Assessing the Consequences of Dam Failure

A How-To Guide

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FEMA

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Acronyms and Abbreviations

EAP	Emergency Action Plan
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
GIS	Geographic Information System
H&H	Hydrologic and Hydraulic
Hazus-MH	Hazards U.S. – Multi-Hazard (Software)
NFIP	National Flood Insurance Program
PMP	Probable Maximum Precipitation
USACE	U.S. Army Corps of Engineer
USDA	U.S. Department of Agriculture

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SECTION ONE INTRODUCTION

1.1 WHAT THIS GUIDE PROVIDES

The Federal Emergency Management Agency (FEMA) developed *Assessing the Consequences of Dam Failure: A How-To Guide* to provide community officials and interested stakeholders with a process for assessing the potential economic, social, and environmental impacts of dam failure.

For this guide, the word *dam* is defined as any barrier, wall, or embankment, along with its abutments and appurtenant works, constructed for the purpose of storing water or other liquid material either temporarily or permanently. The term *dam failure* means that the dam is overtopped or fails to operate in the manner for which it was designed. This may include catastrophic failure whereby a breach would allow the dam's reservoir to suddenly drain. Failure may also refer to a dam's inability to operate correctly resulting in uncontrolled releases; for example, a dam with a flood pool that cannot be used because of structural concerns could increase flooding downstream during storm events. Dam failure can occur with little to no warning, or it may be an anticipated event.

This guide presents an analytical method particularly appropriate for a community-level examination of the potential damage posed by the tens of thousands of dams in the United States. Information developed as a result of the assessment can be included in the description of potential impacts of a dam failure hazard in a local hazard mitigation plan or Emergency Operation Plan.

1.2 PURPOSE OF THIS GUIDE

The purpose of this guide is to outline a procedure for identifying and assessing the potential consequences of dam failure at the community level using readily available information. A good assessment will establish the potential short- and long-term economic, social, and environmental effects of dam failure that will inform planning efforts.

1.3 LIMITATIONS OF THE GUIDE

This guide provides information for a cursory assessment of the potential consequences of dam failure. Some investment of time and resources is required to conduct the assessment. Communities can use available resources, which can vary from paper maps and tax assessor records to the results of hydrologic and hydraulic (H&H) studies or geographic information system (GIS) data. Limitations include:

- The consequence assessment methodology described in this guide does not address the probability of a dam failure. Dam failure is typically considered a low-probability, high-consequence event. FEMA encourages the determination of consequences regardless of the probability of dam failure.

- The consequence assessment methodology is not a substitute for detailed engineering or academic analyses. Therefore, the results should not be considered sufficient for use in a benefit-cost analysis of mitigation or rehabilitation measures.
- This guide does not provide all of the information necessary for developing an Emergency Action Plan (EAP). An EAP is typically developed by dam owners and outlines procedures to minimize risks to life and property when the integrity of a dam or similar structure may be in jeopardy.

1.4 AUDIENCE FOR THIS GUIDE

This guide is intended for a variety of stakeholders, including community planners and emergency managers. The procedures outlined are intended to be performed by staff at the community level. This guide is not intended to be a substitute for academic research or engineering analysis.

1.5 HOW THIS GUIDE IS ORGANIZED

This guide is divided into nine sections:

- Section 1: **Introduction**: Discusses the intent and the organization of this guide.
- Section 2: **Overview of Assessment Methodology**: Outlines the procedure for examining potential consequences of a dam failure.
- Section 3: **Define Dam Failure Scenario**: Defines the first step of the methodology, which is to choose a scenario to be assessed.
- Section 4: **Identify Inundation Area**: Discusses how to delineate the dam failure inundation area.
- Section 5: **Inventory Assets**: Discusses how to conduct an inventory of structures, infrastructure, and other resources that would be inundated.
- Section 6: **Identify Consequences**: Prescribes a methodology for identifying the potential impacts of a dam failure (e.g., structure damage, road closure).
- Section 7: **Assess Consequences**: Recommends using both quantitative and qualitative methods to assess the potential economic, social, and environmental impacts of a dam failure.
- Section 8: **Identify Follow-up Activities**: Recommends next steps after completion of the consequence assessment.
- Section 9: **Sources of Information:** Lists the resources used to develop the guide.

1.6 FURTHER APPLICATION OF RECOMMENDED PROCEDURES

Dams are not the only structures that can fail; levees, barriers, and other structures that retain water can fail and cause flood damage and loss of life. While this guide refers only to dams, the same procedures can also be applied when analyzing the potential consequences resulting from the failure of other structures.

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SECTION TWO OVERVIEW OF ASSESSMENT METHODOLOGY

This section summarizes the methodology described in this guide for conducting an assessment of dam failure consequences.

The consequence assessment begins by gathering information about the dam and determining the dam failure scenario that will be the basis of the assessment. Depending on the resources available, several types of dam failure scenarios may be considered.

2.1 DEFINE THE INUNDATION AREA

After determining specific dam characteristics, the inundation area should be defined. The inundation area is the total flooded area that would result from dam failure. The inundation area may be localized or may cover several square miles. The size of the inundation area depends on the size of the impoundment, the dam failure scenario being analyzed, the topography of the area, and the flow of water from the impoundment.

2.2 CREATE AN INVENTORY OF ASSETS

Next, create an inventory of assets that could be impacted by a dam failure. Assets are structures, infrastructure, and other features in the inundation area; assets are used for residential, commercial, institutional, agricultural, industrial, or recreational purposes. Assets may be locally important such as homes, schools, parks, or roads or they could be critical infrastructure and resources that have regional or national importance. Examples of local and regional critical infrastructure and resources are large employers, power-generating plants, transmission lines, airports, government offices, hospitals, and industries on which several other industries are dependent.

Developing the inventory of assets involves researching such features as the number of occupants, number of jobs created by the asset, cost of replacement, and contents value. If an EAP has been developed, it may contain valuable information that can be used throughout the analysis. For this and subsequent steps in the assessment of consequences, involving a variety of stakeholders with local knowledge of the inundation area, the local economy, and the area surrounding the inundation area is necessary to determine whether the assessment is complete and justifiable, and whether the assumptions are reasonable.

2.3 ESTIMATE THE POTENTIAL CONSEQUENCES

The next step in the process is to identify the consequences for each asset. The potential consequences of a dam failure include loss of life and injury, damage to structures and infrastructure, loss of services, and road closures resulting from flood damage, fallen trees, and debris.

2.4 DETERMINE THE IMPACTS

The final step in the process is to identify the economic, social, and environmental impacts of dam failure for the dam failure scenario under consideration.

Economic impacts can be direct or indirect. Direct impacts appear immediately following a dam failure event and typically include the need to repair and rebuild structures and infrastructure and reopen businesses. Indirect economic impacts that might be identified during the consequence assessment are unemployment leading to population shifts, difficulty in attracting new businesses to the area, the need for governmental assistance, and lower property tax revenues. Indirect impacts may also include the closure of an industry outside the inundation area that depends on the output of a factory within the inundation area that would be destroyed by the dam failure scenario under consideration.

Dam failure has the potential to cause significant and long-term social effects, resulting in changes to the quality of life in the affected community. Social impacts may include a loss in the public's confidence in public officials, difficulty delivering necessary social or medical services to the community, or the loss of connections among community members that provide support and enrichment.

A dam failure can also have negative environmental impacts, such as the pollution of surface or groundwater, air, and soil; the release of hazardous materials; or the destruction of environmentally sensitive areas.

Figure 1 summarizes the key steps recommended in this guide for assessing the potential consequences of dam failure. Should more than one dam failure scenario be examined, the process would be repeated for each scenario.

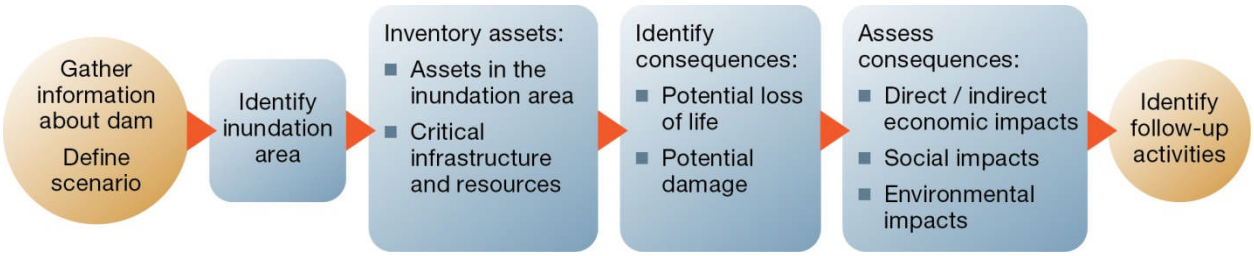

Figure 1: Assessment Process

2.5 LIMITATIONS OF THE RECOMMENDED APPROACH

As stated earlier, this guide does not recommend procedures for determining the probability of a dam failure. The recommended approach leads to identification of potential consequences and impacts, but does not constitute a full assessment of risk. A full risk assessment requires an estimate of the probability of dam failure. The U.S. Department of the Interior Bureau of Reclamation, the U.S. Army Corps of Engineers (USACE), and FEMA have published documents and various models that can help you assess the probability of dam failure.

SECTION THREE DEFINE DAM FAILURE SCENARIO

Hundreds of dam failures have been documented in the United States. Many have resulted in the destruction of residential, commercial, industrial, and agricultural structures, equipment, and infrastructure, as well as injuries and loss of life. The first step in conducting the consequence assessment is to gather information about the dam and to define the scenario that will be examined.

