Dams Sector

Estimating Economic Consequences for Dam Failure Scenarios

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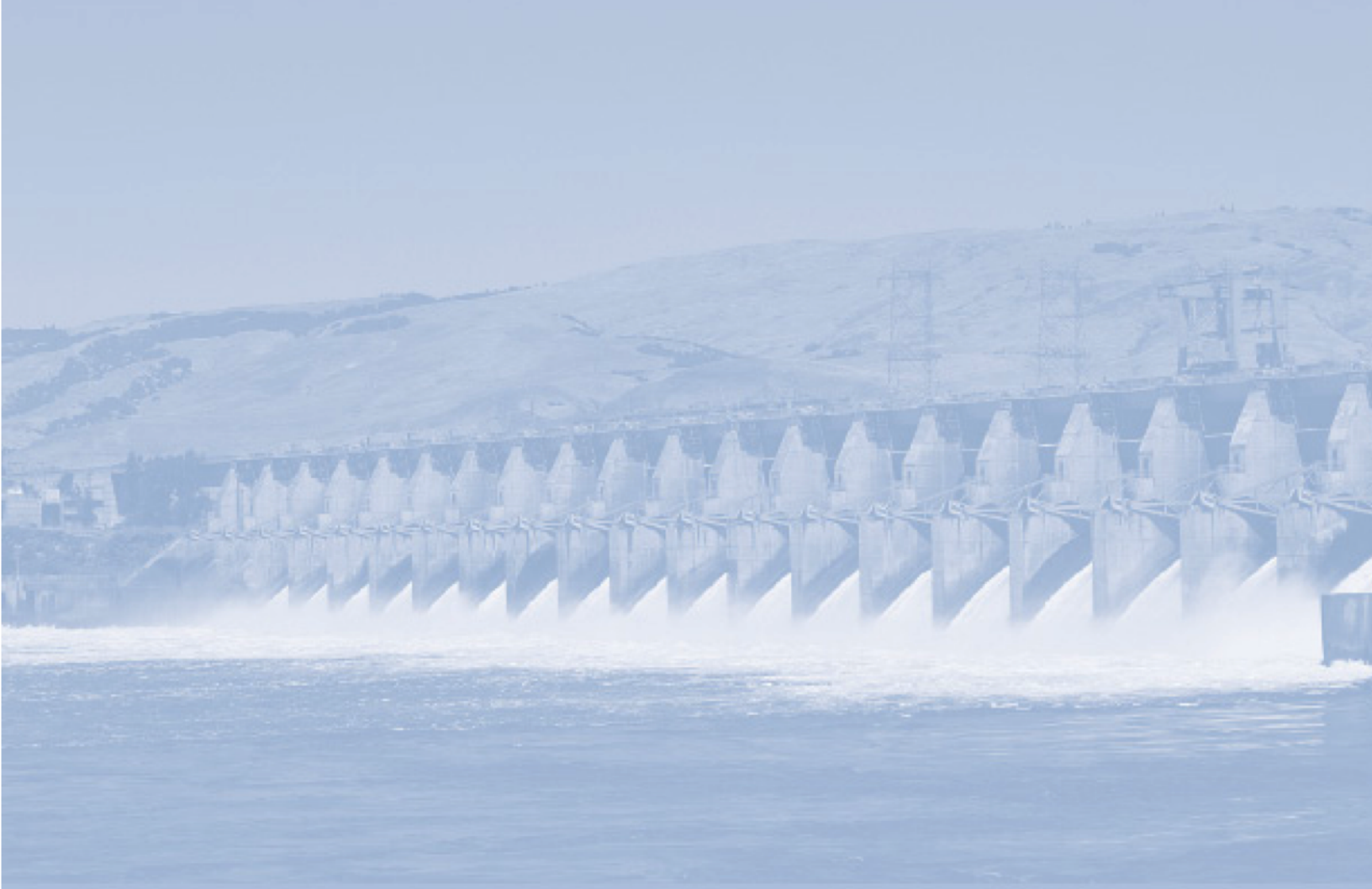

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Executive Summary

Homeland Security Presidential Directive (HSPD) -7, Critical Infrastructure Identification, Prioritization, and Protection, directs the U.S. Department of Homeland Security (DHS) to develop a National Infrastructure Protection Plan (NIPP) in order to identify, prioritize, and coordinate the protection of the Nation's critical infrastructure. The NIPP provides the unifying structure for the integration of a wide range of efforts for the enhanced protection and resilience of the Nation's critical infrastructure into a single national program.

As one of the 18 critical infrastructure sectors, the Dams Sector comprises a wide range of assets, including dam projects, navigation locks, levees, hurricane barriers, mine tailings impoundments, and other similar water retention and/or control facilities. The potential risks associated with the failure or disruption of Dams Sector assets could be considerable and potentially result in significant destruction, including loss of life, massive property damage, and severe long-term consequences. Therefore, consistent consequence estimation approaches must be incorporated as part of a sector-wide risk assessment framework to preliminarily identify those assets within the sector whose failure or disruption could potentially lead to the most severe impacts. Guidelines for consequence estimation are needed to directly facilitate the comparison of results and support the development and implementation of sector-wide risk management strategies. As indicated by the NIPP, consequences are divided into four main categories: public health and safety; economic (direct and indirect); psychological; and governance/mission impacts.

This report provides information on methodologies for estimating direct and indirect economic consequences resulting from dam failure or disruption. The objective of this report is to assist in the development of consequence assessments that are consistent and can be systematically compared across multiple owners and different jurisdictions. The general approaches presented in this report can be applied to both safety and security scenarios; therefore, this report provides the necessary consistent framework for an all-hazards perspective, as required by the NIPP. This report does not address the probability of the triggering event or the probability of unsatisfactory performance leading to the failure or disruption consequences. Of course, consistent estimation of these probabilities constitutes a critical step in the development and implementation of a sector-wide risk assessment framework, but is beyond the scope of this report.

This report is the result of a sector-wide collaborative effort involving public and private partners. The initial version of this document was developed by the U.S. Bureau of Reclamation under Interagency Agreement HSHQDC-07-X-00612 with DHS. This version incorporates additional contributions provided by multiple public and private Dams Sector stakeholders.

1. Introduction

HSPD-7, Critical Infrastructure Identification, Prioritization, and Protection, directs the DHS to develop a NIPP in order to identify, prioritize, and coordinate the protection of the Nation's critical infrastructure. The NIPP provides the unifying structure for the integration and coordination of protection and resilience efforts for all 18 critical infrastructure sectors. The goal of the NIPP is to build a safer, more secure, and more resilient America by preventing, deterring, neutralizing, or mitigating the effects of deliberate efforts by terrorists to destroy, incapacitate, or exploit elements of the Nation's critical infrastructure and to strengthen national preparedness, timely response, and rapid recovery of critical infrastructure in the event of an attack, natural disaster, or other emergency. The NIPP and corresponding Dams Sector-Specific Plan provide a strong foundation for identifying and implementing programs that help enhance protection and resilience across the Dams Sector from an all-hazards perspective.

The Dams Sector comprises a wide range of assets, including dam projects, navigation locks, levees, hurricane barriers, mine tailings impoundments, and other similar water retention and/or control facilities. As such, the sector is not conducive to a "one size fits all" approach to risk management. Therefore, development of a consistent framework that allows a direct comparison of risk variables (i.e., consequence, vulnerability, and threat) among different assets across the sector is needed to better identify sector critical assets, define the sector risk profile, facilitate the prioritization of sector-wide programs, and justify the implementation of sector-wide protective programs and resilience strategies.

The potential risks associated with the failure or disruption of Dams Sector assets could be considerable and potentially result in significant destruction, including loss of life, massive property damage, and severe long-term consequences. Therefore, consistent consequence estimation approaches must be incorporated as part of a sector-wide risk assessment framework to preliminarily identify those assets within the sector whose failure or disruption could potentially lead to the most severe impacts. Guidelines for consequence estimation are therefore needed to directly facilitate the comparison of results and support the development and implementation of sector-wide risk management strategies.

As indicated by the NIPP, consequences are divided into four main categories:

- Public Health and Safety: Effect on human life and physical well-being (e.g., fatalities, injuries/illness).
- Economic: Direct and indirect economic losses (e.g., cost to rebuild asset, cost to respond and recover, downstream damages, and long-term costs due to environmental damage).
- Psychological: Effect on public morale and confidence in national economic and political institutions. This encompasses changes in perceptions emerging after a significant incident that affect the public's sense of safety and well-being and can manifest in aberrant behavior.
- Governance/Mission Impacts: Effect on government or industry's ability to maintain order, deliver minimum essential public services, ensure public health and safety, and carry out national security-related missions. Under the general rubric of governance/mission impacts are several federally-mandated missions that may be disrupted. Although many of these missions are directly fulfilled by government agencies, some are fulfilled or supported by the private sector. These include the responsibility to ensure national security, ensure public health, maintain order, enable the provision of essential public services, and ensure an orderly economy.

In general, indirect and cascading impacts are difficult to understand and may be even more difficult to quantify. Some indirect and cascading impacts may be accounted for in estimates of economic losses, while others may require further

development efforts to be considered in a more comprehensive risk assessment. A full consequence assessment should take into consideration all four consequence categories; however, estimating potential indirect impacts may be beyond the capabilities commonly available (or the analytical sophistication needed) for a given risk assessment. At a minimum, consequence assessments should focus on the two most fundamental impacts: those corresponding to human consequences, and those associated with the most relevant direct economic consequences.

Consistent estimation of consequence variables constitutes a problem of paramount importance. Common definitions, scenarios, assumptions, and metrics are needed to ensure risk assessment efforts can effectively contribute to a shared understanding of the sector risk profile among sector partners. This report provides information about methodologies for estimating economic consequences that may result from severe dam incidents such as failure or disruption. The objective of this report is to assist in the development of consequence assessments that are consistent and can be systematically compared across multiple owners and different jurisdictions. The general approaches presented in this report can be applied to both safety and security scenarios. A companion DHS Dams Sector report with the same objective, *Estimating Loss of Life for Dam Failure Scenarios*, provides information on methodologies for consistently estimating loss of life due to dam safety emergencies.

2. Direct Economic Consequences

For the purpose of this reference document, direct economic consequences are defined as those costs and/or capital expenditures directly resulting from a flood event. The categories of direct consequences for this analysis are *Benefit Losses*, which are considered to be the losses of the first year benefits produced by the dam or the services the dam provides which is actually a cost of the dam failure; *Remediation Costs*, which are the costs of downstream damages and other direct expenditures to environmental restoration efforts, emergency efforts, and other costs; and *Repair/Replacement Costs*, which include the repair and/or replacement of onsite assets.

2.1 Benefit Losses

Benefit losses are considered to be one of the direct economic costs associated with a particular failure event. According to the Principles and Guidelines (P&Gs),[1] the loss of any future benefits is actually a cost resulting from the incident. This analysis takes into account only the losses or costs for the first year after the event. Although some losses could extend into subsequent years, considering only first year losses will promote consistency in results and aligns with other efforts currently underway, including the annual implementation of the Dams Sector Consequence-Based Top Screen methodology. 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 the project can no longer fulfill its intended functions due to failure or disruption, benefit losses are estimated. Under the P&Gs, this loss or reduction in benefits is considered a National Economic Development (NED) cost.

