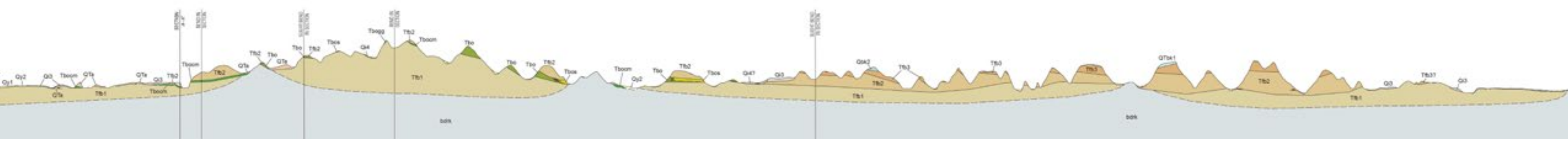
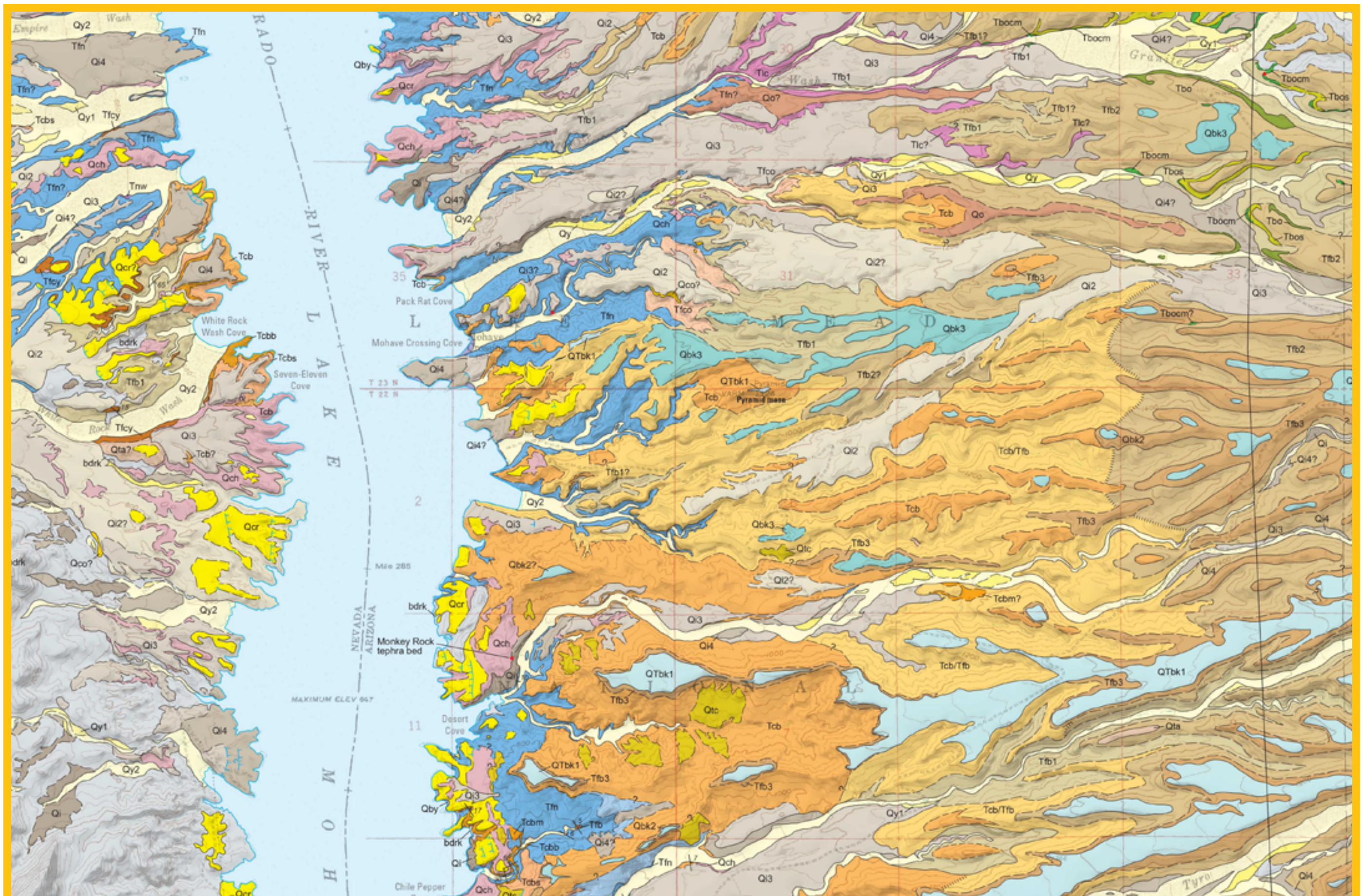
Economic Analysis of the Costs and Benefits of Geological Mapping in the United States of America from 1994 to 2019



Richard C. Berg and
James E. Faulds, Editors



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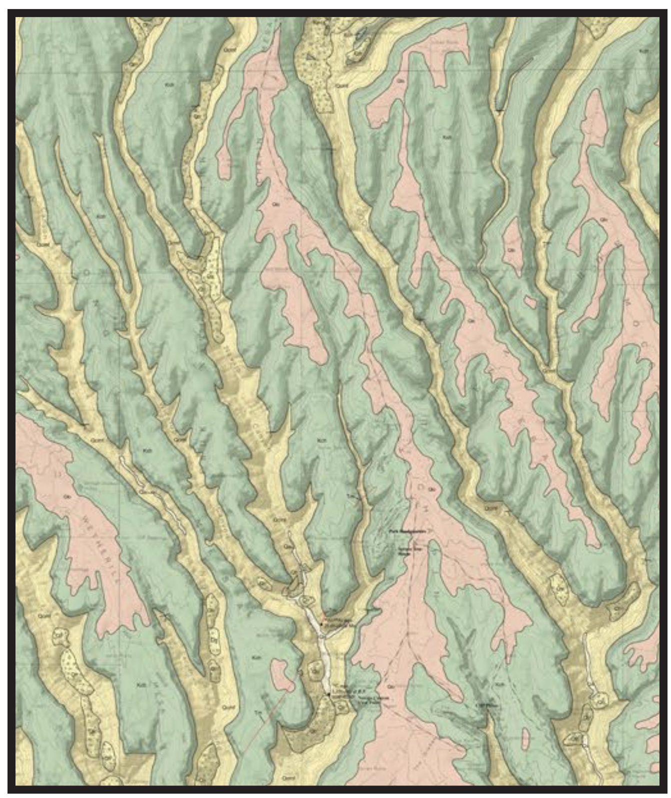
Front cover: Portions of map:
House, P.K., Crow, R.S., Pearthree, P.A., Brock-Hon, A.L., Schwing, Jonathan, Thacker, J.O., and Gootee, B.F., 2020, Surficial geologic map of the Spirit Mountain SE and part of the Spirit Mountain NE 7.5′ quadrangles, Nevada and Arizona: USGS Scientific Investigations Map SIM-3448, scale: 1:24,000.

ACKNOWLEDGMENTS

This project was awarded to the Nevada Bureau of Mines and Geology (NBMG) at the University of Nevada, Reno. It was funded by the U.S. Geological Survey (USGS) under Award Number G19AC00417. We thank John Brock and Kevin Gallagher of the USGS for securing funding for this project, Michael Marketti of the USGS for administrative support throughout the project, and Dave Soller for insights and implementation of the National Geologic Map Database. In addition to the co-editors of this report (Richard Berg and James Faulds), several individuals provided valuable guidance for this study by serving on the steering committee, including Rich Bernknopf, Steve Masterman, John Parrish, David Spears, and Nick Tew. John Parrish also provided constructive reviews of several chapters that significantly improved the report. We greatly appreciate Eli Mlawsky of the NBMG for organizing the nearly 4,800 responses to the stakeholder questionnaire, including the many narrative answers, into one massive spreadsheet that greatly facilitated data analysis. Eli also organized the cost sheets from the State Geological Surveys and the USGS. Thanks to the efforts of Margo Regier, the National Academies of Sciences, Engineering, and Medicine who organized an ad hoc meeting of experts that provided individual expert opinions on the preliminary report. Individual participants' responses and feedback on the preliminary report were provided orally. Invited experts included Yusuke Kuyawama, University of Maryland, Baltimore County; Tim Haab, The Ohio State University; John Whitehead, Appalachian State University; Øystein Nordgulen, Geological Survey of Norway; David Schofield, British Geological Survey; Vanessa Bateman, U.S. Army Corps of Engineers; Krystle Pelham, New Hampshire Department of Transportation; Katherine Ensor, Rice University; Suparna Das, Center for Behavioral Health Statistics and Quality. Although the experts provided many comments and suggestions, they were not asked to provide written reviews of the report, nor to endorse its methods or conclusions. Thanks also go to Sayali Mohite and Jack Marshall, University of Illinois students, who helped develop the initial search for data collection and then data organization. A special thanks is extended to all of the State Geological Surveys who provided cost and geological map download, view, and sales data, as well as disseminated the ~81,000 questionnaires to their stakeholders. Finally, we thank Kathy Henry of the Illinois State Geological Survey for assisting with stakeholder identification, Christina Clack of the NBMG for layout/typesetting of the review copy of the report, and John P. Rasanen and Brenna Tobler of the American Geosciences Institute for final copy editing and publication.



Portion of: Carrara, P.E., 2012, Surficial geologic map of Mesa Verde National Park, Montezuma County, Colorado: USGS Scientific Investigations Map SIM-3224, scale 1:24,000.

► Table of Contents

EXECUTIVE SUMMARY

Geological maps convey the composition, spatial relationships, and age of rocks and structures at, near, and below the Earth's surface. They have a wide spectrum of applications ranging from mitigating the effects of natural hazards, enhancing public safety, facilitating environmentally sound economic development of Earth resources, and resolving fundamental research questions regarding the evolution of Earth's physical environment. Notably, geological maps produced by State Geological Surveys (SGS) and the U.S. Geological Survey (USGS) are viewed as a public good, are a vital component of the Nation's information infrastructure, are available and accessible to all, and can be used by many at the same time without being "consumed". They commonly remain for decades as the "best available data" and can be used multiple times by many stakeholders for numerous applications. Therefore, their benefits to society are cumulative, and geological maps generally accrue their value to society over a long timeframe. However, despite their importance, there have been very few quantitative analyses of the actual costs and, more importantly, the resultant benefits of geological maps.

This report provides the first economic analysis of geological mapping conducted for the entire United States. Globally, this is the largest and most comprehensive jurisdictional economic assessment for geological mapping ever conducted. It is timely given substantial investment by the federal government in geological mapping since the early 1990s, with significantly enhanced funding since 2019. An important question is the degree to which this public investment has yielded tangible results. Four different approaches were employed to analyze the costs, benefits, and economic impacts of geological mapping, and all consistently demonstrated large returns on investment and significant societal benefits.

Costs dedicated to geological mapping were gathered from SGS and the USGS for the period 1994 to 2019. The USGS provided most of the geological map funding to SGS through the National Cooperative Geologic Mapping Program (NCGMP), with SGS commonly exceeding the matching USGS grants. Funding from other federal, as well as state, local, and private sources also supported geological mapping by many SGS. Total spending for geological mapping by SGS and the USGS from 1994 to 2019 was $1.99 billion in 2020 dollars. Data were also collected from SGS and the USGS on mapping accomplished at various scales and types of available derivative maps. Geological maps can be large (1:62,500 or more detailed), medium (e.g., 1:100,000), or small scale (1:500,000 or less detailed). Greater coverage has been accomplished at small scales. SGS generated 73 different types of derivative maps (e.g., maps focused on a specific natural resource or hazard).

Estimating the total number of maps used (e.g., downloaded or sold) during the 1994–2019 project period was critical for evaluating the cost effectiveness of geological mapping. The project period experienced a rapid decline of geological map sales, as paper copies were increasingly replaced by digital maps. Thus, geological map demand over the project period was based primarily on numbers of map downloads and online views, as provided by 24 SGS. A complicating factor was the interaction of robots, or "bots", which can make websites appear more popular than reality. Data from nine SGS and the USGS were employed to evaluate bot activity and develop a conversion rate of 3.32% to estimate what percentage of online web page views resulted in transactions. Considering numbers of reported downloads, views equal to downloads, application of the conversion rate, and paper maps purchased by the reporting SGS and the USGS, as well as extrapolation to those SGS unable to report such data, more than 7.1 million maps were downloaded or sold in the project period.

A challenging task was assessing the "returns" on the mapping investments, because as a "public good", geological maps, data, and reports, are not sold at prices determined by market demand and supply in contrast to "private goods". Thus, a questionnaire was developed to solicit information on the willingness to pay and perceived benefits of geological mapping. This questionnaire was sent to more than 81,000 stakeholders, who were map users or who could reasonably be expected to benefit from geological information portrayed on the maps. Questions were intended to (1) obtain respondent background; (2) gather information on preferences for geological mapping; (3) acquire quantitative estimates of geological map value in monetary terms and time saved; and (4) collect qualitative/descriptive input on the benefits of geological maps. Responses were received from 4,779 individuals and all 50 states. Many respondents worked in multiple states. About 63% worked in the private sector and 37% in the public sector. Nearly every industry, economic sector, and activity related to the environment and geosciences are represented in this study. About 81% of respondents indicated a preference for large-scale maps, with 37% preferring 1:24,000-scale maps and 35% favoring more detailed maps.

Several approaches were utilized to assess the monetary value of geological maps, and all indicated high returns on investment. The first was based on questionnaire responses about (1) money and time saved because maps were available from SGS and the USGS at little or no cost; (2) willingness to pay for a map; and (3) estimates of the long-term value of geological maps. Median project time and cost savings were 20% and 15%, respectively. The median value per map use ranged from ~\$11,000 to \$18,000, with a long-term median of ~\$10,000. Median amounts for willingness to pay and expected to pay were similar at \$3,000 and \$2,883, respectively. Using the most conservative median amount for expected to pay per map (\$2,883), the cumulative value of the actual maps downloaded and sold (>4.8 million) together with the extrapolated amounts (>7.1 million) ranges from \$13.9 to \$20.6 billion. Based on these results and the \$1.99 billion cost (in 2020 USD) of producing the geological maps from 1994–2019, the most conservative cumulative monetary value of maps ranges from ~7 to more than 10 times higher than the production cost, with maximum value estimates ranging between ~23 to 35 times the expenditure.

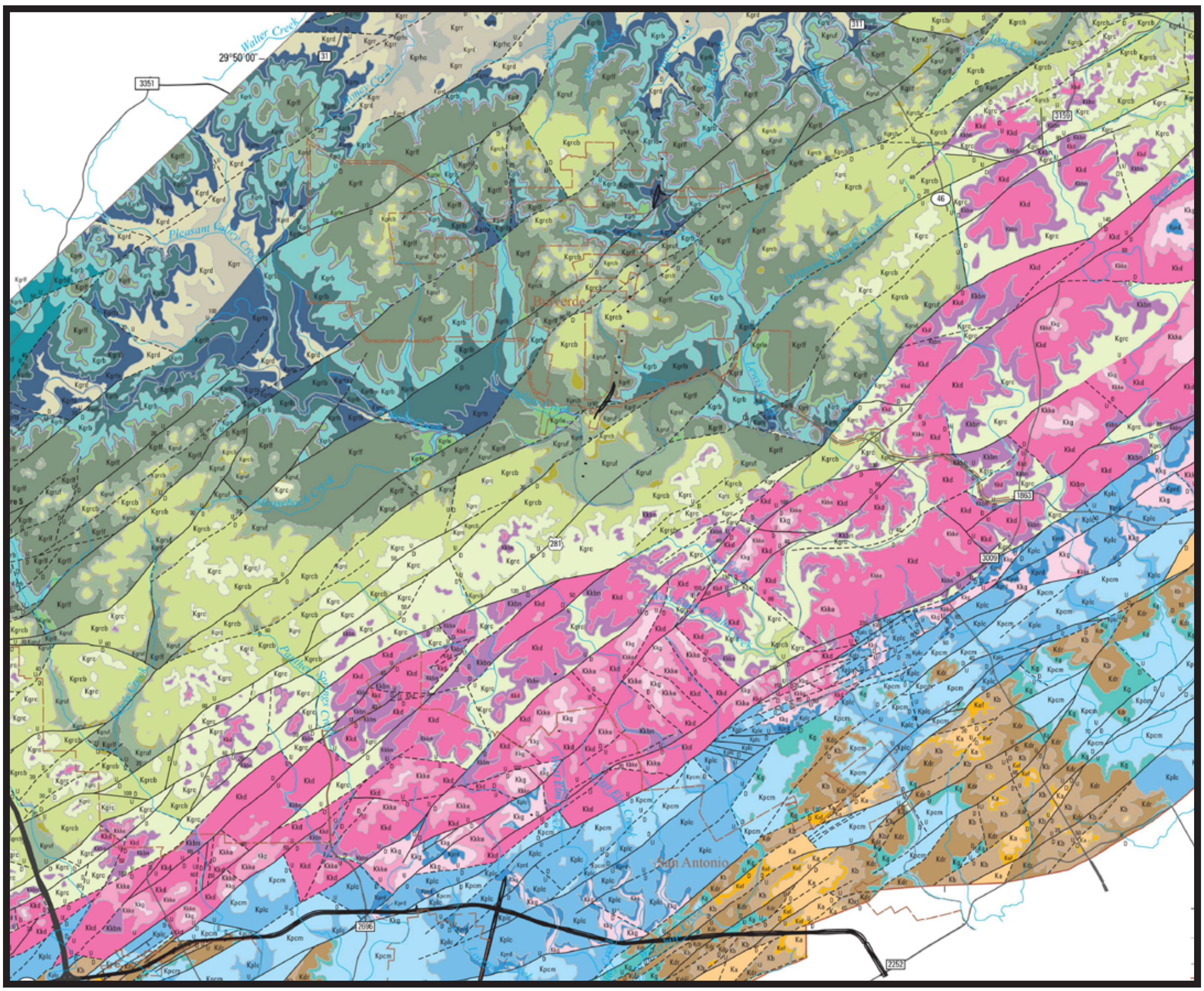
The second approach to evaluating the costs and benefits of geological mapping analyzed the stakeholder questionnaire datasets from the private and public sectors and the USGS/SGS geological mapping expenditure datasets across six regions (Northeast, Southeast, Great Lakes/Great Plains, South-Central, Intermountain West, and Pacific Rim). In this analysis, the estimates on how much respondents would spend on a map were viewed as costs, while appraisals of long-term value were viewed as benefits. All regions showed a high percentage of positive long-term values (benefits), ranging from 71% to 87% for both public and private sectors. The average “cost-savings” for each region ranged from ~\$11,000 to \$30,000 for both the private and public sectors, with the Intermountain West region having the highest cost savings. To provide an estimate of the average cost of generating a relatively detailed geological map (1:24,000 to 1:100,000), expenditures on geological mapping by SGS and the USGS were compared to the number of maps produced each year using representative states from each region. The average cost ranged from ~\$42,000 to \$123,000, with the lowest cost in the Southeast region and highest in the Pacific Rim region.