3.1 CHARACTERISTICS OF THE DAM

It is important to collect information about the dam to determine the impacts of a dam failure. Relevant information includes:

- Type of construction (e.g., earth, rock, concrete, masonry, wood, steel, other artificial and natural materials)
- Volume of reservoir
- Height and length of the dam
- Purpose of the dam and reservoir (e.g., flood control, recreation, water supply, electric generation)

3.2 DAM FAILURE SCENARIO

The scenario or type of dam failure that will be considered during a dam failure consequence assessment must first be specified. Scenarios are described not only by the type of dam failure or disruption, but also by the time of year, time of day, and the weather and/or level of ground saturation. Possible scenarios include an unexpected failure on a sunny day or during a Probable Maximum Precipitation (PMP) event. The PMP is the greatest precipitation that is theoretically possible for a particular geographic location. The scenario may also consider the failure of another dam located further upstream, which could trigger multiple dam failures along the waterway. Everyone involved in conducting the assessment must understand the scenario under consideration to ensure that the findings are consistent.

A simple example of an assessment of dam failure consequences is provided in this guide. In the example, the dam failure scenario under consideration is collapse of the dam during the day with 30 minutes to warn the directly affected community to evacuate.

3.3 COMMUNITY

For this guide, the word *community* refers to people who may be directly or indirectly affected by a dam failure. People directly affected are those whose homes, workplaces, or schools would be inundated. People indirectly affected would be those linked in some way to the people or structures directly affected. The community can also include upstream residents and businesses that would be adversely affected by the loss of the reservoir. In a rural area, the community may be either directly or indirectly affected by dam failure and may involve fewer than 100 people. In a developed area, the community may involve many thousands and may include more than one

political jurisdiction. For very large dams, the area at risk of being affected by dam failure may extend across multiple municipal, county, or State boundaries. Analysts and stakeholders must understand this and carefully define the community early in the process of assessing the consequences of dam failure.

Tips for Writing the Consequence Assessment Report

It is important to write a report that describes both the methodologies used to complete the consequence assessment and the conclusions. The report should have information to guide planning efforts. In addition, the report can form the basis for assessing the potential consequences of a different type of dam failure so that consequences can be compared. The consequence assessment report should:

- State that no analysis was conducted to estimate the probability of dam failure and that the probability of experiencing catastrophic dam failure is typically very low. The purpose of writing a report is not to scare the public, but to have a record of the process used and the conclusions drawn about the potential consequences of dam failure.
- Explain briefly why the dam was built or the purpose of the dam. For example, the dam may have been erected to create a fresh water reservoir, for flood damage reduction, to create a lake for boating and fishing, or for other purposes. This information will be used to identify some of the critical infrastructure and resources that depend on the proper functioning of the dam.
- Describe the scenario or type of dam failure on which the consequence assessment is based. Explain, for example, if the assessment refers to the consequences of sudden collapse of the dam during a severe storm, to long-term leakage, or to another situation. The scenario is the basis for the consequences that are identified and assessed through this analysis.

SECTION FOUR IDENTIFY INUNDATION AREA

The second step in conducting an assessment of the consequences of dam failure is to identify the inundation area. The shape and size of the inundation area depend on the underlying topography, dam height, and reservoir volume, and on the dam failure scenario under consideration. For example, if the area below the dam is relatively flat, the inundation area may be quite broad, as the released water would spread out. If the area below the dam is incised and bordered by rock walls, the inundation area may be quite narrow because the released water would flow within these rock walls.

4.1 METHODS FOR IDENTIFYING INUNDATION AREA

Four different methods can be used to identify the inundation area for a consequence assessment:

- If the inundation area has already been identified by the dam owner or the State dam safety office, or is included in the EAP, request a hard copy or electronic map of the inundation area. Different inundation maps may apply to different dam failure scenarios or different weather conditions.
- A rough indicator of potential areas of inundation areas and the course of flooding may be assessed by reviewing FEMA Flood Insurance Rate Maps (FIRMs). FIRMs typically identify the 0.2-percent-annual-chance (500-year) floodplain, the 1-percent-annual-chance (100-year) floodplain, and the floodway. FEMA products are available online through the Map Service Center (http://www.msc.fema.gov/). The area of inundation may be much greater than that presented on the FIRM if the scenario is a catastrophic failure.
- If neither an inundation map nor a FIRM has been created, the community can estimate the boundaries of the inundation area and develop a simplified inundation map using the guidelines in *Federal Guidelines for Inundation Mapping of Flood Risks Associated with Dam Incidents and Failures* (FEMA 2012).
- Use topographic and hydrologic data (such as Digital Elevation Models or Light Detection and Ranging data) to conduct an H&H analysis to delineate the inundation area digitally. Topographic data may be obtained from the department of planning or natural resources at the local or State level, or from Federal agencies such as the U.S. Department of Agriculture's Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/) or U.S. Geological Survey (http://ngmdb.usgs.gov/).

4.2 GUIDELINES FOR CONDUCTING A HYDROLOGIC AND HYDRAULIC STUDY

The following guidelines are provided for communities that decide to conduct an H&H study using engineering software to delineate the inundation area:

- Gather information pertaining to the dam, including any plans, drawings, survey data, and operation manuals or reports that may include the dam height and elevations of key components including spillways and gates, dam type, and reservoir volume. Identify best-

available topography for developing the model geometry and delineating the inundation area. Select one or more dam failure scenarios to model.

- Select a dam break modeling platform. Many dam break modeling programs are available through Federal agencies (e.g., National Weather Service, USACE), universities, other public agencies, and commercial entities. The functionality and limitations of each model should be carefully reviewed. Create the numerical model by extracting the geometry from the topographic data and inputting information from the dam and reservoir. Breach parameters should be chosen by considering the dam type, height, material, and other characteristics of the dam. If a hydraulic failure is modeled, a rainfall-runoff model should be developed to determine the inflow hydrograph to the reservoir.
- After running the hydraulic model, extract the peak inundation elevation at the modeled cross sections and export them to GIS software.
- Import the elevations and topographic data and delineate the inundation extent and depths. GIS software can be a valuable tool for automating the delineation of the dam failure floodplain.
- Extract other model information needed for a consequence assessment, such as the arrival time of the flood wave to determine warning times and velocities to determine the severity of the flooding.

4.3 IMPORTANCE OF DEPTH AND VELOCITY

In addition to understanding where water will flow as a result of dam failure, consider how deep the water would be and how fast the water would be moving. Even without sophisticated engineering models, developing some understanding of depth and velocity for the scenario under consideration is possible by qualitatively reviewing relevant variables.

The failure scenario, distance from the dam, and topography of the inundation area can affect depth and velocity in various ways. Consider the following examples:

- If the scenario is the discharge of a limited amount of water due to a malfunction of the dam, the depth and velocity of the water moving through the inundation area may be no more than the depth of water in the watercourse during heavy rain.
- If the scenario is a sudden collapse of the dam and release of a large amount of water, the depth and velocity of water moving through the inundation area would be greater closer to the dam and somewhat reduced farther from the dam if the topography allows for the water to spread out across flat areas or to be diverted into numerous channels.

Depth and velocity of water depend on a number of variables, including:

- Failure scenario under consideration
- Volume of impoundment and height of dam
- Distance from dam
- Topography of inundation area
- Existence of levees
- Opportunities for flow of water to be impeded

Identify Inundation Area

A qualitative review of the map of the inundation area can provide insight into the potential depth and velocity of water at various locations. Depth and velocity affect the potential for damage to structures, loss of life, and impacts on the environment.

- As the depth of water inside structures increases, the damage increases. However, even shallow water moving at high velocity[1] can significantly damage a structure or move it from its foundation.
- Flowing water can carry debris, which may collide with existing structures or infrastructure and cause significant damage.
- The faster the water moves the greater the chance of loss of life.
    - People unable to evacuate may be trapped in a home or business that is being destroyed by high velocity water or rising floodwaters.
    - Emergency responders may not be able to access the area.
    - Vehicles can be washed off roads and bridges - during a typical flood event the leading cause of death is people trapped in their vehicles.
- Increased velocity will lead to increased erosion, or scour, and loss of environmental assets.

Tips for Writing the Consequence Assessment Report

The consequence assessment report should include:

- A copy of the map of the inundation area or a narrative description of the inundation area. This map will be the basis for identifying assets in the inundation area.
- The depth or velocity of the water along the inundation area for the dam failure scenario under consideration, if it is available. This information will be the basis for estimating damage for the dam failure scenario under consideration.
- Documentation of the source of the inundation map or the sources used to delineate the inundation area and to describe expected depth or velocity of the water.

[1] According to the National Flood Insurance Program (NFIP), floodwaters moving faster than 5 feet per second comprise a high-velocity flood, requiring special design considerations for buildings, roads, bridges and other manmade structures in its path.

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SECTION FIVE INVENTORY ASSETS

The third step in assessing the consequences of a dam failure is to identify the assets. This is a two-step process.

First, catalog or list the economic, social, and environmental assets in the inundation area, as these are vulnerable to damage should the dam fail.

Second, identify critical infrastructure and resources that rely on the impoundment or are dependent on assets in the inundation area. If, for example, the dam provides drinking water, examine the number of structures that receive water from the impoundment. If the dam provides water for cooling, identify the industry or industries that depend on receiving this water.