In the case of dam failure or disruption, benefit losses include several categories:

- Agricultural Irrigation Water Supply
- Municipal and Industrial (M&I) Water Supply
- Power Generation
- Recreation
- Flood Damage Reduction
- Fish and Wildlife
- Treaty Water Supply
- Indian Water Rights
- Inland Navigation

A brief description of the basis for and methods used to compute losses for the various benefit categories is presented below, with P&Gs serving as reference for these categories. In estimating benefit losses, the 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 of a dam, incidental benefits may accrue to the downstream population due to the dam's presence. Every effort is made to capture

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

these additional benefits that the dam and reservoir may provide.[2] Benefits are not limited to 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.

Prior to calculating benefit losses, it is useful to know the amount of water released during an event. This information can typically be found in inundation reports and can be used to determine water deliveries for various purposes (e.g., agriculture, M&I, etc.) and to estimate the reservoir elevations before, during, and after the event. Inundation studies are typically conducted by water management entities; however, information contained within the inundation report may be obtained from an individual or agency that operates the facility. The reprioritization of water deliveries (i.e., purposes that would first receive water deliveries considering the diminished water supply availability) is not always readily available. In some instances, the political nature of water deliveries is also be an issue. Sometimes, professional judgment is necessary to define a reasonable scenario.

2.1.1 Agricultural Irrigation Water Supply

Delivery of water for agricultural production is a major purpose of many dams and reservoirs. To estimate 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 using a three- to five-year average of recently delivered water 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:

- 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 'sunk' farm investment costs that are not recoverable, such as irrigation development costs, in the farm income calculation. In a NED analysis, expenditures made in the past are not relevant for current decision making. In the event that a farm budget net income estimation has already been calculated for a previous study, it should be used. However, to value short-term benefit losses, the gross income estimate should be used. Time and budget constraints do not often allow for this in-depth type of estimation procedure.
- An alternative approach to estimate a value for lost agricultural benefits is to use a 'shadow value' or opportunity cost for water. This value is typically 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.
- The most readily available cost- and time-saving value available is the market value of water. This is the dollar value that water is leased and/or sold at in the region based on recent market transactions. This information can typically be found in publications such as Water Strategist (http://www.waterstrategist.com).
- 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. This would also require more detailed information than is typically available.

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.

2.1.2 Municipal and Industrial 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 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 three- to five-year average of recently delivered water for M&I purposes if the annual amount of delivered M&I water varies from year to year. The average assists in capturing the trends in deliveries and serves as 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:

- In areas where there is an active wholesale water market in which project or non project 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 evaluating 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-foot is then multiplied by the annual amount of M&I water lost under the failure scenario.
- 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 to develop a groundwater well or construction of a new dam and reservoir. As with the use of market prices, it is necessary to ensure that the benefit value of the alternative is based on water of the same quality, quantity, timing of deliveries, and location as the project supply. However, constructing a new M&I water supply project can be a more lengthy and costly process than repairing/replacing the failed facility. Therefore, new construction may not be the most efficient method to pursue when estimating costs for the first year of impacts.

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 that define 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 unforeseen circumstances.

2.1.3 Power Generation

To estimate 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 three- to five-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 power generated can be estimated using different approaches:

- Power values can be difficult to predict due to volatile 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 are usually

expressed in 'mills per kilowatt hour' or 'dollars per megawatt hour (MWh).' 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 non-firm, 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 are subsequently multiplied by the amount of net generation lost as a result of the event and any subsequent generation lost during the reconstruction process.

- 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. Again, this may not be the most efficient method to pursue when estimating costs for the first year of impacts.

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 because water and power are essentially wholesaled to entities that layer on costs before the product reaches the consumer. Use of retail rates to value wholesale power would involve removing these layered costs, which can be a cumbersome process.

2.1.4 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 have significant economic value.

Several approaches can be utilized as indicated below:

- As stated 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 pay, to recreate the site. This amount is known as 'consumer surplus,' and is usually 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. In some instances, site-specific values may be available and should be used when they can be obtained. Fortunately, numerous studies have already been performed for recreation sites and activities across the United States that can be utilized to approximate benefits at reservoirs with similar activities, amenities, and characteristics (economists typically call this procedure 'benefits transfer'). The per trip or visit value is multiplied by the number of lost recreational trips or visits associated with the failure event. When recreation visits are available by type of activity (e.g., 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.
- The U.S. Army Corps of Engineers (USACE) also suggests the use of published unit day values (UDV) to estimate the 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 judgment to approximate the average willingness of users to pay. The USACE Engineer Regulation 1105-2-100 (ER 1105-2-100) Planning Guidance provides guidelines for assigning values and the process for converting them to dollars when 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 06-03, Unit

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.

Day Values for Recreation. The selected value is utilized 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 is typically available or can be determined by the managing entity. They calculate or estimate these figures using 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 three- to five-year average of recent visits 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 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 would not simply substitute another nearby reservoir or recreation site for their recreation activity. In assessing the possibility of substitution, it is important to look at congestion (carrying capacity) of alternate sites, as well as whether those other sites offer the same type and quality of activities.

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; however some State fish and game agencies do collect this information. In some instances, a focused study may have been previously conducted if the area is heavily used for river recreation purposes.

2.1.5 Flood Damage Reduction

Dams and reservoirs often provide flood damage reduction benefits, either through reservation of specific reservoir storage volume or incidentally through operation of the reservoir to meet other project purposes. These benefits are computed as downstream damages prevented 'with' versus 'without' the reservoir, and are usually relevant for floods with recurrence levels of 100 years or less. Measurement of benefits can be complicated and time consuming; however, in many cases, USACE has developed damage curves allowing staff to easily estimate historical damages prevented over a given period.[4] In these cases, 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 are not generally computed due to the level of effort required.

2.1.6 Fish and Wildlife

To estimate lost benefits of water reserved for fish and wildlife purposes, the amount of water unavailable for these purposes must be estimated as well as the value of the water. Flows from reservoirs, also referred to as low flow augmentation to meet minimum flow requirements, may be legally allocated to in-stream flows for fish and wildlife or their habitat. This is usually for compliance under the National Environmental Policy Act or Endangered Species Act. 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 by a study focused on contingent valuation or similar type of willingness to pay, the market value of replacement water is multiplied by the annual acre-feet of water lost to this purpose in order to arrive at lost fish and wildlife benefits.

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

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, it can be included under the *Fish and Wildlife* benefits category. However, it is often difficult to separate fishing because it can become intertwined with other recreation activities such as boating.

Any costs incurred to restore a damaged ecosystem, species, and/or habitat will be included under *Environmental Restoration Costs in the Remediation Costs* section (below).

2.1.7 Treaty Water Supply

To estimate 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. It is not typically known exactly where or how water is used after it crosses the United States border. Moreover, there are possible political and/or legal ramifications from not delivering treaty water.

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 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.

2.1.8 Indian Water Rights

When water has been allocated for 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.

2.1.9 Inland Navigation

Lost benefits associated with waterway disruptions may be estimated based on the increased cost of shipping due to rerouting and use of alternative shipping modes.

The long-term loss of a dam and/or associated lock can have significant impacts on the continued transport of commodities along the waterway; moreover, the choice of effective alternative waterway routes to a destination may be limited. Practical alternative transportation modes (typically rail) and routes for affected waterborne commodity shipments can be identified using Shipper Response Surveys appropriate for each waterway (e.g., Casavant et al. 2008), based on existing railheads and estimated alternative mode system surge capacity determined using a routing model such as the Transportation Routing Analysis Geographic Information System (Johnson and Michelhaugh 2006).

Total origin-to-destination costs in the Shipper Response Surveys include loading and unloading charges at origin and destination; rates for movements to or from the line-haul; modal line-haul rate; and any intermodal transfer, handling, and storage costs. The estimated total transportation costs incurred for existing system usage are compared with those that would be incurred if existing system movements were forced to use some alternative mode of transportation. A more detailed explanation of the estimation of lost benefits for inland navigation including shipping costs and alternate transportation modes are available in Appendix D.

2.2 Remediation Costs

There are four categories of remediation costs:

- Downstream property damages;
- Environmental restoration costs;
- Cost for temporary structures; and
- Emergency response costs.

Remediation costs exclude the costs of lawsuits, increased insurance costs, or higher financing/borrowing costs and liability costs associated with damage to other property or the environment, including fines imposed by regulators, as well as the costs associated with the financial write-off of a facility.

2.2.1 Downstream Property Damage Estimates

Downstream property damage estimates should reflect replacement costs for all types of property affected by an event. This includes residential, commercial, industrial, essential facilities (e.g., hospitals, fire stations, and police stations), as well as infrastructure such as roads, bridges, canals, airports, railroads, dams, and utility lines. Section 4.4.1 has additional property type descriptions for consideration when computing property damage estimates.

To begin the assessment of property damage that results from flooding, a suitable inundation map for the selected scenario is needed. This is a necessary input for a realistic estimation of downstream damages. Appendix A addresses flood inundation modeling and mapping in more detail.

Downstream property damage can be determined by various methods. The most comprehensive method for estimating downstream property damage is to utilize one of the software products that are available from Federal agencies such as the Federal Emergency Management Agency (FEMA) or USACE. Descriptions of methodologies from these two agencies along with other more simplified methods are provided in the following sections.

2.2.1.1 FEMA HAZUS-MH

Addressing the downstream damages estimation problem can be effectively done by taking advantage of software products such as Hazards US-Multi Hazard (HAZUS-MH) developed by FEMA under a contract with the National Institute of Building Sciences. HAZUS-MH is a nationally applicable standardized methodology and risk assessment software program for analyzing potential losses from floods, hurricane winds, and earthquakes.

In particular, HAZUS-MH software provides the ability to determine damages resulting from a dam failure based on flood depth and extent.[5] 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 FEMA, the Federal Insurance and Mitigation Administration, and the USACE Institute for Water Resources (IWR). Functions have been compiled for the following USACE districts: Chicago, Galveston, New Orleans, New York, Philadelphia, St. Paul, and Wilmington.

5 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."

HAZUS-MH offers the ability to perform analysis at three levels. A Level 1 analysis with the HAZUS-MH flood model is the simplest analysis, requiring minimal to no expert input. The model is implemented from the provided default inventory data. This level is used for determining possible mitigation sites to potentially reduce damage losses. It is also useful for preparing emergency response and recovery plans for various flood scenarios. Level 1 can be used to calculate rapid loss estimates following an actual event. Loss estimates will be crude and are most appropriate for regional levels. Level 1 analysis should not be used for dam failures, as the default hydraulic data is not appropriate for these scenarios.

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

Level 2 analyses 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 hydrologic/hydraulic 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 would likely include detailed building-specific information. More information from external hydraulic models (e.g., MIKE 21 or HEC-RAS) would be required. Level 3 analyses requires detailed engineering data regarding individual buildings that may not be economically feasible for large areas such as those involved in a dam failure.

Some of the inventory data that may also be inundated and damaged is not yet considered with the HAZUS-MH Flood Model; linear features such as roads and canals are also not considered by HAZUS-MH. Additionally, some transportation and energy facilities are not analyzed in the flood model. Therefore, these types of facilities must be manually considered.

