ESTIMATING ECONOMIC CONSEQUENCES FROM DAM FAILURE IN THE SAFETY OF DAMS PROGRAM

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This publication is designed to enhance the economic analysis of safety of dams screening studies as part of the agency's effort to maintain dam safety. These studies estimate the total damages that would happen should dam failure occur. As these studies are brief screening studies, usually they do not have funding adequate for in-depth research to determine accurate impacts. Therefore, this document was created to help estimate costs given that other options are not available to provide some algorithms to help with this effort.

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TABLE OF CONTENTS

Estimating Economic Consequences From Dam Failure in the Safety of Dams Program

INTRODUCTION

Public safety is the principal concern of the Safety of Dams (SOD) program within the U.S. Bureau of Reclamation (USBR). If it is determined that there is an unacceptable probability that a dam would fail under certain hydrologic loadings, or under static and dynamic (seismic) loadings, and the failure would result in loss of human life, then SOD corrective actions are justified to the point where there is no significant loss of life. Corrective actions beyond that point must be economically justified. Determination of potential dam failure flood damages and project benefit losses is necessary for those instances in which corrective actions must be economically justified. Also, a summary of potential damages and lost benefits is typically included in USBR's SOD modification reports as additional information in support of corrective actions, even if those actions are justified by potential loss of life.

For instance, assume that loading and failure probabilities are significant enough to be of concern, but also assume that the potential loss of life for any significant level of probability could be addressed with an early-warning system. Then protection beyond any associated costs of the early warning system would have to be justified based on potential economic losses.

This research has the goal of expanding the information set used to estimate economic values without requiring primary data gathering. This expanded information will provide better estimated values in some studies and allow the analyst the opportunity to estimate values for some property types that previously could not be included due to lack of data.

The following discusses economic principles that guide SOD damage analyses, methods used to estimate potential inundation damages and lost benefits, and how those potential losses are converted to risk costs. Following the discussion of economic theory and application methods, an example is presented.

GENERAL DESCRIPTION

Economic Principles

The objective of damage screening studies is to determine the extent to which potential economic losses due to dam failure provide economic justification to expend federal funds to ensure against those losses. If the justifiable expenditure is large enough, a correction may be warranted. On the other hand, if dam failure inundation would not appreciably change flood boundaries and project benefit losses are not substantial, there would be few economic effects, implying little potential economic liability. Also, for floods having very small recurrence intervals, a justifiable expenditure will likely be small unless the replacement cost of damaged property and project economic output is considerable. Scoping the economic analysis should consider these influencing factors to ensure the study and related cost are the minimum necessary to determine the justifiable expenditures. The detail, extent, and type of additional data development should be limited to only what is necessary to provide a reliable damage estimate.

During the process of preparing this document, the Remote Sensing and Geographic Information Group (RSGI) developed a method for identifying assets in greater detail through the use of a graphical computer interface creating a Geographical Information Systems (GIS) dataset. This group has brought together data from the Federal Emergency Management Agency (FEMA), the Environmental Protection Agency (EPA), the U.S. Census Bureau (Census), and other agencies and groups. The results of this work has improved identification of assets. They can provide physical descriptions of most assets that would be inundated. These assets include:

-residential housing data from the 1990 Census block group level (number of units),
-commercial sites, other than schools and hospitals, from FEMA (number of units and total employees),
-hospital data from FEMA and the National Hospital Association,
-industrial site data from FEMA,
-names of downstream, inundated dams from the 1993-94 National Inventory of Dams,
-mileage of inundated roads from the EPA,
-number of inundated highway bridges, from the 1994 National Inventory of Bridges,
-mileage of inundated major utility lines from FEMA,
-rail lines from EPA
-railroad yards of all types from the FEMA database.

The RSGI Group can also provide the total irrigated acres and number of farms for the inundated counties. At this time, they are unable to identify where these irrigated acres are in relation to the flood inundation boundary.

The economic analysis considers the impacts based on a constant dollar assessment. Past and future flows of funds should be adjusted by an appropriate price inflator/deflator to take into account the changes of prices in the economy. Past flows need to be inflated while future flows deflated to the current dollar level. Constant dollars allow the analyst the opportunity to equitably compare expenditures from different time periods. All projected flows of money should be discounted to the present using the current Federal discount rate for water resources development, as specified by law.

In addition, the USBR economic analyses must comply with the guidelines provided by the publication commonly referred to as the "Principles and Guidelines,"[1] a publication from the U. S. Water Resources Council. This document contains detailed guidance on both property damages and project benefits.

Property Losses

An economic analysis report is generally organized into an introduction, inundation damages, lost project benefits, and a derivation of the justifiable expenditure. The introduction to the report describes the dam and other project assets and the consequences of dam failure inundation, including the volume of water flow. This section identifies the communities and the amount of inundation expected within those communities.

The second section identifies the affected property in more detail, including damages that would occur due to loss of residential property, commercial property, public property, and infrastructure. The physical quantities of assets are estimated and a replacement value applied to the assets. Total replacement value is estimated by multiplying the average replacement cost per structure times the number of structures, leading to a total replacement value. Note that the measure of economic loss is replacement cost, not market value. Other costs that could be considered include individual loss of income and government costs required for investigation, training, and other relevant costs in the short run.

