damage analysis scenarios.

- Compile the pertinent damage summary report available from HAZUS-MH.

- Determine exposures for infrastructure and property not included in the HAZUS-MH process. Identify and include features that cannot be integrated into the HAZUS-MH schema.

- Create report of the quantities of downstream properties and infrastructure damage losses.

As more dam failure studies are completed, it is possible that the integration of local nondefault data will require less effort since counties already included in previous studies will have the information in the proper format. Updating of the data still will be required to ensure that the most current data is being used.

It also should be noted that the census data used in the current version of HAZUS is 2000, so the step in the above process summary that refers to a spatial ground truth is important. In the latest version of HAZUS-MH, 2006 commercial data and building valuations are included in the default data.

Flood Inundation Mapping

Because the Flood Inundation Mapping is a necessary input to estimating economic consequences, this section is included as appendix B.

Unquantified Losses

No attempt is made to quantify the cost of emergency services, environmental damages, disruption of government services, cleanup, the disruption of people's lives, or other categories of loss that would follow a dam breach. Data constraints preclude such an estimate for these analyses.

Dam Repair/Replacement Costs

For consistency, dam replacement costs typically are determined based on their original construction costs. These costs then are indexed to the current year of analysis using a Construction Cost Index for the type of facility analyzed.

Under certain scenarios, only a part of the dam will fail, such as the spillway gates, penstock, or powerplant. In these instances, it may be appropriate to have Reclamation's Cost Estimating Group in the TSC provide appraisal level cost estimates fairly quickly and inexpensively for these facility features. This estimation may also be provided by a construction/engineering individual or organization familiar with dam design and construction.

Indirect Impacts

In this context, indirect impacts refer to the county-level changes in business output as measured in dollars and changes in employment from a failure scenario. Because secondary or indirect impacts may represent a large portion of the economic consequences from a dam failure or similar scenario, a model has been created specifically to address indirect impacts from a dam failure event. For each impact analysis, a Computable General Equilibrium (CGE) model is used. General equilibrium modeling is a comparative static exercise which begins at an initial point, called the "benchmark," then computes how households and businesses respond to hypothetical external events. The new outcome is called the "counter-factual" scenario. This type of model combines regional input-output data, household expenditure data, government expenditure data, and neoclassical economic theory to determine how "optimizing" agents (households and businesses) would respond to the change in capital, labor, and natural resources.

A CGE analysis differs from traditional input-output (multiplier) techniques or from a simple "adding up" approach.[8] In the CGE approach, each economic

[8] An adding up approach computes the number of lost worker days in the office or the number of lost "sales" days for a business. This approach tends to overestimate the adverse effects of a disaster because it ignores the fact that sales volumes and workloads can be shifted across days and recovered through higher volume or longer hours after an incident.

agent in the model reallocates time, energy, and resources to maximize their economic welfare or, conversely, to minimize losses stemming from an adverse event. In these analyses, the agents will reallocate resources to minimize the economic hardship brought about by the disaster. A review of similar catastrophic events[9] confirms the idea that local residents, business owners, and even the government all act in a manner consistent with welfare maximization. By capturing the reallocation of local output, trade, business activity, and investment, the CGE analysis appears to be the best-practice approach to economic impact analysis for dam failure studies where a large economic shock to an area would occur.

Each impact study uses a unique dataset defined by the geographical location and the specific economic characteristics in question. The source of this data is the Minnesota Impact Planning Group, who produces a dataset called the "IMPLAN data." IMPLAN is the only data source available with a sufficient level of detail, internally consistent accounts, and broad availability. An Economic Consequences Assessment Model (ECAM) was developed using the CGE method of analysis. ECAM uses county-level data so that any county or group of counties in the United States can be analyzed. This county or group of counties is the "study area." Statistics for production, employment, income, and all other economic indicators are based upon the IMPLAN dataset unless otherwise indicated. However, the IMPLAN data can be augmented or adjusted if warranted.

After an economic impact area is defined, each county in the impact region is faced with five possible adverse impacts:

- Labor reduction due to flooding
- Capital reduction due to flooding
- Water shortages due to reduced agricultural deliveries
- Water shortages due to reduced M&I deliveries
- Lost tourism

One or more of these impacts may be applied to each county. The inputs are the percent reductions for these five resources (in 5-percent increments) estimated from the direct impacts from the event. The model determines price and quantity changes in each market as a result of the external event and then estimates the overall change to annual production and employment for the study area. The primary outputs are dollar reductions to regional production and number of jobs lost in the local area.

[9] See Murlidharan and Shah (2003) or van der Veen, et al. (2003).

Estimating Reductions

The "event" or "scenario" typically is characterized by a physical change taking place in the study area. Because the ECAM is designed for adverse economic events, the changes are usually *reductions* to key production factors or disruptions to supply channels. The physical impacts of an event must be translated into economic changes to input into the ECAM. These changes (labor, capital, water, tourism) define the scenario for the ECAM.