The following is a summary of the methodology that may be employed for damage estimates using HAZUS-MH:

- Define the study region based on the dam failure inundation boundary. Select all of the counties and United States Census blocks that are affected by the dam failure.
- Run the HAZUS-MH 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. This requires the digital elevation for the study area, flood boundary polygon, and a set of cross sections attributed to flood elevations.
- Alternatively, if a flood depth grid is available, bypass the FIT process.
- Review HAZUS-MH default inventory data.
- Collect additional necessary data and integrate into HAZUS-MH. This step constitutes a substantial part of the effort, as mentioned in the HAZUS-MH User Manual, and in the methods section of 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 HAZUS-MH.
- Create a report of the quantities of downstream properties and infrastructure damage losses.

2.2.1.2 Damage Estimation Utilizing GIS Data

If the use of HAZUS-MH software is not practical, the inventory of infrastructure in the inundated area must first be estimated in order to determine the damages from the flood event.

It must be emphasized that reliable inundation maps are essential for identifying the portions of the downstream floodplain that are flooded by the event being assessed. Once the flood boundaries have been identified, estimating the quantity of affected infrastructure is best made utilizing a computerized Geographic Information System (GIS). The GIS-derived inventory should be extracted from a data source that contains the level of detail needed to thoroughly analyze the inundation area. Inventory categories should include homes, businesses, essential facilities (e.g., hospitals, fire stations, and police stations), airports, roads, railroads, canals, bridges, other dams, electric transmission lines, etc.

If GIS capabilities are limited or non-existent, the option of using Google Earth, Google Maps, or similar programs to determine infrastructure and measure miles of inundated linear features is available. Google Earth is a virtual globe, map, and geographic information viewer. It provides mapping capabilities by superimposing images obtained from satellite imagery, aerial photography and GIS-dimensional globe. Google Earth enables the user to hand count infrastructure within the visually estimated floodplain. This can be a huge undertaking if the inundation area is large and/or urbanized. Therefore, this method is recommended only when HAZUS-MH software capability is not available or when the inundation area is small and rural. Google Earth Pro provides the option to import an inundation polygon, thus simplifying the process of determining flooded infrastructure. However, hand-counting infrastructure is still necessary.

A brief summary of the methodology to estimate downstream inundated inventory when GIS data is available, but HAZUS-MH technology is unavailable, 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. If available, these data are imported into a GIS platform such as the Environmental Systems Research Institute, Inc. (ESRI) ArcGIS.
- GIS geo-processing functions are performed on the various data features. This produces amounts and areas of the various features involved in the flood boundary. Alternatively, this information can be hand-counted using available programs such as Google Earth.
- Any data not in a spatial database format are visually interpreted on-screen and recorded.
- A summary spreadsheet is created for the various data themes.
- The percent of damages incurred from the flood is typically not available using this methodology; all infrastructure inundated is therefore considered a total loss. The information produced is binary in nature; the features are either in or out of the flood boundary.

ESRI ArcGIS Explorer is a free downloadable GIS viewer. It can be used to access online mapping services that provide information similar to that provided by vehicle navigation devices. Custom data such as inundation polygons or local infrastructure data can be imported from a GIS software product for viewing on a streamed aerial photo background. Some GIS analysis can be conducted through the use of custom scripting. This would also require a background in GIS and/or ArcGIS to use successfully.

No software has yet been identified that is capable of a complete infrastructure count for an inundation area without the use of GIS-based software and/or GIS background.

If a successful inventory count of the inundated infrastructure has been made, cost estimates can be applied to the inventory to estimate damages. If depth-damage information is not available, it must be assumed that all infrastructure within the inundation boundary is a total loss under this estimation procedure. Lacking the ability to incorporate detailed flood characteristics, this may be a reasonable assumption considering the potential for high flood water velocities from a dam failure near the stream channel. In addition, floods of this magnitude carry large amounts of debris that compound the destructive force of flood waters. Nonetheless, this method may overstate damages; therefore, it is determined that it is not the best or most accurate method to analyze downstream property damages given the recent availability of more advanced tools. This is especially true for property and infrastructure located away from the river channel centerline and on the fringe of the inundation boundary.

The economic standard for determining property value is replacement costs. 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 can be derived using fairly inexpensive building construction cost software tools (e.g., http://myestimator.com), and infrastructure damages are generally based on unit cost data collected from local transportation and utility entities.[6] Total replacement value is estimated by multiplying the average replacement cost per structure by the number of structures within the inundation boundary or the average cost of linear features by the mileage of inundated features.

2.2.1.3 USACE HEC-FIA

The USACE Hydrologic Engineering Center's Flood Impact Analysis Model (HEC-FIA) provides capabilities to efficiently estimate various impacts and consequences for a specific flood event. HEC-FIA is a stand-alone, GIS-enabled software tool that can generate required economic and population data for a study area from readily available data sets and use that data to compute urban and agricultural flood damage, area inundated, number of structures inundated, population at risk (PAR), and loss of life. Economic impact consequence estimates are primarily determined by the temporal and spatial distribution of flooding, the initial distribution of people and property within the resulting flooded area, and the redistribution of people and property over time as a result of warnings and evacuations. All damage assessments in HEC-FIA are computed on a structure-by-structure basis using inundated area depth grids. Basic input requirements include: a digital elevation model, inundation depth grid, and structure inventory. Depth grids can be obtained from hydraulic modeling, digital elevation models can be obtained from a national elevation dataset, and a structure inventory can be derived from HAZUS.

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

2.2.1.4 Simplified Damage Estimation Procedure

Federal, State, and local government agencies as well as the private sector can obtain access to HAZUS-MH and HEC-FIA free of charge from FEMA and USACE, respectively. However, the models require a certain amount of technical knowledge to use as well as ertain hardware and software requirements. It is recognized that not all sector stakeholders may have access to the resources and/or expertise required to derive damage estimates using the methodologies described above. Therefore, there are current efforts underway to develop a simplified approach for estimating downstream damages based on PAR.[7] A simple regression analysis was plotted (Figure 1) with damages—determined using the HAZUS-MH methodology described above—as the dependent variable and the PAR as the independent variable. Damages used in the regression analysis are determined by HAZUS-MH and described in Section 4.4.1 as the sum of downstream property damages to buildings and their contents, transportation infrastructure, essential facilities and their contents, utilities, vehicles, and agriculture. The PAR used in the regression analysis is the worst-case PAR which is typically a daytime scenario.

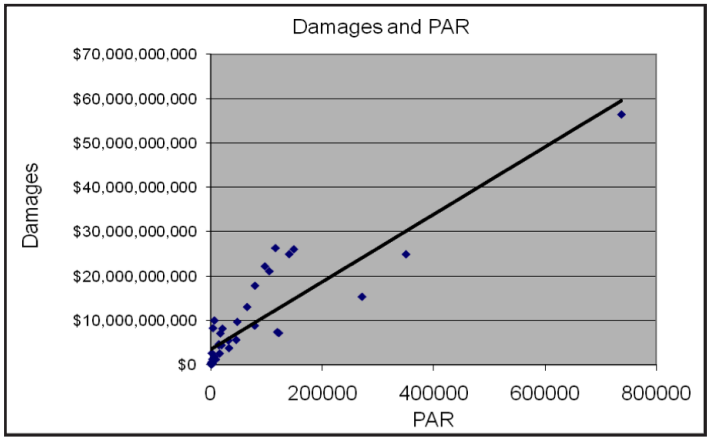

Figure 1: Damages and PAR Regression
(Source: Bureau of Reclamation)

Regression analysis evaluates the relative impact of particular variables on a particular outcome. Results support the theory that a statistically significant relationship may exist between damages and PAR. Currently, there is a statistically significant relationship using 54 data points and this model is statistically significant at better than the 1.0-percent level. While the sign of the estimated coefficient is appropriate (positive), the percent of variation explained by the model to the data (R2) is very good (0.78) given the number of observations. The Adjusted R2 is a general measure of goodness of fit, which is good (0.78) given that it is generally lower for analyses conducted with only two variables. It should be noted that regression does not necessarily imply causation. Causality must be justified from the theory and empirically tested. Currently, results suggest that if PAR increases by one, damages can be expected to increase by approximately $78,000.

This approach is expected to become more accurate as more results are generated. Although preliminary, it is expected that with continuous improvement, this type of simplified approach may be applicable for analysis of smaller facilities and also support quick portfolio screening efforts such as the Dams Sector Consequence-Based Top Screen approach.
There is currently no evidence that using this simplified methodology results in accurate damage estimates for any facility, only that there is a statistically significant relationship between downstream damages and PAR at those facilities included in the study. Currently, there are additional efforts being conducted to expand the initial data set and evaluate the proposed alternative approach. See Appendix C for PAR estimation discussion.

7 Bureau of Reclamation. "Determining a Relationship between Population at Risk and Economic Consequences," Working Draft.

2.2.2 Environmental Restoration Costs

For the purpose of this reference document, remediation costs include environmental restoration costs and any other costs associated with environmental restoration efforts which may include but are not limited to the following:

- Air, land, or water pollution testing, clean-up, treatment, and disposal costs especially those associated with toxic, hazardous, and radioactive wastes and groundwater contamination;
- Removal of vegetation, silt, sediment, etc.;
- Clearing, leveling, seeding, planting, etc.;
- Developing nesting and habitat areas;
- Developing wetlands, grasslands, wet meadows, riparian areas, etc.;
- Other efforts associated with recovery programs for listed Threatened and/or Endangered Species;
- Surveying, monitoring, and maintenance of environmental programs needed in conjunction with environmental restoration;
- Purchase of water and land associated with environmental restoration; and
- Other costs associated with the planning and implementation of environmental restoration activities.

Since environmental restoration efforts are very site-specific and the scope can be rather large depending on the area and environmental impacts, there is no standard methodology to estimate these types of costs. The types of studies used for environmental-related valuation can also be time-consuming and costly. However, several accepted valuation methods are available as guidelines to estimate these types of costs.[8]

2.2.3 Temporary Structures Costs

The cost for temporary structures includes capital expenditures for temporary constructed facilities, rented/leased facilities, temporary infrastructure such as roads and bridges, and/or other temporary structure costs.

Since these types of costs can be very site-specific, there is currently no standard methodology to estimate them.

2.2.4 Emergency Response Costs

Emergency response costs include activities such as search and rescue as well as additional safety/security measures provided for public protection and/or protection of critical facilities.

Since these types of costs can be very site-specific, there is currently no standard methodology to estimate them.

8 See Platt, Jon and Steven Piper. 2010 draft. Measuring the Economic Value of Fish and Ecosystem Resources Using Habitat Based Approaches. Draft Technical Memorandum. U. S. Department of Interior, Bureau of Reclamation, Technical Service Center, Economics and Resource Management Group and Harpman, D. 2008. Introduction to Conjoint Analysis for Valuing Ecosystem Amenities. Technical Memorandum # EC-2008-08. U. S. Department of Interior, Bureau of Reclamation, Technical Service Center, Economics and Resource Management Group and King, D. and M. Mazzotta. Ecosystem Valuation website (located at: www.ecosystemvaluation.org). University of Maryland and University of Rhode Island respectively. Site funded by: USDA Natural Resources Conservation Service and National Oceanographic and Atmospheric Administration.