5.1 ECONOMIC, SOCIAL, AND ENVIRONMENTAL ASSETS

To conduct an inventory of assets, first identify sources of information for identifying structures, infrastructure, and environmental assets. Sources of information may include aerial photographs; land use plans; GIS databases; economic studies; Federal, State, county, and municipal data; and interviews with people familiar with the area. Hazus-MH may provide useful information about structures in the inundation area. For more information on Hazus, go to http://www.fema.gov/plan/prevent/hazus/. Local hazard mitigation plans may have information about assets at risk of damage due to dam failure, and local emergency management agencies may have gathered vulnerability information in preparing other studies. If an EAP has been developed, it may contain information that could reduce data collection efforts.

Examples of Assets

Residential Assets:

- Homes, apartment buildings, or mobile homes
- Garages
- Contents of residential structures

Commercial and Industrial Assets:

- Retail stores, malls, and shopping centers
- Office buildings
- Warehouses
- Agricultural buildings
- Pastures and cropland
- Contents of commercial structures (e.g., computer equipment, machinery, furniture, inventory)
- Factories
- Campgrounds and RV parks

Cultural Resources:

- Churches, community centers, and gymnasiums
- Museums, art galleries, stadiums, and concert halls
- Historic structures or monuments
- Parks and trails
- Cemeteries

Environmental Resources:

- Streams, rivers, lakes, and ponds
- Wildlife habitat (e.g., wetlands, forests)
- Threatened and Endangered Species

Institutional Assets:

- Schools (e.g., elementary, colleges)
- Government office buildings
- Postal service and other shipping facilities
- Hospitals and nursing homes
- Day care facilities
- Special needs facilities (e.g., group homes, halfway facilities)
- Emergency services facilities

Infrastructure Assets:

- Dam
- Transportation networks (e.g., roads, railways, airports, mass transit centers)
- Utility networks (e.g., electric, water, sewer)
- Water and sewage treatment facilities
- Communications networks
- Levees
- Pipelines (e.g., natural gas, water, sewer)

Inventory Assets

Similarly, a variety of sources of information will be used to identify characteristics of the assets in the inundation area. Some information about structures in the inundation area may be available through tax assessor records. In many communities, tax assessor records are part of a GIS system; if the limits of the inundation area are also available digitally and can be made part of the GIS system, assets can be identified using GIS. Information about other assets may be identified on road maps and through interviews with leaders of local highway and public works departments or other local or State agencies. For example, to establish the characteristics of unique wildlife habitat in the inundation area, contacting wildlife biologists or representatives of the U.S. Fish and Wildlife Service may be necessary.

List the assets in a spreadsheet or worksheet; a sample worksheet is included in Appendix A, and additional guidance is provided below.

For each asset listed in the worksheet, enter the following information:

- Location or address.
- Approximate distance from the dam. This distance will provide insight into the level of damage that might be sustained should the dam fail, as well as information that can be used in planning for evacuation.
- Estimated occupancy. Typically, Census data can be used to estimate occupancy of residential units. To use Census data, go to www.Census.gov, select a State, and locate the estimate of "Persons per Household." The information about occupancy of assets will be used to estimate the number of people at risk of injury or death in the event of a dam failure. Occupancy will vary by time of day, day of the week, and time of year; a community may conduct several assessments to examine these different states of occupancy or may choose to conduct a single assessment assuming that each structure is fully occupied when the dam fails, which would be the worst case.
- Replacement value. The replacement value data will be used to estimate the potential cost of replacing or repairing structures. Remember that replacement value is not necessarily the same as the cost of repairing a structure or infrastructure after it is damaged because damage may not entail complete replacement. Sources of replacement value include:
  - Tax assessor data can be used for structure values.
  - Local planning documents may provide estimates of structure or infrastructure values.
  - Census data can be used to develop a rough estimate of replacement value. To use Census data, go to www.Census.gov, select a State, and find "Median value of owner-occupied housing units."
  - The local engineer may have value of infrastructure or cost to rebuild.

  Even an asset that is not currently active has value. For example, a vacant building may have the potential for future use as a community center or apartments. It may be difficult to estimate the replacement value of assets such as parking lots, construction sites, or

vacant buildings or lots; nevertheless, these can be listed as assets, and replacement value can be roughly estimated for the assessment.

- Contents value. Unless the value of contents is known to be much greater, contents value for residential structures can be estimated as 50 percent of the replacement value.

  Contents of museums, libraries, historic structures furnished with antiques, and the like may be expensive and irreplaceable. For these assets, contacting owners or operators may be necessary to obtain an estimate of the contents value.

- Potential high impact pollutants. If a structure or infrastructure is flooded because of dam failure, contents may be washed away and lead to pollution of surface and groundwater resources, as well as contamination of soils. When conducting the inventory of assets in the inundation area, note assets that may contain hazardous materials that if present in sufficient quantities could damage or impact environmental resources; residential structures and commercial facilities typically have small quantities of cleaning supplies and other commodities with the potential to contribute to water pollution. Attempt to contact operators of warehouses, commercial, industrial, or agricultural facilities identified as possibly storing large quantities of pollutants.

Table 1 illustrates how the first several columns of the asset worksheet might be completed for identified assets in the inundation area. Figure 2 is a basic illustration of the inundation area and the location of the assets for the example dam failure scenario.

Table 1: Assets in the Inundation Area

Asset	Location or Address	Approximate Distance from Dam	Typical Occupancy	Replacement Value	Contents Value	Potential Large Quantity Pollutants
Reservoir	Behind dam	0 miles	0	Several million dollars	N/A	N/A
Single-family home	222 Flood Street	0.5 mile	4	$100,000	$50,000	N/A
Restaurant	334 Flood Street	1 mile	115 (100 seats; 15 staff per shift)	$1.5 million	Not available	N/A
Industry XYZ	440 Flood Street	2 miles	175	$55 million	$15 million	Large quantities of salt
Cornfield	Between State Route 62 and County Highway A2A	1.25 miles	0	$350,000	N/A	N/A
Single-family home	12420 Flood Street	5 miles	3	$150,000	$75,000	N/A

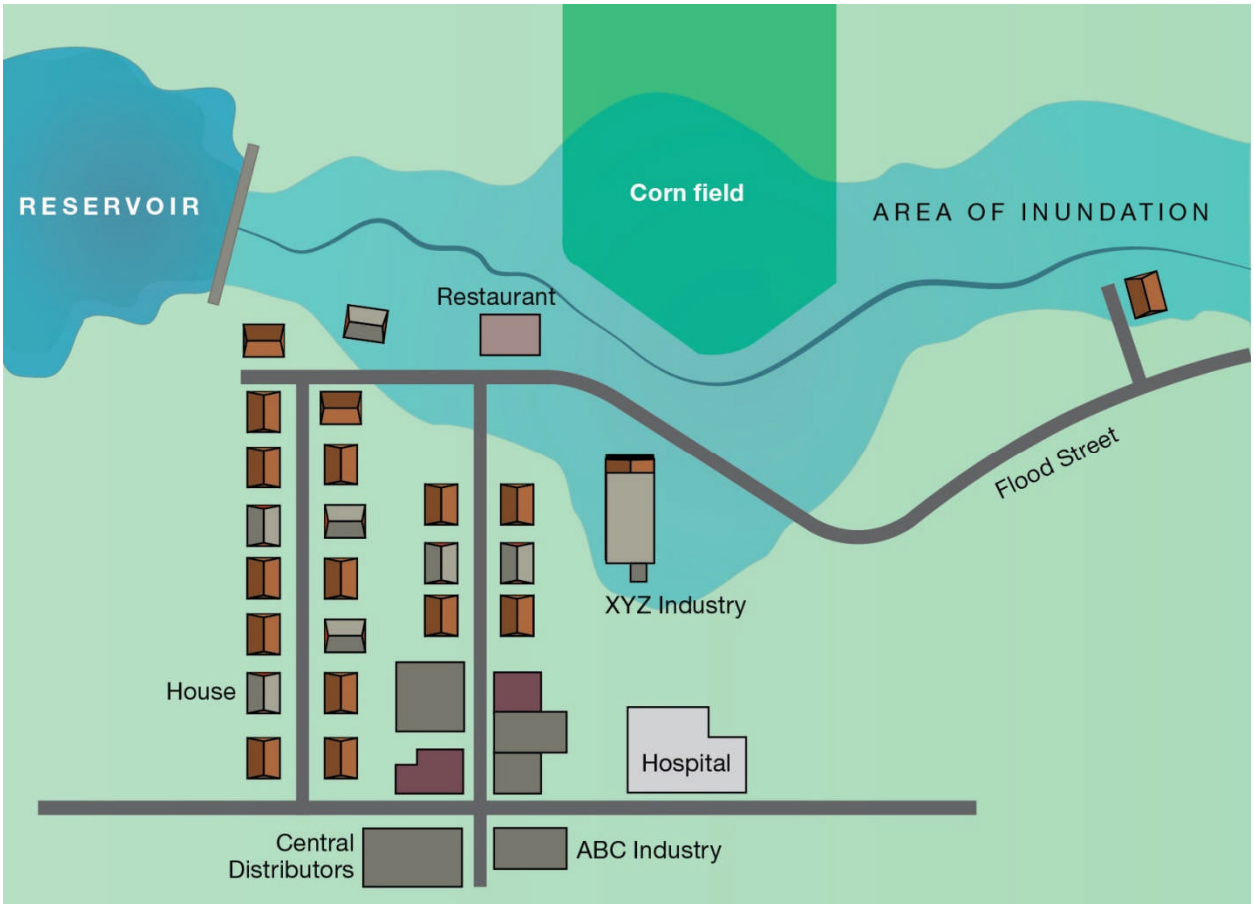

Figure 2: Inundation Area for Example Scenario

Also consider that some direct damage may occur outside of the area of inundation. For example, the resulting flood may cause sewers to back up into homes and businesses. Although damage to these structures would be significantly less than those impacted by overland floodwater, it would still cause disruptions to the community.