A third approach assessed the general benefits of geological mapping based on data from the U.S. Environmental Protection Agency (USEPA) for the SuperFund program designed to clean up polluted industrial sites. About \$86 billion (inflation adjusted to 2020) were spent on cleaning polluted sites from 1994 to 2019. If detailed geological maps had been available and used prior to development of these sites, it is possible that some of the environmental impacts may have been reduced. Notably, a mere 2.3% cost savings would have paid for the entire geological mapping program, indicating that the societal investment in geological mapping is relatively small compared to the many benefits and value of geological maps to society.

The final and fourth approach involved an econometric analysis to evaluate the impacts of geological mapping. A key premise of this analysis was that geological maps are a public good that supports multiple economic sectors. The market for maps indicates that geological maps produced by SGS and the USGS provide sufficient detail, reliability, and consistency to make actionable decisions. While scientific sufficiency of geological maps is critical, a private capacity to invest to produce a map comparable to the public good map has a threshold based on the required return on investment for that firm. Logistic regressions were tested to establish the capacity to pay for a geological map. The analysis included evaluation of how the economic value of each sector was expressed by various levels of investment of that sector in geological mapping. Using the gross domestic product (GDP) component of each sector, the sectoral contribution to per capita GDP was identified. Analyzing the actual survey response rates by economic sector, and whether the projects likely used publicly available geological maps or generated custom maps, the allocation of each mapping type was calculated for nine major sectors of the GDP, including mining, energy, real estate, construction, professional, transportation, education, state/local government, and federal government. For projects that likely included all or some publicly produced geological maps, sector per-capita input ranged from ~\$131 to more than \$4,700 per person, with a collective economic value of greater than \$19,000 per person for 2019. Real estate had the highest sector per-capita allocated by rate for geological maps in the public good category. Aggregate behaviors of respondents were generally consistent across the U.S., with some regional differences such as a demand for finer-scale mapping in the Northeast.

Finally, narrative responses by stakeholders conveyed that not all benefits of geological maps could be expressed in monetary terms. Therefore, stakeholders were asked in various ways to provide written narratives of the benefits and uses of geological maps provided by SGS and the USGS. Examples of common themes in the responses included time and cost savings, assistance in resource exploration and development, general education, geological research, filling information gaps, enhancing decision making (particularly land and water-use planning), providing credibility as well as accurate and unbiased information, and furnishing context to site-specific work.

In summary, four different approaches to an economic analysis of geological maps across the entire U.S. yielded strikingly similar results. All approaches demonstrated that geological maps have tremendous value to multiple economic sectors and nearly all aspects of society. Moreover, the value of geological maps accrues through time and far exceeds initial investments, with conservative estimates of monetary value ranging from 7 to 10 times higher than the production cost and per-capita input for various economic sectors ranging from ~$131 to more than $4,700 per person.



Portion of: Clark, A.K., Golab, J.A., Morris, R.R., and Pedraza, D.E., 2023, Geologic framework and hydrostratigraphy of the Edwards and Trinity Aquifers within northern Bexar and Comal Counties, Texas: USGS Scientific Investigations Map 3510, scale 1:24,000.

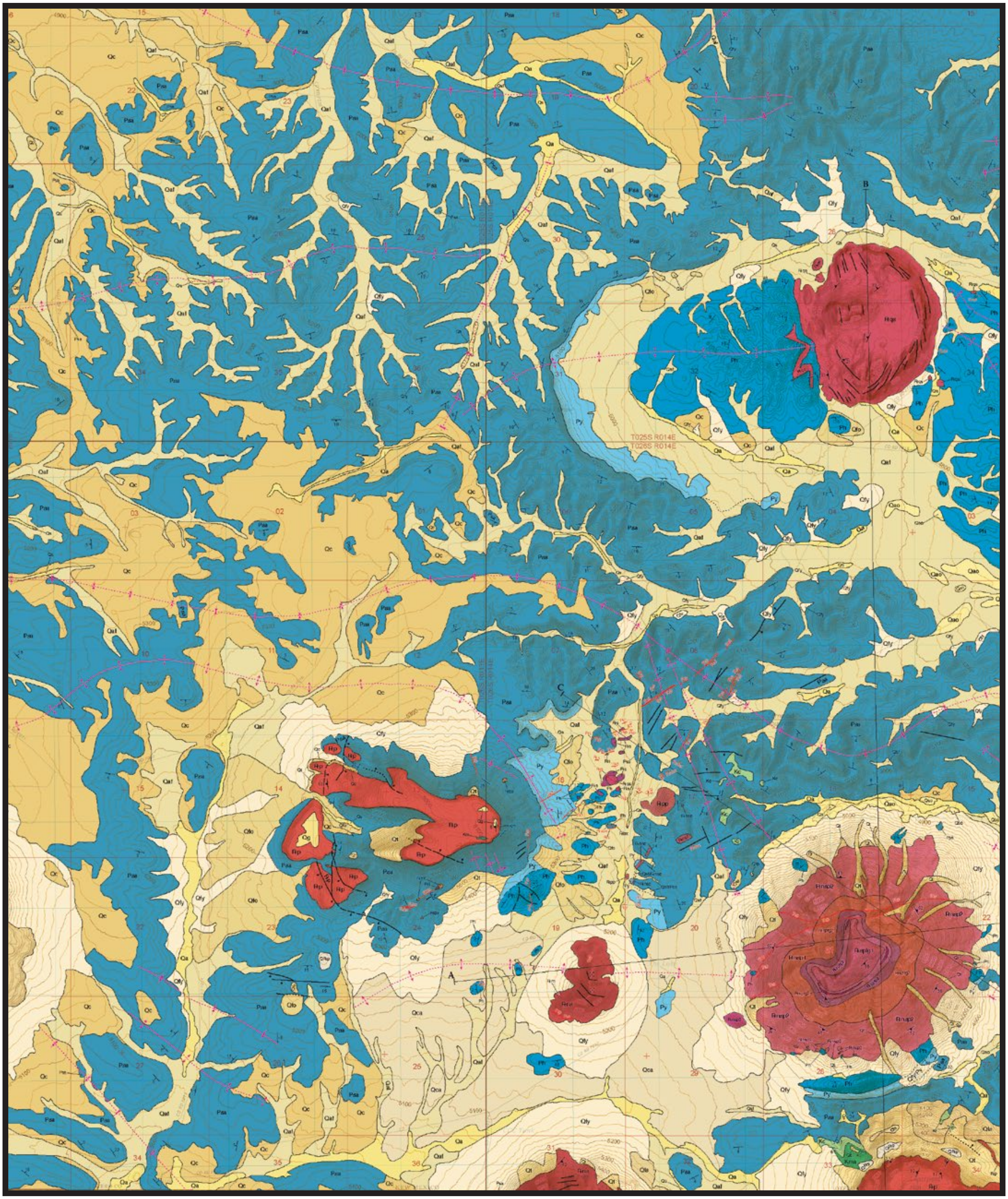
ABSTRACT

Geological maps show the composition, spatial relationships, and age of rocks and structures at and near the surface of the Earth and have a wide array of applications ranging from mitigating the effects of geologic hazards, facilitating environmentally sound development of natural resources, and resolving fundamental research questions in the geosciences. Geological maps are typically produced by State Geological Surveys (SGS) and the U.S. Geological Survey (USGS) as public goods that are used by most economic sectors, with their value to society accruing through time. This report provides the first economic analysis of geological mapping for the entire United States. Total spending on geological mapping by SGS and the USGS during the project period from 1994 to 2019 was approximately $1.99 billion in 2020 USD. The number of maps downloaded and sold during that period was estimated at 7.1 million. The value and returns on investments of geological maps were obtained from a questionnaire distributed to 81,000 likely users of geological maps. Responses were received from 4,779 individuals and all 50 states. Key questions included information on respondent background, preferences for types and scales of geological maps, and quantitative estimates of geological map value in monetary terms and time saved.

Four different approaches were employed to analyze the value of geological mapping, and all demonstrated large positive returns on investments. The first was based on questionnaire responses about money and time saved, and because maps were available from SGS and the USGS at little or no cost, information was obtained on the willingness to pay for a map, estimates of the long-term value of geological maps, and expected payment for one map if unavailable. Median project time and cost savings were 20% and 15%, respectively. The median value per map use ranged from ~$11,000 to $18,000, with a long-term median of ~$10,000. Median amounts for willingness to pay and expected to pay were similar at $3,000 and $2,883, respectively. Using the most conservative median for the expected amount to pay per map ($2,883), the cumulative value of the actual maps downloaded and sold ranges from $13.9 to $20.6 billion. Based on these results, and the $1.99 billion cost of producing the geological maps from 1994–2019, the most conservative cumulative monetary value of maps ranges from ~7 to 10 times higher than the production cost, with maximum value estimates ranging between ~23 to 35 times the expenditure. The second approach evaluated the value of geological maps for six different regions of the U.S. (Northeast, Southeast, Great Lakes/Great Plains, South-Central, Intermountain West, and Pacific Rim), with results showing a high percentage of positive long-term values, ranging from 71% to 87%, for both public and private sectors for all regions. Average "cost-savings" (mean benefit value) for each region ranged from ~$11,000 to $30,000. Using representative states from each region, the average cost of producing a relatively detailed geological map (1:24,000 to 1:100,000 scale) ranged from ~$42,000 to $123,000, with the lowest cost in the Southeast and highest in the Pacific Rim region. A third approach assessed the general benefits of geological mapping based on data from the U.S. Environmental Protection Agency for the Superfund program. About $86 billion (inflation adjusted to 2020) were spent on cleaning Superfund sites from 1994 to 2019. If detailed geological maps had been available and used prior to development of these sites, it is possible that some of the environmental impacts may have been mitigated. A 2.3% cost savings would have paid for the entire geological mapping program. The fourth approach involved an econometric analysis to evaluate the impacts of geological mapping. While scientific sufficiency of geological maps produced by SGS and the USGS is critical, the capacity of a private firm to invest to produce a new map comparable to the public-good map has a threshold based on a required return on investment. This analysis included evaluation of how the economic value of each sector was expressed by the various levels of geological mapping investment of that sector. Using the gross domestic product (GDP) component of each sector, the sectoral contribution to per capita GDP was identified. The allocation of each mapping type was calculated for projects that likely used publicly available geological maps or generated custom maps for nine major sectors of the GDP, including mining, energy, real estate, construction, professional, transportation, education, state/local government, and federal government. Sector per-capita input ranged from ~$131 to more than $4,700 per person, with real estate yielding the highest value and a collective economic value of greater than $19,000 per person for 2019. All approaches demonstrate that geological maps are a foundational part of our societal infrastructure with the benefits far outweighing the costs.

TABLE OF CONTENTS

Contents



Portion of: McLemore, V.T., Iverson, N., Woodard, M., Attia, S., Dietz, H., Owen, E., Haft, E.B., Trivitt, A., and Kelley, R., 2022, Geology and mineral deposits of the Cornudas Mountains, Otero County, New Mexico: New Mexico Bureau of Geology and Mineral Resources Open-File Report 619, scale 1:24,000.

CHAPTER 1: INTRODUCTION

James E. Faulds (Nevada Bureau of Mines and Geology, University of Nevada, Reno), Richard C. Berg (Illinois State Geological Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign), and Subhash B. Bhagwat (Illinois State Geological Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, Ret.)

As Simon Winchester opined in the highly acclaimed ***The Map That Changed the World: William Smith and the Birth of a Science (Winchester, 2001)***, William Smith created, in 1815, "the first true geological map of anywhere in the world." This map was entitled "The Delineation of Strata of England and Wales and a part of Scotland." Winchester further commented that this "… is a map that heralded the beginnings of a whole new science. It is a document that laid the groundwork for the making of great fortunes-in oil, in iron, in coal, and in other countries in diamonds, tin, platinum, and silver — that were won by explorers who used such maps. It is a map that laid the foundations of a field of study that culminated in the work of Charles Darwin. It is a map whose making signified the beginnings of an era not yet over, that has been marked ever since by the excitement and astonishment of scientific discoveries that allowed human beings…to understand something certain about their own origins-and those of the planet they inhabit. It is a map that had an importance, symbolic and real, for the development of one of the great fundamental fields of study — geology — which, arguably like physics and mathematics, is a field of learning and endeavor that underpins all knowledge, all understanding."

Since the development of the first geological maps over 200 years ago, such maps at some scale have been created for nearly the entire Earth and provide a scientific foundation for all modern societies. Geological maps are two-dimensional representations of vast amounts of three-dimensional geological information, and they convey the composition, spatial relationships, and age of rocks and structures at, near, and below the Earth's surface. Geological maps are uniquely suited to solving problems involving Earth resources, hazards, and environments. For example, geological maps are used to discern the origin and distribution of mineral, energy, and water resources, as well as document the location and history of geological hazards, such as earthquakes, floods, sinkholes, and landslides. Furthermore, geological maps are the primary source of information for various aspects of land-use planning, including the siting of buildings, landfills, and transportation systems. Because the distribution and age of geologic strata and structures (e.g., faults and folds) are shown on geological maps, it is also possible to use such maps as a self-propelled time machine to progress through thousands and even millions of years of Earth history at a single location. To read a geological map is to understand not only where materials and structures are located, but also how and when these features formed. Thus, geological maps have a wide spectrum of applications to modern society ranging from mitigating the effects of natural hazards, enhancing public safety, facilitating environmentally sound economic development of Earth resources, and resolving fundamental research questions regarding the evolution of Earth's physical environment.

Geological mapping is indeed a foundational activity of geology and remains a core scientific function of all geological surveys. When geologists embark on a mapping project, they review previous literature, including older geological maps. Based on this initial review, they develop hypotheses of what might be encountered. Once investigations begin, then every outcrop observed, every sample collected and analyzed, every drill core examined or obtained, every dataset that provides information on the geology of the surface and subsurface, and every iterative computer visualization and draft map that is constructed all contribute to a dynamic and ongoing progression of geological understanding. Through this process, geologists either confirm or reject initial hypotheses, form additional hypotheses, and/or create multiple working hypotheses along the way. Field activity and data collection almost always involve evaluating portions of a mapping area where additional information is needed, and this progresses with laboratory work and computer visualization until an acceptable measure of predictability of observations emerge. The final geological map integrates multiple interpretations of stratigraphy, geological structures such as faults, unit correlations and ages, paleontology, mineralogy, etc. This entire process follows the scientific method from initial background research, to forming and testing multiple working hypotheses, to analyzing data and drawing conclusions, and finally reporting results through publication of the geological map. The outcome of geological mapping can have a profound influence on our economy and ability to sustain and protect our natural resources. However, despite the importance of geological maps to nearly all aspects of society, and the scientific rigor required for their development, there have been very few quantitative analyses of the actual costs and, more importantly, the resultant benefits of such maps.

The purpose of this report is to provide economic analyses of the costs and benefits of geological mapping across the entire United States of America (U.S.), particularly as related to: ***"Public Law 102–285 102d Congress. Program Objective of the National Geologic Mapping Act of 1992. SEC.4c. 3B. studies that lead to the implementation of cost-effective digital methods for the acquisition, compilation, analysis, cartographic production, and dissemination of geologic-map information."*** Costs dedicated to geological mapping were gathered from State Geological Surveys (SGS) and the U.S. Geological Survey (USGS) for the period extending from 1994 to 2019. In addition, estimates of the benefits of mapping were collected in a questionnaire sent out to more than 81,000 individuals in both the private and public sectors. Nearly 4,800 responses to the questionnaire were received. This analysis is particularly timely given the substantial investment by the federal government in geological mapping over the past 30 years, with significantly enhanced funding since 2019. An important question is whether this public investment in geological mapping has yielded tangible results.

In this chapter, we describe the justification for this report, briefly review previous economic analyses of geological mapping, discuss the methods used in the remainder of the report, and outline subsequent chapters. An integrated approach is developed in the following chapters to (1) analyze the cost effectiveness of geological maps; (2) provide qualitative summaries of the societal applications and potential benefits of such maps; (3) analyze map investment choices; and (4) furnish compilations of national and regional returns to investments supported by geological mapping. Our analysis is the first thorough assessment of the Federal and State geological mapping programs across the U.S.

1.1: JUSTIFICATION

Geological maps are important tools to nearly all aspects of society, and thus it is critical to produce unbiased, scientifically supported maps. Thus, geological mapping has become a foundational activity for both the SGS and USGS. As discussed above, geological maps are generated to evaluate geological deposits at the land surface and in the subsurface for their potential to host water, energy, and mineral resources, as well as to identify and delineate geological hazards, all in support of environmentally sound economic development, community sustainability, and public safety.

Since the passage of the National Geologic Mapping Act in 1992, most investments for geological mapping have been made by the federal government through the National Cooperative Geologic Mapping Program (NCGMP) enabled by the National Geologic Mapping Act of 1992 administered by the USGS and matched at 100%+ by individual states through their SGS. Some funds have also been provided by other federal programs, state and local governments, and private sector sources. The NCGMP is designed specifically to perform geological mapping and associated research in high-priority areas to sustain and improve the quality of life and economic vitality of the Nation (US DOI, 2023). There are three components to the NCGMP: (1) FEDMAP, (2) STATEMAP, and (3) EDMAP. FEDMAP directly funds the USGS for geological mapping; STATEMAP provides funding to SGS for geological mapping and requires a 1:1 match from the states for any federally awarded funds; and EDMAP provides funds to universities and colleges to train students (i.e., the next generation of geoscientists) in geological mapping and requires a 1:1 match from those universities and colleges for any federally awarded funds. Total funding for the NCGMP slowly ramped up between 1993 and 2011, but then declined in 2012 and remained stable between 2013 and 2019. However, since 2019, federal funding for mapping has increased significantly. The NCGMP experienced growth from $24.4 million in 2019 (US DOI, 2019) to $44.6 million in 2023 (US DOI, 2023). This resulted from congressional support for an acceleration of geological mapping by SGS (AASG, 2014) and the USGS (Brock et al., 2021) to meet strategic national, state, and local mapping priorities.

In late 2017, the USGS launched an initiative (now called the Earth Mapping Resources Initiative or Earth MRI) to modernize and accelerate geological mapping and geophysical surveys in areas where there may be reserves of critical minerals (USGS, 2023). These studies assist the minerals industry in increasing the domestic supply as directed by White House Executive Order 13817 (White House, 2017) and the Infrastructure and Jobs Act of 2021 (P.L. 117–58, 135 Stat. 529). Geophysical surveys complement the geological mapping efforts by facilitating interpretation of the subsurface. Based on the Executive Order and the Infrastructure and Jobs Act, congressional actions added ~$11 million per year and $320 million ($64 million/per year for five years), respectively, to the annual USGS budget for the Earth MRI program.

Considering the sustained congressional support for the past 30 years and recent enhancements of the NCGMP, combined with the newly launched Earth MRI program, it is especially timely to evaluate the costs and benefits of public sector geological mapping to help gauge the value of the federal investment. In this report, economic analyses of the costs and benefits of geological mapping are used to estimate the value of geological maps that were produced and disseminated by SGS and the USGS during the period from 1994 to 2019. Several approaches are applied to assess the costs and potential benefits of the value of geological maps. As previously mentioned, this is the first economic analysis of geological mapping conducted for the entirety of the U.S., and the largest and most comprehensive jurisdictional economic analysis for geological mapping ever conducted worldwide.