Capital Reduction

This is accomplished by first estimating the loss of physical infrastructure and then using this information to compute the percentage of productive capital lost due to the "event." The economic impacts are based upon these changes to physical factors of production. The percent of inundated infrastructure may be used as an estimate of capital reduction.

Labor Reduction

This is accomplished by first estimating the loss of physical infrastructure and then determining the number of displaced and unemployed individuals. The percent of inundated residences multiplied by the number of adults in the homes supplemented by the number of inundated businesses multiplied by the number of employees at those businesses may be used as an estimate of labor reduction.

Irrigation Water Reduction

Counties that will experience reductions in irrigation water need to be identified, and the percent reduction in the water supply needs to be estimated. This is accomplished by determining the amount of irrigation water that is undeliverable to a county due to the failure event and then determining its percent in relation to all irrigation water supply used in that county. When estimating the water supply lost from the failure event, impacted surface water supplies as well as groundwater supplies that may be reliant on releases made from a reservoir should be considered. In addition, if water supplied by pumping plants, wells, and/or pipelines supplying water are damaged or destroyed or other surface water supplies are impacted, they also must be considered.

M&I Water Reduction

Counties that will experience reductions in M&I water need to be identified, and the percent reduction in the water supply needs to be estimated. This is accomplished by determining the amount of M&I water that is undeliverable to a county due to the failure event and then determining its percent in relation to all M&I water supply used in that county. When estimating the water supply lost from the failure event, impacted surface water supplies as well as groundwater supplies that may be reliant on releases made from a reservoir should be considered. In addition, if water supplied by pumping plants, wells, or water treatment plants that directly supply treated water, and/or pipelines supplying water are damaged or destroyed or other surface water supplies are impacted, they also must be considered.

Tourism Reduction

If the region has tourist attractions such as the reservoir that was compromised, casinos, wineries, golf courses, museums, etc., the percentage of total tourism lost as a result of the failure event needs to be computed. The percent of travel spending lost as a result of the failure event may be used as an estimate of tourism reduction.

Economic Indictors

The primary economic indicator is overall production. Production is the easiest indicator to understand (similar to Gross Domestic Product [GDP]), and it has a clear, measurable benchmark: initial output before the event. The Minnesota Implan Group (MIG), a for-profit data-compilation company, combines economic data from a large array of government publications to produce county-level economic datasets. These datasets are useful because they are balanced, they are highly disaggregate (509 sectors), and they include most of the economic information needed to build a CGE model.

Other available indicators are: change in employment, farming impact, and changes to inter-regional trade (imports and exports to domestic and international partners). Explicit consideration is given to changes in farm output and related services for counties with large agriculture sectors. Tourism services are a focus in counties that depend heavily upon tourism.

To compute the total change in economic activity, each individual county is subjected to a combination of economic events, as discussed above. Those counties that lay directly in the inundation path face significant losses to economic activity. A portion of the losses arise because the infrastructure and people used in the production process are no longer available, and part of the losses come from shortages of irrigation and M&I water. The events are imposed onto each county simultaneously; then the losses for each county are added together to derive indirect economic impacts.

Data Limitations

Due to time and cost constraints, dam repair and/or replacement costs are indexed from their original construction costs using Construction Cost Trends (http://www.usbr.gov/pmts/estimate/cost_trend.html). Indexing over such a long period of time can skew costs. However, for consistency, timing, and budget purposes, this indexing may be used for estimating economic consequences. It also should be noted that under such circumstances where a facility needs to be completely replaced or rebuilt, a similar facility may not be feasible or efficient (due to changes in technology, etc.) nor built in the same location as the original facility. Determining the most efficient type of replacement is a lengthy process that could take years. However, a more technically feasible approach would be to create a new, updated design for the replacement of the older facilities and estimate costs associated with the new design. Although this would increase the budget and schedule by approximately $20–40 thousand and 2–6 months for a pre-appraisal level estimate, it would yield a more accurate estimate of the replacement costs of the facilities.

Currently, there is no methodology to estimate costs for emergency response or relief/recovery efforts or costs of cleanup. Approaches are being researched to incorporate emergency costs and/or cleanup costs into the methodology.

Currently, Reclamation does not estimate nor does it have a methodology to estimate costs for emergency response or relief/recovery efforts or costs of cleanup. The Economics and Resource Planning Group (86-68270) will be researching ways to incorporate emergency costs and/or cleanup costs into the standard methodology in FY 2009.

Often, assumptions for the delivery of remaining water supplies from a damaged facility or alternative water supply source must be made. It would be beneficial to have contingency plans in place that defined the "emergency" deliveries of the remaining water supply or emergency alternative sources of water in the event that facilities cannot make their normal deliveries for a period of time due to an unforeseen circumstance.