5.2 CRITICAL INFRASTRUCTURE AND RESOURCES

After identifying assets in the inundation area, identify local and regional critical infrastructure and resources that may be affected. Critical infrastructure and resources are facilities, systems, and networks, whether physical or virtual, sufficiently vital to the routine operation of the economy and government. Incapacitation or destruction of these resources would have a debilitating effect on the economy, security, public health, or safety. Such resources can be publicly or privately controlled and identified

Examples of Interdependencies

- Hospitals and schools depend on water, wastewater, energy, communications, shipping, and transportation networks.
- Industries depend on a supply of water, treatment of wastewater, energy, communications, and transportation networks.
- Shipping facilities depend on energy, information technology, communications, and transportation networks.

based on what is important to the functioning of the community. Examples of critical infrastructure and resource facilities that would be important to the broader community beyond the inundation area include water treatment plants, healthcare facilities, industries that employ a large number of people, communications networks, and transportation networks. Although these resources may not be directly impacted by flooding, they could be impacted by a dam failure. For those resources outside of the inundation area, it is important to identify interdependencies with the infrastructure that would be impacted by a dam failure.

Table 2 illustrates a sample list of critical infrastructure and resources and how these resources would be impacted by a dam failure. This information corresponds to the worksheet in Appendix B.

Table 2: Critical Infrastructure and Resources Beyond the Inundation Area

Resource	Function	Dependency
Industry ABC	Large manufacturing	Requires water from reservoir for cooling; no alternative source of water is available for cooling
Hospital at 76 Water Street	Health care services	Requires potable water from treatment plant at reservoir; no alternative source of potable water is available. Requires sanitary water for cleaning and waste disposal.
Central Distributors	Distribution center and warehouse	Trucks use the 200 block of Flood Street (in the inundation area) to reach the interstate highway

Tips for Writing the Consequence Assessment Report

The consequence assessment report should:

- Present appropriate data in a table or spreadsheet.
- Explain the method used to identify assets in the inundation area, as well as the method for estimating the distance between each asset and the dam.
- List the source or sources of data for assets in the inundation area.
- Logically organize and link the assets listed to potential consequences and impacts. For example, if the inundation area is large, developing several spreadsheets that represent different geographic areas may be appropriate. The spreadsheet should list residential, commercial, and industrial structures; public, nonprofit, and privately owned structures and infrastructure; and environmental, water, ecological, recreational, cultural, historic, and archaeological resources.
- Document the sources of information used to learn the characteristics of the assets in the inundation area. Readers will need to know the sources of information to update or verify information in the report. If, for example, the consequence assessment is being developed for a total sudden collapse of the dam scenario, the report could be used in the future to assess the consequences of a different type of failure.

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SECTION SIX IDENTIFY CONSEQUENCES

The fourth step in assessing the consequences of dam failure is to identify the potential consequences, both inside and outside the inundation area. Consequences inside the inundation area could be directly caused by flowing water and debris; typically, injury and loss of life and damage to structures and infrastructure. Consequences outside the inundation area could be indirectly caused by dam failure, such as unemployment caused by closure of a damaged business inside the inundation area. Consequences outside the inundation area will be indirect and result from disruptions in the provision of services or the lack of a commodity normally provided by assets in the inundation area.

Examples of Direct Consequences:

- Injuries and/or loss of life
- Damage to commercial structures and/or their contents
- Damage to residential structures and/or their contents
- Damage to equipment and supplies at an industrial site
- Damage to facilities that provide services
- Flooding of transportation, water, electrical, and communication infrastructure
- Loss of livestock and agricultural crops
- Reduction in agricultural output due to loss of irrigation
- Loss of recreation opportunities
- Loss of electrical generation
- Debris removal
- Sediment removal
- Cost to repair or rebuild dam

Examples of Indirect Consequences:

- Increased traffic congestion while repairs occur
- Increased occupancy in nursing homes to accommodate patients from nursing homes in the inundation area
- Prolonged operations of temporary shelters for residents of the inundation area
- Closure of industries due to lack of water or wastewater treatment
- Loss of tourism

6.1 DETERMINE ANTICIPATED LEVEL OF DAMAGE

Potential damage to structures and infrastructure in the inundation area depends on depth and velocity of water. Section 4 discusses factors that affect the depth and velocity of water in the inundation area following dam failure. For some dam failure scenarios, depth and velocity will be similar to the depth and velocity that would occur after a heavy rain storm, and damage will be low. For other dam failure scenarios, depth and velocity will vary in the inundation area, and damage to assets close to the dam might be very high, while damage several miles downstream might be negligible.

Use a worksheet to create a preliminary estimate of the anticipated level of damage for the scenario. Use descriptive terms such as high, medium, and low; the goal is to differentiate among assets that would be seriously damaged, assets that would experience some flooding, and assets that would not be expected to be damaged by dam failure because of their location at the periphery of the inundation area.

If information about the topography of the inundation area and the possible depth and velocity of water following dam failure is limited, base the anticipated level of damage on distance from the dam.

Identify Consequences

If additional information has been gathered about assets, such as first floor elevation and construction type, drawing further distinctions about the anticipated level of damage may be possible. For example, as the first floor elevation increases, the level of damage would be expected to decrease, and for structures with steel-reinforced frames, the level of damage would probably be less than the level of damage for wood-frame structures.

Table 3 illustrates some of the columns of the worksheet used to determine anticipated level of damage. Note that in this simple example, one structure is 5 miles downstream from the dam, and although it is in the inundation area, the anticipated level of damage for this structure is low; this structure would be removed from further analysis.

Table 3: Anticipated Level of Damage

Asset	Location or Address	Approximate Distance from Dam	Anticipated Level of Damage for Scenario (High, Medium, Low)
Reservoir	Behind dam	0 miles	High
Single-family home	222 Flood Street	0.5 mile	High
Restaurant	334 Flood Street	1 mile	High
Industry XYZ	440 Flood Street	2 miles	Medium
Cornfield	Between State Route 62 and County Highway A2A	1.25 miles	Medium
Single-family home	12420 Flood Street	5 miles	Low

Following the initial failure event, it should be remembered that repeat flooding and damage could occur until the dam is repaired or replaced, or other mitigation measures are implemented.

6.2 DETERMINE POTENTIAL FOR LOSS OF LIFE

The possible loss of life from a dam failure depends on a number of variables, including:

- Occupancy of the inundation area
- Warning time
- Public perception

The potential for loss of life can be determined by:

- Estimating the typical occupancy of each asset using local demographic or economic development data
- Using Census Block data to estimate occupancy based on the area or portion of the Census Block that is covered by the inundation area

  - For example, if a Census Block has 100 occupants and is half covered by the inundation area, then an estimated 50 occupants would be at risk.

- Using parcel data
  - For example, if 430 residential parcels are in the inundation area and the average number of residents per household is 2.3, then the estimated occupancy of the inundation area would be 430 * 2.3 = 989.

Examples of Adjustments to Occupancy

- If a campground in the inundation area has 500 occupants during the summer, adjust the occupancy if the scenario is for dam failure during the winter.
- If a school in the inundation area has 1,200 students during the school day, adjust occupancy if the scenario is for dam failure at night.
- If the scenario is for a malfunction of the dam causing somewhat higher flooding in the inundation area than would occur if the dam is functioning as designed, anticipated loss of life might be zero.
- If the community has a good warning system and the scenario affords ample time for evacuation of areas several miles from the dam, adjust the occupancy for those parts of the inundation area.

The anticipated level of damage is not necessarily an indicator of the potential for loss of life. In addition to estimated occupancy for the dam failure scenario under consideration, factors that can affect the potential for loss of life include whether the community has a warning system to alert people of imminent or actual dam failure, whether the situation provides time for people to evacuate, and whether people have the capacity to evacuate all affect the potential for loss of life and injury. A warning signal can be triggered by findings of instability, leaks, or changes in the dam; warning signals can include reverse 911 call systems, bullhorns and sirens, and radio and television broadcasts. Even with catastrophic dam failure, if several hours would be required for the flood waters to reach a particular part of the inundation area, there would be time for warning and for people to evacuate; thus the number of people in the inundation area is not a constant and, for this analysis, is an adjustment of typical occupancy.

Warning systems can be very effective at reducing the loss of life following a dam failure. However, public perception of danger and of the reliability of the evacuation warning will affect the degree to which people heed warnings and evacuate the inundation area; thus affecting the potential for loss of life and injury.