1.2: ECONOMIC ANALYSES OF GEOLOGICAL MAPPING — REVIEW OF PREVIOUS STUDIES

For more than 100 years, analyses of the costs and benefits have been used to economically evaluate and prioritize federal and state programs, as well as private-sector projects. These analyses can be useful for apportioning resources or comparing projects for development (White House Office of Management and Budget, 2022). A cost estimate followed by assessment of the long-term value of those costs can help influence, rank, and direct decision making to justify and optimize present and future government and private investment. Therefore, cost and benefit economic analysis represents an important approach and can systematically help to identify and quantify the costs of proposed projects or a product (e.g., geological maps), as well as the benefits derived from that product. Such analyses can help to provide a justification for the proposed investments based on the expected outcomes.

Geological mapping generates geological maps and various derivative products based on credible Earth science practices, which require investments that may occur well before the outcome of that work is recognized or the monetary benefits realized. The benefits of geological mapping have been discussed anecdotally for more than 200 years. However, starting in the 1980s, governments began demanding more quantitative analyses and specific explanations regarding the expenditures of publicly-supported government activities. For example, a 1989 Illinois Senate Resolution (ISR-881) required that the Illinois State Geological Survey document the costs and benefits of their geological mapping programs. In response, Bhagwat and Berg (1991) first used the “avoided costs are benefits” approach for assessing the savings that could have been derived from utilizing geological information in two counties in Illinois using clean-up costs of contaminated sites from waste disposal and industrial activities as the basis. They concluded that the proper and adequate use of geological information can avoid costs during project execution as well as in the future. However, the magnitude of avoided costs is always an estimate. They discovered that the benefits of geological mapping were 5 to 11 times greater than the costs in their most conservative scenario. On the national level, the White House Office of Management and Budget requested the USGS to quantify the value for conducting their geological mapping (Bernknopf et al., 1993). Their estimation used a modeling approach that compared the costs of a project with and without the availability of geological information. The cost estimates in this approach also required estimation based on expert opinions from personal interviews. The expected net benefit (societal value) of using improved geological map information ranged from about $1.28 million to $3.50 million, with a cost and benefit ratio that ranged from 1:2 to 1:4.

Following the above early assessments, there have been several other economic analyses conducted for geological mapping and related studies. For example, Reedman (2000) and Reedman et al. (1996, 2002) examined different approaches to estimating costs and benefits of geological information. They reported on a Kenyan geological mapping study that permitted targeted drilling and reduced exploration costs by more than $307,000 USD. They further reported on the value of geological information based on several large mineral exploration projects in South America, Africa, and Asia, and for groundwater exploration in Nigeria. The latter resulted in a groundwater potential map that improved drilling success rates in multiple geological settings, yielding net benefits of greater than $1.15 million. Bhagwat and Ipe (2000) applied an approach at the state level in Kentucky to demonstrate that costs were exceeded in value by benefits with a ratio of at least 1:2 and possibly up to 1:28. Utilizing the same methodology as used in Kentucky, the Geological Survey of Spain arrived at a similar cost-to-benefit ratio estimate of a minimum of 1:2 (Garcia-Cortes et al., 2005). Bernknopf et al. (2007) studied an operational mining project in Canada and demonstrated that the use of newer geological maps resulted in the discovery of significantly more ore reserves. The economic value of the updated map ranged from $CAN2.28 million to $CAD15.21 million as compared to the $CAN1.86 million that it cost to produce the updated, finer resolution map (a multiplier effect of 8:1). Duke (2010) also investigated the impact of government investment in mineral exploration in Canada. Although not a mapping project, the study found that every dollar invested by the government created at least $5 invested by private industry. The mining association of Canada estimated that those benefits were up to 75 times the government investment. Kleinhenz and Associates (2011) used a questionnaire to solicit user input on benefits of utilizing geological maps and information in Ohio. In addition, an input-output model approach was used to estimate the multiplier effect of investment in geological research on jobs and wealth creation. They calculated that the aggregate value of the Ohio Division of Geological Survey was a minimum of approximately $575 million to the economy of Ohio, and only for the year 2010. In a report on the benefits of the Nevada Bureau of Mines and Geology, University of Nevada, Reno (Nevada's state geological survey) to the state's and region's economy, Bhagwat (2014) estimated that the total value for geological maps sold was $13 million, and map user's "willingness to pay" for each map was $6,414. With an estimated cost of $90,000 to $200,000 to produce each map in Nevada, the cost and benefit ratio ranges from 1:66 to 1:147 (Bhagwat, 2014). This high ratio was attributed primarily to the high value of Nevada's mineral resources (e.g., gold and silver). Chiavacci et al. (2020) focused on a specific aspect of geological information as it related to variabilities of radon emissions and their health impact. In response, the Kentucky Geological Survey developed statewide and county-scale radon potential maps (Haneberg et al., 2020). This study found that over 200,000 cases of radon related lung cancer and 15,000 to 20,000 deaths were reported in the USA. The cost of caring and treatment per patient in the first year of having access to this geological information alone may be $3 million. Radon remedial action per house, on the other hand, costs less than $1,500. Finally, Lizzuo et al. (2020) reported that the economy of Arizona gained an estimated $30 million annually because of the availability of geological maps prepared by the Arizona Geological Survey, which has an annual budget of less than $1 million.

A summary of most of the above studies and many others can be found in Häggquist and Söderholm (2015) and Berg et al. (2019). Häggquist and Söderholm concluded that *"Geological information can play a key role in addressing challenges of sustainable development, such as land degradation and groundwater protection, and contribute to improved decision-making processes…. The review of prior research shows significant economic benefits attached to the generation of this type of public information"*. Similarly, Berg et al. (2019) concluded that "*While methodologies for conducting the various economic assessments have many similarities, they do differ in scope and detail, but all show a very positive valuation for the mapping and modeling activity ranging from benefit-cost ratios of 4:1 to >100:1. All of them were conducted to report on the need for geological information to address resource, hazard, and other societal issues, and with the specific intent to justify the activity*".

These economic studies reported the need for geological information to address specific issues, protect the environment, and lower costs both for the public and private sectors. They importantly (1) marketed the value of geological mapping to stakeholder users and potential funders, and (2) promoted the need for mapping within jurisdictions that lacked a dedicated mapping program, thereby providing a significant economic incentive for conducting the activity.

1.3: GEOLOGICAL MAPPING— A CANDIDATE FOR FURTHER ECONOMIC ANALYSIS

Geological maps are based on extensive geological research, and their production has been a core activity of geological surveys since William Smith's geological map of much of Great Britain in 1815. Allen (2003) reported that this map strongly influenced geological investigations by the world's first geological survey organization, the British Geological Survey that was founded in 1835. For the first time, cross-sectional subsurface depictions, portrayal of the ages of strata and lithological differences, and structural relationships depicted on Smith's map permitted predictions of rock occurrences and their properties in areas of sparse data. That map even included text that described various uses for the geological deposits. The 1815 map established a precedent for the next 200+ years of geological mapping and portrayal of geological information.

Geological surveys were founded on the premise of economic development, with mineral and energy resource discovery being their primary focus. The USGS was founded in 1879, with geological mapping at the core of its initial mission and continuing to the present. The first state geological survey was established in 1823 in North Carolina. By 1840, there were at least 15 SGS, and by the first few decades of the 20th Century, geological surveys had been founded in nearly every state. Today, geological surveys exist in every state, with the exceptions of Hawaii and Georgia. Most were initially charged with the investigation, delineation, and analysis of mineral and energy resources within their state or territory. Similar to the USGS, geological mapping has been a primary responsibility of SGS since their founding.

When the "environmental movement" accelerated in the 1960s (Frye, 1967), geological surveys maintained their traditional role of geological mapping in support of mineral and energy resources, but many also began to focus on mapping projects related to groundwater resources and protection issues, as well as geological hazards (e.g., earthquake faults, floods, landslides, and sinkholes), all of which additionally contributed to the economic prosperity and public safety of their jurisdictions. Most recently, a wider variety of economic sectors (e.g., real estate and construction) have directly utilized information derived from geological maps, and this has led to the need for investments in geological mapping for new developments (e.g., general infrastructure, transportation systems, pipelines, housing subdivisions, etc.). There are clearly many applications of geological mapping across a wide spectrum of economic sectors and therefore a broad range of benefits.

The process of creating a geological map is usually a focused, labor intensive, long-term exercise with an outcome in the form of a "map product". The geological map not only has value to a broad range of industries, government agencies, and research institutions, but also can be used to minimize future and potentially costly liabilities resulting from uninformed land, resource, and/or development decisions that may occur without the map. In essence, having access to geological knowledge through maps can avoid some user costs in terms of time saved to gather the geological knowledge and by avoiding other costs that may result from insufficient knowledge about local geological conditions.

Geological maps typically have a relatively long "shelf life". However, a high-quality geological map can be improved when advances in scientific methods allow for gathering of new or more detailed data and observations, thus permitting new interpretations. Nevertheless, considering the cost and considerable effort of initial government investment, once a map has been published, geological survey organizations generally "move on" to other areas prioritized for mapping. Revising an already mapped region usually does not occur within relatively short timeframes. Existing geological maps commonly remain for decades as the "best available data", and the same map can be used multiple times by many stakeholders for numerous applications. Therefore, their benefits to society are cumulative, and maps generally accrue their value to society over a long timeframe.

It is important to note that, in recent decades, numerous computer and other electronic applications have influenced the mechanisms by which geological maps are produced, viewed, distributed, and used. Most geological maps are now produced in digital format. The paper geological map, although still useful and available, is employed much less often. Digital geological maps can serve as interactive electronic documents that package Earth science issues into geospatial frameworks. They capture the size, shape, depth, and composition of earth materials and allow for independent or blended displays of various data layers depending on the focus of the user. The combination of geological maps and supporting digital databases facilitates assessment of a wide variety of complex geological, land-use, mineral and energy resource, natural hazard, and hydrological issues.

Most importantly, geological maps produced by SGS and the USGS are viewed as a public good. They are a vital component of the Nation's information infrastructure, available and accessible to all, and can be used by many at the same time without being "consumed". Additionally, geological knowledge derived through mapping is typically provided free or at minimal cost by geological survey organizations after the initial cost of producing the map. To obtain a geological map, the consumer does not pay a price that is based on supply and demand, which differs from a consumptive good in a marketplace. Instead, a nominal cost is commonly charged for a paper copy (if needed by a user) to cover printing expenses, or in some cases a minor charge is assessed to download the digital database to help cover website and data dissemination costs incurred by the geological survey organization.

Geological maps are generally produced by the SGS and USGS and then used by a wide variety of industries, groups, and organizations. Because government organizations produce the bulk of geological maps in the U.S., the general costs incurred to produce the maps (i.e., federal and state investments) are typically available. For this report, the costs incurred for geological mapping for the period from 1994 to 2019 were obtained from every SGS and the USGS. The more challenging part of the analysis was quantifying the benefits or perceived value of the geological maps by major user groups, quantities that are generally not systematically recorded and may differ significantly per user group and/or region. A relatively detailed questionnaire (Appendix 2) was therefore developed to assess the benefits and/or perceived value of geological maps. This questionnaire was widely distributed across the entire country and received nearly 4,800 responses.

1.4: SCOPE OF WORK AND OUTLINE OF REPORT

For this economic analysis, we used a multi-pronged approach to assess the value of geological maps in the U.S. Major components of this national study included the following:

- Assessment of costs incurred by SGS and the USGS with funds provided by the USGS through the NCGMP, matching funds provided by SGS, as well as funds furnished by other federal, state, and local sources. These costs were tracked through time for each SGS and the USGS.

- Compilation of comprehensive lists of known and potential map users for each SGS for distribution of the online questionnaire, which was designed to help define the value (benefits assessment) of geological maps.

- Assessment of benefits of the mapping programs in monetary terms where possible and in qualitative/descriptive terms, where quantitative input was not available.

- Establishment of the scope of geological mapping in terms of area covered, scale of mapping, and types of mapping (e.g., topographic, Quaternary, bedrock, and derivatives focused on specific natural resources and/or earthquake potential, geothermal energy, etc.) for each SGS and the USGS.

- Reporting of geological map demand based on online geological map views, downloads, and maps sold.

- Analyzing the questionnaire datasets for six defined regions across the U.S. to determine potential correlations between economic sectors within and between the regions.

- Providing a quantitative measure of geological map value assessment from independent U.S. Environmental Protection Agency (EPA) data based on the rationale that future Superfund mitigation costs could be minimized, or possibly avoided, if geological information had been available and used prior to the adverse development at the Superfund sites.

- Developing a qualitative assessment of the perceived value of geological maps based on stakeholder responses to the questionnaire.

- Estimating the use of different levels of investment in geological maps by U.S. economic sectors as a latent demand for specific map uses. The latent demand or capacity to invest in geological maps was based on the value of the map as an input in the production of private and public goods and services.

The above content is grouped into the following chapters, which collectively incorporate four approaches to assessing the value of geological mapping. Chapter 2 provides an overview of the major objectives and methodologies employed in this study. Chapter 3 reviews assessments of map producing agencies, such as SGS and the USGS, as gleaned from the questionnaire. Chapter 4 addresses the costs incurred for geological mapping by SGS and the USGS from 1994 to 2019. Chapter 5 describes the major components of a geological mapping program as a framework for understanding the associated costs. Chapter 6 analyzes results from the questionnaire to provide an initial approach to evaluating the quantitative benefits of geological mapping, including descriptions of respondent preferences for map type and scales and quantitative assessment of the perceived value of geological maps. Chapter 7 reviews the historical demand for geological maps, as evidenced by online views, downloads, and actual sales, thus providing insights on the usage of maps versus their perceived value estimates as benefits. Chapter 8 provides the second approach to assessing the costs and benefits of geological mapping by incorporating data from the cost sheets and questionnaire relative to six geographic regions of the U.S. This analysis includes funding levels for geological mapping by state and region, projected cost ranges for geological maps by region, and projected map costs for representative states from each region. Chapter 9 is the third approach and provides a quantitative value assessment of geological mapping from independent data from the U.S. Environmental Protection Agency. Chapter 10 incorporates narrative responses to the questionnaire to provide a qualitative assessment of the value of geological maps, which complements the quantitative evaluation of costs and benefits covered in Chapters 4, 6, and 8. Chapter 11 presents the fourth approach in an econometric analysis involving major economic sectors and the capacity of such sectors to invest in producing geological maps. Chapter 12 covers input by respondents to the questionnaire about future geological mapping. Chapter 13 discusses lessons learned from this project and provides suggestions for future studies. Major conclusions are then reviewed in Chapter 14.

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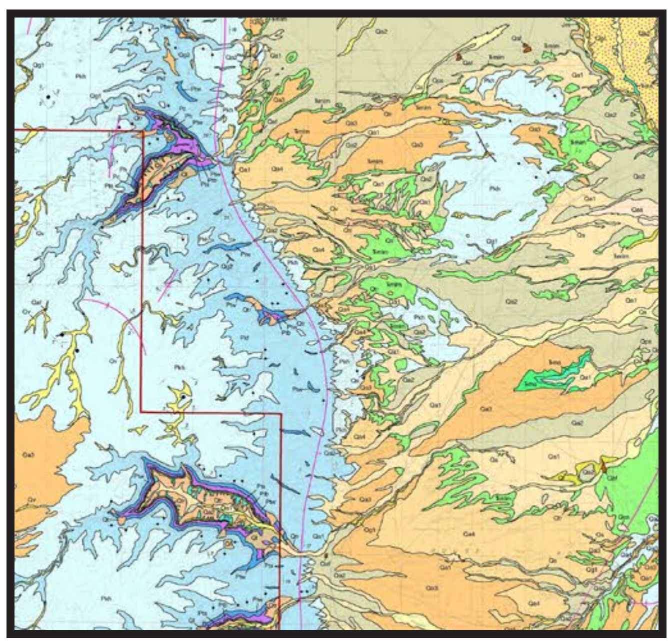

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CHAPTER 2: STUDY OBJECTIVES AND METHODOLOGY

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ABSTRACT

Measuring the costs and benefits of geological mapping by State Geological Surveys (SGS) and the U.S. Geological Survey (USGS) involved the distribution of two questionnaires. The first questionnaire compiled data on SGS and USGS costs for geological mapping, while the second gathered comprehensive stakeholder assessments of the usefulness and value of geological maps (i.e., benefits data). For SGS, federal funding sources were from the STATEMAP program of the National Cooperative Geologic Mapping Program, other USGS mission areas, and other federal agencies. State funding sources included the 1:1 match requirement for funds received under the STATEMAP program, funding from other state agencies, as well as from county, municipal, private industry, and nongovernmental organizations (NGOs). USGS federal funding sources were those received directly from congressional appropriations, as well as from other USGS mission areas involved with geological mapping and other federal agencies. To acquire data on valuation, an online questionnaire was sent to >81,000 stakeholders and nearly 4,800 responses were received (~6% response rate). Stakeholder categories included individuals representing economic development, NGOs, state and local government agencies, associations and societies, consulting companies, large industries, rock and mineral clubs, etc. Specific map-value questions were easily tabulated. However, to overcome the review of the overwhelming responses (~700 pages) to several long text-based narrative questions, training data were used to analyze word-use frequency to generate additional predictive keywords.

2.1: INTRODUCTION

The primary purpose of publicly funded institutions such as SGS and the USGS is to generate scientific knowledge of geology and make it available for natural resources, geological hazard, economic, and environmental applications. Geological maps present this knowledge in a concise form and are supported by reports and data sets to enhance and interpret the maps. The process is a two-way street, where feedback from users of geological maps and reports helps identify what kind of geological knowledge is needed in practice and which geographical areas need prioritization for geological mapping. Businesses and public policy makers require geological information to guide investment decisions as well as balance economic development with evaluations of natural resources (water, mineral, and energy) and geological hazards, and in so doing address environmental and public safety issues. The continuous interaction between users of geological knowledge and its generators is key to maintaining the quality, efficiency, and usefulness of the process.

Unlike some physical commodities used as ingredients in the production of other goods, scientific knowledge such as geological maps, data, and reports are not "consumed" by its users, but rather remain available for decades of use. The maps and reports commonly need to be enhanced, adapted, and/or modified to suit the application. For example, for most users it is not sufficient to create only site-specific geological knowledge. It is generally beyond the user's ability and means to generate geological knowledge outside of a specific project site. In cases where some users may have the means to generate geological knowledge beyond the project site, they are unlikely to make it freely available to others. If other users must each create the same geological knowledge repeatedly as needed, the result is economic inefficiency. It is essential that publicly funded agencies take the responsibility of creating geological knowledge and making it available as a "public good". Therefore, the basic methodology for conducting this assessment on the value of geological maps is based on the premise that geological knowledge (maps, data, reports) is a "public good".