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

ESTIMATING ECONOMIC COSTS

Initially, the researcher needs to identify the assets that will be affected by the failure of the dam. In general, this task requires a brief description of the inundation area and identification of the communities to be affected, and a description of assets within this inundation area. The description of the inundation area requires mapping the boundaries of the inundation flood in order to visually identify where the flooding would occur. This mapping might be available from previous efforts or might be available through the effort of the RSGI to map the inundation area as part of the study program.

With the map of the flood inundation area available, the researcher then can begin to identify assets that would be affected. These assets can be described by combining them into two groups. The first group of assets are those other than project assets and include residential property, commercial and industrial property, public property, and infrastructure. Infrastructure includes items such as roads that can be further delineated as highways, primary roads, secondary roads and city streets. Infrastructure also includes railroads, power lines, telephone lines, and other utility structures.

The second group includes those assets that exist because of the project. The first asset will likely be the dam being studied. Damage to the dam would need to be estimated. Other project structures may be damaged such as diversion dams downstream and other structures used in the diversion and storage of water. Also, assets at risk can include power generation stations that would be damaged due to inundation.

Our damage screening studies are performed with minimal time and budget available. Because of this, it is impossible to collect primary data necessary to estimate values (replacement cost) of property. For this reason, a study requires use of whatever data are available. Usually, datasets have been limited to information in Census reports and other government reports unless local sources become available as the study progresses.

Residential and Commercial Structures

Ideally, a survey of all property should be attempted to determine an accurate count of structures and values. However, this is not possible nor economically justified. The gain in accuracy due to additional information from a survey of the inundation area would not justify the extra cost. Therefore, estimation from secondary data remains the preferred method.

Buildings should be valued with an estimate based on depreciated replacement value of the structure with land values identified separately. However, estimating an expected life and depreciated condition would be costly. A proxy for depreciated replacement values of buildings can be found through use of market values. If possible, market values can be obtained from property value assessment data from each county or from average property selling prices obtainable from local realtors. Unfortunately, most county assessors offices tend to be understaffed. Often they are unable to provide the required information. Taxes are assessed based on a percentage of property value. For communities that do not update values annually, cost of living adjustments may be necessary.

Another method is use of the U.S. Census data, which provides an average value for each county. The Census occurs once every 10 years, so these data would need to be adjusted for the cost of living. Even though these data are not current and are county averages, they are often the best information available. However, these data are generally only available for residential properties.

Residential Housing

Often, studies have required the analyst to estimate the number of inundated residential housing units from visual inspection of maps. These maps usually are not up-to-date, compromising accuracy. The RSGI data-set provides a more accurate count of the number of affected units.

The analyst needs to estimate the percentage of damage from flooding to buildings by inspecting the inundation map and trying to determine the level of flow along with the depth of the expected inundation. Structural units that would be in the direct path would likely be completely damaged while those units that stand on the edge of the inundation area would be partially damaged, and other units having damage at some percentage in between. Eventually, the RSGI group may be able to provide some data on flood depths within various sectors of the flood plain. Until then, damage percentage estimates are problematic. Currently, the Corps of Engineers has depth-damage curves[2] that show the percentage of damage likely for different levels of inundation. A copy of depth-damage curves are shown in Appendix B. These curves are a summary of the data presented by the Corps of Engineers within their publication.

[2] U.S. Army Corps of Engineers, Huntsville Division. November 1989. "Urban Flood Economics" Section Titled: "Survey of Depth-Damage Functions".

Loss of residential property includes damages to homes and personal property such as furniture, clothes, and automobiles. Personal property could be estimated as a percentage of the value of the building. The Corp of Engineers' depth-damage curves exist also for personal property. The cost of temporary housing may also be considered.

If Census or realtor data are not available, the researcher could use an estimate of property values based on average values per person estimated from a sample of 145 counties in the Western states[3]. This estimate found that population level could be used to predict residential values with an R^2 of about 81 percent. The resulting equation is:

Residential value = 63,248,184 + 22,337 w person,

with "person" = the population level for the area being inundated.

Because of the large constant term, this equation will predict values for larger population areas more accurately than smaller population areas.

Commercial Sites

Commercial property includes businesses, industries, golf courses, airports, mining operations, etc. These properties are often located near rivers, in areas likely to be inundated. Commercial property includes all the remaining private property other than residential, and may be broken into sub-categories by industry, if necessary. As with residential property, commercial property includes the buildings plus property contained within the structures. The percentage of damage due to inundation depth needs to be considered for these structures as well. Losses to commercial property will also cause loss of incomes to those depending on those businesses. Various government agencies have estimates of wage rates for job categories to aid in this effort. In addition to wage losses, business profit losses should be considered. An estimate of these values can be

[3] All of the counties in Colorado, North Dakota, and Utah. Data from other states were unavailable at the time of this study.

determined from various sources, including past financial documents from the businesses themselves.

Identifying the number of inundated units and value of commercial sites has been the primary need of this project. Unfortunately, limited information is available to fulfill this need. Flooding could lead to a large percentage of economic damage to commercial property as this property makes up a large percentage of property within communities and is often found along flood plains. However, there is some information available for estimating property values of these sites. The RSGI dataset provides a listing of the names of businesses that would be inundated based on the expected inundation area. In addition, this dataset identifies these businesses by distance from the dam in question and provides an estimate of the number of employees working at the identified site.