Studies have not identified a method for estimating the number of people who would remain in the inundation area after a warning or evacuation order has been issued. Therefore, for this assessment, an adjusted occupancy value for each asset can be entered in the column of the worksheet labeled “Estimated Occupancy for Dam Failure Scenario” by:

- Entering zero for occupancy of assets for which the anticipated level of damage is low, as people in structures at the periphery of the inundation area would not experience deep flooding or fast-moving water.
- Entering zero for all assets if the dam failure scenario is for a slow and steady discharge resulting from a malfunctioning spillway and if no loss of life is anticipated.
- Entering zero or a lower occupancy for assets in locations sufficiently remote from the dam where evacuation could occur, such as locations where an hour or more would be possible

between the time the warning is issued and the time the water reaches a particular location. However, if evacuation from the asset would not or could not occur, then Estimated Occupancy for Dam Failure Scenario for that asset would equal the Typical Occupancy.

- Adjusting occupancy figures based on the dam failure scenario under consideration. For example, if dam failure were to occur late at night, the Restaurant and Industry XYZ may be vacant or have only a couple of people inside, so Estimated Occupancy for Dam Failure Scenario would be zero.

Various resources exist for estimating the loss of life resulting from a dam failure, including the U.S. Department of Homeland Security document, *Dams Sector: Estimating Loss of Life for Dam Failure Scenarios* (2011b) and the U.S. Department of the Interior, Bureau of Reclamation document, *A Procedure for Estimating Loss of Life Caused by Dam Failure* (1999). Procedures for estimating loss of life in these documents can be somewhat complicated; however, the procedures in these documents use the following basic analysis:

Estimate the flood severity at each of the assets as it applies to loss of life; this may not be the same as how flood severity applies to the anticipated level of damage, as identified in Table 3. The following is a summary of guidance for selecting the flood severity category:

- Low flood severity occurs when no buildings are washed off their foundation. Most structures are exposed to flood depths of less than 10 feet.
- Medium flood severity occurs when homes are destroyed but trees or mangled homes remain where people can seek refuge. Most structures are exposed to flood depths of greater than 10 feet.
- High flood severity occurs when the flood sweeps the area clean and nothing remains. The event will result in very deep floodwater reaching its ultimate height in just a few minutes.

Table 4 illustrates the use of asset data to estimate the occupancy of the inundation area and flood severity for the dam failure scenario under consideration.

Table 4: Occupancy of Inundation Area

Asset	Anticipated Level of Flood Severity for Scenario*	Typical Occupancy	Estimated Occupancy for Dam Failure Scenario
Reservoir	High	0	0
Single-family	High	4	4
Restaurant	Medium	115 (100 seats; 15 staff per shift)	115
Industry XYZ	Low	175	175
Cornfield	Medium	0	0
Single-family home	Low	3	0
		TOTAL OCCUPANCY	**294**

*Note: The anticipated level of flood severity is used for estimating the loss of life and may not be the same as the estimated damage to the asset.

Estimate the loss of life by determining the fatality rate for each flood severity category based on guidance in *A Procedure for Estimating Loss of Life Caused by Dam Failure* (U.S. Department of the Interior 1999), then multiplying the fatality rate by the occupancy of the inundation area (Table 5). Round the loss of life estimates up to the nearest whole number.

Table 5: Method for Estimating Loss of Life

Flood Severity Category	Fatality Rate	Estimated Occupancy for Dam Failure Scenario	Loss of Life
Low	0.7%	175	2
Medium	4%	115	5
High	75%	4	3
		Total Loss of Life	10

Present this estimate for loss of life in the report and include a description of the methodology used to make the estimate.

Next, estimate the potential number of injuries using the estimated loss of life. No reliable and robust models are available to estimate the number of injuries from the loss of life. However, some research has demonstrated the relationship is not linear; one study found that in general if the loss of life is small, the number of injuries is also small, but if loss of life is large, the number of injuries can be more than twice the number of fatalities (Jonkman 2007). Thus two different approaches can be used to estimate the number of injuries:

- Develop an estimate based on the experience and knowledge of local floodplain administrators and emergency managers about the relationship observed in the past between the number of lives lost and the number of injuries experienced.
- Estimate the number of injuries as twice the number of fatalities.

Assuming the community in the sample dam failure scenario above determines that estimating the number of injuries as twice the number of fatalities is reasonable, then for this example:

$$Possible\ Number\ of\ Injuries = 2 * Possible\ Loss\ of\ Life = 2 * 10 = 20$$

The assessment of the consequences of dam failure requires the use of local knowledge; the estimates for loss of life and injury should be reviewed and adjusted if they seem too high or too low given the unique characteristics of the inundation area. For example, the estimates could be increased if the inundation area is occupied primarily by elderly people (e.g., nursing home), children (e.g., daycare center, after school activity center), or mobility-impaired residents (e.g., rehabilitation facility).

As with all of the estimates of the consequences, the results should be reviewed to ensure that they are reasonable. For example, review the estimates to ensure that the total loss of life and injuries does not exceed the occupancy of the inundation area.

If, as in this example, the entire population of the inundation area is located close to the dam, and if the dam failure scenario under consideration is sudden collapse with no warning time, the loss of life may be very high and there may actually be very few injuries.

Note that no amount of research can exactly predict the loss of life or number of injuries that would occur. The purpose of this assessment is to systematically develop a reasonable representation of the potential consequences of a dam failure.

6.3 DETERMINE OTHER POTENTIAL CONSEQUENCES

The final step in identifying the potential consequences of the dam failure scenario under consideration is to identify anticipated consequences other than loss of life and injuries; use a worksheet as illustrated in Tables 6 and 7 to document these. The anticipated consequences will be used in the next phase of the methodology to assess the consequences. Enter a brief description of anticipated consequences for the assets in the inundation area that are still a part of the analysis in the worksheet as illustrated in Table 6.

Table 6: Anticipated Consequences of Dam Failure

Asset	Anticipated Consequences
Reservoir	Loss of usual supply of potable water (would switch to pumping water from nearby river) and loss of sufficient supply of water for Industry XYZ; need to repair the dam
Single-family home	Extensive damage to structure and contents; temporary relocation of residents
Restaurant	Extensive damage to structure, contents, and parking lot; loss of incomes
Industry XYZ	Damage to equipment by flood waters; insufficient water supply
Cornfield	Loss of crops on 50 acres
Single-family home (5 miles downstream)	Negligible

Identify anticipated consequences for critical infrastructure and resources using a worksheet as illustrated in Table 7 for the dam failure scenario under consideration.

Table 7: Anticipated Consequences for Critical Infrastructure and Resources Beyond the Inundation Area

Resource	Function	Dependency	Anticipated Consequences
Industry ABC	Large manufacturing	Requires water from impoundment area for cooling; no alternative source of water is available for cooling	Without water, Industry ABC would close temporarily; about 100 people would be temporarily unemployed
Hospital at 76 Water Street	Health care services	Requires potable water from treatment plant at reservoir; no alternative source of potable water is available. Requires sanitary water for cleaning and waste disposal.	The hospital would evacuate all patients and close temporarily; about 250 people would be temporarily unemployed
Central Distributors	Distribution center and warehouse	Trucks use the 200 block of Flood Street (in the inundation area) to reach the interstate highway	Trucks would be flooded; a detour would be needed to reach the interstate highway

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SECTION SEVEN ASSESS CONSEQUENCES

The fifth step in the methodology is to assess the implications of the consequences. After identifying the dam failure consequences for each asset inside the inundation area, consider the impacts. In this guide, three types of impacts are considered:

- Economic impacts include the costs of repair, debris removal, replacement of contents, and the loss of jobs.
- Social impacts include disruptions in social patterns, loss of services provided by institutions in the inundation area, and loss of recreational opportunities.
- Impacts on the environment include polluted water and soils, loss of habitat, and erosion of stream banks.

7.1 ECONOMIC IMPACTS

Economic impacts are not limited to assets in the inundation area, but may extend to infrastructure and resources that serve a much broader area. In addition to direct damage from dam failure, economic impacts include the amount of time required to repair or replace and reopen businesses, governmental and nonprofit agencies, and industrial facilities damaged by the dam failure.

This guide presents one approach for estimating the economic consequences of the dam failure scenario under consideration. Additional guidance on estimating the economic consequences of a dam failure can be found in the U.S. Department of Homeland Security document, *Dams Sector: Estimating Economic Consequences for Dam Failure Scenarios* (2011a).

Another approach for assessing the potential economic consequences of dam failure is to use software such as the Hydrologic Engineering Center's Flood Impact Analysis and Hazus-MH, which are available from the USACE and FEMA, respectively. These models estimate the degree to which a structure and its contents would be damaged by flooding and calculate the potential dollar losses. Care should be taken when using these models to ensure that the results are reasonable. For example, conducting a level 1 analysis ("out of the box") in Hazus can give very misleading results (i.e., Hazus requires detailed data input to get reasonable results for a dam break scenario).

The consequence assessment methodology provided in this guide accounts for a variety of direct and indirect economic consequences. Direct economic consequences include the costs of repairing damage and replacing lost items. Indirect economic consequences include the loss of jobs, the loss of sales, and the cost of securing alternative space for residential or business purposes.

Step 1

Unless a more sophisticated method has been developed locally, use the Anticipated Level of Damage to develop a **Damage Factor,** as follows:

- If the Anticipated Level of Damage is High, the Damage Factor is 100 percent.

- If the Anticipated Level of Damage is Medium, the Damage Factor is 50 percent.
- If the Anticipated Level of Damage is Low, the Damage Factor is 10 percent.

Damage Factors should be determined locally; the examples provided in this guide are only illustrations. After the results of the economic consequence assessment are calculated, a decision may be made to revise the Damage Factors and repeat the analysis to reach conclusions that seem more appropriate to local stakeholders. Document the rationale for the Damage Factors selected in the consequence assessment report.