The economic justification for handling a "public good" differently from a "private good" has been discussed in previous studies on costs and benefits of geological maps. In the U.S., such studies have been conducted in several states such as Illinois (Bhagwat and Berg, 1991), Kentucky (Bhagwat and Ipe, 2000), Nevada (Bhagwat, 2014), Ohio (Kleinhenz & Associates, 2011), and Indiana (Capstone Class, 2017). Briefly, unlike a private good, such as a mobile phone or a car, a public good can be procured by many at the same time without being "consumed". It remains available for others in the present and in the future. Therefore, the benefits of public goods to society are additive over many users.

The benefits of geological knowledge to society are measured indirectly because, as a public good, this knowledge is provided free or at minimal cost, mostly equivalent to the cost of printing and/or helping to maintain a website where geological maps are served. The consumer does not pay a market determined price. However, having geological knowledge can avoid some costs to the consumer in terms of time saved to gather the knowledge and by avoiding other costs that may incur from the lack of adequate knowledge of geology. Cost savings and cost avoidance are concepts used in business management, which differ from one another in that cost savings refers to known expenses that could be saved by taking certain actions, whereas cost avoidance refers to anticipated future costs that could be avoided by taking certain actions now. Unlike current costs, future costs are unknown. Therefore, cost avoidance necessarily involves estimation of future costs that seem rational. Management steps taken in the present can be justified by the expectation that they will lead to savings in the future. In short, avoided costs are equivalent to benefits (e.g., Lizzou et al., 2019; Chiavacci et al., 2022). Specific literature concerning public goods, such as geological maps, has been cited (e.g., Bhagwat and Ipe, 2000; Garcia-Cortes et al, 2005; Kleinhenz & Associates, 2011; Bhagwat, 2014). In the case of SuperFund sites, the criteria used by the U.S. Environmental Protection Agency (USEPA) to determine how much contribution to expect from entities responsible for the pollution of sites targeted for clean-up are known and listed. The underlying rationale for the SuperFund program is that expected societal costs caused by the environmental pollution are greater than the clean-up costs, even though the societal costs are not known. The value of geological knowledge to the user may depend instead on the amount of time and money that the user may otherwise have to spend to create the knowledge themselves. Using geological maps may affect the economic outcome of projects, but the extent of this effect and whether it influences how much the user is willing to pay were not investigated.

The usefulness of the above approach has been tested and confirmed by others who conducted such studies in the U.S. and overseas, (e.g., Bhagwat and Ipe, 2000; Garcia-Cortes et al., 2005; Kleinhenz & Associates, 2011; Bhagwat, 2014), as well as by reviewers of economic literature at academic institutions (e.g., Häggquist and Söderholm, 2015). A brief summary is discussed in Chapter 1.

This report is the first of its kind at the national level in the U.S. It consists of two major parts. Chapters 3, 4, and 5 take stock of public perceptions of geological maps produced by SGS and the USGS, funds spent on geological mapping, and the extent of mapping accomplished. Second, the report solicits user input on map preferences, the usefulness of maps and their perceived value, as well as user input to guide future mapping, as addressed in Chapters 6, 7, 8, 10, 11, and 12. To accomplish this, two different questionnaires were drafted.

The first questionnaire, designed to compile data on the costs or spending for geological mapping, mapping accomplishments, and future mapping needs was sent to SGS and the USGS. It essentially consisted of a spreadsheet within which funding allocations from state, federal, and other sources were tabulated for individual SGS and the USGS for the 1994 to 2019 time period. In addition, it requested information on the proportions of completed mapping for bedrock and Quaternary geology at specific scales, as well as progress to date on a variety of derivative maps.

The second questionnaire, designed to seek comprehensive assessments of the usefulness and value of geological maps, was distributed by SGS to traditional map users and stakeholders. It consisted of 25 questions requesting information on the respondent's (1) type of organization (e.g., various types of private vs. public institutions); (2) activities related to geological maps; (3) estimates of time and costs saved by having access to publicly available geological maps; (4) type of preferred map product (e.g., digital vs. paper copy); (5) descriptive narrative of the benefits of publicly available maps; (6) approximations of additional incurred costs on individual projects if maps were not publicly available; (7) willingness to pay for geological maps if not publicly available; (8) perception of the long-term value of geological maps; (9) preferred scale of maps; (10) inferred importance of digital online access to geological maps; (11) descriptions of how maps are obtained for projects if not publicly available; (12) ratings of map quality from various organizations (e.g., government vs. private); (13) perceived impacts of publicly available geological maps on the quality of projects; and (14) priority areas for future geological mapping.

Both questionnaires had significant input on content and review from a Steering Committee that consisted of Richard Berg (Director of the Illinois State Geological Survey), James Faulds (Director of the Nevada Bureau of Mines and Geology, University of Nevada, Reno), Steven Masterman (Retired Director of the Alaska Division of Geological and Geophysical Surveys), John Parrish (Retired Director of the California Geological Survey), David Spears (Director [now retired] of the Virginia Department of Mines, Minerals, and Energy), Nick Tew (Director of the Alabama Geological Survey), and Richard Bernknopf (USGS-Retired and now with the University of New Mexico).

2.2: DATA ACQUISITION — COST INFORMATION

Following review and approval by the Steering Committee of the Excel spreadsheet for obtaining cost information from SGS and the USGS, the data gathering process commenced for this national economic analysis of the costs and benefits of geological mapping. On July 1, 2020, an email was sent to State Geologists and the National Cooperative Geological Mapping Program (NCMGP) coordinator of the USGS requesting their full participation in the national assessment. The email contained (1) the blank Excel cost spreadsheet (Appendix 1) requesting their data on annual geological mapping costs from 1994–2019, present-day staffing, geological map coverages at various scales, and derivative mapping, and (2) an introductory letter detailing the program and its timelines. September 15, 2020 was given as the submission date of the cost information. However, this deadline was incrementally increased several times as SGS and the USGS requested additional time because of problems associated with (1) obtaining the cost data going back to 1994; (2) assessing geological mapping coverages and status of derivative maps; and (3) the Covid-19 pandemic. Therefore, to ensure completeness of the national assessment, cost sheets were accepted through September 2021.

The cost sheet contains three sections. Section 1 provides cost data from federal, state, and other sources estimated to the best of the abilities of SGS and the USGS. For SGS, federal funding sources included those from the STATEMAP program of the NCGMP, as well as from other USGS Mission Areas and other federal agencies. Much of the geological mapping funds that SGS received were from the STATEMAP program, and those data were readily available from an annually updated USGS spreadsheet. State funding sources included the 1:1 match requirement for funds received under the STATEMAP program, funding from other state agencies, and any personnel or other costs that contributed to geological mapping. Other sources included funding from county, municipal, private industry, and non-governmental organizations (NGOs, e.g., typically non-profit entities).

USGS federal funding sources included those received directly from congressional appropriations under the 1992 (and subsequent reauthorizations) National Geologic Mapping Act requirements, as well as from other USGS Mission areas involved with geological mapping and other federal agencies. USGS figures do not include funds received for STATEMAP, since those funds were distributed directly to SGS.

Also requested was a best estimation of the number of internet visitors, with the realization that these data may be difficult to assess by SGS and the USGS.

Section 2 of the spreadsheet documents geological mapping that was accomplished from 1994 to 2019 on a per square mile and percentage of jurisdiction basis. Also included were data on the extent of geological mapping at various scales (from >1:24,000 to <1:500,000) and, if possible, split between Quaternary and bedrock mapping products.

Section 3 of the spreadsheet focuses on derivative maps at small, medium, and large scale, including present-day availability, what needs updating, and desired future products. A list of 25 derivative options were provided with the proviso to add others to the list. It was also stressed that the production of derivative maps was dependent on geological mapping, and therefore derivative map costs should be included in Section 1. It would be too difficult and nearly impossible to separate costs between derivative and basic maps.

Between July 2020 and September 2021 cost sheets were obtained for 49 states. Hawaii is the only state that lacked an SGS over the 1994–2019 project period and therefore could not provide any cost data, nor send out questionnaires to stakeholders. However, members of the steering committee worked with colleagues in Hawaii to distribute the stakeholder questionnaire. Since stakeholder data (via national efforts described below) were obtained for Hawaii, as well as the District of Columbia, it was assumed that geological mapping for these two jurisdictions were covered with direct USGS funds. Also, for two other states (Georgia, which has not had an active SGS for several years, and Louisiana, which was transitioning to find a new State Geologist), there were no responses to email requests for participation in the assessment. Therefore, cost sheets were produced showing only STATEMAP funding and the required 1:1 state match.

For many of the SGS, the 1:1 match data were difficult to obtain, as these data were commonly not retained as paper copies or early computer files. Fortunately, the USGS NCGMP program office provided much of the needed match data. The match data are significant, because many states matched the Federal STATEMAP funds considerably greater than the required 1:1, as they were trying to justify their capacity for increasing Congressional and USGS STATEMAP funding.

2.3: DATA ACQUISITION — VALUATION INFORMATION

Following review and approval by the Steering Committee of the online questionnaire seeking information (Appendix 2) on the benefits of geological mapping, as well as following numerous beta testing of the questionnaire's online operability, a second email was sent to SGS on August 20, 2020. This email contained an online link to the questionnaire and requested distribution of the link to stakeholders and constituents. To increase the size of state stakeholder lists, it was requested that they extend their stakeholder engagement to include statewide associations and societies for oil and gas, aggregates, water-well drillers, etc., with the intent that these statewide groups could send the questionnaire to their members and thereby significantly increase feedback. November 2, 2020 was given as an initial submission date for the questionnaires. Similar to obtaining the cost data, this deadline also was incrementally increased several times. Submission extensions were needed for two primary reasons: (1) the time required for national and state associations and societies forwarding the questionnaire to their members was underestimated due to delays in obtaining required permissions from their management as well as timing of the distribution of the questionnaire in a monthly mailing or a newsletter, and (2) delays due to the Covid-19 pandemic, which prevented face-to-face participation at association and society meetings to encourage stakeholders to participate. Therefore, to ensure completeness of the national assessment, questionnaire responses also were accepted through September 2021.

Also provided was a Word document with a template letter that SGS could modify accordingly and then send to their stakeholders and constituents. For example, emphasizing the importance of this endeavor to the mining industry is quite different from that to county planning agencies. Appendix 3 is an example of one letter that was distributed to economic development agencies. We asked that the number of distributed questionnaires be recorded, minus bounce backs, so that we could best evaluate the overall response rate. Stakeholders were also asked to answer as many of the questions as possible, with the full realization that all questions could not be answered by everyone.

Between August 2020 and September 2021, the email link to the online questionnaire was reported as sent to 81,072 stakeholders and constituents, and 4,779 responses were received, which was a ~6% response rate. Of those 81,072 questionnaires that were sent, 25,192 were sent by 10 national associations and societies (Table 2.3.1) as well as by numerous state associations and societies. For example, in Illinois, 10,247 questionnaires were sent by 17 associations and societies (Table 2.3.2). Participating national and state associations included those representing professional geologists, planners, and water professionals, as well as those from mining, the construction industry, state, city and county governments, academia, and the engineering community, all of which are direct and indirect beneficiaries of geological mapping produced by SGS and the USGS.

Table 2.3.1. Questionnaire Distribution to National Associations and Societies

- American Council of Engineering Companies.
- American Inst. of Mining, Metallurgical, Petroleum Engineers.
- American Institute of Professional Geologists.
- American Institute of State Boards of Geology.
- American Planning Association.
- American Water Works Association — included with 28 states numbers.
- Geological Society of America (5 Divisions).
- Industrial Minerals Association, North America.
- National Asphalt Paving Association.
- National Mining Association.

Table 2.3.2. Questionnaire Distribution to State Associations and Societies — Illinois Example

- Association of General Contractors of Illinois.
- Chicagoland Association of General Contractors.
- Great Lakes Construction Association.
- Illinois Asphalt Paving Association.
- Illinois Association of Aggregate Producers.
- Illinois Association of Counties.
- Illinois Chapter, American Planning Association.
- Illinois Coal Association.
- Illinois Municipal League.
- Illinois Oil & Gas Association.
- Illinois Road Transportation Builders Association.
- Illinois Rural Water Association.
- Illinois Section, American Society of Civil Engineers.
- Illinois Section, American Water Works Association.
- Illinois Society of Professional Engineers.
- Illinois Underground Contractors Association.
- Structural Engineering Association of Illinois.

The number of questionnaires that was sent (81,072) was a minimum figure. Despite regular reminders to national and state associations and societies to report the number of questionnaires distributed to their members, several failed to report, and even among those who reported numbers, there was not any control on individuals forwarding the questionnaire link to others. Also, some of the organizations posted the questionnaire on their website, with little reporting of the number of "hits". In fact, all stakeholders were encouraged to forward the link, knowing full well that actual responses were obviously more significant than sends.

The online nature of the questionnaire and how mechanisms of its distribution to members of national and state associations and societies might differ required a standardized approach depending on whether the questionnaire link and an explanation of the program was either (1) in a direct email, or (2) included in a bi-weekly, monthly, or quarterly newsletter. For the former, they simply provided the number of emails that were directly sent, and that number became part of the 81,072 sent questionnaires. For the latter, when they reported the number of newsletters that were sent, and not knowing if the newsletters were opened, we followed up with a request for how many of the newsletter emails were opened. For both of the above scenarios, we assumed that an opened email and an opened newsletter were similar to opening a piece of "hard mail" containing the questionnaire and then filling it out. Most were able to report the number of newsletter emails that were opened, and for those few that did not, we used the number of newsletters that were sent as a part of the 81,072 sent questionnaires.

A total of 55,880 questionnaires were sent by SGS directly to their individual constituents. It was assumed that SGS and the USGS stakeholders were the same pool, and therefore to reduce duplication of effort, only the SGS distributed the questionnaire link.

Twelve SGS either asked for assistance in assembling lists of stakeholders or had no capacity to do so. Therefore, staff at the Illinois State Geological Survey (ISGS) developed stakeholder lists for these 12 states and did so based on extensive web searches. As an example of the stakeholder categories chosen to receive the questionnaires, the ISGS classified stakeholders into categories including: (1) economic development; (2) NGOs; (3) state government (planning, engineering, water resources, emergency management, EPAs, public health, natural resources, and mining); (4) county and municipal government (planning, zoning, highways/engineering, GIS, emergency management, public health, and real estate); (5) associations and societies; (6) excavation, construction, and site development companies; (7) environmental, geotechnical, and engineering companies; (8) rock and mineral clubs; and (9) conservation districts. They also developed customized email text to accompany the questionnaire link. Those SGS that requested assistance were then provided with their stakeholder lists, asked to review it, and add or delete entries. They were then given the option of sending the questionnaire to their stakeholders or jointly sending it with ISGS project staff, and importantly reporting the number of distributed questionnaires back to the project staff. For SGS lacking capacity to participate in the project, stakeholder lists with a customized email to stakeholders, were distributed by ISGS project staff.

It was recognized in the first few months of acquiring questionnaire responses that ~40% of respondents had not completed the online form. Those respondents were identified, provided access to their original submissions, and then given the opportunity to complete the questionnaire and re-submit the form. Unfortunately, only ~150 respondents availed themselves of the opportunity. However, all questions answered by the respondents were accepted and are part of the database.

There was also concern with the viability of the response rate, following communication from some respondents regarding their reluctance to click on the questionnaire link for fear that it would lead them to an unsafe website. This concern was despite clear identification of the program and who was conducting it, its goals and outcomes, and direct phone and email contact information from those distributing the questionnaire. Others responded that they did not complete the form, saying that the questionnaire was too long. However, it was made clear in introductory emails and letters that were distributed with the questionnaire that respondents did not have to answer all questions, but only those that they felt qualified to do so. Also, they did not have to provide long text answers to several questions.

Research on response rates for surveys does not provide a definitive guide to their adequacy. Online surveys usually have lower response rates than in person surveys. Wu et al. (2022) conducted "*a comprehensive search, screened 8,672 studies, and examined 1,071 online survey response rates reported in education-related research….The average online survey response rate was 44.1%..... sending an online survey to more participants did not generate a higher response rate. Instead, sending surveys to a clearly defined and refined population positively impacts the online survey response rate. In addition, pre-contacting potential participants, using other types of surveys in conjunction with online surveys, and using phone calls to remind participants about the online survey could also yield a higher response rate….Other factors that impacted the rates included the funding status of a project, and the age and occupation of the participants.*"

Marketing companies work with their own assessments or survey response rates. For example, Malnik (2023) reported a range of response rates depending on the survey method. The average good response rate was reported as 30%, whereas a good online survey response rate was reported at 29%.

Lastly, previous economic analyses that evaluated costs and benefits in the discipline of geology showed a wide range of response rates — Kentucky (20%) (Bhagwat and Ipe, 2000), Spain (26%) (Garcia-Cortes, et al, 2005), Nevada (4.6%) (Bhagwat, 2014), Indiana (28.5%) (Capstone Class 7933, V-600, 2017), and Ohio (63.6%) (Kleinhenz & Associates, 2011). The 6% response rate of the present study needs to be viewed differently from these previous studies because previous studies all covered relatively small geographic areas compared to the present study which covered the entire U.S. The method of reaching intended audiences of the present study had to be less direct. The survey included many more questions than in previous studies and many queries required descriptive responses. Long and descriptive surveys tend to elicit fewer responses.

2.4: DATABASE DEVELOPMENT

2.4.1: Questionnaire Response Data

The questionnaire yielded 4,779 viable response sets (then reduced to 4,577 by deleting those from SGS and foreign-only respondents) from geoscience and other stakeholders nationwide (see Chapter 2). Raw data was received from a contracted third-party online survey vendor in the form of a Microsoft (MS) Excel flat file report. Prior to analysis, these data were transformed into an MS Access relational database format. The relational database model improved machine readability and facilitated powerful query operations via built-in Structured Query Language (SQL). The database also provided a convenient package for query versioning and portability, while integrating well with various analytical tools such as R, Python, and GIS software.

In migrating these data, the following cleaning and quality-of-life transformations were made:

- Implementation of controlled vocabulary — common categorical responses were identified among several free-response questions. For these responses, various spellings and abbreviations of like categorical values were assimilated to establish controlled domains. This practice simplified SQL operations for selecting and filtering the data.

- Feature scaling of disparate ranked data to common scales — the questionnaire contained several groupings of questions that asked for a ranked response, typically evaluating expert opinion. However, different questions employed varying bin scales (e.g., 1–5, 1–10, etc.). This contrast was not recognized during the pre-survey review; however, all ranked responses were normalized to a common scale to mitigate errors that otherwise would have arisen in analysis.

- Miscellaneous parsing of data from the vendor-supplied format into schema that simplify analysis workflows — for example, multi-select response data were delivered as many individual columns in the flat file report; these were transformed into a single array-like entry per question, optimal for the writing and execution time of queries and analysis code.

- Aliasing of questions and categorical responses for short yet human-readable queries.

- Redaction of personal identifiable information (PII), such as IP addresses logged by the survey vendor, or contact information volunteered by responders in the additional comments section of the questionnaire.

2.4.2: Narrative Response Data

A particular challenge to the data ingestion process was encountered in the overwhelming response to long text-based narrative questions. These questions took such forms as "Please describe an example of […]" or "Optionally, provide additional comments on […]." The questionnaire contained eight of these long-form questions. Among these, we received approximately 14,000 individual non-null responses, at an average of 26 words per response — or roughly 700 pages of narrative information.