2.3 Repair/Replacement Costs

For consistency, dam replacement costs are typically determined based on their original construction costs. These costs are subsequently 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 (e.g., the spillway gates, penstock, or power plant). In these instances, it may be appropriate to estimate appraisal level costs for repair or replacement of these facility features. This estimation may be provided by a construction/engineering individual or organization familiar with dam design and construction.

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 should also 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 older facilities and estimate costs associated with the new design. Although this would increase the budget and schedule by approximately $20,000 to $40,000 and 2 – 6 months for a pre-appraisal level estimate, it would yield a more accurate estimate of the replacement costs of the facilities.

3. Indirect Economic Consequences

For the purpose of this reference document, indirect economic consequences refer to the county-level changes in business output as measured in dollars and changes in employment from a failure scenario. These types of secondary or indirect impacts may represent a large portion of the economic consequences from a dam failure or similar scenario. Due to the complexity of the problem, specific models may need to be considered to address indirect impacts associated with a dam failure or disruption event.

Several methods were considered that could be used to estimate indirect economic consequences. The methods were economic base analysis, income-expenditure analysis, input-output analysis, and computable general equilibrium (CGE) analysis. Two types of analyses, economic base and income-expenditure, were excluded due to the nature and complexity of the data to be analyzed; these two methods were not appropriate due to their simplistic approaches and inherent applicability to smaller, less complex regions. Therefore, it was concluded that either an input-output analysis or a CGE analysis was appropriate to conduct the secondary impact analysis for indirect impacts from a dam failure scenario. A brief description for the input-output analysis and a more extensive description for the CGE analysis are provided below.

3.1 Input-Output Analysis[9]

Input-output models are fixed priced models; that is, prices are assumed to be constant, and no price effects will occur with changes in final demand. Input-output accounting describes commodity flows from producers to intermediate and final consumers. The total industry purchases of commodities, services, employment compensation, value added, and imports are equal to the value of the commodities produced. Purchases for final use (final demand) drive the model. Industries produce goods and services for final demand and purchase goods and services from other producers. These other producers, in turn, purchase goods and services. This buying of goods and services (indirect purchases) continues until leakages from the region (imports and value added) stop the cycle.

A major potential problem with an input-output based analysis is the assumption of fixed production coefficients combined with the assumption of no price effects on the mix of inputs used. The assumption of linear relationships is problematic when changes in final demand are large enough that the production relationships are no longer linear but are exhibiting increasing or decreasing returns to scale. If an indirect impact analysis is completed for a large region that produces many goods and services, large exogenous changes in final demand for goods and services produced in the region could potentially affect prices and change the mix of production inputs (Piper, 2000). Applicability to an event at a major facility would be minimal in this case. However, for changes in final demand that are relatively small, the input requirements may increase more or less in direct proportion to the increase in output. In addition, there is evidence that the average cost of producing some goods is independent of the scale of output in some cases.

An error that is frequently made when using input-output based techniques is the multiplication of a sales multiplier by the total spending on an activity to get total sales effects. This generates an inflated estimate of regional impacts as total spending is not the same as the direct effects appearing in the multiplier formula. To properly apply total spending to an input-output model, various margins must be deducted from the purchaser price to factor out returns to the producer. In an input-output model, retail margins accrue to the retail trade sector, wholesale margins to wholesale trade, and transportation margins to

9 U.S. Bureau of Reclamation. Estimating Secondary Impacts at Reclamation Facilities: A Review and Comparison of the Methodologies. Security, Safety, and Law Enforcement Office R&D Paper. October 2005.

the transportation sector and producer prices are assigned to the sector that produces the good. In cases where the producer lies outside the local region, an immediate leakage is created in the first round of spending because the producer portion of the final cost is not a local impact.

3.2 Computable General Equilibrium Analysis

CGE models are useful because they depict the economy as a system of interrelated sectors, allowing a theoretically correct analysis of effects that account for price changes. CGE models can incorporate a large amount of detail through the use of available national accounting data. Their advantage over input-output models, which rely on fixed coefficients, is the inclusion of market responses to changes in economic variables. These responses may be fairly general, such as elasticity estimates from previous studies, but they are important in understanding the response to exogenous impacts.[10]

General equilibrium modeling is a comparative static exercise that 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 and from a simple 'adding-up' approach.[11] 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 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[12] confirms the idea that local residents, business owners, and 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 that produces a dataset called 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. The Economic Consequences Assessment Model (ECAM) was developed based on the CGE method. 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.

10 Ibid.

11 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.

12 See Murlidharan and Shah (2003) or van der Veen, et al. (2003).

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

- Capital reduction due to flooding;
- Labor 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 may be applied to each county. The inputs are the percent reductions for these five resources in five-percent increments. The model determines price and quantity changes in each market as a result of the external event, and subsequently estimates the overall change to annual production and employment for the study area. Primary outputs consist of dollar reductions to regional production and number of jobs lost in the local area.

The costs to rebuild infrastructure could be considered to have a positive impact on the study area, but are not considered in this analysis. Instead, it is assumed that reconstruction would not take place in the first year after the event.

3.2.1 Estimating Reductions

The 'event' or 'scenario' is typically characterized by a physical change taking place in the study area. Since 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 ECAM. These changes (capital, labor, water, tourism) define the scenario for ECAM and are described below. Additional ECAM and user information can be found in the "*Economic Consequence Assessment Model (ECAM) Technical Documentation*" manual.

3.2.1.1 Capital Reduction

Capital reduction is determined by first estimating the loss of physical infrastructure, as described in the previous section (Downstream Property Damage Estimates, section 2.2.1) and subsequently 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. First, the total number of businesses or non-residential buildings within a county should be estimated. This can be accomplished using HAZUS, which contains a database that has the total number of buildings within a county, or a publication such as Dun and Bradstreet that publish a database containing the total number of businesses and buildings contained within a county. Then the number of businesses or non-residential buildings inundated by the flood should be estimated. This may be accomplished using HAZUS, a similar GIS-based database, or by hand-counting. Dividing the number of inundated businesses or non-residential buildings by the total number of businesses or non-residential buildings can be used as the percent reduction in capital to be input into ECAM. Caution should be exercised to make sure that the user is dividing inundated non-residential buildings by total non-residential buildings, or inundated businesses by total businesses, and not mixing non-residential buildings and businesses. This methodology assumes that capital is represented by non-residential buildings or businesses.

3.2.1.2 Labor Reduction

This is accomplished by estimating the loss of residential infrastructure divided by total residential infrastructure within the county. For example, U.S. Census Housing unit counts (also available within the HAZUS database) contain the total number

of single family dwellings and manufactured housing within a county. After determining the total residences within the county, the user should estimate the number of inundated residential buildings within the flood boundary by using HAZUS, a similar GIS-based database, or by hand-counting. The percent of inundated residences to total residences represents the reduction in labor. This methodology assumes that labor is represented by residences.

3.2.1.3 Irrigation Water Reduction

Counties that will experience reductions in irrigation water should be identified and the percent reduction in the water supply estimated. This is accomplished by determining the amount of irrigation water that is undeliverable to a county due to the failure event and then dividing that number by the total amount of irrigation water used in that county, which can be found at http://water.usgs.gov/watuse/data/2005. This yields the percent reduction in irrigation water supply to the county to be entered into ECAM.

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, that must also be taken into consideration.

3.2.1.4 Municipal and Industrial 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 dividing that number by the total amount of M&I water used in that county, which can be found at http://water.usgs.gov/watuse/data/2005. This yields the percent reduction in M&I water supply to the county to be entered into ECAM.

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 must also be taken into consideration.

3.2.1.5 Tourism Reduction

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

First determine the impacted tourism sites within the county, including but not limited to reservoir recreation, casinos, wineries, golf courses, etc. Next determine the amount of tourism visitation or travel spending lost due to the flood. Then determine the amount of total tourism visitation or travel spending within the county.[13] The percent of tourism reduction is the amount of tourism visitation or travel spending lost divided by the total visitation or travel spending within the county.

13 http://www.deanrunyan.com/index.php?fuseaction=Main.Travelstats&section=ImpactStudies

For example, if the annual lost expenditures to tourism are $2 million, and the total travel spending in the county[14] is $20 million, a 10 percent reduction in tourism would be entered into ECAM. Similarly, if 200,000 visitors are lost due to an

inundated landmark or tourism site where the county typically experiences 1 million tourists each year, a 20 percent reduction in tourism would be entered into ECAM.

Note that while some locations may have historic visitation or tourism revenue data, others may require professional judgment to determine the amount of visitation or tourism dollars spent. Potential sources of information may include county travel and tourism, parks and recreation, U.S. Forest Service, National Park Service, and local universities.

3.2.2 Economic Indicators

The primary economic indicator is overall production. Production is the easiest indicator to understand (similar to gross domestic product [GDP]), and has a clear, measurable benchmark: initial output before the event. Other available indicators include change in employment, farming, and 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 are directly within 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 impacts are imposed onto each county simultaneously, and the losses for each county are subsequently added together in order to derive indirect economic impacts. Note, the dollar year for indirect impacts is the same year as the data in ECAM, therefore, the output may need to be indexed using the Consumer Price Index, GDP, Implicit Price Deflator, or another appropriate index. Also, it is technically inaccurate to index employment numbers using this same method.

14 Some recent travel spending data can be found at:
http://www.deanrunyan.com/index.php?fuseaction=Main.Travelstats&section=ImpactStudies

4. Application Example

An economic analysis was conducted to assess the direct and indirect impacts that would occur with the sudden failure of a notional facility, Blue Dam. For this analysis, economic assessments were made based on the information obtained by flood inundation studies, GIS data incorporating HAZUS-MH software, and a 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.

4.1 Summary Results

The summary table below displays the results of the analysis for a sudden failure of Blue Dam. Total economic consequences from the failure are estimated to be over $4.3 billion. The following sections of the report describe the estimation methods utilized and provide a more detailed breakdown of the dollar estimates.

4.2 Dam Characteristics

Lake Orange and Blue Dam are features of the Skyline Project and are located on the Laminar River about 15.5 miles northeast of the notional city Keystone. The reservoir provides storage for irrigation, municipal and industrial, recreation, power generation, in-stream flows for fish and wildlife, and flood control.

Table 1 - *Summary Table* (2008 million $)

Lost Project Benefits (year 1)	$229.6
Remediation Costs	$590.0
Dam Repair/Replacement Costs	$167.9
Direct Economic Impacts[15]	$987.5
Indirect Impacts	$3,376.0
Total Economic Consequences	**$4,363.5**

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 (ft3/s or cfs), over three times the downstream safe channel capacity.

For this study, the assumption is made that Blue Dam fails quickly during normal operations while the reservoir is full. Under this scenario, the peak outflow from the failure of Blue Dam would be nearly 3.1 million cfs.[16] Blue Dam's sunny day (non-flood scenario) failure analysis from the year 2000, for which flood inundation exists, is used in this analysis to determine economic consequences.