The dataset from the RSGI group also identifies the SIC[4] code for each business. These are shown on the two digit level and are identified below. The groupings in this tabulation represent the breakdown used in this study.

SIC Code	Industry
01-09	Agricultural Production, Agricultural Industries, Natural Resource Usage
10-14	Mining
15-49	Industrial Production
50-79	Miscellaneous, mostly commercial

[4]A common method classifying businesses or industries by type is the 1987 Standard Industrial Classification (SIC) System, commonly referred to as the SIC Code. It was developed by the US Government in conjunction with US businesses. This system divides virtually all economic activity into divisions that are further broken into numbered major groups. The reference book is the Standard Industrial Classification Manual, 1987, prepared by the Executive Office of the President, Office of Management and Budget, and available through National Technical Information Service.

82	Education
83	Social Services
84	Museum
86	Memberships
87	Professional services
88	Private res.
89	Other services
91-97	Government services

An estimation of commercial values can be determined using an equation estimated from relationships in a sample of commercial properties. This sample was derived from property listings in Larimer County, Colorado. As this was the only county that had computerized listings available at the time of this study that could be matched to data available from the RSGI group, properties from this county were the only ones included in the sample. It was necessary to match properties from the two datasets as each contained vital components used to generate this regression.

There are more than 100,000 commercial and industrial properties in the dataset acquired from Larimer County Assessor's Office. Of these, a sample of 5,438 properties were selected. The remaining 95,000 properties were missing vital data and could not be included. This sample dataset included the property description along with the assessor's valuation estimate. These properties were then matched to data that provided SIC codes along with the number of employees working at the properties. From this sample, a regression was estimated using the number of employees, along with SIC codes as predictor variables. Only two groupings of SIC codes had significant coefficients and these two are included as predictor variables. These groups are "commercial" and the "forties." Commercial group includes all businesses with SIC codes from 50 through 79. Forties group is the group of businesses with SIC codes between 40 and 49. Groups that proved to have non-significant coefficients include agriculture (01 to 09), mining (10 to 14), industrial production (15 to 39), services (80 to 89), and government (90 and above). Specific combinations were also tried but none were significant other than the two mentioned.

The regression equation that resulted from the sample of 5,438 businesses had a very low R^2 of 3 percent. This low value indicates that the equation is likely missing some key variables that predict property values. Unfortunately, other variables that could have been included normally would not be available to the researcher in an analysis of this type. Therefore, use of these variables in the regression would not be useful in estimating property values. The resulting equation uses only three predictor variables, with these three having significant coefficients with a "t-statistic" indicating probability of over 99 percent of being different from zero. The equation is:

Property Value = 249,331 + 10,977wemployees + 769,451wforties + 1,135,023wcommercial

with "employees" = to the number of employees at the site of the business,
"forties" = SIC codes between 40 to 49, and
"commercial" = SIC codes between 50 to 79.

This equation will predict larger areas more accurately than smaller areas. As indicated, it will be a poor predictor of each property value, but in a sample test, predicted property values fairly well in total.

Public Buildings

Another classification of property to consider is public property. Public property includes schools and hospitals, government buildings, and other facilities owned by government entities. Loss of income to employees may be a factor for public property.

The RSGI dataset identifies schools and other buildings along with the number of employees. Unfortunately, no data were available to identify property values for public buildings since public buildings do not pay taxes and they are not sold in real estate markets. There are various publications that identify construction costs for public buildings based on the square footage of each building. The problem with using construction costs is that there is no information available showing square footage of buildings in the inundation zone. Construction costs also fails to include the value of the contents. In the case of public buildings, contents may be more valuable than the structure. For instance, equipment in hospitals is very expensive.

One method for valuing public buildings and contents is to contact the agencies to determine if a guideline exists for space per employee to estimate damage to government buildings. If this method fails and nothing else is available, construction costs can provide a proxy for building values.

Construction Costs for Public Buildings, based on an average of samples[5]:

Type of Structure	Square Foot Size (SQ.Ft.)	Sample Building Cost	Total Cost
High School	$ 113.86	150,000	$ 17.1 million
Middle School	116.40	175,000	20.4 million
Elementary School	116.74	55,000	6.4 million
Senior Citizens Center	102.10	8,200	0.8 million
General Hospital	133.21	107,950	14.4 million
County Jail	181.66	42,000	7.6 million
Urban Library	157.49	15,000	2.4 million
Church with a school	94.74	30,200	2.9 million
Post Office	85.43	7,400	0.6 million
Courthouse	124.71	109,000	13.6 million

Ideally, a researcher could estimate the number of employees relative to the square footage of a building and use the resulting cost per employee as the number of employees as part of the RSGI dataset.

Infrastructure Items

Infrastructure includes miles of highways and other roads, miles of railways, pipelines, utility lines, power generation plants, and sewer systems. Sources for the cost of repair or replacement can be obtained from various sources, including the agencies or businesses responsible for maintenance and building of the structures originally.