To summarize these responses for use in these analyses, the narratives were assigned with categorical values corresponding to major topics. This task was partially automated through development of a custom Python code using the open-source Natural Language Toolkit (NLTK) package. NLTK is a leading platform for building programs to work with human language data and computational linguistics.

At a high level, the analytical approach involved labeling training data by manually reading and categorizing 15% of the responses for each question. In parallel, lists of non-overlapping keywords were initiated and thought to be indicative of each category. The training data were then analyzed in NLTK for word use frequency to generate additional predictive keywords based on a frequency threshold. The NLTK analysis included a Snowball (or "Porter2") stemming algorithm to consider word roots only, as well as the dismissal of common English and geology-related stop words (e.g., "a," "the," "is," etc.) expected to have no bearing on keyword-based categorization. Upon supervised determination of additional keywords, category codes were mapped to each response based on keyword presence.

The analysis resulted in automated categorization of 65–90% of responses per question. Remaining outliers were categorized manually, and predicted categories were spot assured to evaluate the accuracy of the automation. Internal reviewers were satisfied with the results of the NLTK approach, and thus the coded narrative data were incorporated with further statistical analysis (see Chapters 10 and 12). Additionally, robust pattern recognition tools were developed and implemented for parsing of dollar value ranges and other useful numerical figures from the narratives.

2.4.3: Geological Survey Cost Reporting Data

Similar to the questionnaire response data, the forms showing SGS and USGS reported cost data were organized into a second MS Access relational database. Here, data were systematically ingested from 49 individual SGS MS Excel reporting files and from a cost report furnished by the USGS. These data are captured in thematic tables, with a relational SGS ID, and included such attributes as: state vs. federal funding of agency mapping over the 1994–2019 project period; employee type distribution (geoscientist, administrative, etc.); existing state map coverages at various scales; and derivative map status and needs. The SGS and USGS cost data were augmented with web product view/download statistics (see Chapters 4, 5, and 7).

2.4.4: Metadata Documentation

All prompts, codes, aliases, and other data definitions were documented in the data dictionary tables within each database. This ensured that databases could be effectively explored by others as stand-alone products and facilitated queries of metadata alongside responses. This documentation also will be available on the repository listing page of the corresponding data release.

All working datasets, documentation, analysis products, and project management materials for this effort were maintained on a collaborative cloud storage service, with organization, version control, access control, and backups internally managed by the NBMG Geoscience Data Manager.

Both databases described above (Questionnaire Results and Survey Cost Reporting) are publicly available from AGI in parallel with this report. The data release includes Microsoft Access database (.accdb), DuckDB (.db), Comma Separated Value (.csv) and Apache Parquet (.parquet) file formats, with plain-text documentation. The release contains full response data minus any redacted PII.

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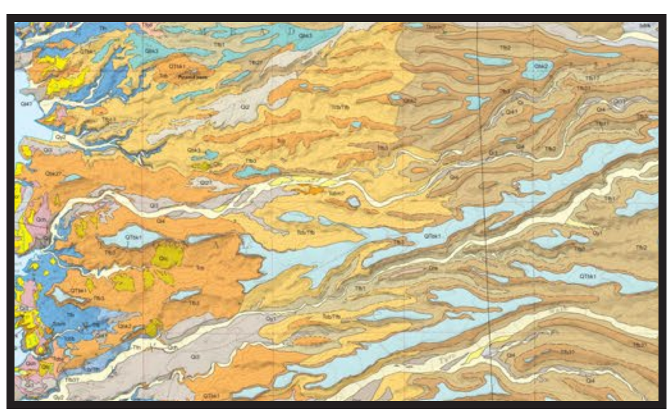

Portion of: House, P.K., et al., 2020, Surficial geologic map of the Spirit Mountain SE and part of the Spirit Mountain NE 7.5′ quadrangles, Nevada and Arizona: USGS Scientific Investigations Map 3448, scale 1:24,000.

CHAPTER 3: STAKEHOLDER ASSESSMENT OF MAP PRODUCING AGENCIES

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ABSTRACT

Stakeholder valuation of geological maps may be influenced by their trust in the map making agencies. Geological maps produced by State Geological Surveys (SGS) and the U.S. Geological Survey (USGS) are considered the gold standard, with ratings for such maps averaging 9.5/10 as opposed to other sources with a 6.7/10 rating. Another good indicator of stakeholder views was how often and for what purpose they visit map producing agencies, what products they use, and how satisfied they are with the visits, whether in person or online. More than 70% of respondents to the questionnaire reported visiting SGS or USGS offices or web sites at least several times per year, and 80% of them implied that additional money would have to be spent on their projects if geological maps were not available from SGS or the USGS. Questions directed at stakeholders to that end indicated a high regard for the scientific capabilities and the independence (i.e., unbiased products) of SGS and the USGS.

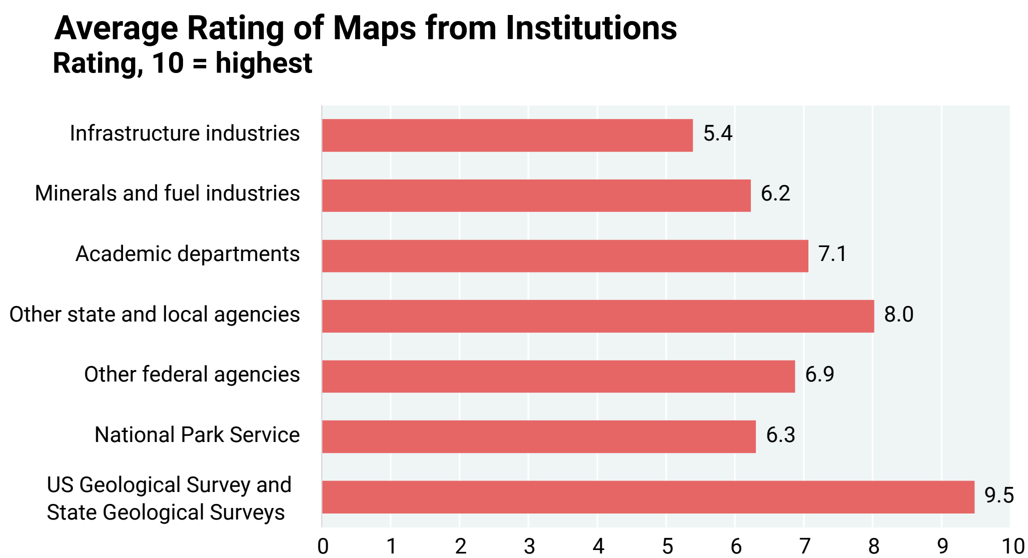
3.1: RESULTS AND DISCUSSION

In addition to assessing the perceived value of geological maps (see Chapters 6 and 8), the questionnaire also included queries that addressed the reputations of the map-producing agencies themselves. Geological maps, as well as reports and other data, are generated by several organizations and agencies, each with a special focus and based on the technical and economic capabilities of those producing the products. Respondents provided input about their preferences for products from these organizations (question 18). The overall averages of the ratings for each organization and agency (Figure 3.1.1) indicate that geological products generated by State Geological Surveys (SGS) and the U.S. Geological Survey (USGS) are rated the highest and are clearly considered the gold standard for geological maps. Ratings of geological maps produced by SGS and the USGS averaged 9.5/10. The mean rating assigned to all other entities was 6.7/10. It makes sense that geological maps produced by SGS and the USGS would have the highest confidence level for procurement by stakeholders. They perform considerably more geological mapping than other agencies, academia, and private industry. It is part of their core mission to do so, and their products are open access, designed to be publicly available, and have unbiased interpretations

The importance to the respondents of public entities producing geological maps is further elaborated by answers on how they would acquire maps if not available (question 16). About 12.8% of respondents would contract with state agencies and pay for it. However, about 47.7% preferred to do their own mapping, and about 18.6% would hire outside consultants to do the mapping. Affordability was also an important consideration in these responses. Notably, about 14.5% would do without geological maps if they were not available from state or federal agencies (Figure 3.1.2). As briefly discussed earlier and covered in more detail in Chapter 9, such a decision may have negative consequences, such as reducing the quality of work or causing adverse environmental impacts. Looking at Figure 3.1.2 another way, about 80% of stakeholders implied that additional money would have to be spent for the required geological information if maps were not available from SGS and the USGS. This is discussed in detail in Chapter 6 (Table 6.5.1.), whereby stakeholders provided values of project cost increases and willingness to pay if maps were not available, the long-term value of a map, and expected payment for a map.

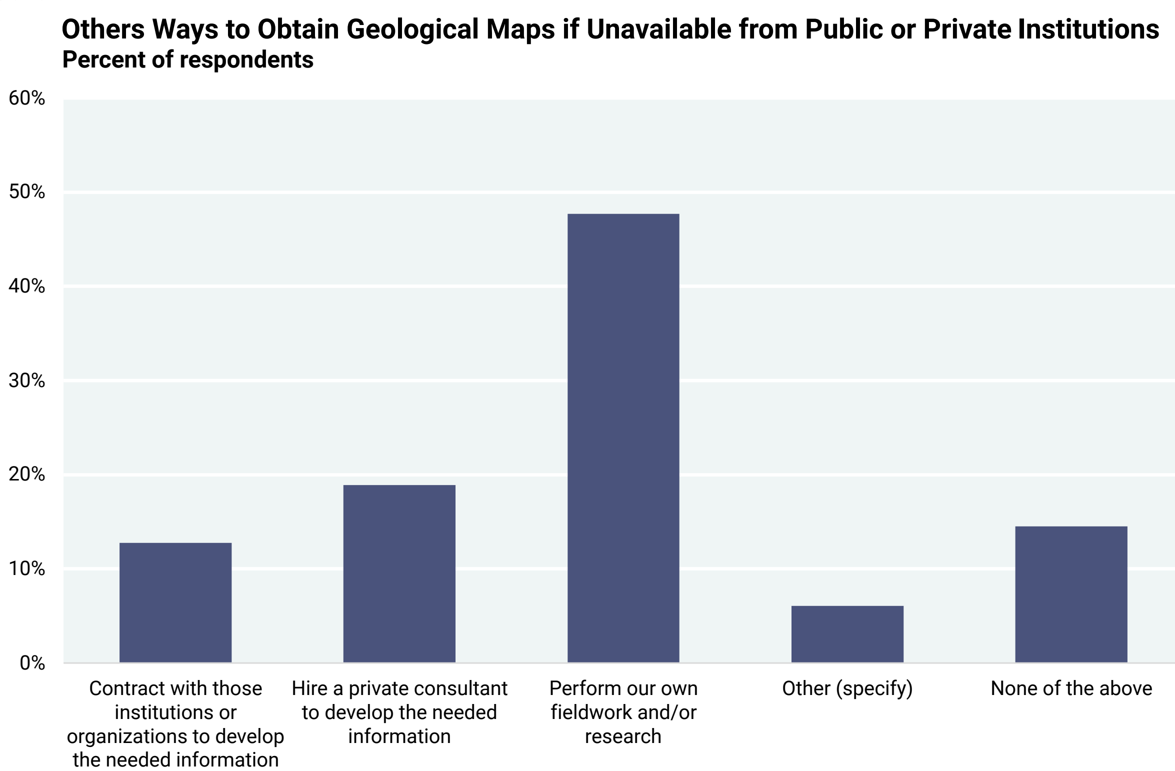
Another indicator of how respondents viewed map producing agencies is the frequency with which they visit these agencies. Visits to offices, facilities, or web sites of agencies that produce geological maps appear popular (question 13), with over 70% visiting SGS and/or the USGS at least several times per year (Figure 3.1.3). Specific reasons for personal visits were not solicited. However, 54.5% of respondents found visits to offices, facilities, or web sites "very useful" and 30% "moderately useful" (question 14). (Figure 3.1.4).

Figure 3.1.1



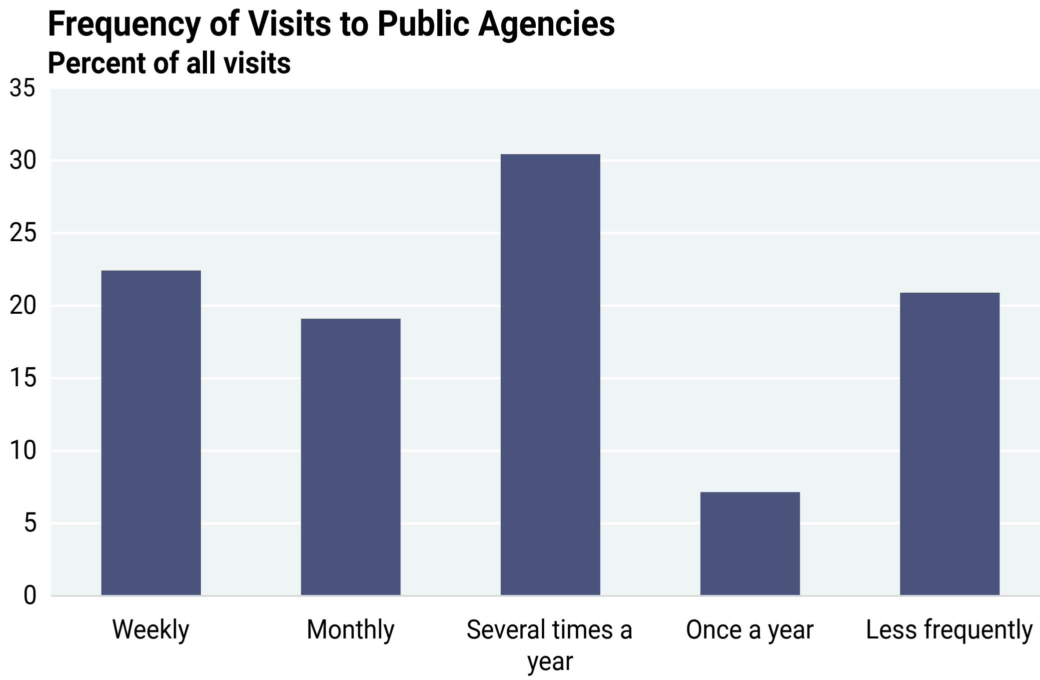
Mean ratings of maps from different institutions.

Figure 3.1.2



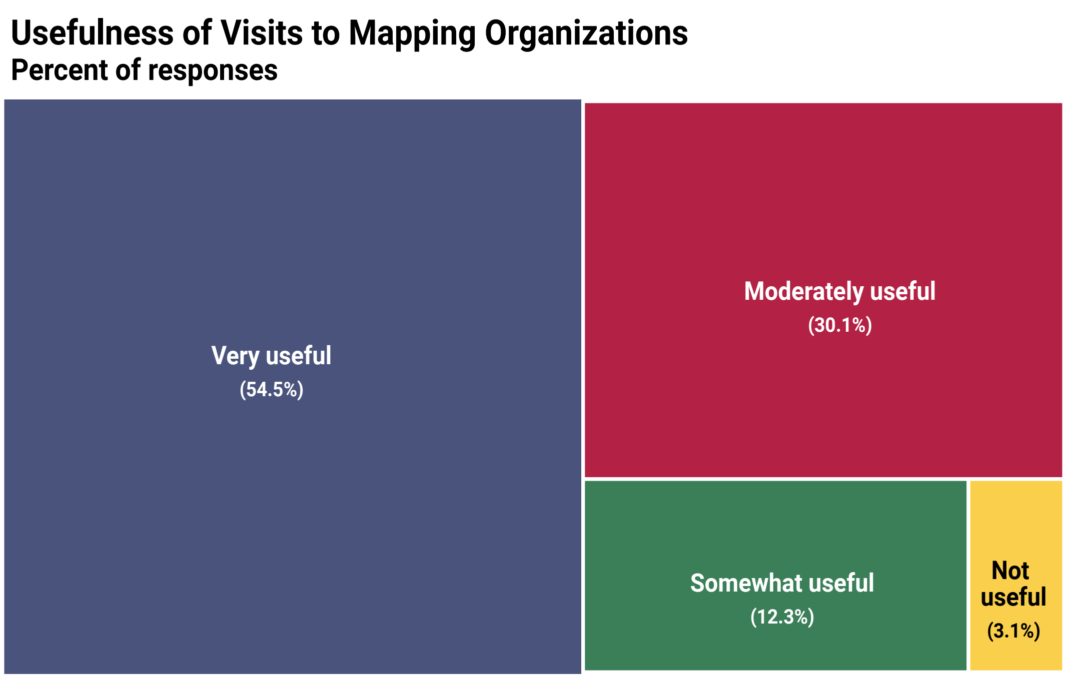
How maps are acquired if not available from public entities.

Figure 3.1.3

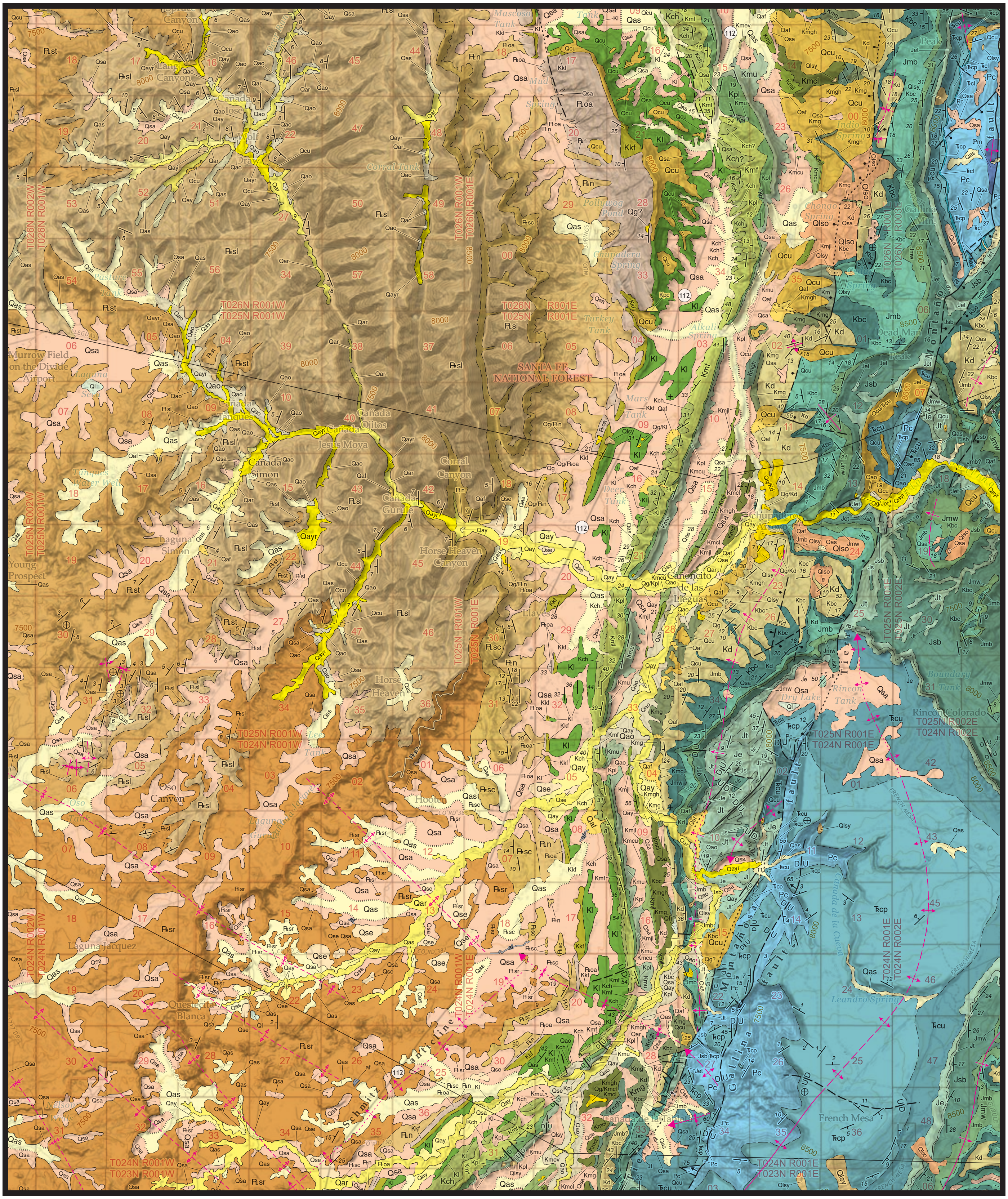


How often do you visit public agencies?