Reconstruction activities are not considered to be a benefit to the (local) economy. The costs to rebuild infrastructure could be considered to have a positive impact to the study area but are not considered in this manner for this estimation procedure due to uncertainties such as in-kind replacement and replacement schedule.

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Definition of Economic Terms

Benefits – NED benefits are a measure of direct net benefits to the Nation that accrue in the study area and the rest of the United States as a result of a Federal action. In this context, also referred to as "project benefits," are those beneficial purposes for which a dam and its water supply provide for. Reclamation has several categories for which benefits (or lost benefits) are measured including agriculture, M&I, fish and wildlife, recreation, and hydropower. These lost benefits are one component of the total economic consequences.

Benefits Transfer – Approach used to estimate values by transferring available information from studies and/or economic analyses already completed at other sites/context similar in nature and character. This can be done as a unit value transfer or a function transfer.

Computable General Equilibrium (CGE) – A CGE model consists of a system of simultaneous equations representing cost of production functions, demands for factor inputs, and demand for household goods and services. An optimal mix of production inputs is generated by the model that meets the demands resulting from an exogenous shock caused by an event or project. With this model, all markets within the economy are simultaneously in equilibrium. While in equilibrium, all markets clear (supply equals demand), and prices and quantities do not have a tendency to change. This model combines regional input-output data, household expenditure data, government expenditure data, and neoclassical economic theory to determine how "optimizing" agents (households and businesses) would respond to the change in capital, labor, and natural resources. In the CGE approach, each economic agent in the model reallocates time, energy, and resources to maximize their economic welfare, or conversely, to minimize losses.

Direct Economic Consequences/Impacts – Defined in this context as the costs of lost project benefits, downstream property damages, and repair/replacement costs.

Direct Effects – Direct effects are the initial changes in the industry to which there is a change in final demand. The direct effects are equal to the value of the change in final demand used to estimate regional impacts. For example, the direct effects of a management action resulting in water delivery changes may be changes in the value of agricultural production due to changes in irrigated acreage.

Economic Consequences – As used in this context, the impacts from a failure event measured as the downstream property damages, the lost project benefits, a repair/replacement value, and the indirect or secondary impacts.

National Economic Development (NED) – The national stance by which costs and benefits to all affected parties, literally every entity in the Nation, should be evaluated. The P&Gs stipulate the procedures and format for appraising and assessing the alternatives under the NED account. A complete NED analysis should evaluate the positive and negative consequences of the action for everyone who is affected, not just the Federal Government, and the project beneficiaries responsible for repayment of dam costs.

Indirect Economic Consequences/Impacts – In this context, indirect impacts refer to the changes in the valuation of business output as measured by the CGE model and changes in employment from a failure scenario.

Indirect Effects – Indirect effects are the secondary economic effects on regional and local economies that occur as a result of the direct impacts. Using the example above of changes in irrigated acreage, indirect impacts would be changes in final demand for industries needed to support the primary agricultural input requirements.

Input-Output (I-O) Model – I-O models are used to estimate changes in the value of regional output, employment, and income brought on by changes in expenditures for final demand.[10] Regional impacts are determined by the interdependence of production and consumption sectors within a region. Industries must purchase inputs from other industries, or potentially from within their own industry, to use in producing outputs which are sold either to other industries or final consumers. Thus, a set of I-O accounts can be thought of as a “snapshot” of an impact area’s economic structure.

[10] Final demand represents purchases by the final consumer (households, government, investment, exports).

Appendix A: Economic Consequences of a Generic Dam Failure

Introduction

An economic analysis was conducted to assess the direct and indirect impacts which would occur with the sudden failure of Generic Dam. For this analysis, economic assessments were made based on the information obtained by flood inundation studies, Geographic Information System (GIS) data incorporating HAZUS-MH software, and a Computable General Equilibrium (CGE) model specifically developed to estimate indirect changes in economic activity from a flood event. The direct economic losses as well as secondary or indirect economic effects on individuals and industries are estimated in this report.

Summary Results

The summary table below displays the results of the analysis for a sudden failure at Generic Dam. Total economic consequences from the failure are estimated to be over $5.2 billion. The following sections of the report describe the estimation methods utilized and provide a more detailed breakdown of the dollar estimates.

Table 1. Summary table (2008 million $)

Lost Project Benefits (Present Worth)	**$1,135.4**
Downstream Property Damages	**$577.0**
Dam Repair/Replacement Costs	**$167.9**
Direct Economic Impacts[1]	**$1,880.3**
Indirect Impacts	**$3,376.0**
Total Economic Consequences	**$5,256.3**

[1] Direct impacts are defined in this context as damages, lost project benefits, and dam repair/replacement costs. Indirect impacts are the changes in the economic value of output and employment as measured by the CGE model. A traditional use of the terms direct and indirect impacts may not apply here.