Infrastructure Items: **Roads**

The RSGI database provides the mileage of potentially inundated roads, including primary roads such as interstate highways, secondary roads such as state highways, and local roads. This database is more up-to-date than most maps, which was the only previous source of roads that would be inundated. Using this information, the analyst would need to multiply the mileage by the construction cost per mile. Past studies have estimated these costs to range from about

[5] Found at “http://www.buildeval.com/dataindex.html”

$275,000 per mile for secondary and local roads to $1,000,000 per mile for highways. Costs are available from state departments of transportation.

Infrastructure Items: **Railroads**
The RSGI dataset identifies the number of miles of potentially inundated rail lines. Prior to the RSGI dataset, studies were required to measure the mileage of roadbeds on maps using manual methods. The only estimate for railroad bed replacement costs come from the railroads themselves. These are the values used in past studies and these costs have been estimated at more than $1,000,000 per mile in recent years.

Project Benefit Losses
Inundation will likely cause loss of project benefits. The reservoir created by the dam often has primary purpose of providing storage for water used for irrigation, power, and municipal and industrial purposes. These uses would be lost, given the loss of the dam, at least temporarily until a replacement structure is constructed. A major step in evaluating project losses requires estimating whether the permanent loss of project benefits would be greater than or less than the cost of replacing or repairing the dam plus benefit losses during construction. From the calculation of these two values, the lesser of the two choices would be used in the analysis. However, there may be factors other than economics to consider. Management may decide that rebuilding lost facilities is the only option. Given this, then the comparison would not be necessary and repair and replacement of facilities is the only option for analysis. Repair of facilities would include the cost of rebuilding the dam and associated structures, plus canals, diversion dams, and other structures that would be damaged.

As projects provide irrigation, power generation, municipal and industrial water, and flood control, each of these categories will need to be considered. Measuring damages takes into account the length of time that the losses would occur, along with the level of damage. For example, irrigation benefits represent a gain to agricultural output due to the addition of water to farms. It may take a few years for the facilities to resume delivering irrigation water after inundation. During the years that the water is not delivered, farmers' production is decreased, resulting in loss of project benefits. If the project's assets are not repaired, then these losses need to be determined for the remaining life of the project.

Project Benefit Losses: **Dam Replacement Costs**
Flood losses may entail loss of downstream dams in addition to the dam at the reservoir. Based on the assumption that these dams would be replaced, along

with the dam that failed, an estimate of the replacement cost is necessary. If the dam is not too old and original construction costs are available, it may be possible to estimate replacement costs by application of a construction cost index.

Many factors go into estimating cost of construction. For this purpose, a base estimation of dam replacement cost will be considered. Adjustments will be necessary for factors such as power stations, additional construction needs, and other structural components beyond the basic dam. Some previous studies have had estimates of repair costs determined by qualified personnel. Based on these estimates of dam repair costs, a regression was estimated. This regression used the size of the reservoir as the independent variable. The coefficient estimated was .13965 with a t-statistic of 2.49, indicating that this is a significant coefficient. The R^2 was about 47 percent in this equation indicating high level of predictability. The resulting equation was:

$$\text{Replacement Cost} = 17.6065 + .13965\text{wKAF},$$

with the cost in millions of dollars and
KAF = thousand acre feet of reservoir storage.

This equation would predict a replacement cost of about $87.5 million for a reservoir with 500,000 acre-feet of storage. This equation could be used when direct cost data is unavailable.

Project Benefit Losses: **Irrigation Benefits**
Economic benefits would be lost because project waters would not be diverted to agricultural producers during the time necessary to repair the damage. Assuming dam replacement, these benefits would be estimated by determining what crops are produced on project lands and estimating the economic value of these crops. Much of this information can come from the annual Reclamation Summary Statistics[6] or from other sources. This estimate would require identifying the average value of crop output (less the value of crops that could be grown on unirrigated land) from irrigated land that would be unavailable due to loss of the identified dam.

[6] The latest annual issue was published in 1992.

After estimating the net value of crop output per acre of land, the researcher needs to estimate the average acre-feet of water delivered to each acre. Dividing the crop output value by the average volume of delivered water determines a value for an acre-foot of water from the project. Then multiplying the value per acre-foot of water times the volume of water that would be lost due to dam failure gives the annual economic loss. The researcher would need to determine the present value of annual economic losses for as long as the project would be unavailable for water delivery. Usually, the analyst estimates that the replacement construction would take about 3 years.

Damages can include loss of output from agricultural and other lands not part of the irrigation project. Much of land that lies along rivers is prime agricultural land. Generally, the loss due to inundation of farmland equals the net value for the crops that would have been grown on the land while the land is out of production. In addition, farm structures, farm equipment, and other assets that are lost need to be recognized. If flooding is severe, damages could include loss of farmland, if that land cannot be recovered.

Project Benefit Losses: **Municipal Water**
Project water is also used as a source for municipal and industrial water supply. Project records can supply the volume of water used by these end users. Water rates for the region in question should be available. As with irrigation water, the volume of water times the value of replacement water provides a total annual loss. The present value estimation then provides the total loss due to dam failure.

Project Benefit Losses: **Recreation**
Loss of the reservoir would reduce recreation opportunities. Fishing, camping, motor boating, and picnicking are examples of the activities that occur at reservoirs. An estimate of the total dollar value of loss is equal to the number of visitor-days of recreation at the site times the economic value per visitor-day. This total value would likely be estimated on an annual basis, requiring a determination of the number of years before recreation would resume. This number of years is either the length of time to repair the project or the remaining life of the reservoir if the project is not to be repaired.