Figure 3.1.4



How useful are your visits?



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CHAPTER 4: COST OF GEOLOGICAL MAPPING

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ABSTRACT

Spending on geological mapping within the National Cooperative Geologic Mapping Program (NCGMP) from 1994 to 2019 was reported by State Geological Surveys (SGS) and the U.S. Geological Survey (USGS). These funds were commonly overmatched by SGS. In addition, SGS also received third-party funding (public and private). In 2020 U.S. dollars, the total cost for geological mapping from all sources was $1.99 billion from 1994 to 2019. State and other non-USGS funds amounted to $362.6 million or 18.3% of the total. Geological maps differ in scale, geographic area covered, geological formations targeted, as well as specific commodities or types of derivative products such as for geological hazards and pollution potential. It was not practical to break down the mapping costs by the various derivatives nor separate costs associated with traditional surface/near surface geological mapping from 3D subsurface mapping and modeling. The total spending over the 26 years is used in this study to compare with estimates of economic values, also independent of the specific nature of maps used, as stated by the responding stakeholders.

4.1: RESULTS AND DISCUSSION

The spending on geological mapping and related research within the National Cooperative Geologic Mapping Program (NCGMP) of the U.S. Geological Survey (USGS), as well as from other sources, was reported by State Geological Surveys (SGS) and the USGS from 1994 to 2019. Data reported by SGS included funds received from the USGS (STATEMAP component of the NCGMP), required matching funds contributed by SGS, as well as third-party funding (public and private). The annual SGS/USGS expenditures on mapping were converted to 2020 U.S. dollars using the national Consumer Price Index (CPI). The total spending in the 26-year period amounted to $1.991 billion (2020 US$) with $1.43 billion expended by the USGS (72%) and $563.9 million (28%) by SGS.

Figure 4.1.1 shows considerable fluctuations of mapping expenditures during 2000–2004 and an overall declining trend over the study period. For many years, and particularly starting around 2003, the actual dollar amount of available, congressionally-appropriated federal funds for geological mapping remained fairly constant and did not keep pace with inflation. Therefore, the inflation-adjusted downward funding trend is evident. However, not captured in this study with an ending year of 2019, federal funding for geological mapping increased by $10 million in 2020, $6 million in 2021, and $2 million in 2022. Figure 4.1.1 shows the difference between the USGS expenditure and the total expenditure, including funds spent by SGS. Figure 4.1.2 provides an overview of SGS spending by source. The total amount spent by states from 1994–2019 was $563.9 million, of which $201.3 million came from the USGS, $331.4 million from state's budgetary allocations, and $31.2 million from other state sources, private and public. Several SGS spent more than the 1:1 matching required by the USGS. Non-USGS funds spent by SGS totaled $363 million, or 1.8 times the amount received from the USGS.

Assigning expenditures to specific maps created during the study period is complicated, because maps are revised, worked over, and improved over time. Their current form may be the result of such revisions extending much farther back into the past than the 1994–2019 project period. For example, the 707 geological quadrangles (1:24,000 scale) in Kentucky were mapped from 1960 to 1978 with USGS financial support (Cressman and Noger, 1981), but revisions and new mapping continues. The NCGMP has been operational long enough to allow the total spending in this period ($1.99 billion) to be used as the basis of assessment of mapping costs. However, geological maps themselves are not a uniform product. They focus on various aspects of geology, such as the bedrock, Quaternary deposits, or derived interpreted applications. They also differ in scale. In addition, they can differ by the specific purpose for which they were developed, like the many derivative or interpretive maps that are developed from them.

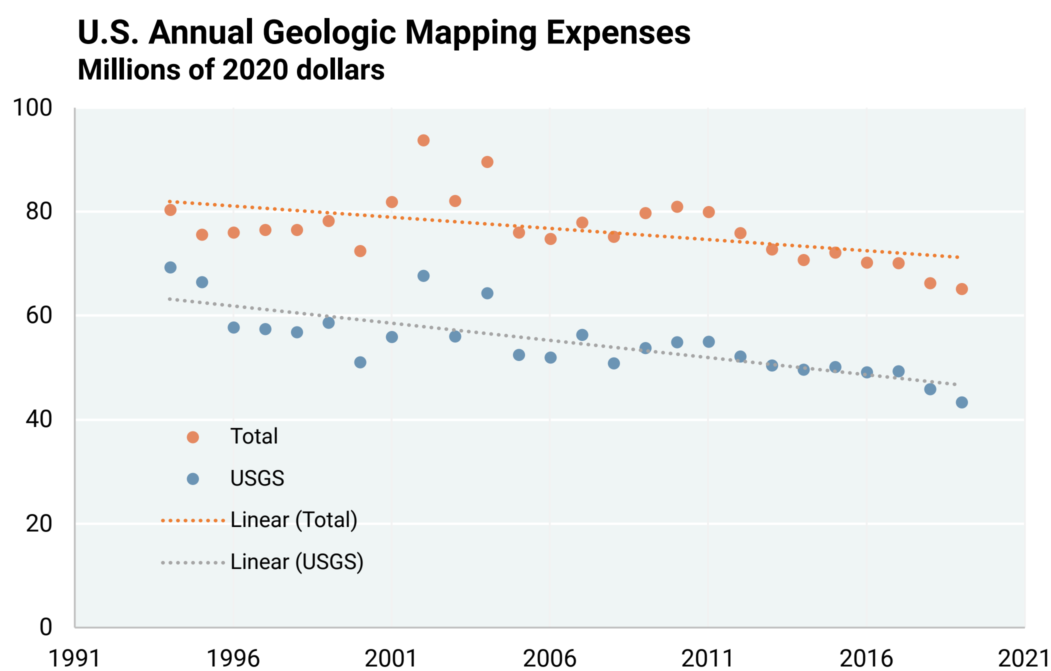
Lastly, this analysis focuses on geological mapping that traditionally depicts two-dimensional representations of the composition, spatial relationships, and age of rocks at, near, and below the Earth's surface and commonly do so by covering large regions where three-dimensional geological information is displayed on the surface (e.g., mountainous terrain). These traditional maps are generally accompanied by a few cross sections depicting areas of the shallow subsurface, but not "true 3D". Beginning in the early 1980s, there has been a very slow increase in 3D subsurface mapping and modeling (MacCormack et al., 2019), which portray "blocks of Earth". However, subsurface data acquisition costs have significantly slowed progress. For those few regions of the U.S. where 3D mapping and modeling has been accomplished, those costs were included in the above $1.99 billion, but no attempt was made to separate out allocations for the 3D mapping. For all of the above reasons, it is therefore not possible to disaggregate the money spent on mapping to determine the actual cost of each type of map.

4.2: REFERENCES

Cressman, E.R., and M.C. Noger, 1981, Geologic mapping of Kentucky – A history and evaluation of the Kentucky Geological Survey: U.S. Geological Survey mapping program, 1920–1978: U.S. Geological Survey Circular 801, 22 p.

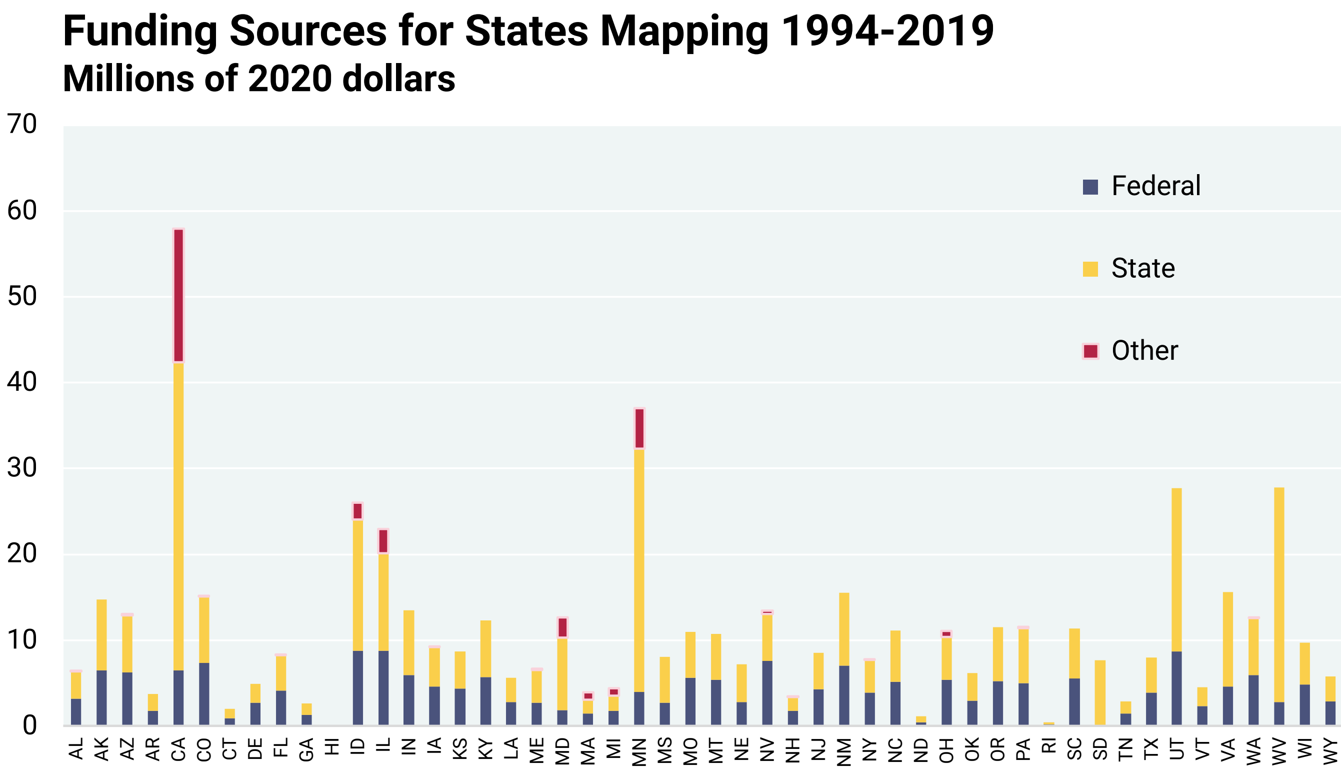
MacCormack, K.E., R.C. Berg, H. Kessler, H.A.J. Russell, and L.H. Thorleifson, 2019, 2019 synopsis of current three-dimensional geological mapping and modelling in geological survey organizations: Alberta Energy Regulator/Alberta Geological Survey AER/AGS Special Report 112, 307 p.

Figure 4.1.1



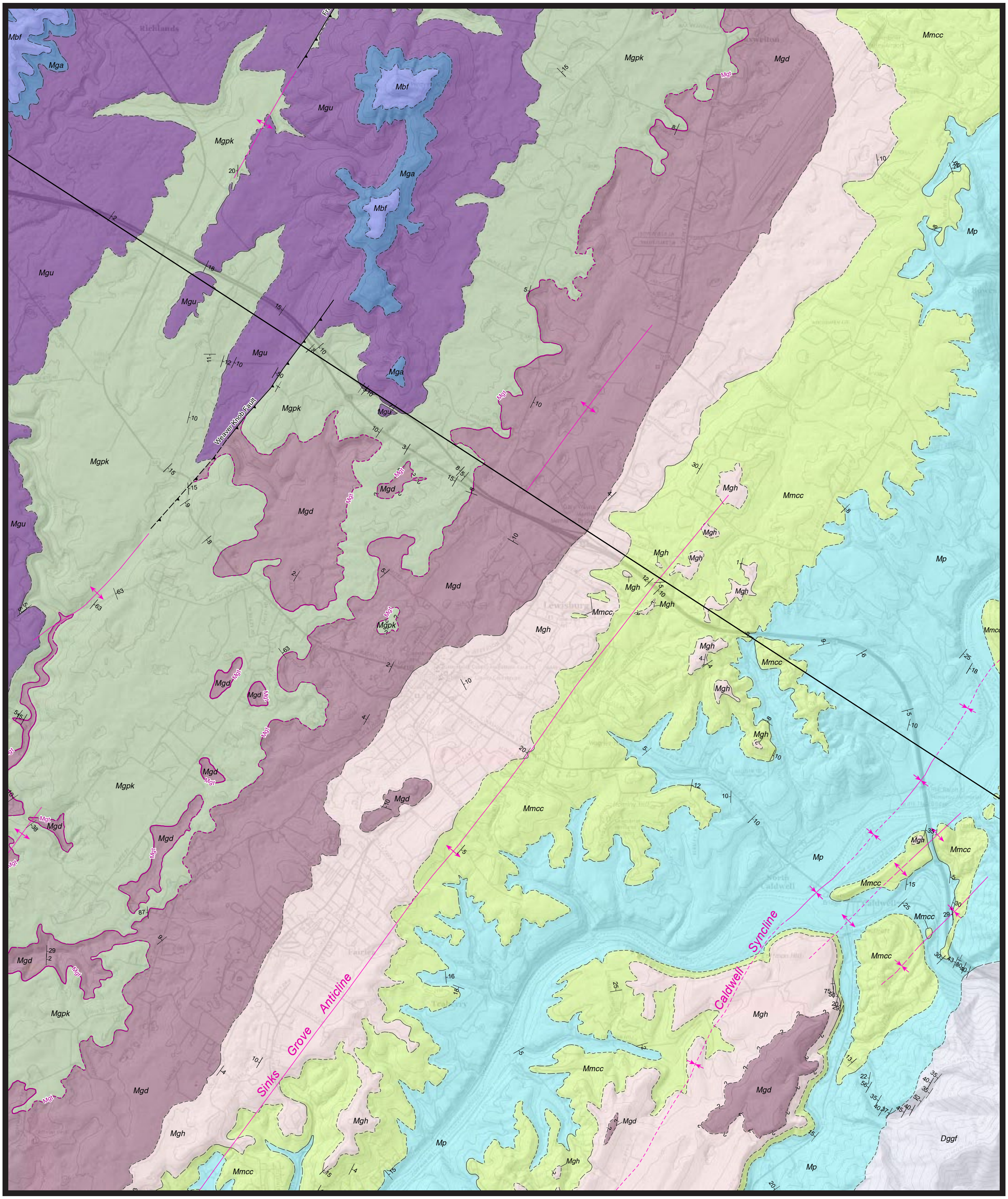
Annual mapping expenditure.

Figure 4.1.2



State spending on mapping by source.

▶ Table of Contents



Portion of: Tudek, J.K., Rhenberg, E.C. PhD, Spurgeon, D.L., El-Ashkar, S.E., Dinterman, P.A., and Perkins, J.W., 2022, Bedrock geologic map of the Lewisburg 7.5′ quadrangle, Greenbrier County, West Virginia: West Virginia Geological and Economic Survey Publication OF-2103, scale 1:24000.

CHAPTER 5: GEOLOGICAL MAPPING PROGRAM ACTIVITIES — CRITICAL COMPONENTS

Subhash B. Bhagwat (Illinois State Geological Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, Ret.)

ABSTRACT

Recognizing the value of accountability of the mapping program, State Geological Surveys (SGS) and the U.S. Geological Survey (USGS) provided as much information as possible about how their funds were spent, what types of mapping were accomplished, and the extent of mapping coverage that was achieved. SGS and the USGS employed 24% and 76%, respectively, of total geologists in geological surveys in the U.S in 2020–21. Their salaries, travel, and equipment comprised the bulk of funds expended over 26 years. Mapping by USGS scientists emphasized smaller, more regional scale mapping, whereas SGS provided larger scale, more localized or detailed maps in addition to some regional scale mapping. The USGS accomplished 87% coverage in small scale mapping of the Quaternary nationwide and 20% of the bedrock. It was revealed that recordkeeping and reporting of geological mapping accomplishments needs greater attention by SGS. Only 28 states reported data on large-scale Quaternary mapping, with 21 of them reporting area coverages of <30%. Medium-scale Quaternary mapping was reported by 20 SGS, all but four of which reported <30% coverage. Only nine SGS reported small-scale Quaternary mapping, but they reported 100% coverage in at least one of the small scales. Large-scale bedrock mapping was reported from 36 SGS, three of which reported 100% coverage. Medium-scale bedrock mapping was reported by 19 SGS, four of which reported 100% coverage. Small-scale bedrock mapping at 100% coverage was reported by 12 of 14 SGS. Paper map sales have been declining for many years. However, e-visits for geological maps, data, and reports have been increasing. Data reporting on e-visits began in the late 1990s. The trend indicated that electronic information transfer will gradually replace traditional paper versions of geological maps. Lastly, SGS and the USGS produced a list of 73 map products derived from geological maps recognizing that derivative geological maps address specific societal needs. They also provided a status of derivative map availability, those that need revision, and desired future derivative maps.