Background and Overview of Dam

Lake Generic and Generic Dam are features of the Vague Project. The dam is owned by the Bureau of Reclamation (Reclamation) and is located on the Generic River about 15.5 miles northeast of Nowhere. The reservoir provides storage for irrigation, municipal and industrial (M&I), recreation, power generation, instream flows for fish and wildlife, and flood control.

The dam is constructed of compacted earthfill, has a structural height of 300 feet, and has a crest length of 900 feet. The reservoir has a capacity of 800,000 acre-feet. The spillway can pass 10,000 cubic feet per second (cfs) over three times the downstream safe channel capacity.

For this study, the assumption is made that Generic Dam fails quickly during normal reservoir operations and a full reservoir. Under this scenario, the peak outflow from the failure of Generic Dam would be nearly 3.1 million cfs.[1] Deliveries of water to agricultural and M&I users would not be made for approximately 5 years; 4 years for the dam reconstruction period[2] and 1 year for the reservoir to refill assuming no annual deliveries. Power production would also cease or be severely reduced for approximately that same amount of time. In addition to the downstream property damages due to flooding, the recreation resource at the reservoir would be lost or significantly reduced for 5 years until the dam was reconstructed and the reservoir was refilled.

Generic Dam's year 2000 sunny day failure (SDF), for which flood inundation exists, is used in this analysis to determine economic consequences.

Lost Project Benefits and Methodology

Methodology

The benefit categories used in this analysis are irrigation water supply, M&I water supply, recreation, hydropower, fish and wildlife, and flood control. Unit values for each were applied to annual outputs (i.e., acre-feet, visitor days, and megawatthours) where applicable and then discounted over the period that the dam is expected to be inoperative. A real interest rate (one adjusted for inflation) of 2.3 percent (%) is used. This rate is the real interest rate recommended by the Office of Management and Budget for use in 2008. The period of analysis is 5 years, and all present values are rounded to the nearest $1,000. Complete loss of the dam would result in the loss of the associated benefits until repair and/or replacement is made; a partial loss may greatly reduce but not completely eliminate all benefits.

M&I Water Supply

In this context, the term water supply refers to the deliveries to water users for M&I and agricultural purposes which would be lost with reduced capacity to supply their water. The scenario analyzed is likely to result in no water being

[1] Bureau of Reclamation. *Dam Failure Inundation Study, Generic Dam*.

[2] Reclamation's Construction Management Group estimated an appraisal level duration total embankment dam replacement assuming some repair of outlet works and spillway with minimal duration for an environmental assessment/environmental impact statement.

delivered for approximately 5 years from Lake Generic. The average annual M&I water lost is approximately 200,000 acre-feet which are the M&I deliveries from Lake Generic.

The average annual value for water used for estimating the loss of M&I water from Generic Dam is approximately $250/acre-feet. This is an average non-Reclamation M&I water rate for the area where M&I deliveries are made. This would be a reasonable replacement value for water in the area in the absence of Generic Dam. Although the loss of this magnitude of water could drive the price of water up, it cannot be speculated what the higher price would be. As illustrated in table 2, annual lost benefits from lost M&I deliveries are approximately $50.0 million from the dam failure.

Table 2. Lost M&I deliveries and value

Annual Lost M&I Water Deliveries	Annual Value of Lost M&I Water Deliveries	Present Value[1] of Lost M&I Water Deliveries
200,000	$50,000,000	$233,635,000

[1] Rounded to the nearest $1,000.

Irrigation Water Supply

Generic Dam helps stabilize the agricultural and industrial economy of Nowhere. It is particularly effective each year during late summer months of the irrigation season and has a tremendous impact throughout the season in drought years.

Principal crops include sugar beets, potatoes, beans, corn, small grains, fruits, alfalfa, vegetables, dairy products, poultry, and eggs. In addition, lambs, hogs, and cattle are fattened from the byproducts of the sugar beets.

In the absence of Generic Dam, allocated irrigation water would eliminate delivery of water for agricultural purposes for 5 years.

The 3-year average annual lost irrigation water would be 100,000 acre-feet. The revenues lost from this undelivered water are estimated by using the value of M&I water, $250 per acre-feet, as described in the "M&I Water Supply" section above. As illustrated in table 3, the total lost benefits have a present value of more than $179.2 million.

Table 3. Agricultural losses and value

Annual Lost Agricultural Deliveries (acre-feet)	Annual Value of Lost Agricultural Deliveries	Present Value of Lost Agricultural Deliveries
100,000	$25,000,000	$179,253,000

Recreation

Lake Generic is the second largest body of water in Nowhere and offers 50 miles of shoreline. Recreation facilities at Lake Generic are managed by the U.S. Forest Service. Developments include 270 campsites and 4 boat-launch ramps. Total water surface available for recreation is approximately 8,000 surface acres. Primary recreation activities are power boating, fishing, and camping. Primary sport fish are rainbow trout, bass, and salmon. As part of their management effort, Nowhere State Parks collects and reports annual visitation (table 4). Average annual visitation to the Lake Generic is about 530,000.