4.3 Lost Project Benefits

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 (e.g., acre-feet, visitor days, and MWhs) where applicable. All present values are rounded to the nearest $1,000. Complete loss of the dam would result in the loss of associated benefits until repair and/or replacement is made; a partial loss may greatly reduce but not completely eliminate all benefits.

15 Direct economic consequences are defined in this context as damages, lost project benefits and dam repair/replacement costs. Indirect economic consequences 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.

16 Bureau of Reclamation. Dam Failure Inundation Study, Blue Dam.

4.3.1 M&I Water Supply

In this context, the term water supply refers to the deliveries to water users for M&I and agricultural purposes that would be lost with reduced capacity to supply their water. The average annual M&I water lost is approximately 200,000 acre-feet which are the M&I deliveries from Lake Orange.

Table 2 - *Lost M&I Deliveries and Value*

Annual Lost M&I Water Deliveries (acre-feet)	Annual replacement value of M&I water	Annual Value of Lost M&I Water Deliveries
200,000	$250/acre-feet	$50,000,000

The average annual value for water used in estimating the loss of M&I water from Blue Dam is approximately $250/acre-feet. This is an average 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 Blue Dam. Although a water loss of this magnitude could increase the price of water, the approximate or exact increased cost cannot be speculated. As illustrated in Table 2, annual lost benefits from lost M&I deliveries are approximately $50 million from the dam failure.

4.3.2 Irrigation Water Supply

Blue Dam helps stabilize the agricultural and industrial economy of Keystone. 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.

Table 3 - *Agricultural Losses and Value*

Annual Lost Agricultural Deliveries (acre-feet)	Annual Replacement Value of Agricultural Water	Annual Value of Lost Agricultural Deliveries
100,000	$250/acre-feet	$25,000,000

The three-year average annual lost irrigation water would be 100,000 acre-feet. The value of this water is estimated by using a recent transaction of agricultural water or the market value of agricultural water which is $250 per acre-feet for this region. As illustrated in Table 3, the lost benefits have a first-year value of $25 million.

4.3.3 Recreation

Table 4 - *Recreation Visitation*

Year	Orange Reservoir Visitation
2006	500,000
2005	550,000
2004	525,000
2003	600,000
2002	475,000
5-year rounded average	**530,000**

Lake Orange is the second largest body of water near Keystone and offers 50 miles of shoreline. Recreation facilities at Lake Orange are managed by the U.S. Forest Service. Developments include 270 campsites and four 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, State Parks collects and reports annual visitation (see Table 4 for figures). Average annual visitation to Lake Orange is about 530,000.

To estimate annual recreation benefits, the five-year rounded average visitation at Lake Orange was multiplied by the average value of a recreation visit to a Pacific Coast reservoir. Values, derived from past research for States on the Pacific Coast for the most common recreational activities available at Lake Orange, were averaged to obtain the expected value per visit for recreation use at impacted recreation sites which is $50 (in 2008 dollar value). The first-year lost benefits are calculated to be $26.5 million, as illustrated in Table 5.

Table 5 - *Lost Recreation Visits and Value*

Annual Lost Visits	Value of a Recreation Visit	Annual Value of Lost Recreation Visits
530,000	$50/visit	$26,500,000

4.3.4 Hydropower Generation

Table 6 displays net generation figures at Freedom Power Plant for five recent years. The annual net generation figures are used to estimate the lost benefits of hydroelectricity.

Table 6 - *Electricity Generation (kilowatt hour)*

Year	Freedom 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 California-Oregon Border Region were used to derive an estimated average price of electricity.[17] The average firm peak price for electricity is approximately $62.65/MWh. The first-year value of benefits is approximately $33.1 million (Table 7).

Table 7 - *Lost Generation and Value*

Annual Lost Generation (MWh)	Average Value of Hydropower	Annual Value of Lost Generation
528,431	$62.65/MWh	$33,106,000

4.3.5 Fish and Wildlife

Flows of 300,000 acre-feet are annually allocated to fish and wildlife on the Orange Reservoir. The water is stored until needed to provide adequate flows for fish and wildlife. The regional value of agricultural water and M&I water ($250/acre-feet) is also used for the value of this water provided for environmental purposes. As shown in Table 8, the annual value is $75 million.

Table 8 - *Lost Fish and Wildlife Benefits*

Annual Lost F&W Water (acre-feet)	Replacement Value of Water	Annual Value of Lost Benefits
300,000	$250/acre-feet	$75,000,000

4.3.6 Flood Control

Blue Dam and Lake Orange have been used for flood control regulation when the owner of Red Dam upstream is releasing large quantities of water to vacate the flood control pool behind the dam. The accrued benefits (1950-2007) realized from the flood control operation at Blue Dam is $1 billion. On an annual basis, this equates to approximately $20 million.

Table 9 - *Lost Flood Control Benefits*

Annual Lost Flood Control Capacity (acre-feet)	Annual Value of Flood Control Benefits
200,000	$20,000,000

17 Dow Jones Electricity Price Indices purchased from LCG Consulting, 2007.

4.3.7 Benefit Loss Summary

As displayed in Table 10, the benefits lost due to a Blue Dam failure are nearly $230 million for the first year.

Table 10 - *Analysis of Lost Project Benefits*

	Annual Benefits (million $)
M&I Water Supply	**$50.0**
Irrigation Water Supply	**$25.0**
Recreation	**$26.5**
Power	**$33.1**
Fish and Wildlife	**$75.0**
Flood Control	**$20.0**
Total	**$229.6**

4.4 Remediation Costs

Remediation costs include environmental restoration, downstream property damages, cost for temporary structures, and emergency response costs. The total for these remediation costs is $590 million as summarized in Table 11 and explained in more detail in the proceeding sections.

Table 11 - *Remediation Cost Summary* (million $)

Downstream Property Damages	$577.0
Environmental Restoration	$4.5
Cost for Temporary Structures	$6.2
Emergency Response Costs	$2.3
Total	**$590.0**

4.4.1 Downstream Property Damages

To begin the assessment of property damages resulting from flooding, an inundation boundary for the scenario must be obtained. An inundation boundary from the year 2000 already existed for the selected analysis scenario.

Inundation boundaries can be obtained from inundation reports developed utilizing GIS technologies. The corresponding data contains details for the inundation area being analyzed and can be incorporated into the HAZUS-MH software to estimate potential damages. For this example, potential damages are provided by an existing Flood Report that was developed using HAZUS-MH. When HAZUS-MH flood information is not available, alternative methods for estimating potential damages are provided in Section 2.2.1.

4.4.1.1 Building-Related Losses

The direct building losses are the estimated costs to repair or replace the building and its contents damaged by the flood. Information on the number of commercial businesses in addition to residential and industrial buildings, including building contents potentially flooded, is provided in the Flood Report. Damages to these types of buildings and their contents are estimated at approximately $120 million, of which $60 million is residential losses.

4.4.1.2 Transportation

The Flood Report identifies direct losses for highway bridges only; highway segments, railways, light rail, bus facilities, ports, ferries and airports are not accounted for in the HAZUS-MH flood model. Therefore, the depth-damage function is manually entered for these items based on flood depth if these types of infrastructure are located within the flood boundary. Transportation losses are estimated to be $175 million.

4.4.1.3 Essential Facilities

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

4.4.1.4 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 are not accounted for in the HAZUS-MH flood model. Therefore, the depth-damage function is manually entered based on flood depth if these types of infrastructure are located within the floodplain. Other infrastructure that is manually entered include: mileage of canals, electric transmission lines, fiber optic lines, and microwave towers in the flooded area. The direct losses for utilities and other infrastructure are estimated to be approximately $250 million.

4.4.1.5 Vehicles

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

4.4.1.6 Agriculture

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 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.

4.4.1.7 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 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 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**

4.4.2 Environmental Restoration

Downstream of the dam, there is designated habitat for the endangered Santa Cruz Island bush-mallow. The destruction of this habitat would wipe out the species and is estimated to cost $4.5 million to restore the habitat areas and rejuvenate the species to current levels from the figures provided by T&E Species Consultants, Inc.

4.4.3 Temporary Structures Costs

Temporary infrastructure included converting three school gymnasiums into shelters and fairgrounds into an animal shelter, using construction equipment to clear and construct two temporary roads and two temporary bridges, and the rental of 50 trailers to house victims and volunteers. Temporary facilities for the security personnel are needed as well. The cost for these temporary structures is estimated to be $6.2 million.

4.4.4 Emergency Response Costs

Additional costs for security at the dam and reservoir while repairs are being made are necessary due to access issues to non-public facilities caused by the event. An eight week search and rescue effort was also conducted. These costs are estimated to be $2.3 million.

4.5 Repair/Replacement Costs

Blue 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.

4.6 Indirect Impacts

For each impact analysis, a 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 in order 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 are directly in the inundation path face significant losses to economic activity. A portion of the losses arise because the infrastructure, physical machinery, and labor resources used in the production process are no longer available and a portion of the losses come from water supply shortages. Again, each county is considered individually, and each county can experience multiple events. The events are imposed on each county simultaneously in five-percent increments, then the losses for each county are added together in order 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 in order to minimize the economic hardship brought about by the disaster. A review of similar catastrophic events[18] 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 Blue Dam.

The counties of Gray, Yellow, and Green (Figure 2) have been selected as the impact region. These counties are located in the floodplain below the dam, and encompass the surrounding farmland that depends upon dam-supplied irrigation water, and the urban regions that depend upon drinking water which may be disrupted by the uncontrolled release.

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.

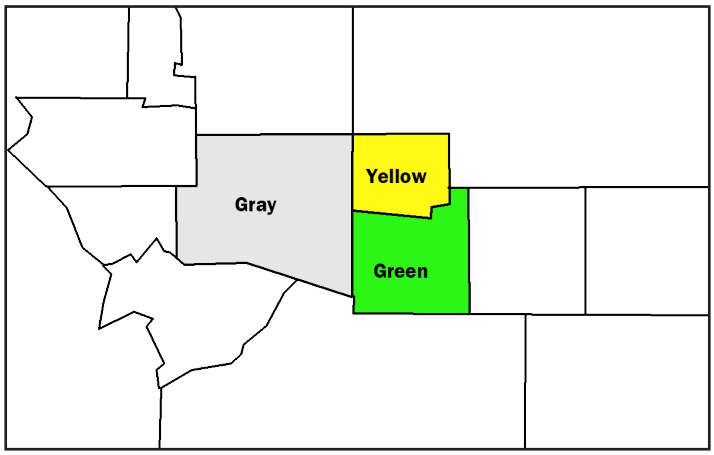

Figure 2. Impact Area County Map

18 See Murlidharan and Shah (2003) or van der Veen, et al. (2003).

4.6.1 Capital Reduction

Only Gray County would endure any significant physical damage directly related to the flood event. Approximately 19 percent of businesses would be inundated in Gray County. In the economic model, this event is characterized as a loss of productive capital as a result of the flood. This loss of productive inputs limits production possibilities in the counties, which lowers output and incomes.

Table 13 - *County Reductions*

	Gray	Yellow	Green
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%

The expected downstream damages in the region as a result of the flood are about $577 million and occur mainly in Gray County. This figure must be converted into a percentage change in available capital. The number of inundated businesses as a percentage of total businesses is used as the estimate for the reduction in capital for Gray County. Since the model runs reductions in five percent increments, the percent reduction in capital is 25 percent in Gray County.