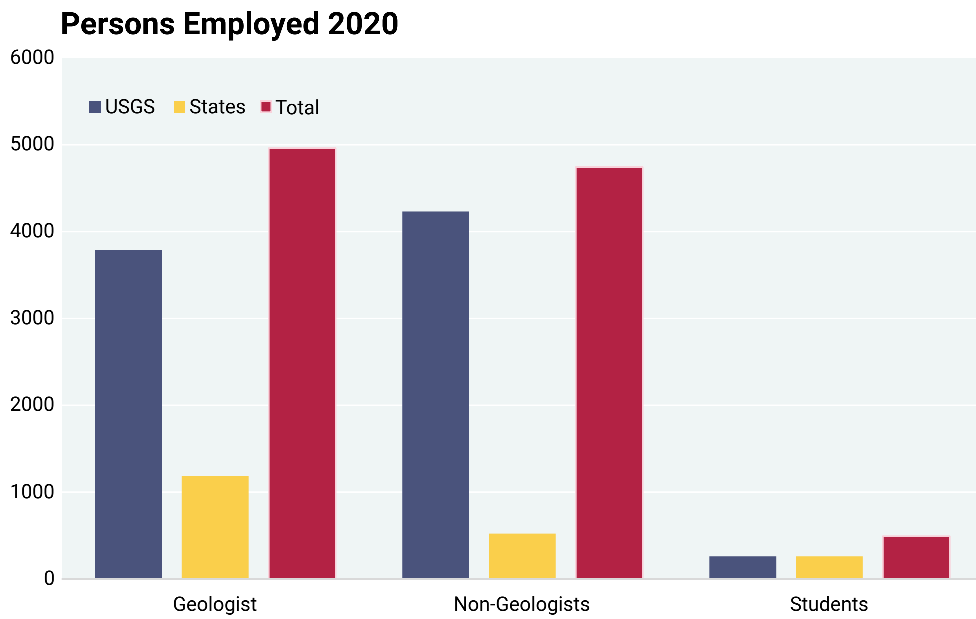
5.1: INTRODUCTION

As reported in Chapter 4, the total spending for geological mapping by State Geological Surveys (SGS) and the U.S. Geological Survey (USGS) over the 26-year (1994–2019) period totaled $1.99 billion (2020 US$). This chapter discusses how those funds have been spent on geological mapping. However, the discussion does not focus on specific dollar amounts (as that would be well beyond the scope of this report), but rather on the personnel, mapping activities, and overall accomplishments over the 26-year period. Major expenditures would include salaries for scientists and support staff, travel expenses for fieldwork, various hardware and software for map preparation and production, and website development. The cost sheets distributed to SGS and the USGS asked, in addition to actual mapping costs as discussed in Chapter 4, for information on the (1) annual number of visitors to their websites; (2) geological mapping that was accomplished from 1994 to 2019 on a square mile and percentage of jurisdiction basis; (3) extent of geological mapping at various scales (from >1:24,000 to <1:500,000 and, if possible, the split between Quaternary and bedrock mapping products); and (4) status of derivative mapping including present-day availability, updating needs, and desired future products.

5.2: STAFFING AT STATE GEOLOGICAL SURVEYS AND THE U.S. GEOLOGICAL SURVEY

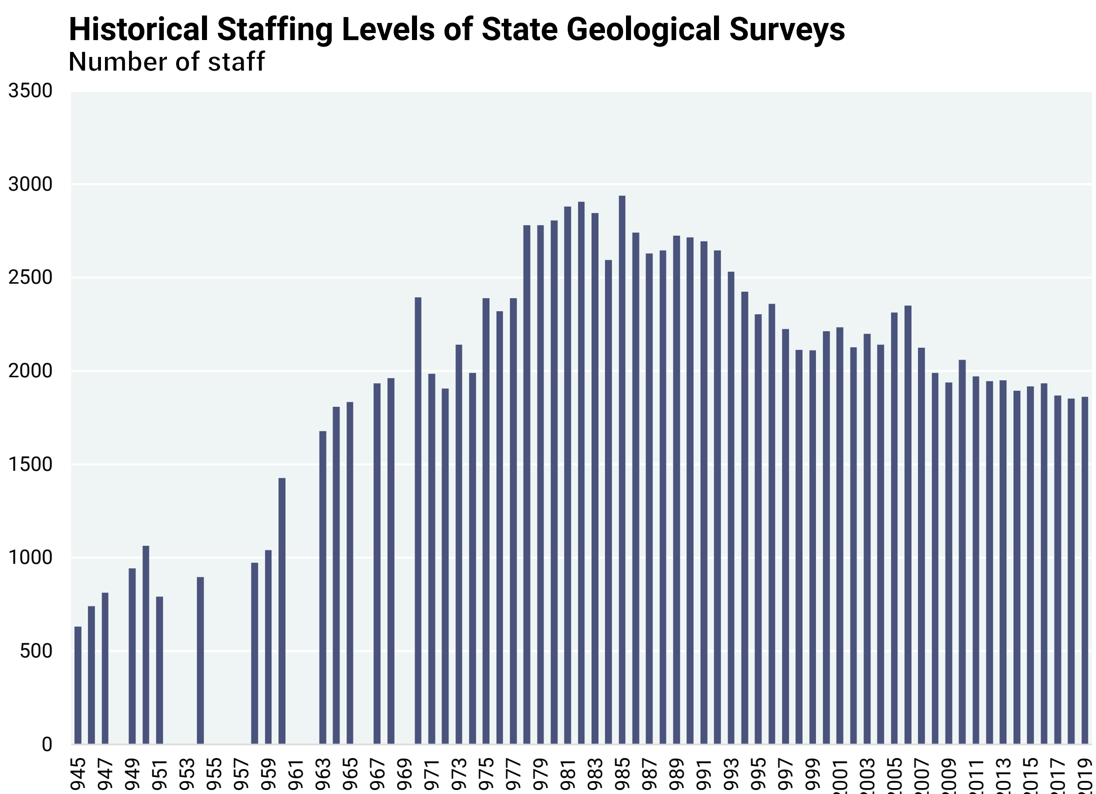
Geological research and mapping are among the prime missions of SGS and the USGS, and as such, employment of geologists and other support professionals has great significance and bears considerable costs of all mapping programs. Data reported by SGS and the USGS in 2020–2021 (Figure 5.2.1) show that of all the geologists employed by these institutions, 76% were employed with the USGS and 24% with SGS. Figure 5.2.2, from the Association of American

Figure 5.2.1



Persons employed in geological agencies in 2020.

Figure 5.2.2



Trend showing total SGS staffing by year – 1945 to 2021 (Bradbury, 2021).

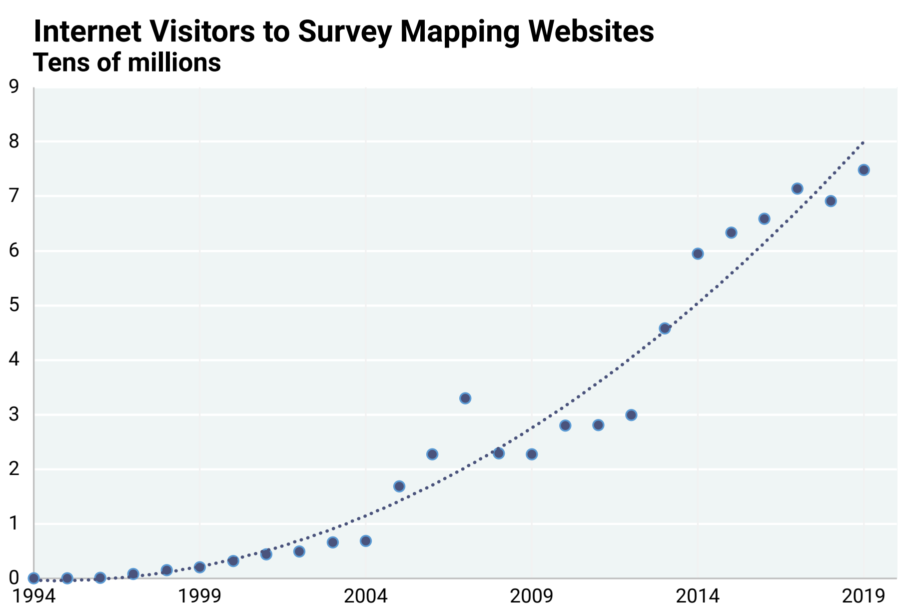
State Geologists Statistical Report, shows staffing trends from 1945 to 2019 at SGS. The early/mid 1980s experienced peak staffing at nearly 2,800, followed by a precipitous decline. Noteworthy over the 1994 to 2019 project period is the staff decline from about 2,300 to 1,800 that began in the early 1990s. Numerous budgetary issues at the state government/ university level are to blame.

5.3: WEBSITE VISITS

Any estimation of cost per map or value of a map without reference to the type, scale, or specific use can only be an approximation. As will be discussed later (Chapter 7), records of geological map sales are not easy to acquire because of staffing and funding constraints and record keeping problems, all experienced by the mapping agencies. Additionally, increasing numbers of map users now access maps in digital format, as the capabilities of mapping agencies have improved to provide them online. To keep up with an ever-increasing demand and the optimum most up-to-date and user-friendly technology, SGS and the USGS have allocated considerable funds for hardware and software and have been required to hire IT professionals, as well as additional mapping staff trained in geographic information systems (GIS) and, most recently, geomodelling. Chapter 7 discusses in more detail the issues associated with providing online access to geological maps.

To gain a first glimpse of the effects of computerization and accessing geological maps and related information, SGS and the USGS reported annual e-visits (electronic visits) to their web pages. Although e-visits are not necessarily the same as visits to the geological map page or map downloads, the increase in e-visits was observed in parallel with the decline in sales of printed maps. Twenty-nine states reported e-visitor data at least for one year. Four states reported e-visitors beginning in 2000, seven states reported e-visitors beginning in 2005, 11 states reported e-visitors beginning in 2010, 23 states reported e-visitors beginning in 2015, and 26 states reported e-visitors beginning as recently as 2019. The USGS reported e-visit data starting in 1997. The total number of e-visits increased exponentially from 1994 to 2019, as shown in Figure 5.3.1.

Figure 5.3.1



E-visits to agency websites.

Some agencies could monitor and count e-visits to specific pages, where geological maps and related data were viewed and downloaded. The trend is clearly toward more complete reliance on electronic access, not only for maps but also for other relevant geological data and reports.

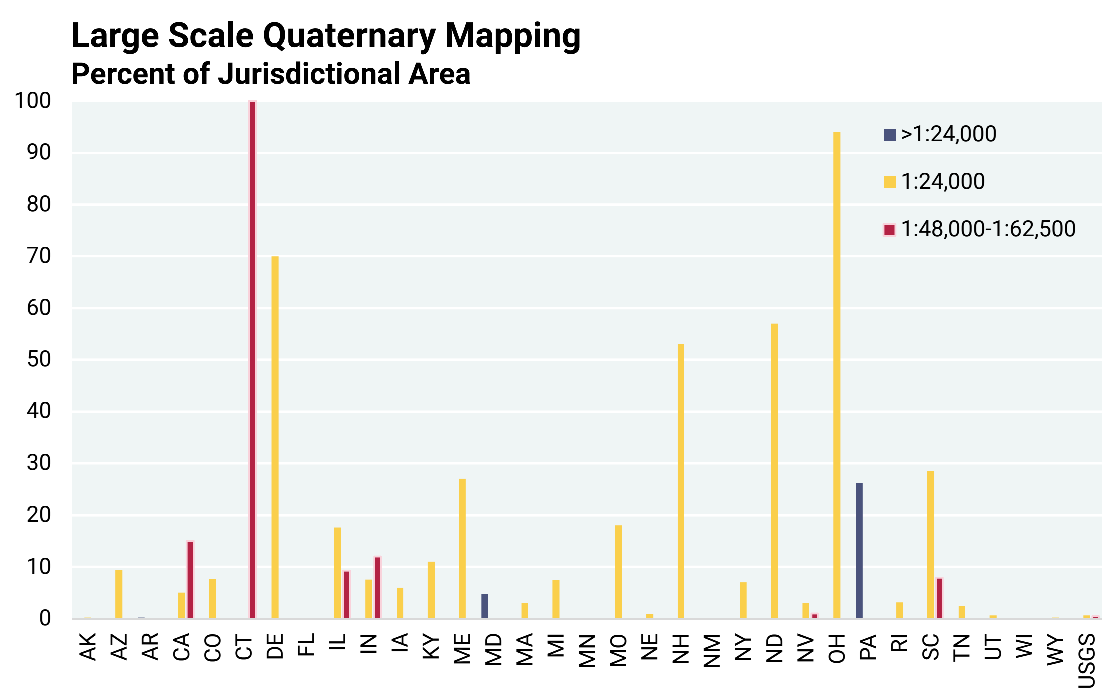
5.4: GEOLOGICAL MAPPING ACCOMPLISHMENTS

Data on mapping accomplishments, as reported by SGS and the USGS, refer to cumulative historic accomplishments from 1994–2019. Mapping accomplishments were reported in terms of square miles mapped, as well as in the percent of the total area of their respective jurisdictions that have been mapped. The percentage area covered is discussed here, because it provides a means to assess how much work has been accomplished and how much lies ahead.

Bedrock and Quaternary mapping accomplishments were reported separately. In each category, the mapping accomplishments were broken down by mapping scale. Reporting of mapping accomplishments has been uneven. Thirty-two SGS reported Quaternary mapping accomplishments, while 35 reported bedrock mapping accomplishments, and 42 SGS reported the total mapping accomplishments. These are not necessarily the same SGS in each group, and if a specific type of mapping was not reported, it should not necessarily be assumed that it has not been completed.

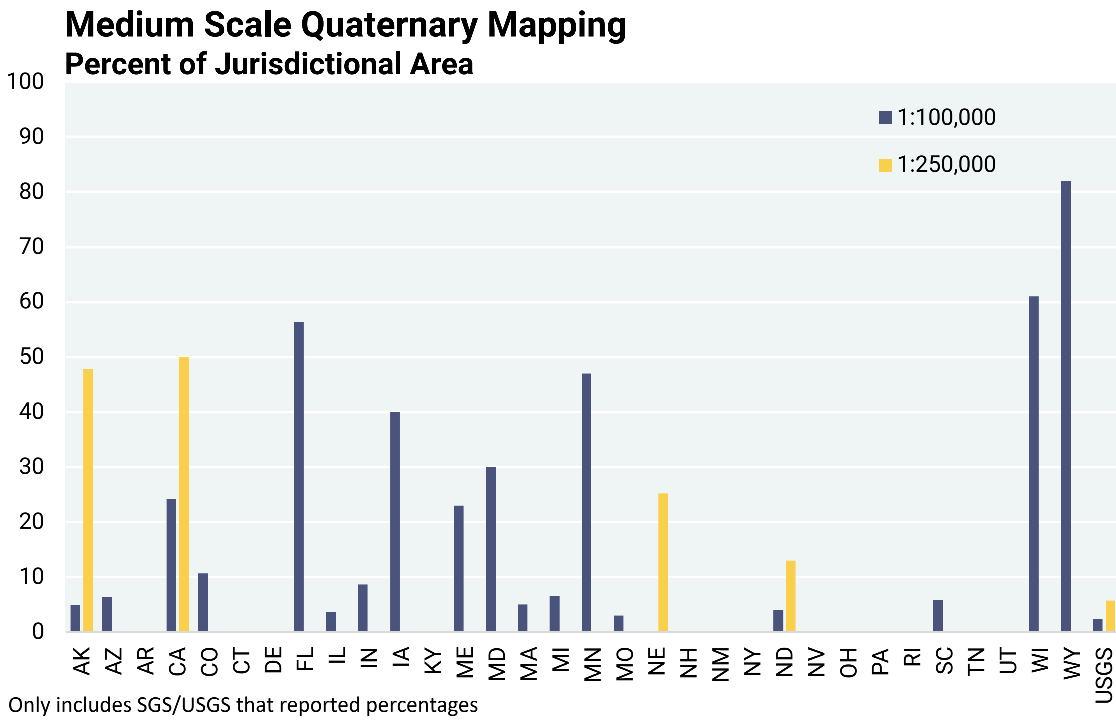
Figures 5.4.1, 5.4.2, and 5.4.3 show the reported Quaternary mapping accomplishments at large, medium, and small scale, respectively. It is important to note that small scale refers to regional or broad-scale maps, and large scale correlates with local or fine-scale maps. Small versus large scale reflects the relative size of the fraction; that is, for example, 1:100,000 is smaller scale than 1:24,000. Regionally aggregated analysis of SGS mapping expenses versus mapping accomplishments do not provide useful insights into the causes of uneven mapping accomplishments. Overall, the data show that geological mapping coverage is far from complete in most states. A visual comparison indicates some patterns:

Figure 5.4.1



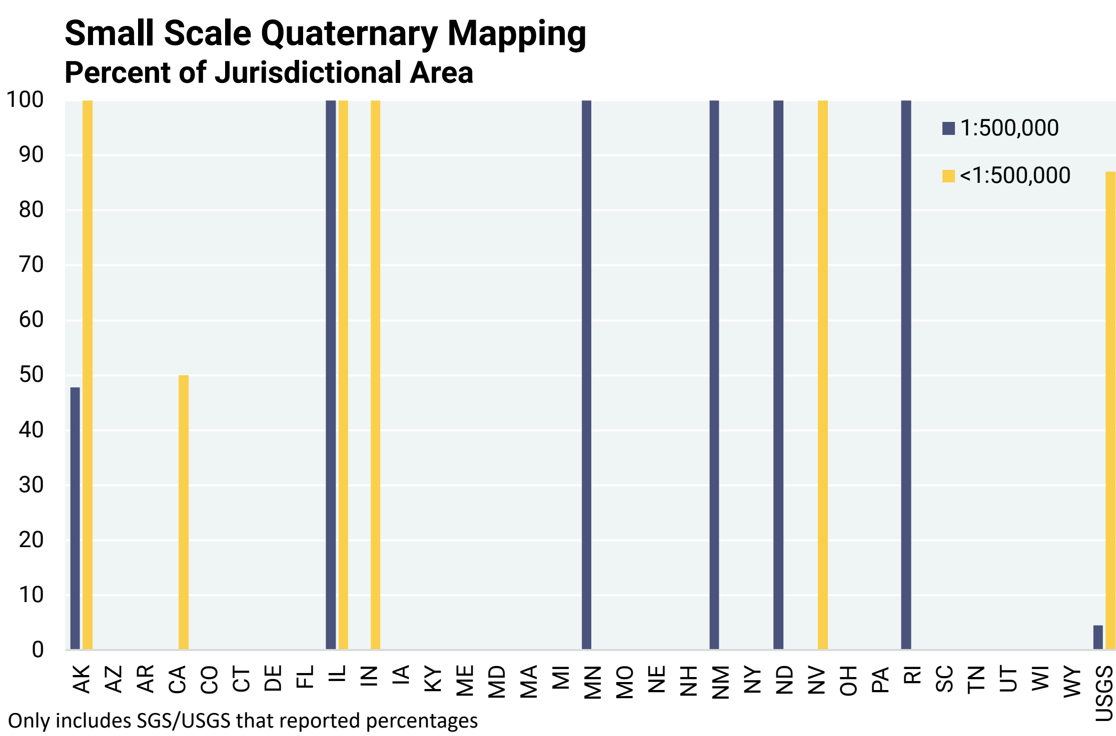
Large scale Quaternary mapping accomplished (% of area).

Figure 5.4.2



Medium scale Quaternary mapping accomplished (% of area).

Figure 5.4.3



Small scale Quaternary mapping accomplished (% of area).

- The USGS accomplishments in mapping during this period were primarily at small scale (1:500,000 and 1:<500,000). According to them, 87% of the Quaternary deposits in the country have been mapped at the smallest scale of 1:<500,000, and 20% of the bedrock has been mapped at the 1:500,000 scale. In either case, the USGS emphasis on small-scale mapping facilitates larger-scale mapping in the future by SGS and others.

- Like the USGS, SGS mapping accomplishments tend to be greater at smaller scales than at larger scales, i.e., coverages at small scale are more complete than at large scale.

- Quaternary mapping was reported by 28 SGS in at least one of the large-scale categories. Five SGS reported >50% coverage at least at one scale, with Connecticut as the only state reporting 100% large-scale Quaternary coverage, followed by Ohio at 90%. All other states report <30% coverage. (Figure 5.4.1).