Table 4. Recreation visitation

Year	Generic Dam Visitation
2006	500,000
2005	550,000
2004	525,000
2003	600,000
2002	475,000
5-year rounded average visitation	530,000

To estimate the annual recreation benefits, the 5-year rounded average visitation at Lake Generic was multiplied by the average value of a recreation visit to a Pacific coast reservoir. Values, derived from past research for the Pacific Coast States for the most common recreational activities available at Lake Generic, were averaged to obtain the expected value per visit for recreation use at impacted recreation sites which is $50.00 (in 2008 $). The damages caused by a failure of Generic Dam are expected to decimate recreation at the reservoir for the 5-year rebuilding period. Present values were calculated to be nearly $124.0 million and illustrated in table 5.

Table 5. Lost recreation visits and value

Annual Lost Visits	Annual Value of Lost Recreation Visits	Present Value of Lost Recreation Visits
530,000	$26,500,000	$123,826,000

Hydropower Generation

Table 6 displays net generation figures at Generic Powerplant for 5 recent years. The annual net generation figures are used to estimate the lost benefits of hydroelectricity.

Table 6. Electricity generation (kilowatthours [kWh])

Year	Generic Powerplant
2005	586,835,457
2004	572,759,816
2003	469,699,951
2002	529,986,542
2001	482,874,250
5-year Average	**528,431,203**

Average daily prices for electricity generated during 2007 in the Four Corners Region were used to derive an estimated average price of electricity.[3] The average firm peak price for electricity is approximately $62.65 per megawatthour (/MWh). The present value of benefits during a 5-year reconstruction period is approximately $154.7 million (table 7).

Table 7. Lost generation and value

Annual Lost Generation (MWh)	Annual Value of Lost Generation	Present Value of Lost Generation
528,431	$33,106,000	$154,695,000

Fish and Wildlife

Flows totaling 300,000 acre-feet are annually allocated to fish and wildlife delivered from Generic Reservoir. The water is stored in the reservoir until needed to provide adequate flows for fish and wildlife. These flows would be lost for approximately 5 years while the dam was being repaired. The regional value of agricultural water and M&I water ($250 per acre-foot) is also used for the value of this water provided for environmental purposes. As shown in table 8, the annual value is $75.0 million. The present value of this loss for 5 years is $350.5 million.

Table 8. Lost fish and wildlife benefits

Annual Lost F&W Water	Annual Value of Lost Benefits	Present Value of Lost Benefits
300,000	$75,000,000	$350,452,000

[3] Dow Jones Electricity Price Indices purchased from LCG Consulting, 2007.

Flood Control

Generic Dam and Lake Generic have been used for flood control regulation when the U.S. Army Corps of Engineers (USACE) is releasing large quantities of water to vacate the flood control pool behind Unknown Dam. The accrued benefits (1950–2007) realized from the flood control operation at Generic Dam is $1.0 billion. On an annual basis, this equates to approximately $20.0 million in damages prevented (table 9).

Table 9. Lost flood control benefits

Annual Lost Flood Control Capacity (acre-ft)	Annual Value of Flood Control Benefits	Present Value of Lost Flood Control Benefits
200,000	$20,000,000	$93,454,000

Benefit Loss Summary

As displayed in table 10, the benefits lost due to a Generic Dam failure are nearly $230.0 million annually and have a present value of over $1.1 billion.

Table 10. Analysis of lost project benefits

	Annual benefits (million $)	Present Value (million $)
M&I Water Supply	$50.0	$233.6
Irrigation Water Supply	$25.0	$179.3
Recreation	$26.5	$123.8
Power	$33.1	$154.7
Fish and Wildlife	$75.0	$350.5
Flood Control	$20.0	$93.5
Total	**$229.6**	**$1,135.4**

Downstream Property Damages

Methodology

To begin the assessment of property damages that result from flooding, an inundation boundary for the scenario must be obtained. For a Generic Dam failure, a year 2000 inundation boundary already existed for a SDF. A “sunny day” failure is an unexpected failure which would be the preferable scenario used to evaluate inundation damages from an unanticipated event as compared to a probable maximum flood (PMF) event in which there would be a larger volume of water but potentially fewer people at risk and damages due to warnings and evacuations.

The inundation boundaries are necessary to provide inundation reports developed utilizing a computerized GIS. This GIS data contains the level of detail for the inundation area being analyzed. The flood inundation boundaries are developed using GIS technologies and incorporate HAZUS-MH software developed by the Federal Emergency Management Agency (FEMA) under contract with the National Institute of Building Sciences (NIBS). HAZUS-MH is a nationally applicable standardized methodology and risk assessment software program for analyzing potential losses from floods, hurricane winds, and earthquakes. HAZUS-MH reports the majority of the locations and types of infrastructure that would be inundated as well as the estimated damages. The GIS Group gathers this data and produces a flood report that shows this information.