Enter the appropriate Damage Factor in the worksheet illustrated in Appendix A for each asset.

Step 2

Multiply the Replacement Value by the Damage Factor to estimate the **Cost of Repair or Replacement**. Sum the Costs of Repair or Replacement for all assets retained in the analysis and report this as the **Total Cost of Repair or Replacement.**

Step 3

Multiply the Contents Value by the Damage Factor to estimate the **Cost to Replace Contents** and enter values in the worksheet, Sum the Cost to Replace Contents for all assets retained in the analysis and report this as the **Total Cost to Replace Contents.**

For Steps 1 through 3 of the procedure, use the columns of the worksheet shown in Table 8.

Table 8: Potential Economic Impacts Steps 1 through 3

Worksheet Continued						
Asset in Inundation Area	Replacement Value	Contents Value	Anticipated Level of Damage for Scenario (High, Medium, Low)	Damage Factor	Cost of Repair or Replacement (Multiply Replacement Value * Damage Factor)	Cost to Replace Contents (Multiply Contents Value * Damage Factor)
Asset #1						
Asset #2						
Asset #3						
					Total Cost of Repair or Replacement	Total Cost to Replace Contents

To develop an estimate of the costs that would be borne by property owners, consider the contribution of flood insurance payments to covering some of the costs of replacing contents and repairing structures. Institutional, commercial, and residential structures can be covered by NFIP

policies. Although insurance and other sources of recovery funds do not reduce the total impact, they can reduce the impact to the local community and aid in recovery efforts.

Step 4

Next, estimate the **Number of Months to Repair or Replace** damaged structures, infrastructure, or environmental resources, or the approximate length of time that each asset in the inundation area would not be usable for the dam failure scenario under consideration. This estimate should be based on local knowledge and/or previous experience with repairing damage to a large number of facilities in this or another community. Agricultural experts may be able to provide estimates of the number of months or years required to return cropland to productive use depending on the type of damage or pollution anticipated. Estimates should be consistent with the anticipated level of damage; for example, 6 months for facilities with a medium level of damage and 2 years for facilities with a high degree of damage may be reasonable.

Additional Examples of Direct Economic Consequences

- Loss of emergency response, police, fire, or rescue service facilities and vehicles
- Emergency response and rescue
- Loss of power generation, sewer, water, or telecommunications services
- Damage to roads, bridges, rail lines, or mass transit facilities or vehicles
- Debris removal
- Removal of dead animals

Remember that not all of the costs and losses would be the result of direct damage to an asset. For example, a community may be responsible for cleaning debris from roads and parks, even though there may not be direct damage to the assets. Also, farms outside of the inundation area may experience reduced crop yield due to the loss of irrigation water provided by the reservoir. Planners should consider the full range of impacts when conducting an assessment.

Step 5

For assets that provide jobs, estimate the **Number of Months Closed**. Some operations would resume after a short time at alternative locations while repairs are being made, and for these the estimated number of months closed would be low. Other operations would close until repairs are made and the Number of Months Closed will equal the Number of Months to Repair or Replace. For the sample analysis, it would be reasonable to assume that alternative space would be found for office work and for some retail work, but that other retail establishments and industries would close until repair or replacement of the damaged facility is complete.

Step 6

For each commercial, industrial, or government facility in the inundation area, estimate the **Number of Jobs** provided at the facility. Estimates of the number of employees may be found in economic development studies or studies of various types of industries, or may require interviews with owners of some of the businesses in the inundation area. Enter zero in the worksheet under Number of Jobs for assets such as residential structures or roadways that are not generally considered places of employment.

Step 7

For each asset, multiply the Number of Months Closed by the Number of Jobs to determine the total economic consequence in **Months of Employment Lost**. Add up the number of Months of Employment Lost that would be lost for all assets due to dam failure; include the **Total Months of Employment Lost** in the assessment report.

For Steps 4 through 7 of the procedure, use the columns of the worksheet as shown in Table 9.

Table 9: Potential Economic Impacts Steps 4 through 7

Worksheet Continued				
Asset in Inundation Area	Number of Months to Repair or Replace	Number of Months Closed (for businesses)	Number of Jobs	Multiply Months Closed * Number of Jobs
Asset #1				
Asset #2				
Asset #3				
				Total Months of Employment Lost Total Months of Employment Lost * Average Monthly Wage = Cost of Lost Employment

Consider the possibility that sales outside of the affected area will increase, that new jobs will be available, and that some workers may take these new jobs; reduce the total months of employment lost to cover these new jobs. Estimate the average wage per month and multiply total months of employment lost by the average wage to estimate the total cost of loss of employment.

To develop an estimate of the impact on the local community, consider the contribution of unemployment insurance. Although insurance and other sources of recovery funds do not reduce the total impact, they can reduce the impact to the local community and aid in recovery efforts.

Step 8

For retail, commercial, and industrial facilities in the inundation area, estimate **Monthly Sales** to develop an understanding of the amount of business that would be lost or customers that would not be served. Estimates of daily or monthly or annual sales may be found in economic development studies or studies of various types of industries, or may require interviews with owners of some of the businesses in the inundation area.

Step 9

For each asset, multiply the Number of Months Closed by the Monthly Sales; sum these products to estimate **Total Sales Lost** and include this number in the report. Consider, however, the possibility that sales outside of the affected area will increase and adjust the estimate of total sales lost accordingly.

Step 10

For some operations, estimating **Monthly Customers** may be more reasonable than Monthly Sales; this would be appropriate for government service agencies, medical clinics, some tourist destinations, or parks. (For roadways that are closed because of the dam failure scenario, see Step 12 in this procedure.)

Step 11

Multiply the Number of Months Closed by Monthly Customers, sum for all assets for which Monthly Customers is more appropriate than Monthly Sales to estimate the **Total Customer Service Lost**, and document this as another estimate of the economic consequences of dam failure.

For Steps 8 through 11 of the procedure, use the columns of the worksheet as shown in Table 10.

Table 10: Potential Economic Impacts Steps 8 through 11

Worksheet Continued					
Asset in Inundation Area	Number of Months Closed (for businesses)	Monthly Sales	Multiply Number of Months Closed * Monthly Sales	Monthly Customers	Multiply Number of Months Closed * Monthly Customers
Asset #1					
Asset #2					
Asset #3					
...					
			Total Sales Lost		Total Customer Service Lost

Step 12

For roadways that would be closed as a result of the dam failure scenario under consideration, consider the cost of taking a detour. Estimate **Monthly Trips**; look in transportation plans or consult the State and local departments of transportation for information about the number of trips on that roadway each month.

Step 13

Enter the number of miles required to detour around the closed road or bridge in the column titled **Miles in Detour**.

Step 14

Estimate the **Cost per Mile** using the Internal Revenue Service Standard Mileage Rate, which is available online at http://www.irs.gov/taxpros/article/0,,id=156624,00.html.

Step 15

Multiply the Number of Months Closed by the Monthly Trips by the Miles in Detour by the Cost per Mile to estimate the cost of detouring around the closed section of a road or bridge damaged by dam failure. Add these estimates for all such roadways to estimate the **Total Cost of Detours.** The Total Cost of Detours can be further developed by considering the value of time required by drivers and passengers to use the detours; consider also the increased time necessitated by traffic congestion along the detour.

For example, suppose a bridge would be closed for 3 months, that 3,000 trips are made across the bridge each month, that the detour is 18 miles, and that the cost of driving a mile is $0.50. The cost of the detour for this one bridge is:

3 months * 3,000 vehicles/month * 18 miles/vehicle * $0.50/mile = $81,000

For Steps 12 through 15 of the procedure, use the columns of the worksheet as shown in Table 11.

Table 11: Potential Economic Impacts Steps 12 through 15

Worksheet Continued					
Asset in Inundation Area	Number of Months to Repair or Replace	Monthly Trips	Miles in Detour	Cost per Mile	Multiply Monthly Trips * Miles in Detour *Cost per Mile
Asset #1					
Asset #2					
Asset #3					
					Total Cost of Detours

Step 16

For residential units, estimate the monthly cost of a rental unit in the worksheet under **Monthly Cost of Alternative Space**.

Similarly, for businesses, ask local stakeholders whether assuming that alternative space can be found is reasonable. If alternative office or retail space can reasonably be expected to be found, estimate the monthly cost of renting alternative office or retail space and enter it in the column for **Monthly Cost of Alternative Space**. Enter $0 in this column if alternative space is not expected to be rented. This cost can be estimated by consulting with real estate professionals about the cost of office space; however, if a large number of businesses would be seeking alternative space following a dam failure, the demand may exceed supply and costs may rise.

Step 17

Multiply Estimated Months to Repair or Replace by Monthly Cost of Alternative Space. Sum these products and include this **Total Cost of Alternative Space** in the report as an economic consequence.

For Steps 16 and 17 of the procedure, use the columns of the worksheet as shown in Table 12.