The amount of recreation available as a result of the reservoir can be substantial[7].

[7]It could be suggested that some or all of the recreation days lost at a reservoir will be replaced with other activities at other sites. However, as these are screening studies, the

Estimates of economic value per visitor-day for the activities affected can be determined with a benefits transfer technique unless a recent estimation of economic value for the sites are available. Because determining values using benefits transfer is a lengthy process and many guides exist, that information will not be repeated here. The researcher does need to remember to index the result to the current year, as benefits transfer uses values from previous years in the estimation process. The value estimated using benefits transfer method needs to be in the same units per visitor as the quantity measurement, usually a visitor day or visitor trip.

Besides the economic value per visitor that would be lost, the number of visitor days or trips need to be estimated. The agency that manages the recreation sites can provide some estimate of numbers of users annually. The net loss would need to be determined and this loss in visitor days or trips multiplied by the appropriate economic value gives an estimate of the total annual loss to recreation. As before, the present value would be necessary.

Project Benefit Losses: **Flood Control Benefits**
If an estimate exists showing the annual flood control benefits contributed by the project, then this value would be used. Often no one has estimated flood control benefits for this project, or for this dam. If annual benefit are used, the present value would be necessary, for the length of time repairs would be necessary.

The researcher then adds the present value of all the project benefits calculated. The value used in the study would be the lesser of (a) either dam replacement costs plus lost benefits during re-construction or (b) lost project benefits for the remaining life of the project assuming that the dam would not be replaced.

Justifiable Expenditure
If necessary, a justifiable expenditure value is determined. The justifiable expenditure is an estimate of the amount that can be spent to prevent inundation damages and loss of project benefits based on the probability of flood occurrence. This process uses the pre-determined probable maximum flood (PMF) percentages to estimate the probability of flooding. The justifiable expenditure is based on the median annual flood probability for the interval which is that percentage of flows that would cause overtopping to the maximum PMF. This is computed by subtracting the median probability of the PMF from the median

substitution effects are ignored in this type of analysis since the dollar amount will be relatively small.

probability of a flood of that percent of the PMF that would cause overtopping. This results in an annual probability of a certain value for the flood interval. Application of this probability to estimated total economic losses provides an estimate of the annual justifiable expenditure. The annual justifiable expenditure is then capitalized over the estimated remaining life of the project to derive the total justifiable expenditure.

EXAMPLE STUDY

In the appendix is the economic analysis that was performed on Horsetooth Reservoir Dam located in Larimer County, Colorado, performed in the Fall 1998 providing an estimate of potential damage equal to $6,023.4 million. This analysis was based on secondary data only, with no fieldwork performed. This analysis had the benefit of using the dataset available from the RSGI group, providing detailed descriptions of assets in the area of inundation. This example will be estimated item by item and compared to the results in the original study.

The introduction of the report indicates that Horsetooth Dam is located just west of the City of Ft. Collins, Colorado, and is part of the Colorado/Big Thompson Project in northern Colorado. Horsetooth Dam is one of four dams that help create Horsetooth Reservoir, which has a capacity of about 151,000 acre-feet of water. This reservoir provides water for irrigation, municipal use, and recreation, among other uses. The inundation area follows the Cache la Poudre River and the South Platte River as they flow northeast from Ft. Collins to Ft. Morgan, Colorado. The report further indicates that failure of Horsetooth Dam would result in damage for about 87 miles downstream.

The researcher would need to keep in mind that these estimates are approximate and the study assumed that most properties would experience substantial damage. Areas close to the dam would have flows of a velocity and depth sufficient to destroy all the structures. At reaches more distant from the dam, structures may remain standing after the flood subsides. However, these structures would likely be filled with sediment and suffer interior damages. The level of repairs would likely equal the cost of the structure. Most communities farther from the dam sit in lower areas and could receive at least four-foot depths of water during the crest of the flows. Water levels of those depths are assumed to cause substantial damage in this analysis.

Residential Property

Residential property losses were determined from Census data which included the number of residences and average values of properties. The Census data indicates that there are 31,198 residences within the inundation boundaries, generating an original estimate totaling about $1,971.1 million. According to the inundation maps, a Horsetooth Dam failure would severely damage or destroy all or parts of the towns of Ft. Collins, Timnath, Windsor, Greeley, Kersey, Hardin, Masters, Orchard, Goodwin, and Weldona, along with other communities in Larimer and Weld Counties.

Using the equation generated in this research to estimate property values requires knowledge of the number of persons living in the inundation area. As there are about 31,000 residences, and assuming an average size household of 2.71 persons[8], there would be about 84,000 persons living in the area. Inputting this data into the equation shown on page 6, the result is $1,939.8 million, a little lower than the original estimate, but within 5 percent of the original estimate of $1,971.1 million.

Commercial Property

The RSGI provided a listing of the commercial properties that are within the inundation boundaries. The list contains about 2,700 individual businesses that would be affected. These businesses employ approximately 31,000 employees and a summary is shown below aggregated into groups:

60 agricultural businesses with 599 employees,
1,727 commercial businesses with 13,777 employees,
159 government facilities with 4,858 employees,
71 health facilities with 936 employees,
584 industrial production facilities with 10,116 employees,
13 mining operations with 116 employees, and
58 recreation facilities with 510 employees.