FEMA HAZUS-MH software provides the ability to determine economic loss impacts resulting from a dam failure based on flood depth and extent. The HAZUS-MH Flood Model includes over 700 depth-damage functions that relate water depth to structure and content percent damage. The damage functions include buildings, essential facilities, transportation systems, utility systems, agricultural products, and vehicles. Depth-damage curves are compiled from a variety of sources including the Federal Insurance and Mitigation Administration (FIMA), USACE, and the Institute for Water Resources. Functions have been compiled for the USACE Chicago, Galveston, New Orleans, New York, Philadelphia, St. Paul, and Wilmington Districts.

Some of the features that may be inundated during a flood are not yet dealt with in the HAZUS-MH Flood Model. Linear features such as roads and canals are examples of features not dealt with by HAZUS-MH. Additionally, some transportation and energy facilities are not analyzed in the flood model. All these types of facilities are manually accounted for and, therefore, assigned a replacement value based on flood depth.

Once the flood boundary is identified, additional information can be input into the model and run to estimate damages. The *HAZUS-MH User Manual* is a 355 page working document that details the mechanics of using the software.

Damages

Building-Related Losses

The direct building losses are the estimated costs to repair or replace the damage caused by the flood to the building and its contents. Information on the numbers of commercial businesses in addition to residential structures and industrial structures including building contents potentially flooded was provided in the flood report. The damages to these types of buildings and their contents are estimated at approximately $120 million of which $60 million is residential losses.

Transportation

The flood report identifies the direct losses for highway bridges only; highway segments, railways, lightrail, bus facilities, ports, ferries, and airports that are not accounted for in the HAZUS-MH flood model. Therefore, the depth-damage function is entered manually for these items based on flood depth if these types of infrastructure are located within the flood boundary. Transportation losses were estimated to be $175.0 million.

Essential Facilities

The essential facilities identified in the flood report were three police stations, two fire stations, and two hospitals. Twenty schools were also identified within the inundation boundary. The damage estimates to these buildings and their contents are estimated to be $5.5 million.

Utilities and Other Infrastructure

The flood report identifies facilities for potable water, wastewater, oil systems, and natural gas pipelines for these infrastructure as well as electric power and communication facilities and pipelines that are not accounted for in the HAZUS-MH flood model. Therefore, the depth-damage function is entered manually based on flood depth if these types of infrastructure are located within the flood plain. Other infrastructure that is entered manually includes mileage of canals, electric transmission lines, fiber optic lines, and microwave towers in the flood area. The direct losses for utilities and other infrastructure are estimated to be approximately $250.0 million.

Vehicles

The flood report estimates vehicle damages which include cars and light and heavy trucks. HAZUS-MH gives estimated damages to vehicles for a flood that occurs during the daytime and one that occurs at nighttime. The average value between daytime losses and nighttime losses is used to estimate vehicle damages to be $1.5 million.

Agriculture Products

A flood event would cause damage to agricultural lands, buildings, and crops. The flood report estimates that nearly 15,000 acres of irrigated land would be flooded in two counties. HAZUS-generated crop damages across these two counties are nearly $25.0 million. Damages to farm buildings and structures are included in the "*Building-Related Losses*" section. Future crop losses from undelivered water supplies are included in the "*Lost Benefits*" section.

Quantified Damage

Table 12 displays total estimated direct damages. Damages are presented in 2008 dollars and rounded to the nearest $100,000. These figures are only estimates, but they provide a sense of the magnitude of damages expected to occur in the event of a catastrophic failure. Total estimated damages for the failure of the dam are approximately $577.0 million.

Table 12. Estimated damages (million $)

Property Category	Damages
Building-Related Losses	$120.0
Transportation	$175.0
Essential Facilities	$5.5
Utilities and Other Infrastructure	$250.0
Vehicles	$1.5
Agriculture	$25.0
Total	**$577.0**

Dam Repair/Replacement Cost

Generic Dam was constructed in 1969 at an estimated cost of $30,000,000. Using Reclamation's Construction Cost Trends for an earthfill dam and indexing to January 2008 yields, a $167.9-million replacement value.

Indirect Impacts

Methodology

For each impact analysis, a Computable General Equilibrium (CGE) model was used to estimate the indirect impacts. This type of model combines regional input-output data, household expenditure data, government expenditure data, and neoclassical economic theory to determine how "optimizing" agents (households and businesses) would respond to the change in capital, labor, and natural resources.

To compute the change in economic activity, each individual county is subjected to a combination of economic events. Those counties that lay directly in the inundation path face significant losses to economic activity. A portion of the losses arises because the infrastructure and people used in the production process are no longer available, and a portion of the losses comes from water supply shortages. Again, each county is considered individually, and each county can experience multiple events. The events are imposed onto each county simultaneously in 5-percent increments, then the losses for each county are added together to derive indirect impacts.