4.6.2 Labor Reduction

Approximately 10 percent of residences would be inundated in Gray County. 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 away. The number of inundated homes as a percentage of total residences is used as the estimate for the reduction in labor supply for Gray County. Since the model runs reductions in five percent increments, the percent reduction in labor is 25 percent in Gray County.

4.6.3 M&I Water Supply Reduction

Blue Dam's failure would halt approximately 200,000 acre-feet of M&I deliveries. The counties that would be impacted the most are Gray and Yellow counties.

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 Orange 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 Orange would not be available to Gray and Yellow counties. M&I water delivery would be reduced by approximately 15 percent in these two counties.

4.6.4 Irrigation Water Supply Reduction

A Blue Dam failure would also result in a loss of approximately 100,000 acre-feet of agricultural deliveries from Lake Orange. 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

Table 14 - *Estimated M&I Water Reductions*

	Total County Water Withdraws[1] (acre-feet)	Proportional Loss from Lake Orange (acre-feet)	Percent Reduction
Gray	850,000	130,800	15.0%
Yellow	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.

the percent of water supply delivered from Lake Orange 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 Orange would not be available to Gray, Yellow, and Green counties. Irrigation water deliveries would be reduced by approximately 10 percent in all three counties.

4.6.5 Tourist Visit Reduction

The reduction in tourism was estimated using the percent of travel spending 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 recreational users may avoid the area if they believe it 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, to alter plans.

Table 15 - *Estimated Agricultural Water Reductions*

	Total County Irrigation Water Withdraws[1] (acre-feet)	Proportional Loss from Lake Orange (acre-feet)	Percent Reduction
Gray	400,000	40,000	10.0 %
Yellow	300,000	30,000	10.0 %
Green	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.

Approximately 45 percent ($55.8 million) of direct impacts from recreation occur in Gray County. Gray County's travel spending in 2006 was estimated to be approximately $174 million.[19] The impacts result in a reduction of approximately 32 percent of tourism spending. Approximately 55 percent ($68.2 million) of the direct impacts from recreation occur in Yellow County. Yellow 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 Yellow 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 Yellow County. Green County would not likely see an impact to tourism.

4.6.6 Multiple Scenarios Imposed on 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 impacts simultaneously. In order 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.

4.6.7 Economic Indicators: Base Year Production

The primary economic indicator is overall production. Production is the easiest indicator to understand (similar to GDP), and has a clear, measurable benchmark: initial output before the event. The Minnesota IMPLAN Group, a for-profit data compilation company, combines economic data from a large array of government publications in order to produce county-level economic datasets. These datasets are useful because they are balanced, highly disaggregated (440 sectors), and include most of the economic information needed to build a computable general equilibrium model.

19 Dean Runyan Associates. Travel Impacts 1996-2006. http://www.deanrunyan.com.

4.6.8 Indirect Impact Results

Table 16 presents the summary findings for each county's indirect economic losses.[20] 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 more than 48,000 jobs (13.6 percent), which is significant for the impact area. The percentage change helps highlight that those counties heavily reliant on water, and those counties directly in the flood path, stand to lose the most (e.g., in the first year after the event, 18 percent of all economic activity and more than 33 percent of employment in Gray County alone). 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 by County*

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

20 Note that the ECAM data year is 2007, so the indirect impacts on output were indexed to 2008.

Acronym List

CAMSYS	Cambridge Systematics, Inc.
cfs	cubic feet per second
CGE	Computable General Equilibrium
DHI	Danish Hydraulic Institute
DHS	U.S. Department of Homeland Security
ECAM	Economic Consequences Assessment Model
EGM	Economic Guidance Memorandum
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
FIT	Flood Information Tool
GDP	Gross Domestic Product
GIS	Geographic Information System
HAZUS	Hazard-United States
HAZUS-MH	Hazard-United States-Multi-Hazard
HEC-FIA	Hydrologic Engineering Center – Flood Impact Analysis
HSPD	Homeland Security Presidential Directive
IMPLAN	Impact Analysis for Planning
IWR	Institute for Water Resources
LOS	Level of Service
M&I	Municipal and Industrial
MWh	Megawatt hour
NED	National Economic Development
NDC	Navigation Data Center
NIPP	National Infrastructure Protection Plan
NWS	National Weather Service
OMB	Office of Management and Budget
P&Gs	Principles and Guidelines
PAR	Population at Risk
TRAGIS	Transportation Routing Analysis Geographic Information Systems
TVA	Tennessee Valley Authority
UDV	unit day values
USACE	U.S. Army Corps of Engineers
VSL	Value of a Statistical Life
WCSC	The Waterborne Commerce Statistic Center
WTP	willingness to pay

Definitions of Economic Terms

Benefits: National Economic Development benefits (see Benefits Transfer below) 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. For the purpose of this document, benefits (also referred to as "project benefits") are defined as the beneficial purposes which a dam and its water supply provide. 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: A benefits transfer is an approach used to estimate values by transferring available information from studies and/or economic analyses already completed at other sites with contexts similar in nature and character to the study at hand. The transfer can be done as a unit value transfer or a function transfer.

Computable General Equilibrium (CGE): A CGE model is a system of non linear equations that represent production functions and demand functions. Businesses have demand functions for factor inputs, while households have demand functions for final goods and services. In a typical CGE exercise, the optimal mix of production and consumption is identified using the base-year dataset. The model is then used to determine a new "equilibrium," where demand and supply are re-balanced after an exogenous shock caused by some event, or government policy action. While in equilibrium, all markets clear (supply equals demand). When an imbalance is introduced, such as a reduction in water supplies, market prices will adjust until supply and demand are returned to a balanced (but new) position. This model type 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 a change in capital, labor, or natural resource levels. 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: Direct economic consequences are defined for the purpose of this reference document as the costs of lost project benefits, downstream property damages, and repair/replacement costs.

Direct Economic Effects: In a multiplier type of analysis, 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 defined in this document, economic consequences are the direct and indirect economic impacts associated with a dam failure or disruption event.

HAZUS: Hazard-United States. FEMA's Mitigation Division (MT) began developing HAZUS modules in mid-1900 as the advent of GIS made such a loss estimation model possible.

HAZUS-MH: Hazard-United States-Multi-Hazard is a nationally applicable standardized methodology and software program that will contain models for estimating potential losses from earthquakes, floods, and hurricanes that was developed under contract with the National Institute of Building Sciences for FEMA.

Indirect Economic Consequences: For the purpose of this reference document, indirect economic consequences, also

called 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 Economic Effects: Indirect economic effects are the secondary economic effects on regional and local economies that occur as a result of the direct impacts.

National Economic Development (NED): National economic development is the national stance by which costs and benefits to all affected parties 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.

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Appendix A: Dam Related Flood Inundation Modeling

The information presented in this section is intended to be a general guideline for the preparation of dam-related flood inundation studies and inundation mapping. Specific expertise in the areas of dam safety, hydraulic engineering, and GIS are required in order to conduct the type of analysis described in this appendix.

Scenario Selection

Flood inundation modeling is required by multiple disciplines such as dam safety, dam security, and emergency management. There are several scenarios that may need to be considered, depending on the field of application and assumptions about reservoir pool elevations, inflows, and other relevant conditions. When selecting a specific dam failure or flood release scenario, it is important to consider a scenario that is appropriate to the application for which the study results are to be used.

Dam Breach Analysis

Hydraulic analysis methods that are commonly used for dam breach analysis include the National Weather Service (NWS) DAMBRK formulation (NWS DAMBRK Model, 1988) and FLDWAV formulation (NWS FLDWAV Model, 1998), and the USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) model that utilizes the UNET unsteady flow formulation (HEC, 2010). The NWS formulations are available in the Danish Hydraulic Institute (DHI) MIKE11 model that is currently used by Reclamation for dam breach modeling applications (http://www.dhi.us). A Reclamation paper titled "Comparison Between the Methods used in MIKE11 2003, FLDWAV 1.0, and HEC-RAS 3.1.1 to Compute Flows Through a Dam Breach" (Comparison Between the Methods used in MIKE11 2003, FLDWAV 1.0, and HEC-RAS 3.1.1, 2004) compares dam breach formations for several commonly used hydraulic models. Information regarding current NWS modeling efforts can be obtained from the NWS Hydrologic Science and Modeling Branch website: http://www.nws.noaa.gov/oh/hrl/hsmb/hydraulics/FLDWAV2HEC-RAS.html.

Breach parameters are often based on empirical relationships developed from dam failure case histories. The Reclamation publication: "Prediction of Embankment Dam Breach Parameters," DSO-98-004, contains a comprehensive listing of commonly used empirical relationships for predicting dam breach parameters. This publication can be downloaded at: http://www.usbr.gov/pmts/hydraulics_lab/pubs/DSO/DSO-98-004.pdf

Significant and high hazard dams have often been studied and monitored extensively. This specific knowledge and information regarding a dam can be used to estimate hypothetical breach parameters in lieu of using the more generalized empirical equations.

Modeling Downstream Effects

Hydraulic models developed by DHI for dam related flood inundation analysis may be used for modeling the downstream effects of a dam breach. The DHI models used for this application include:

- MIKE11—a one dimensional (1D) model that allows for modeling of various types of hydraulic structures including multiple dam operations and multiple dam breach, weirs, tabulated structures, culverts, and bridges. MIKE11 readily interfaces with ArcGIS for pre- and –post processing, by using the M11i interface.
- MIKE21—a two dimensional (2D) finite difference model which enables the simulation of flood modeling on relatively flat terrain and in situations where split flow and the effects of lateral spreading are significant. The structured mesh format of MIKE21 bathymetry and output files allow for easy import/export between the MIKE21 model and ArcGIS.
- MIKEFlood—enables coupling of MIKE11 and MIKE21 models. The MIKEFlood Couple can be used to dynamically link MIKE11 with MIKE21. Coupling of 1D and 2D models is often advantageous in models comprised of relatively long 1D reaches with localized areas that may require 2D simulation. Lateral linking is possible with MIKEFlood, and would allow for in channel 1D modeling with 2D modeling for flood flows occurring outside of the normal flow channel. MIKEFlood also allows the user to employ hydraulic structure routines from MIKE11 into a MIKE21 model.

Additional information about the DHI models is available from the Danish Hydraulic Institute at http://www.dhi.us.

The USACE HEC-RAS is a software tool that performs one-dimensional steady and unsteady flow river hydraulics calculations, sediment transport-mobile bed modeling, and water temperature analysis (Hydraulic Engineering Center [HEC], 2002). The software can be used to perform dam failure analysis for dams where a one-dimensional analysis is appropriate. (Two-dimensional hydraulic modeling approaches are applied when floodplain characteristics downstream of the dam in question require them.) This program is currently used and supported by USACE and is publicly available from HEC (www.hec.usace.army.mil).

FEMA provides a list of approved 1D and 2D hydraulic models that are considered to be acceptable for riverine applications (http://www.fema.gov/plan/prevent/fhm/en_hydra.shtm).