The original study estimated that these facilities would cost $3,143.4 million to replace. This estimate was based on the number of employees within each business and assuming that each employee has to provide a level of value to the business at least equal to the cost of labor, using the economic theory of derived demand.

Using the regression estimated in this research as shown on page 9, each property identified by the RSGI database had a value estimated for it. In addition to the constant term, the number of employees for the firm was multiplied by the coefficient in the equation on page 9, and the result from these two terms added to the result of multiplying the coefficient for commercial firms times one for those firms with SIC codes within the range of 50 to 79. There were no firms identified

[8] Average household size for Larimer and Weld Counties, Colorado, per Census Data.

as having SIC codes between 40 and 49, so the coefficient for "forties" variable was not used in this estimation. The resulting sum is $2,957.8 million. This value is very close to the original estimate.

Public Property

The RSGI data showed that 30 schools with 4,274 employees are within the inundation boundaries. Most of these schools are elementary and high schools, with the University of Northern Colorado being one of the schools that would be partly inundated. It was estimated that damages at these schools would total about $427 million based on the amount of property necessary to accommodate 4,274 employees.

Assuming the estimate of $427 million to be correct allows one to work backwards through the data. Based on the data on page 10, assuming about $115 per square foot in construction costs implies that there would be about 869 square feet per employee within a school. Assuming that employees sit in offices and work, 869 square feet would be higher than expected. For schools, assuming many of these employees are teachers and classrooms hold 20 to 40 students, with hallways, storage areas and workrooms, 869 square feet per employee may seem reasonable. This would imply that each employee represents about $100,000 of value when estimating the value of a school. There is currently no way to test or verify this conclusion.

Infrastructure

The original study for Horsetooth Dam assumed that values for infrastructure were partially based on unit values obtained from other recently completed safety of dams studies. Mileages for the various categories were provided by RSGI data. It is assumed that damages would be 100 percent within the first 10 miles with partial damages farther from the dam.

	Miles	Replacement Cost
Local Roads	300	$ 79.7 million
Secondary Roads	69	36.6 million
Primary Roads	46	43.1 million
Railroad Tracks	78	23.6 million
Total		$183.0 million

No improvement for estimating value has been determined for these assets.
Original totals from the report in the appendix are as follows:

Residential property, about 31,000 residences	$1,971.1 million
Commercial property, about 2,700 businesses	3,143.4 million

Public property, about 30 schools	427.0 million
Total Infrastructure	183.0 million
Total Estimated Flood Inundation Damages	$5,724.5 million

From the methods described in this report, values are estimated as follows:

Residential property, about 31,000 residences	$1,939.8 million
Commercial property, about 2,700 businesses	2,957.8 million
Public property, about 30 schools	427.0 million
Total Infrastructure	183.0 million
Total Estimated Flood Inundation Damages	$5,507.6 million

Project Benefit Losses
Benefits provided by Horsetooth Reservoir include irrigation, municipal water supply and recreation and would not be affected by this research. These totals, originally estimated, are shown below.

Project Benefit Losses: Irrigation
Estimate based on data from the "1992 Reclamation Summary Statistics," water impounded behind Horsetooth Dam produce an average value of about $500 per acre. Assuming annual irrigation requirements of 1.25 acre-feet of water per acre delivered from this project, the value of irrigation water provided from Horsetooth would be about $400 per acre-foot, so that the total annual values were estimated as follows:

100,000 acre-feet x $400 / acre-foot = $ 40 million

Project Benefit Losses: Municipal Water
Outlets at the reservoir supplies water to Ft. Collins, Greeley, Colorado State University, and other water districts. Wholesale water rates in Northern Colorado average about $400 per acre-foot. Therefore, the lost value would be about

50,000 acre-feet of water @ $400 = $20 million

Project Benefit Losses: Recreation
Using benefits transfer approach, a weighted average value for activities at Horsetooth Reservoir was about $22 per visitor-day. This reservoir was estimated to support an annual average of 500,000 visitor-days of recreational activities, according to the Larimer County Parks Department. Total potential annual recreation losses for these lakes are thus computed as follows:

500,000 visitor-days x $22 per visitor-day = $ 11.0 million

All flood inundation damages and benefit losses are computed at a common point in time, in this instance the point of dam failure. Therefore, the losses, which take place after the year of dam failure, are discounted to that point, as is shown below. Accordingly, total losses in irrigation, municipal, and recreation benefits over the dam reconstruction period are discounted to the point of dam failure, assuming 3 years for reconstruction. These benefit losses are summarized as follows:

Irrigation losses in year of flood =	$ 40.0 million
Irrigation losses during reconstruction of dam = $ 120 million x 2.6303 [9] =	$ 105.2 million
Municipal water losses in year of flood =	$ 20.0 million
Municipal water losses during reconstruction of dam = $ 20 million x 2.6303 [1] =	$ 52.6 million
Recreation losses in year of flood=	$ 11.0 million
Recreation losses during dam reconstruction = $ 11 million x 2.6303 [1] =	$ 28.9 million
Total Estimated Benefit Losses Due to Dam Failure =	$ 257.7 million

Project Benefit Losses: Dam Replacement Costs
Current costs to replace Horsetooth Dam were estimated based on estimates from previous safety of dams studies. Other structural damages (irrigation canals, diversion dams, etc.) have not been added to this estimate. Assuming equal annual expenditures over a 3-year construction period, costs for reconstruction are summarized as follows:

[9] Present worth of 1 per period for 3 years @ 6.875%.