In the CGE approach, each economic agent in the model reallocates time, energy, and resources to maximize their economic welfare or, conversely, to minimize the losses stemming from an adverse event. In this analysis, the agents will reallocate resources to minimize the economic hardship brought about by the disaster. A review of similar catastrophic events[4] confirms the idea that local residents, business owners, and even the government all act in a manner consistent with welfare maximization. By capturing the reallocation of local output, trade, business activity, and investment, the CGE analysis appears to be the best-practice approach for indirect impact analysis for the failure of Generic Dam.

Economic Data

The main source of data is the Impact Analysis for Planning (IMPLAN) economic database. IMPLAN is the only data source available with detailed data by economic sector, internally-consistent accounts, and availability for any county in the United States. Statistics for county production, employment, income and all other economic indicators are based upon the IMPLAN dataset unless otherwise indicated.

Regional Description and Impact Types

The counties of X, Y, and Z in Nowhere have been selected as the impact region. These counties are located in the flood plain below the dams, in the surrounding farmland that depends upon dam-supplied irrigation water, or in the urban regions that depend upon electricity or drinking water that may be disrupted by the uncontrolled release. Figure 1 displays the three-county region.

Impact Types

Each county in the impact region is faced with five possible adverse impacts: labor reduction due to flooding; capital reduction due to flooding; water shortages due to reduced agricultural deliveries; water shortages due to reduced M&I deliveries; and lost tourism. One or more of these impacts is applied to each county as defined in table 13 below.

[4] See Murlidharan and Shah (2003) or van der Veen, et al. (2003).

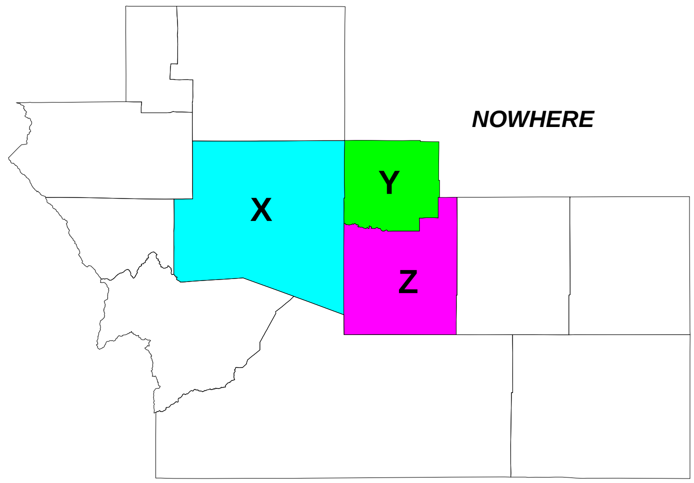

Figure 1. Impact area map.

Table 13. County reductions

	X	Y	Z
Labor Reduction:	25%	0%	0%
Capital Reduction:	25%	0%	0%
M&I Water Supply Reduction:	15%	15%	0%
Irrigation Water Supply Reduction:	10%	10%	10%
Tourist Visit Reduction:	30%	20%	0%

Flood Impact

Only X County would endure any significant physical damage directly related to the flood event. Approximately 14 percent of home residences and 10 percent of businesses would be inundated in X County.[5] In the economic model, this event is characterized as a loss of productive capital and productive labor as a result of the flood. This loss of productive inputs limits production possibilities in the counties, which lowers output and incomes.

The expected direct damages in the region as a result of the flood are about $577.0 million and occur mainly in X County. This figure must be converted into a percentage change in available capital. A percentage change in labor supply must also be included. The change in labor supply will depend upon how many people flee the region as a result of the flood and how long these people stay

[5] Less than ½ percent of Y County businesses and residences would be inundated, which excluded Y County from the impact region.

away. The number of inundated businesses and residences as a percent of total businesses and residences is used as the estimate for the reduction in capital and labor supply for X County. Because the model runs reductions in 5-percent increments, the percent reductions in capital and labor are 25 percent each in X County.

M&I Water Shortage Impact

The failure would halt approximately 200,000 acre-feet of M&I deliveries. The counties that would be impacted the most are X and Y.

A proportional reduction in delivery to total county water consumption was assumed for this analysis. Therefore, reductions in water supply are estimated using the percent of water supply delivered from Lake Generic for M&I purposes to total M&I water consumed in the counties. It is estimated that 200,000 acre-feet (approximately 15 percent of total water consumption in the two counties) of the surface water supply for M&I purposes currently delivered from Lake Generic would not be available to X and Y Counties. M&I water delivery would be reduced by approximately 15 percent in these two counties (table 14).

Table 14. Estimated M&I water reductions

	Total County Water Withdraws[1] (acre-feet)	Proportional Loss from Lake Generic (acre-feet)	Percent Reduction
X	850,000	130,800	15.0 %
Y	450,000	69,200	15.0 %
Total	1,300,000	200,000	15.0%

[1] U.S. Geological Survey. "Estimated Use of Water in the United States," *Data Dictionary for County-Level Data for 2000*.