Typical Steps Taken to Perform Inundation Studies

Basic 1D Analysis with Dam Breach

1. Determine scenarios to be studied, including an evaluation of the required downstream study extent.
2. Collect structural information about the dam and reservoir.
3. Investigate available terrain data, and make a determination of whether the available data can be used to produce reasonable results. If the available data is judged to be less than adequate, explore options for obtaining more suitable quality terrain data.
4. Using the digital terrain data, perform 1D model preprocessing: digitize river centerline, extract model cross sections, export data to the numeric 1D model.
5. Develop breach parameters based on information known about the dam and empirical formulations.
6. Develop reservoir storage data and other input parameters such as reservoir inflow hydrology, downstream channel roughness coefficients, appropriate model simulation time step and downstream boundary condition assumptions for input to the 1D model.

7. Run 1D model and evaluate results. Debug, modify and rerun, if necessary.
8. Check mass balance of reservoir outflow against sum of reservoir inflow plus volume of reservoir storages released by breach.
9. Post-process 1D model output data. Prepare an interpolated maximum flood inundation boundary in digital format.
10. Prepare tabular data for mapping and for the study report. Select cross sections at areas of interest for use as mapping cross sections.
11. Prepare study report and map notes.
12. Create inundation maps.
13. Complete quality control—checking and peer review.

Basic 2D Analysis with Dam Breach

1. Follow steps 1 through 8 of the "Basic 1D Analysis with Dam Breach." A breach outflow hydrograph will be developed using the 1D model, and this hydrograph will be used as an inflow boundary condition in the 2D simulation. The 1D breach model needs only a few downstream cross sections since the modeling of the flood inundation will be simulated by the 2D model.
2. Prepare and export the terrain data to the 2D model.
3. Set up 2D model. Prepare inflow and outflow boundary conditions, output file configuration. Select appropriate input parameters such as simulation time step and roughness coefficients.
4. Run model. Debug if necessary.
5. Check mass balance during run if possible or after completion of the simulation.
6. Post-process output data to prepare a maximum inundation boundary in digital format.
7. Prepare leading edge flood wave output information. This can be in the form of polylines digitized at the front of the inundation boundary for various snapshots in time, or this information can be portrayed by depicting the complete inundation in a separate map frame for each time interval.
8. Extract discharge information, including maximum discharge and time to maximum discharge for selected locations within the flooded areas. This information should also be included on the inundation map.
9. Prepare study report and map notes.
10. Create inundation maps.
11. Checking and peer review.

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Appendix B: Population at Risk Estimation

The PAR can be estimated using United States Census 2000 block data and current one meter resolution aerial photography available from the US Department of Agriculture (http://datagateway.nrcs.usda.gov). Most of this data is dated between 2005 and 2009. To get the data, access the home page, click 'Get Data' button and follow directions to obtain aerial photography of interest.

PAR can be determined using one of two techniques, or a combination thereof, depending upon the geographical area.

In areas where population growth has been minimal as determined from current aerial photography, census block population data is used to determine population within the inundation boundary. For census blocks that are completely inundated, the populations for those blocks are summed. For the partially inundated boundary margins, the census block fractional area inundated is determined and then this fraction is multiplied by the block population number. Photography may be used to ensure that the distribution of housing units in partial census blocks makes sense with regard to the fractional area.

For areas where population growth has occurred and census population does not accurately reflect that growth, current one meter aerial photography can be used to count actual housing units within the inundation boundary. The number of residential housing units are multiplied by the average household size for each census block and then summed. Due to the availability of high resolution imagery, this technique gives the most thorough accounting of the housing units within the inundation boundary. PAR does not take evacuation into account.

Appendix C: Value of a Statistical Life

The value of life should be included in any project evaluation where the result of an action will influence the potential risk of death or injury because this risk represents a real economic benefit or cost. Ignoring this risk ignores real project effects and is not a viable option for an accurate project analysis. The best way to measure the value of life for project analysis is through the Value of a Statistical Life (VSL) approach.

Given that the amount of funding available for programs that improve health, reduce the risk of death, or provide some other benefits to society is limited, some evaluation of the benefit from reduced fatalities and injuries is necessary. The benefit evaluation must, therefore, include a measure that is comparable to the benefits measured for other desirable effects. As a result, a monetary value for life must be estimated in order to determine the outcome that generates the greatest benefit per dollar spent.

Generally, the VSL should approximate the value that people place on their lives in their unrestrained decisions in a market setting. People make decisions every day that carry some risk of harm or death but also provide some benefit. It is through these actual market decisions that willingness to pay (WTP)/willingness to accept studies can be used in a revealed preference framework to infer the VSL. Studies evaluated included the use of seat belts, paying more for crash tolerant automobiles, the use of bicycle helmets, and driving speeds. Each of these situations represent trade-offs between a monetary gain (or loss) and an increase (or decrease) in risk. If an individual is willing to pay the price (the cost associated with a risk) to get a benefit (such as decreased travel time or less time spent buckling up) the consumer is implicitly revealing the value they place on life.

Market behavior indicates that there is a willingness by individuals to accept risk. Consumers do not show that they are willing to pay an infinite amount of their income for safety in their own private market decision making. Private markets indicate that consumers do trade safety for other variables such as time and money.

The studies most similar to the conditions of a loss of life due to a failure of a dam, in terms of the type of risk situation, are most likely transportation related studies using a revealed preference based estimate of WTP. A review of these studies indicates that a likely range of VSL's for a dam is $4.4 million to $6.8 million in 2008 dollars. This is somewhat higher than the value used by the U.S. Department of Transportation, but is well within the range that has been estimated by the U.S. Environmental Protection Agency and other reviews of VSL studies.

Appendix D: Supplemental Information for Analysis of Inland Navigation Lost Benefits

Introduction

Inland waterways are vital to the Nation's economic strength, and to the health and welfare of the American people. More than $100 billion worth (2.2 billion tons) of raw materials, fuels, food, and other goods move annually along this network as part of U.S. domestic and foreign trade. Inland waterways carry about 15 percent of the total freight transported in the U.S. Rail and truck transport is generally more costly than barge transport. Within the 24 inland waterway states, nearly 800,000 jobs exist in industries that ship or receive barge-oriented commodities in counties adjacent to the waterways. Much of the country's critical infrastructure is located near rivers.

Many large rivers are dammed, often in multiple places, to allow efficient transport of large volumes of bulk commodities over long distances. Barge transport over these rivers have the ability to move more cargo per shipment; a single 15-barge tow is equivalent to about 225 railroad cars or 870 tractor-trailer trucks. If the cargo transported on the inland waterways each year had to be moved by another mode, it would take an additional 6.3 million rail cars or 25.2 million trucks to carry the load. According to research by the Tennessee Valley Authority (TVA), this cargo moves at an average transportation savings of $10.67 per ton over the cost of shipping by alternative modes. This translates into over $7 billion annually in transportation savings to economy of the United States (IWR 2000).

In addition to planned and unplanned outage delays, inland waterway lock systems experience unexpected maintenance delays, and the economic impact of such disruptions can be significant. For example, in 2003, the main lock chamber at the Greenup Locks and Dam on the Ohio River was closed to navigation traffic for more than 52 days. Alternative shipping arrangements cost six major shippers and carriers an estimated $28.7 million, while the delay costs were estimated to be about $13.2 million (USACE 2005). In addition to planned and unplanned outage delays, there is also the potential for waterway blockage because of the failure of overhead infrastructure. The collapse of the I-35 bridge in Minneapolis, MN in 2007, for example, closed the river for commercial barges carrying sand and gravel, tourist excursion boats, and recreational crafts (Dulek 2007).

Waterway Commodity Flow Analysis

The ultimate origin and destinations of commercial waterway traffic are determined by using proprietary USACE data on domestic waterborne movements, including the transport of goods by inland barge and ship (USACE Waterborne Commerce Statistics Center [WCSC] 2007). The WCSC, which is a part of the USACE Navigation Data Center (NDC), creates the domestic origin-to-destination movement database from the Vessel Operating Reports submitted by the commercial barge carriers. Data are in theory reported by all vessels and provide estimates of annual tons moved by a five-digit commodity code for all commodities transported on U.S. waterways, on a dock-to-dock basis. Operational attributes included in this data set include origin-to-destination information on foreign and domestic waterborne cargo movements by region and State, and waterborne tonnage for principal ports, states, and territories (Table 1). The data identify the origin-destination pairs in terms of location codes as well as vessel type and net registered tonnage.

Data provided by Waterborne Commerce Statistics Center.
Data is Calendar Year 2005.

COMMODITY	COMM_NAME	PUB_GROUP	PUB_NAME	TRAFFIC	TRAFFIC_NAME	LOC_S	SHIP_LOC	DOCK_S	SHIP_DOCK	STATE SHIP
51623	Acetone	3260	Organic Comp. NEC	50	Internal	15493	THEODORE SHIP CHANNE	710	INEOS PHENOL INC	AL
51623	Acetone	3260	Organic Comp. NEC	50	Internal	15493	THEODORE SHIP CHANNE	710	INEOS PHENOL INC	AL
51623	Acetone	3260	Organic Comp. NEC	50	Internal	20205	LOWER MISS RIVER MILE	501	GEORGIA GULF CHEMICAL	LA
51623	Acetone	3260	Organic Comp. NEC	50	Internal	20205	LOWER MISS RIVER MILE	501	GEORGIA GULF CHEMICAL	LA
51623	Acetone	3260	Organic Comp. NEC	50	Internal	20205	LOWER MISS RIVER MILE	501	GEORGIA GULF CHEMICAL	LA
51623	Acetone	3260	Organic Comp. NEC	50	Internal	20205	LOWER MISS RIVER MILE	501	GEORGIA GULF CHEMICAL	LA

Table 17 - Sample WCSC Data for Commodity Movements along the Illinois Waterway (Source: USACE WCSC 2007)

The geo-locations (latitude and longitude) of the origin and destination points in the WCSC origin-to-destination data set are determined by linking the origin-to-destination data with USACE NDC data on the receipt (destination) points (USACE NDC 2008). Tables created via the Access database software for the geo-located origin-to-destination pairs are subsequently combined to produce one database table that contained the geo-locations for both origin-to-destination pairs.

A geographic information system shapefile of the geo-located origin-to-destination pairs is then developed by using ESRI ArcView® software. Shapefiles are used to determine the inland waterway shipments that would be disrupted based on proximity to the disrupted infrastructure asset and (in the case of a lock or dam) the projected impact on water level in the waterway and navigation.

Rerouting Analysis for Disrupted Commodity Flows

This section analyzes the effects on waterway commodity flows and transportation costs due to changes in conditions on the transportation network (loss of critical nodes, changes in capacity, etc). To accomplish this, the methodology resolves shippers' mode and route based on the prevailing cost of transportation modes. Practical alternative transportation modes and routes for affected waterborne commodity shipments can be identified using Shipper Interviews appropriate for each waterway (e.g., Casavant et al. 2008; TVA 2007), based on existing railheads and estimated alternative mode system surge capacity determined using a routing model such as the Transportation Routing Analysis Geographic Information System (TRAGIS) (Johnson and Michelhaugh 2006).