Total costs for Horsetooth Dam replacement based on the equation on page 12 equals $38.7 million

Present worth of construction expenditures:

$ 38,700,000/ 3 x 2.6303[1] =	$ 34.0 million

Summary of Flood Inundation Damages and Lost Benefits
The following summarizes the estimates of total damages and lost project benefits due to dam failure using the techniques described in this research:

Total Estimated Flood Inundation Damages -	$ 5,507.6 million
Flood Year Benefit Losses and Present Value of Benefit Losses During Reconstruction - (Irrigation, Municipal, and Recreation)	257.7 million
Present Value of Dam Reconstruction Costs -	34.0 million
Total Estimated Incremental Losses Due to Failure of Horsetooth Dam -	$ 5,799.3 million

This compares closely to the original report estimate of about $6,023 million.

CONCLUSION
The goal of this project was to find data that might improve estimates of economic damage screening studies used to estimate justifiable safety of dams expenditures. These studies are often hampered by missing or questionable property value data.

This research was able to expand the information set used to estimate economic values without requiring primary data gathering. Data to be used in these studies are difficult to acquire. That data which were found were used to enhance the ability to estimate property values as required by the program. One success was the improvement in estimating commercial values. These values were often impossible to find in past studies.

The RSGI work was incorporated into this project and databases as part of the methods used for analysis. As long as the RSGI group is able to provide these datasets, this research will be able to coordinate and integrate their information with our work. This coordination and integrations should help improve the accuracy and reduce cost of the analysis.

APPENDIX A:

Economic Consequences of Dam Failure
and Justifiable Expenditures
Safety of Dams Program, Horsetooth Dam, Colorado
November 1998

Economic Consequences of Dam Failure
and Justifiable Expenditures
Safety of Dams Program, Horsetooth Dam, Colorado
November 1998

INTRODUCTION

Estimates of economic consequences resulting from dam failure consist of two categories: (1) flood inundation damages and (2) lost project benefits. Flood inundation damages impact infrastructure, residential and commercial property, and public works. Project benefit losses are limited to the lesser of (a) dam replacement costs plus lost benefits during construction or (b) assuming no dam replacement, lost project benefits for the remaining project life.

FLOOD INUNDATION DAMAGES

Horsetooth Dam is located just west of the city of Ft. Collins, Colorado, and is part of the Colorado/Big Thompson Project in Northern Colorado. Horsetooth Dam is one of four dams that help create Horsetooth Reservoir, which has a capacity of about 151,000 acre-feet of water. This reservoir provides water for irrigation, municipal use, and recreation among other uses. The inundation area follows the Cache la Poudre River and the South Platte River as they flow northeast from Ft. Collins to Ft. Morgan, Colorado.

Failure of Horsetooth Dam would result in damage for about 87 miles downstream. Flood inundation would impact residential, commercial, and public property, and infrastructure throughout the area including several communities. Infrastructure includes major roads, streets, railroads, electric power lines, and telephone lines.

These estimates are approximate and assume that most properties would experience substantial damage. Areas close to the dam would have flows of a velocity and depth sufficient to destroy all the structures. At reaches more distant from the dam, structures may remain standing after the flood subsides. However, these structures would likely be filled with sediment and suffer interior damages.

The level of repairs would likely equal the cost of the structure. Most communities farther from the dam sit in lower areas and could receive at least four-foot depths of water during the crest of the flows. Water levels of those depths are assumed to cause substantial damage in this analysis.

Residential property. Residential property losses were determined from Census data which included the number of residences and values of these properties. According to the inundation maps, a Horsetooth Dam failure would severely damage or destroy all or parts of the towns of Ft. Collins, Timnath, Windsor, Greeley, Kersey, Hardin, Masters, Orchard, Goodwin, and Weldona, along with other communities in Larimer and Weld Counties. These data show the number of properties that are within the inundation boundaries and the average value of the properties. These values were then doubled to reflect personal property that would be lost but not counted as part of the Census values. The Census data indicates that there are 31,198 residences within the inundation boundaries. Therefore, damage estimates total about $1,971.1 million.

Commercial property. The RSGI provided a listing of the commercial properties that are within the inundation boundaries. The list contains about 2,700 individual businesses that would be affected. These businesses employ approximately 31,000 employees and a summary is shown below aggregated into groups below:

60 agricultural businesses with 599 employees,
1,727 commercial businesses with 13,777 employees,
159 government facilities with 4,858 employees,
71 health facilities with 936 employees,
584 industrial production facilities with 10,116 employees,
13 mining operations with 116 employees, and
58 recreation facilities with 510 employees.

It is estimated that these facilities would cost $3,143.4 million to replace. This estimate is based on the number of employees within each business and assuming that each employee has to provide a level of value to the business at least equal to the cost of labor. While this method of estimation will likely understate the total value of the business, it is at least comparable to other methods available.