Irrigation Water Shortage Impact

A Generic Dam failure would also cause a loss of approximately 100,000 acre-feet of agricultural deliveries from Lake Generic to cease. All three counties would be impacted. Since the production structure for agriculture includes irrigation water as a necessary input, total crop production for these counties is expected to fall by the same percentages, respectively.

A proportional reduction in delivery to total county water consumption was assumed for this analysis. Therefore, reductions in irrigation water supply are estimated using the percent of water supply delivered from Lake Generic for irrigation purposes to total irrigation water consumed in the counties. It is estimated that 100,000 acre-feet (approximately 10 percent) of water deliveries for irrigation purposes currently delivered from Lake Generic would not be available to X, Y, and Z Counties. Irrigation water deliveries would be reduced by approximately 10 percent in all three counties (table 15).

Table 15. Estimated agricultural water reductions

	Total County Irrigation Water Withdraws[1] (acre-feet)	Proportional Loss from Lake Generic (acre-feet)	Percent Reduction
X	400,000	40,000	10.0 %
Y	300,000	30,000	10.0 %
Z	300,000	30,000	10.0 %
Total	1,000,000	100,000	10.0 %

[1] U.S. Geological Survey. "Estimated Use of Water in the United States," *Data Dictionary for County-Level Data for 2000*.

Impact of Lost Tourism Revenues

The reduction in tourism was estimated using the percent of direct recreation benefits lost to the total county travel-related spending. Typically, there will be less tourism from both outside and inside the county as a result of the flood, water supply shortages, as well as fewer facilities in the sectors where tourism dollars are spent. Tourists and recreators may avoid the area if they believe the area is unstable and/or unsafe. It is important to note that tourists only require the perception of danger, even if the actual danger level remains constant.

Approximately 45 percent ($55.8 million) of the direct impacts from recreation occur in X County. X County's travel spending in 2006 was estimated to be approximately $174 million.[6] The impacts result in a reduction of approximately 32 percent in tourism. Many reservoirs and rivers available to recreators in Y County would be unavailable due to drawn down reservoirs and high water demand. Approximately 55 percent ($68.2 million) of the direct impacts from recreation occur in Y County. Y County's travel spending in 2006 was estimated to be $423 million. These impacts result in a reduction of approximately 16 percent in tourism in Y County. Several other popular tourism destinations are inundated and destroyed by the flood. These include two golf courses, the region's most popular museum, and several other popular museums. Including the impacts from the loss of these tourist attractions yields a total reduction of approximately 20 percent in Y County. Z County would not likely see an impact to tourism.

Multiple Scenarios Imposed Onto a Single County

A challenging aspect of this analysis is the cross-cutting nature of several distinct types of events. While some counties experience only one type of event, such as an irrigation water shortage, other counties can experience two or three types of

[6] Dean Runyan Associates. *Travel Impacts 1996–2006*. http://www.deanrunyan.com.

impacts simultaneously. To avoid double-counting, all applicable scenarios (or events) are applied to a county simultaneously. For example, a county can experience lost irrigation water as well as reductions to capital, labor, and tourism at the same time. The aggregate impact is reported in the results.

Economic Indicators: Base Year Production

The primary economic indicator is overall production. Production is the easiest indicator to understand (similar to GDP), and it has a clear, measurable benchmark: initial output before the event. The Minnesota Implan Group (MIG), a for-profit data-compilation company, combines economic data from a large array of government publications to produce county-level economic datasets. These datasets are useful because they are balanced, they are highly disaggregate (509 sectors), and they include most of the economic information needed to build a computable general equilibrium model.

Indirect Impact Results

Table 16 presents the summary findings for each county's indirect economic losses. Overall, regional output can be expected to decline by $3.4 billion in the initial year after failure as a result of the flood event, and employment can be expected to fall by over 48,000 jobs or 13.6 percent, which is rather significant for the impact area. The percentage change helps to highlight that those counties heavily reliant upon water and those counties directly in the flood path stand to lose the most, which is over 18 percent of all economic activity and over 33 percent of employment in X County in the first year after the event. The economic losses during subsequent years are likely to be much smaller as investment and re-establishment improve production and facilities.

Table 16. Indirect impacts summary by county

County	2008 Output (million $)	Impact (million $)	Percentage Impact	2008 Employment	Impact (Jobs)	Percentage Impact
X	11,259	-2,113	-18.76%	86,956	-29,304	-33.70%
Y	26,695	-1,232	-4.62%	213,357	-18,620	-8.73%
Z	6,974	-31	-0.44%	53,402	-93	-0.17%
Total Impact	**44,928**	**-3,376**	**-7.51%**	**353,715**	**-48,017**	**-13.58%**

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