Table 12: Potential Economic Impacts Steps 16 and 17

Worksheet Continued			
Asset in Inundation Area	Number of Months to Repair or Replace	Monthly Cost of Alternative Space	Multiply Number of Months to Repair or Replace * Monthly Cost of Alternative Space
Asset #1			
Asset #2			
Asset #3			
			Total Cost of Alternative Space

Step 18

Provide a Summary of Economic Impacts in the report on the consequences of dam failure for the scenario under consideration. The report should include:

- Total cost to repair or replace facilities
- Total cost to replace contents
- Total cost of lost employment
- Total sales lost
- Total customer service lost
- Total cost of detours
- Total cost of alternative space

Additional Examples of Indirect Economic Consequences:

- Reduced economic vitality, locally or regionally
- Loss of schools, nursing homes, day-care facilities, or churches
- Reduced tax base or value of properties
- Loss of features that attract new business investment to the area

Assess Consequences

Conducting an assessment of the potential consequences of dam failure is not an exact science. To improve accuracy, consult with various local officials and people with knowledge of the local businesses and industries, the availability of alternative space, opportunities for and obstacles to repairing and replacing damaged structures, and the roadway network.

Step 19

Consider the potential for further economic impacts of the dam failure scenario to assets located outside of the inundation area. Consider the purpose of the dam or critical functions provided by the dam to identify other potential economic effects. Critical functions of a dam typically include some of the following:

- Water supply
- Irrigation
- Recreation
- Hydropower generation
- Flood damage reduction
- Navigation

Identify the critical functions provided by the dam and consider the potential economic effects of having these functions disrupted according to the dam failure scenario. Identify and, if reasonable, quantify these potential economic effects. The following are examples of the economic effects of the loss of critical functions:

- Cost of securing an alternative supply of water
- Crop losses due to lack of water for irrigation
- Decreased value of properties along the lake that the dam created
- Loss of income from tourism due to loss of the lake
- Loss of jobs in businesses such as hotels and restaurants that depend on tourism
- Increased cost of electricity
- Increased flooding downstream
- Impediments to navigation

Step 20

Consider further implications of the identified economic impacts. In some communities, for example, loss of jobs and relocation may eventually lead to economic impacts such as reduced tax revenue and the need to reduce the size of the police force and the number of teachers in public schools. Predicting these far-reaching indirect effects accurately is impossible, as they would be experienced several months to several years after the dam failure and would be caused not only by the dam failure but also by a number of other social and economic variables.

However, additional impacts of consequences that can reasonably be expected to be caused by the dam failure may be identified.

The loss of jobs may lead to the relocation of workers and their families to other communities shortly after the dam failure. This could lead to an increase in the number of vacant housing units locally, which may cause social support networks to fracture and neighbors to feel insecure about the vacant housing units. If these types of consequences are identified, note them in the worksheet in the column for **Social Impacts**.

The rebuilding could have environmental impacts such as increased dust in the air due to the large number of trucks bringing in construction supplies. Detours necessitated by closed roads or bridges could cause incessant noise in formerly quiet neighborhoods. If these types of consequences are identified, note them in the worksheet in the column for **Environmental Impacts.**

7.2 SOCIAL IMPACTS

Social impacts of the dam failure scenario under consideration can range from out-migration of people who have lost jobs to in-migration of workers to help with repair and rebuilding. Social impacts may include a shortage of safe, affordable housing. They may include loss of confidence in public officials and eventually the election of new officials, loss of social cohesiveness, loss of recreational opportunities, decreased level of government-supported community services, and diminished quality of life, as well as identification with new communities and discovery of new social opportunities.

To identify potential social impacts, convene one or more groups of community residents and discuss the potential effects on:

- Housing
- Jobs
- Social organizations
- Recreation
- Culture
- Mental and physical health
- Loss of government service
- Political climate

Begin the process of assessing social impacts by identifying the types of social benefits provided by each asset in the inundation area. The assets providing social benefits may include schools, government buildings, hospitals, parks, residential neighborhoods, and religious centers. The social benefits may include education, recreation, leisure activity, worship, or a home. Identify benefits that would be lost as a result of the dam failure scenario under consideration. For each benefit, ask:

- Would loss of this asset cause people to relocate permanently?
- Would people find alternative locations for receiving this benefit, such as participating in another activity?
- Would people suffer physical health problems due to the lack of this facility?

- Would people suffer mental health effects or anxiety due to the lack of a facility or due to the dam failure? Disruptions of the social fabric, casualties, and destruction, as well as the stress of rebuilding can be traumatic and negatively affect the mental health of some community residents for a long time.
- Would confidence in government diminish? The role of the government is to protect the health and welfare of its citizens. Under a dam failure scenario, public officials could be held accountable because the loss could be perceived as avoidable.

Note that not all social repercussions are negative. For example, new workers may move into the community to secure jobs clearing debris and rebuilding damaged structures and infrastructure. This would offset some of the negative economic impacts identified and would provide opportunities for new social organizations to develop.

List the potential social impacts of the dam failure scenario in the worksheet as shown in Table 13.

Table 13: Potential Social Impacts

Asset	Potential Social Impacts
Reservoir	None identified, as this reservoir is not used for recreation
Single-family home	Residents move to a rental unit
Restaurant	Some employees find alternative jobs in the community
Industry XYZ	50 percent of employees move away from the area to find jobs
Cornfield	Farm closes and family moves away
Single-family home (5 miles downstream)	Negligible
Other Social Impacts	Community would probably elect new community leaders; lack of water would cause hardship for residents and businesses until alternative supply developed; in-migration of workers to help with rebuilding would lead to a shortage in housing

In the example provided, the primary social consequences identified are that 175 employees of Industry XYZ and their families leave the community to find jobs elsewhere, while other workers arrive to assist with debris removal and rebuilding.

Return to the worksheet for critical infrastructure and resources and identify potential economic impacts and social impacts when these critical facilities are unable to function normally. Table 14 illustrates economic and social impacts for critical facilities that are not in the inundation area.

Table 14: Potential Economic and Social Impacts for Critical Infrastructure and Resources

Resource	Anticipated Consequences	Potential Economic Impacts	Potential Social Impacts
Industry ABC	Without water, Industry ABC would close temporarily; about 100 people would be temporarily unemployed	Industry DEF would reduce production as a result of not receiving products manufactured at Industry ABC	Some employees would relocate; some would find other employment near the current location of Industry ABC
Hospital at 76 Water Street	The hospital would evacuate all patients and would close temporarily; about 250 people would be temporarily unemployed	Nearby hospitals would be overcrowded; hospital staff would be hired temporarily by other hospitals	Non-emergency procedures and check-ups may be postponed
Central Distributors	Trucks would be flooded; detours would be needed to reach the Interstate highway	Costs of replacing trucks and additional mileage would be passed along to consumers	New truck traffic in residential neighborhoods

7.3 ENVIRONMENTAL IMPACTS

Identifying the environmental impacts of a dam failure scenario depends heavily on the information gathered regarding assets in the inundation area and the identification of assets with potentially large quantities of pollutants. For example, an industry may store large quantities of hazardous, radioactive, or other types of toxic materials on site. If these materials are stored in containers that would not rupture under the modeled dam scenario, no negative environmental impacts would result. However, if such materials are released and transported by the water, possible impacts might include disruption to wildlife and their habitats.

Positive environmental impacts of a dam failure scenario might, but would not necessarily, include new silt and nutrient deposits on farmland or increased water levels downstream that would improve opportunities for fishing.

Potential environmental impacts should be identified qualitatively through discussions with community stakeholders or resource agencies/groups. They should then be cataloged using the template in Appendix A, and as shown in Table 15.

Examples of Environmental Impacts:

- Pollution resulting from septic system failure, back-up of sewage systems, petroleum products, pesticides, herbicides, or solvents
- Pollution of the potable water supply or soils
- Exposure to mold or bacteria during cleanup
- Changes in land development patterns
- Changes in the configuration of streams or the floodplain
- Erosion, scour, and sedimentation
- Changes in downstream hydro geomorphology
- Loss of wildlife habitat or biodiversity
- Degradation to wetlands
- Loss of topsoil or vegetative cover
- Loss of indigenous plants or animals

Table 15: Environmental Impacts

Asset	Potential Environmental Impacts
Reservoir	Fish in the reservoir would die; the smell of rotting organic matter would generate complaints from people in the vicinity of the reservoir; increased sedimentation downstream; erosion downstream
Single-family home	None identified
Restaurant	None identified
Industry XYZ	Piles of salt would be dissolved into flood waters and would pollute farmland as well as fish habitat downstream
Cornfield	Field would not be arable for at least 2 years
Single-family home (5 miles downstream)	None identified
Other Environmental Impacts	None identified in this example

In the example, environmental impacts include the loss of habitat and clean water previously provided by the reservoir. For certain communities that can place an economic value on an environmental resource (e.g., tourist areas), analyzing this asset from an economic perspective may be more appropriate. Exercise judgment in analyzing similar assets that can be qualified as either environmental or economic impacts.

Other potential environmental impacts of a dam failure scenario to consider:

- Sedimentation
  - Could result from flood waters rushing across land and moving silt, sand, soil, and rocks downstream
  - Could cause sediments to infiltrate and fill water resources, such as ponds and wetlands, and threaten the health of aquatic plants and fish
- Erosion
  - Could contribute to sedimentation as river banks erode due to rushing water
  - Could lead to collapse or undermining of structures or infrastructure
- Thermal effects
  - Changes in the temperature of the water downstream could negatively affect fish and fisheries
  - Deep impoundments could release very cold water, while shallow impoundments could release warmer water

Continue the assessment by identifying potential environmental impacts caused by critical facilities located outside of the inundation area that would be affected by the closure of assets in the inundation area. Table 16 illustrates this step in the assessment of consequences.