Public property. The RSGI data also show that 30 schools with 4,274 employees are within the inundation boundaries. Most of these schools are elementary and high schools, with the University of Northern Colorado being one of the schools that would be partly inundated. It is estimated that damages at these schools would total about $427 million based on the amount of property necessary to accommodate 4,274 employees.

Infrastructure. Values for infrastructure were partially based on unit values obtained from other recently completed safety of dams studies. Mileages for the various categories were provided by RSGI data. It is assumed that damages would be 100 percent within the first 10 miles with partial damages farther from the dam.

Asset	Miles	Replacement Cost
Local Roads	300	79.7 million
Secondary Roads	69	36.6 million
Primary Roads	46	43.1 million
Railroad Tracks	78	23.6 million
Total		183.0 million

Summary Statistics:

The table below summarizes the total flood damages described above:

Residential property, about 31,000 residences	1,971.1 million
Commercial property, about 2,700 businesses	3,143.4 million
Public property, about 30 schools	427.0 million
Total Infrastructure	183.0 million
Total Estimated Flood Inundation Damages	5,724.5 million

PROJECT BENEFIT LOSSES

Benefits provided by Horsetooth Reservoir include irrigation, municipal water supply and recreation.

Irrigation. According to 1992 Reclamation Summary Statistics (RSS), waters impounded behind Horsetooth Dam are used to furnish irrigation water to thousands of irrigable acres, producing corn, hay, beans, and onions, and other products, with an average value of about $500 per acre. Based on the acre-feet annually delivered from the reservoir on average, considering reuse of return flows, about 100,000 acres benefit from this water. Assuming annual irrigation requirements of 1.25 acre-feet of water per acre delivered from this project, the value of irrigation water provided from Horsetooth would be about $400 per acre-foot, so that the total annual value would be as follows:

100,000 acre-feet x $400 / acre-foot = $ 40 million

Municipal Water. Outlets at the reservoir supplies water to Ft. Collins, Greeley, Colorado State University, and other water districts. In the event of loss of the dam reservoir, substitutes to this water supply would be needed in order for these communities to continue to supply residents with water. Wholesale water rates in Northern Colorado average about $400 per acre-foot.

50,000 acre feet of water @ $400 = $20 million

Recreation. Horsetooth Reservoir with the surrounding land support an annual average of 500,000 visitor-days of recreational activities, according to the Larimer County Parks Department. Primary activities are camping, motor boating, fishing, and hiking. The weighted average value of these activities is about $22 per visitor-day, based on values for the primary activities, as taken from the U.S. Department of Agriculture publication entitled "The Net Economic Value of Recreation of the National Forests: Twelve Types of Primary Activity Trips Across Nine Forest Service Regions." The values in that publication are at a 1986 price level and were indexed to present price levels using the Gross National Product price inflator. Total potential annual recreation losses for these lakes are thus computed as follows:

500,000 visitor-days x $22 per visitor-day = $ 11.0 million

All flood inundation damages and benefit losses are computed at a common point in time, in this instance the point of dam failure. Therefore, the losses, which take place after the year of dam failure, are discounted to that point, as is shown below. Accordingly, total losses in irrigation, municipal and recreation benefits over the dam reconstruction period are discounted to the point of dam failure, assuming three years for reconstruction. These benefit losses are summarized as follows:

Irrigation losses in year of flood =	$ 40.0 million
Irrigation losses during reconstruction of dam = $ 120 million x 2.6303 [10] =	$ 105.2 million

[10] Present worth of 1 per period for 3 years @ 6.875%.

Municipal water losses in year of flood =	$ 20.0 million
Municipal water losses during reconstruction of dam = $ 20 million x 2.6303 [1] =	$ 52.6 million
Recreation losses in year of flood=	$ 11.0 million
Recreation losses during dam reconstruction = $ 11 million x 2.6303 [1] =	$ 28.9 million
Total Estimated Benefit Losses Due to Dam Failure =	$ 257.7 million

DAM REPLACEMENT COSTS

Estimated current costs to replace Horsetooth Dam were estimated based on estimates from previous safety of dams studies. Other structural damages (irrigation canals, diversion dams, etc.) have not been added to this estimate. Assuming equal annual expenditures over a 3-year construction period, costs for reconstruction are summarized as follows:

Total costs for Horsetooth Dam replacement = $ 47 million

Present worth of construction expenditures:

$ 47,000,000/ 3 x 2.6303[1] =	$ 41.2 million

SUMMARY OF FLOOD INUNDATION DAMAGES AND LOST BENEFITS

The following summarizes the estimates of total damages and lost project benefits due to dam failure:

Total Estimated Flood Inundation Damages -	$ 5,724.5 million
Flood Year Benefit Losses and Present Value of Benefit Losses During Reconstruction - (Irrigation, Municipal, and Recreation)	257.7 million
Present Value of Dam Reconstruction Costs -	41.2 million

Total Estimated Incremental Losses Due to Failure of Horsetooth Dam -	$ 6,023.4 million

APPENDIX B:

Examples of Depth-Damage Curves as Presented by the Corps of Engineers in: "Urban Flood Economics" November 1989

MISSION STATEMENTS

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

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