Shipper interviews at barge terminal locations are used to collect data about the mode and origin-destination of their shipments, the next-best alternative mode and origin-destination, as well as factors that might induce the shipper to switch to the next-best alternative. The data included information on annual tons shipped, commodities shipped, barge charges, truck transfer charges, termination of the shipments, and alternative routes that the shippers could have used for that shipment if not sent by barge. Shipper Interviews generally identify multiple alternative shipping modes and routes. Total origin-to-destination costs in the Shipper Interviews include loading and unloading charges at origin and destination; rates for movements to or from the line-haul; modal line-haul rate; and any intermodal transfer, handling, and storage costs.

Individual records of commodity shipments are combined with the results of the Shipper Interviews based on the individual commodity groups to develop shipper response functions by major industrial category, enabling the estimation of shipper reactions to changes in transportation costs. Shipper response functions are estimated by linking each commodity movement to the appropriate shipping costs per mile as well as to the unit cost of alternative shipping modes, including rail and truck

transportation. Estimates are made of the total transportation costs incurred for existing system use, including access and transfer costs. Estimates are also made of the total transportation costs that would be incurred if existing system movements were forced to use some alternative mode of transportation.

This analysis used a modified form of TRAGIS for shipment rerouting that includes a more detailed waterway network necessary to simulate the detailed shipper movements on the inland waterways infrastructure. This waterway routing approach identifies the most likely route considering least distance based on a network composed of dock and wharf locations.

Rerouting Waterway Shipments

Rerouting waterway shipments is dependent on whether shipper-specific information is available to identify key decision variables concerning shipper choice for the marine terminals on the affected inland waterway. If this type of shipper-specific data is available, the various alternatives that could be used in the event that the inland waterway were combined with the commodity flow database provided by the NDC to produce a data set that identifies the various alternative modes and routes that could be taken in the event that a specific waterborne shipment could not be completed due to inland waterway disruption. The price differential between inland waterway transport and alternative transport modes is determined by using commodity and distance specific shipping rates from Shipper Interviews or alternately from truck, rail, and barge costing models.

If shipper-specific information is unavailable, the appropriate regulations (49 Code of Federal Regulation§172 and §173) would be reviewed to determine appropriate transport modes, vehicles, and capacities for bulk transport of each commodity. If the shipper and receiver both have rail connections (as identified in the NDC data set [USACE NDC 2008]), rail would be chosen as the primary alternative transport mode. The number of rail shipments would be determined based on total volume and mass to be transported and the appropriate freight railcar capacity for the commodity being transported.

This analysis used a modified form of TRAGIS for shipment rerouting that includes a more detailed waterway network necessary to simulate the detailed shipper movements on the inland waterways infrastructure. This waterway routing approach identifies the most likely route considering least distance based on a network composed of dock and wharf locations. The various origin-destination pairs are entered into the TRAGIS model (or similar transportation routing model) to determine the rail routes that would be taken, assuming that rail transport will be used when inland waterway transport has been disrupted. The length (in miles) of each rail shipment (i.e., origin-destination pair) is estimated from the TRAGIS output, and the computed rail shipment length and rate/cost is compared with values for inland waterway transport. If the shipper or receiver does not have rail connections, truck transport is assumed and the number of truck shipments is determined based on total volume to be transported and on the appropriate highway truck capacity.

Unit Shipping Costs

Shipping costs were estimated by separating waterborne commodities into various groupings that accounted for the physical nature of the commodity—liquid versus solid (e.g., whether the commodity is a chemical); the unit shipping costs for these commodity groupings were then correlated.

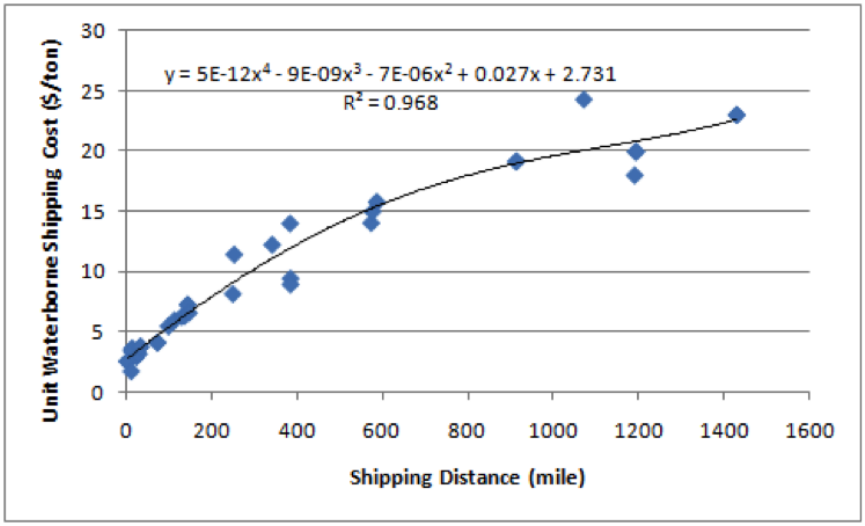

Figure 3: Correlation of Unit Shipping Cost for Waterborne Transport of Aggregates (Source: adapted from WCSC 2005)

Surveys conducted by TVA at the Upper Mississippi River/Illinois Waterway river terminals were used to obtain information about tons and commodities shipped, shipment mode, origin and destination of their shipments, alternative shipping modes and destinations, and transportation rates and costs including access charges, loading and unloading, and line-haul charges. Results for one commodity (aggregates) are shown in Figure 3.

Regression analysis is used to estimate the change in truck rates as the trip distance changes, similar to that performed for waterborne commerce. Because there is a fixed charge for loading and other aspects in beginning the trip, a positive intercept estimate is expected. In addition, the rate would be expected to change at a slightly decreasing rate on longer trips. Beyond some distance, however, additional expenses may be incurred because of the need to have a second driver and to operate at such a long distance from the home base. It seems logical that these long-distance trips would tend to increase the cost. This assumption suggests a cubic form; shorter distances might imply a quadratic equation (Ward and Farris 1990). Figure 4 shows the correlation of truck shipping cost as a function of shipping distance for shorter distance trips.

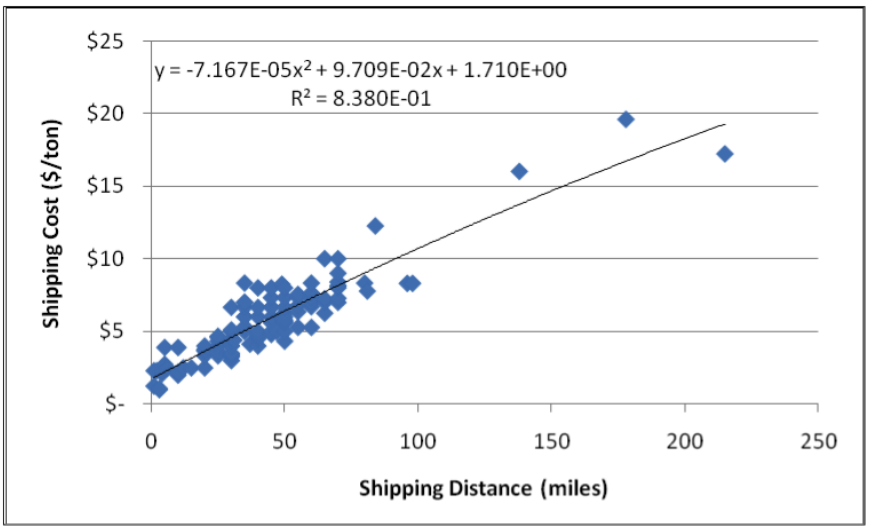

Figure 4: Truck Shipping Cost as a Function of Shipping Distance (Source: adapted from WCSC 2005)

Impact on Transportation Systems-Railroad Capacity

Two variables (railroad capacity and railcar availability) are examined to determine whether freight rail infrastructure has sufficient capacity to absorb the additional rail shipments that would result from a long-term disruption of the waterway. Although railroads have been adding routes as well as shedding some low-margin traffic to make room for higher margin business Transportation Research Board 2007, capacity restrictions may significantly limit the response of the rail transportation network to waterway disruptions. Volume-to-capacity ratios, expressed as level of service (LOS) grades, shown in Figure 5, indicate that 88% of today's primary corridor mileage is operating below practical capacity (LOS A, B, C); 12% is near or at practical capacity (LOS D, E); and less than 1% is operating above capacity (LOS F) (Cambridge Systematics, Inc.[CAMSYS] 2007).

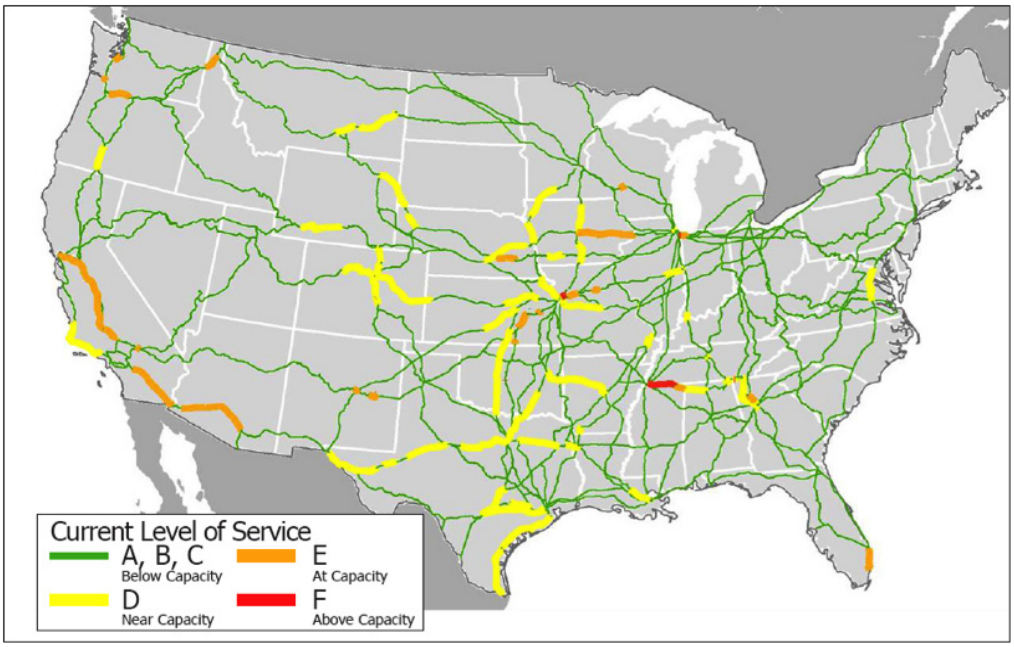

Figure 5: Current Train Volumes Compared with Current Train Capacity (Source: CAMSYS, 2007)

The availability of railcars for shipping commodities disrupted by a long-term waterway blockage might be a significant issue for certain commodity types. The number of required railcars is estimated by comparing the time to complete a round-trip for each commodity shipment with the annual number of rail shipments of that commodity, taking into account public data on recent railcar availability (RailroadPM.org undated).

In the event that sufficient railcars are unavailable, truck transport is assumed for origin-destination pairs with the shortest distances and the number of truck shipments is determined based on total volume and mass to be transported and on the appropriate highway truck capacity.

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