Table 16: Potential Environmental Impacts for Critical Infrastructure and Resources

Resource	Anticipated Consequences	Potential Environmental Impacts
Industry ABC	Without water, Industry ABC would close temporarily; about 100 people would be temporarily unemployed	Lack of cooling water may lead to increased contaminant releases until shutdown is complete
Hospital at 76 Water Street	The hospital would evacuate all patients and would close temporarily; about 250 people would be temporarily unemployed	None identified
Central Distributors	Trucks would be flooded; detours would be needed to reach the Interstate highway	Noise in residential neighborhoods due to new truck traffic

Tips for Writing the Consequence Assessment Report

The consequence assessment report should:

- Explain how estimates for cost of repair and replacement were developed
- Explain assumptions made for estimating the number of months required for repair of a structure or infrastructure element and for estimating the number of months that businesses would be closed or homes uninhabitable
- Indicate the source(s) of information used to estimate the number of jobs provided by businesses
- Identify the questions considered to identify social impacts
- Summarize findings or totals for all consequences

SECTION EIGHT IDENTIFY FOLLOW-UP ACTIVITIES

The final step in the methodology is to review the results of the assessment of economic, social, and environmental consequences of the dam failure scenario under consideration and determine what, if any, further studies or actions are warranted.

The assessment will provide a justifiable estimate of the potential loss of life, the potential number of injuries, potential economic costs, and resulting social and environmental impacts that would be endured for a long period of time and be difficult to overcome.

If the dam failure consequences do not indicate enduring negative effects or high costs of repair, no further examination is needed.

If the potential consequences of dam failure suggest the potential for major, negative economic, social, and/or environmental impacts, further study is recommended.

No dam is completely protected from failure. Although the probability of sudden collapse of most of the dams in the United States is close to zero, other types of failure have a higher probability of occurring and would result in downstream damage. The results of the impact assessment could be used to motivate local officials and dam operators to commence any necessary repairs and preventive maintenances, to revise plans (e.g., Emergency Operation Plan, local hazard mitigation plan), or to consider options to mitigate the potential for damage; however, policy officials should refrain from using these results to scare public officials or the general public.

Because dam failure is possible, long-term strategies could be implemented on the basis of this assessment. Proposed long-term strategies might include land-use planning or zoning to steer new development away from the inundation area; adoption of more stringent floodplain management standards in the inundation area, such as requiring that structures be elevated 1 or 2 feet above the potential flood elevation; or the relocation of valuable artifacts or records to locations outside of the inundation area.

By working through the assessment of the consequences of dam failure, a community may determine that the EAP for the dam is outdated or that the warning system is inadequate. In such cases, rather than developing an estimate of the probability and studying the risk of dam failure further, taking immediate action to update plans or improve the warning system might be reasonable.

Identify Follow-Up Activities

Tips for Writing the Consequence Assessment Report

The consequence assessment report should:

- Reiterate that the assessment does not estimate the probability of dam failure
- State that there is no cause for alarm
- Explain how the report will be used

The following are overall recommendations for writing the report:

- Form a committee or include interested and informed stakeholders throughout the assessment process to verify information, validate assumptions, and review findings for reasonableness.
- Ensure that the report explains assumptions made and methodologies used and that it identifies the sources of information consulted.
- Ensure that the report is logical and does not, for example, mention destruction of important wildlife habitat as a potential environmental effect and fail to list the important wildlife habitat as an asset.
- Link assets to consequences and consequences to impacts. Link recommendations for future actions to the results of the assessment.
- Avoid generalizations that cannot be substantiated or justified.
- Write the report so that it can be understood in the future and used as a basis for another assessment of the potential consequences of dam failure using a different scenario or using new data about assets in the inundation area.

SECTION NINE SOURCES OF INFORMATION

Association of State Dam Safety Officials. 2010. Dam Failures and Incidents. Available at http://www.damsafety.org/news/?p=412f29c8-3fd8-4529-b5c9-8d47364c1f3e.

Brown, Curtiss A. and Wayne J. Graham. 1988. "Assessing the Threat to Life from Dam Failure," *Water Resources Bulletin,* Vol. 24, No. 6, pp. 1303

Dunning, M. and S. E. Durden. 2009. *Handbook on Applying "Other Social Effects" Factors in Corps of Engineers Water Resources Planning*. Institute for Water Resources.

Federal Emergency Management Agency (FEMA). 1979. *Federal Guidelines for Dam Safety*. Available at http://www.fema.gov/library/viewRecord.do?id=1578.

FEMA. 2005. *NFIP Floodplain Management Requirements,* FEMA 480. Washington, DC.

FEMA. 2008a. *Prioritization of Dams through Risk Categorization.* Washington, DC.

FEMA. 2008b. *Risk Prioritization Tool for Dams: User Manual*. Washington, DC.

FEMA. 2012. *Federal Guidelines for Inundation Mapping of Flood Risks Associated with Dam Incidents and Failures: Guidance for State Regulators*. Washington, DC.

FEMA. *HAZUS MR5 Flood Model Technical Manual* (undated). Available at http://www.fema.gov/library/viewRecord.do?id=4454. Washington, DC.

International Association for Impact Assessment. 2003. Social Impact Assessment: International Principles. Available at http://www.iaia.org/publicdocuments/special-publications/SP2.pdf.

Jonkman, S. N. 2007. *Loss of Life Estimation in Flood Risk Assessment.*

University of South Carolina, Hazards and Vulnerability Institute. 2012. The Social Vulnerability Index. Available at http://webra.cas.sc.edu/hvri/.

U.S. Army Corps of Engineers. 2009. National Inventory of Dams. Available at http://140.194.76.129/publications/eng-pamphlets/ep360-1-23/entire.pdf.

U.S. Department of Agriculture (USDA). 2003. *A Human Dimensions Framework: Guidelines for Conducting Social Assessments*. Report SRS-65. Available at http://www.srs.fs.usda.gov/pubs/gtr/gtr_srs065.pdf.

USDA. 2011. Geospatial Data Gateway. Available at http://datagateway.nrcs.usda.gov/.

Sources of Information

U.S. Department of Homeland Security. 2011a. *Dams Sector: Estimating Economic Consequences for Dam Failure Scenarios.* Washington, DC.

U.S. Department of Homeland Security. 2011b. *Dams Sector: Estimating Loss of Life for Dam Failure Scenarios.* Washington, DC.

U.S. Department of the Interior, Bureau of Reclamation. 1999. *A Procedure for Estimating Loss of Life Caused by Dam Failure.* Publication No. DSO-99-06. Available at http://www.usbr.gov/ssle/damsafety/Risk/Estimating%20life%20loss.pdf.

APPENDIX A
ASSETS WORKSHEET

Appendix A: Assets Worksheet

Instructions: A worksheet can be developed using a word processing or spreadsheet program. The worksheets below show how rows and columns can be organized to assess the consequences of dam failure. To show all of the columns clearly in this guide, the worksheet for consideration of Assets in the Inundation Area is split into four parts.

Write the type of dam failure scenario across the top of each table so that data for various scenarios are not confused during analysis or when reviewed in the future.

Scenario Description:							
Asset in Inundation Area	Location or Address	Approximate Distance from Dam	Typical Occupancy	Estimated Occupancy for Dam Failure Scenario	Replacement Value	Contents Value	Potential Large Quantity Pollutants
Asset #1							
Asset #2							
Asset #3							
...							

Worksheet Continued								
Asset in Inundation Area	Anticipated Level of Damage for Scenario (High, Medium, Low)	Anticipated Consequences	Damage Factor	Cost of Repair or Replacement (Multiply Replacement Value * Damage Factor)	Cost to Replace Contents (Multiply Contents Value * Damage Factor)	Number of Months to Repair or Replace	Number of Months Closed (for assets that provide jobs)	Number of Jobs
Asset #1								
Asset #2								
Asset #3								
...								

Appendix A: Assets Worksheet

Worksheet Continued							
Asset in Inundation Area	Multiply Months Closed * Number of Jobs	Monthly Sales	Multiply Number of Months Closed * Monthly Sales	Monthly Customers	Multiply Number of Months Closed * Monthly Customers	Monthly Cost of Alternative Space	Multiply months to repair * monthly cost of alternative space
Asset #1							
Asset #2							
Asset #3							
...							
	Total number of months of employment lost Total Months of Employment Lost * Average Monthly Wage = Cost of Lost Employment		Total sales lost		Total service lost		Total cost of alternative space

Worksheet Continued							
Asset in Inundation Area	Number of Months to Repair or Replace	Monthly Trips	Miles in Detour	Cost per Mile	Multiply monthly trips * miles in detour *cost per mile	Potential Social Impacts	Potential Environmental Impacts
Asset #1							
Asset #2							
Asset #3							
...							
						Other Social Impacts:	Other Environmental Impacts:

APPENDIX B
CRITICAL INFRASTRUCTURE AND RESOURCES WORKSHEET

Critical Infrastructure and Resources Worksheet

Instructions: A worksheet can be developed using a word processing or spreadsheet program. The worksheet below shows how rows and columns can be organized to assess the consequences of dam failure on local critical infrastructure and resources linked to assets in the inundation area.

Write the type of dam failure scenario across the top of the worksheet so that data for various scenarios are not confused during analysis or when reviewed in the future.

Scenario Description:						
Resource	Function	Dependency on or Interdependency with Assets in Inundation Area	Anticipated Consequences	Potential Economic Impacts	Potential Social Impacts	Potential Environmental Impacts
Resource #1						
Resource #2						
Resource #3						
…						