- At medium scale, Quaternary mapping was reported by 20 SGS. California, Florida, Wisconsin, and Montana reported >50% coverage at least at a medium scale. Coverage in the remaining states was <30% (Figure 5.4.2).

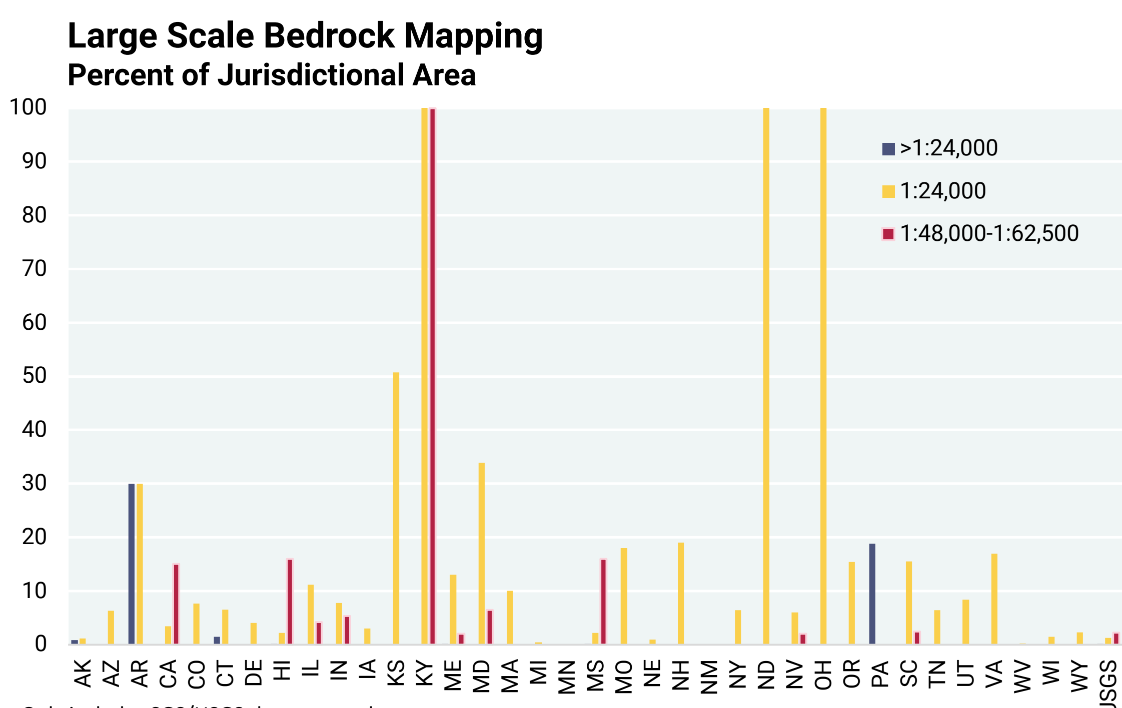
- At small scale, Quaternary mapping was reported by only nine SGS, but with 100% coverage in at least one of the scale categories, except California with 50% Quaternary coverage (Figure 5.4.3).

Figures 5.4.4, 5.4.5 and 5.4.6 show the bedrock mapping accomplished and yield the following key takeaways:

- USGS bedrock mapping coverage is reported to be 20% in the small-scale category, and under 6% at larger scales.

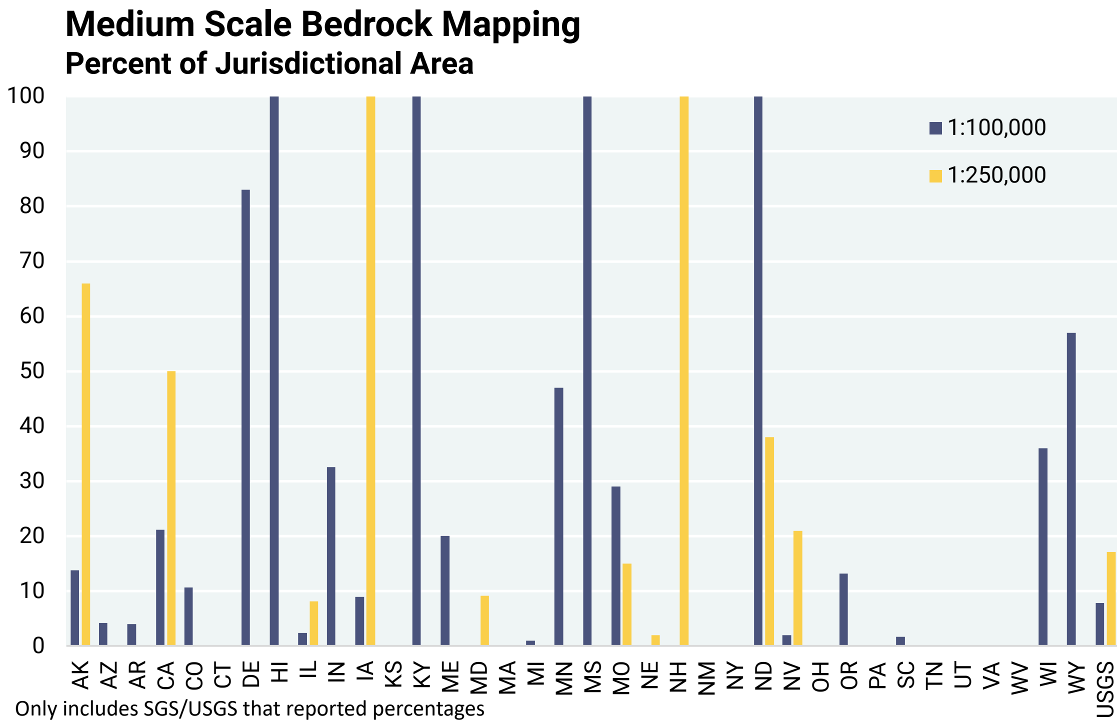
- Large-scale bedrock mapping was reported from 36 SGS. Kentucky, North Dakota, and Ohio reported 100% area coverage of bedrock mapping at large scale. Kansas reported 50% coverage, followed by Maryland at 33.9% and Arkansas at 30%. All other reporting SGS covered <20% of their areas. (Figure 5.4.4).

Figure 5.4.4



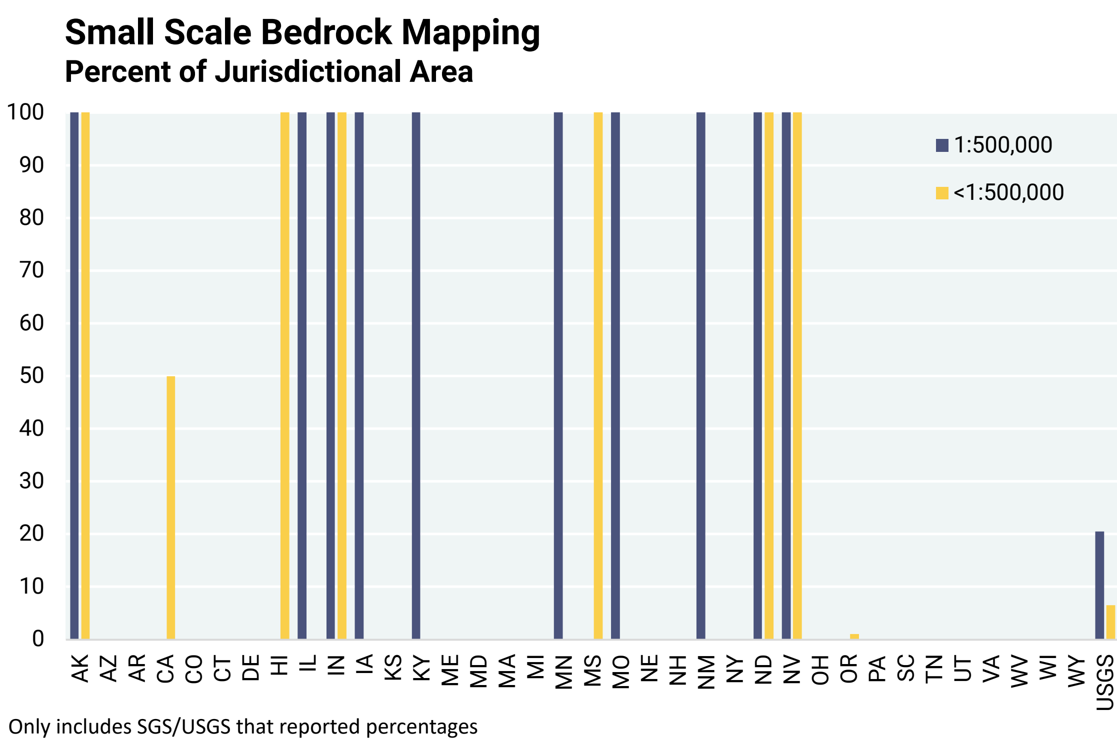
Large scale bedrock mapping accomplished (% area).

Figure 5.4.5



Medium scale bedrock mapping accomplished (% area).

Figure 5.4.6



Small scale bedrock mapping accomplished (% area).

- Eighteen SGS reported medium-scale bedrock mapping. Kentucky, Mississippi, and North Dakota have full mapping coverage in this scale category, followed by Delaware (83%), Wyoming (57%), Minnesota (47%), Wisconsin (36%), and Indiana (32.6%). The remaining 10 SGS reported <30% coverage (Figure 5.4.5). Medium-scale bedrock mapping was reported by the USGS at 100% for Hawaii.

- Small-scale bedrock mapping coverage in 12 of the 14 reporting states was complete (100% of area). One state reported 50% coverage (California), and one state (Oregon) 1% coverage (Figure 5.4.6).

The survey did not seek explanation from SGS or the USGS regarding criteria for setting mapping priorities, with respect to mapping scales, or the Quaternary vs. bedrock options. However, all SGS are required by federal law (National Geologic Mapping Act (NGMA) of 1992, PL 102–285) to set priorities as determined by multi-representational state panels, with the objective of defining areas that the SGS determine to be vital to the economic, social, or scientific welfare of individual states.

5.5: DERIVATIVE MAPPING

The stakeholder survey, analyzed later in this report, includes input about map user views pertaining to future priorities (Chapter 12), as well as scale preferences (Chapter 6). Differences in the quality and quantity of geological outcrops, as well as the depth, extent, thickness, mineralogy, and chemistry of subsurface geologic units, are some of the influences regarding prioritization of mapping. However, the overarching reasons are driven by societal issues (per NGMA requirements), such as population density, industrialization, pollution potential, water and mineral resource identification, geological hazard assessments, and the need for supporting infrastructure development and maintenance. An overarching constraint is the funding that is available to produce a "public good" such as geological maps.

SGS attend to the specific needs of their constituents by setting mapping priorities. Producing "derivative maps" is an important activity that serves specific needs of map users. The survey of SGS included queries regarding derivative maps. A selected list of 25 derivative maps was provided, but additional derivatives could be listed by SGS as well. In the final tally, a list of 73 derivative map products was revealed. Table 5.5.1 shows the 73 map products derived from geological maps. The first 25 were initially provided as options, whereas the remaining were added by respondents. Three questions concerning the status of each derivative were asked:

- A: Is the derivative available?

- B: Does the derivative need revision?

- C: If it does not exist, is it desired in the future?

The responses were categorized under three scale categories: 1:100,000 or larger, 1:101,000 to 1:499,000, and 1:500,000 or smaller. These data were compiled into nine charts. A representative selection of three graphs in the largest scale category is presented on Figures 5.5.1, 5.5.2, and 5.5.3. The derivative number on the x-axes of the graphs corresponds to their number in the list below. Aggregation of data from several SGS in the course of regional interpretation provides no additional insights because of insufficient data.

Table 5.5.1. Derivative Maps

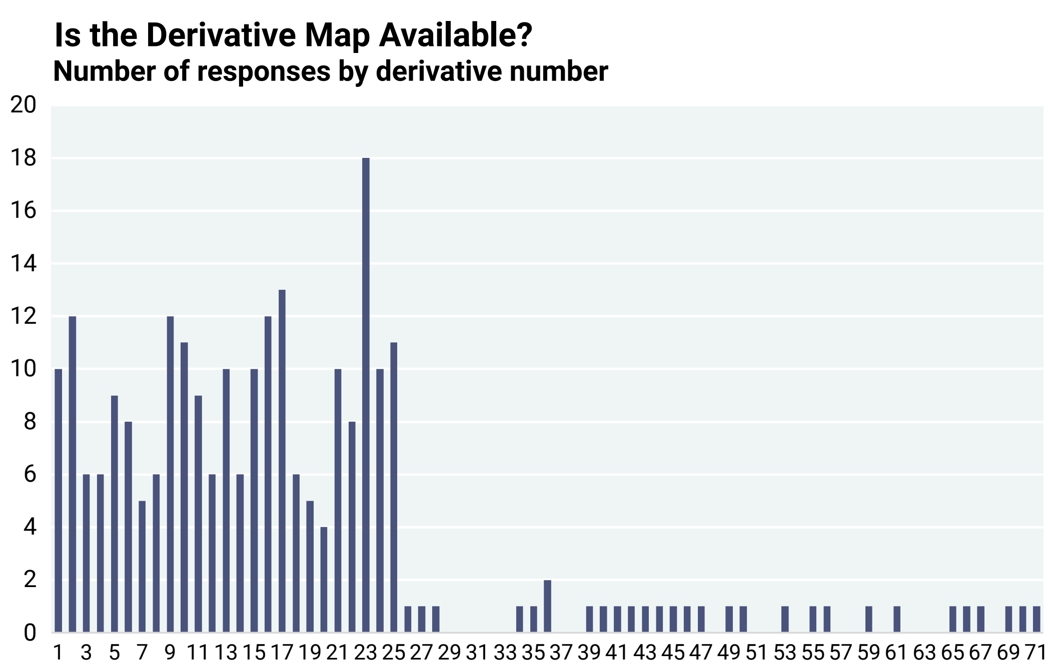
1. Mineral resources - general.
2. Coal.
3. Mined out areas.
4. Hydrocarbons.
5. Aggregates.
6. Industrial minerals.
7. Metals.
8. Critical minerals.
9. Hydrogeology-general.
10. Aquifer delineation.
11. Aquifer sensitivity.
12. Soil drainage.
13. Aquifer recharge.
14. Geothermal.
15. Geohazards – general.
16. Karst.
17. Slope stability.
18. Engineering soil properties.
19. Construction conditions.
20. Tsunami potential.
21. Basic research.
22. Land cover.
23. Surface topography.
24. Bedrock topography.
25. Drift thickness.
26. Minerals hazards.
27. Carbon capture and sequestration.
28. Alluvial fan hazards.
29. Landslides/mass movements.
30. Earth fissures.
31. Thickness of principal aquifer overburden.
32. Structural features.
33. Soils and parent material.
34. Stacked units/3-D.
35. Surface slopes.
36. In-home radon potential.
37. Highway maintenance costs.
38. Landfill suitability.
39. Geology for land use.
40. Lands impacted by sea-level rise.
41. Reservoir sedimentation.
42. Ocean sand mapping.
43. Bottom sediment classification.
44. NEHRP soil classification.
45. Glacial surface features.
46. Bedrock valleys.
47. Wetlands.
48. Geophysical investigations.
49. Water wells.
50. Ground water quality.
51. Geophysics: electromagnetic/magnetic.
52. Depth to water.
53. Coastal erosion.
54. Potentiometric surface.
55. Groundwater yield.
56. Hydraulic conductivity.
57. Bedrock structure.
58. Carbon storage resources.
59. NGL storage resources.
60. Utica Shale resource.
61. Brine disposal resources.
62. Structural features.
63. Bouguer gravity.
64. Rare-Earth elements.
65. Volcano hazards.
66. Earthquake hazards.
67. Permafrost.
68. Avalanche.
69. Flooding.
70. Aquifer potential.
71. Aquifer texture.
72. Gravity.
73. Magnetic.

Figures 5.5.1, 5.5.2, and 5.5.3 depict SGS responses to derivative maps at 1:100,000 or larger. Numbers of affirmative responses are shown on the y-axes. Similar data for other scale ranges (1:101,000 to 499,000, and 1:500,000 or smaller) were collected. Graphical views of those responses display similar patterns but are not provided in this report as figures.

Some observations from Figures 5.5.1, 5.5.2, and 5.5.3 include:

- The 25 derivatives selected by the Steering Committee for this query were appropriate.
- The SGS added 48 derivatives that were deemed important from their regional perspectives, and these underly the importance of the SGS-USGS geological mapping collaboration.
- The numbers of responses from SGS differed greatly from state-to-state.
- No specifics about scale or application of derivative maps were solicited. Therefore, comparisons between regions with regard to the uses of derivative maps are not meaningful.
- The need for a revision of available derivatives is widespread, indicating the need to continue and strengthen the mapping program to address pressing societal issues.

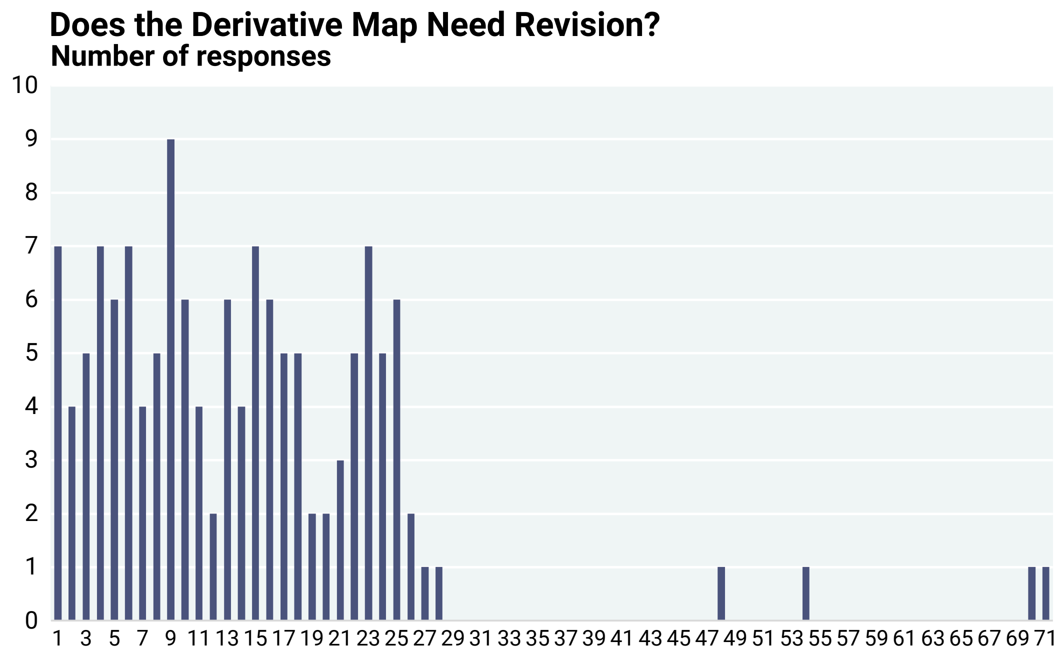
Figure 5.5.1



Is the derivative available?

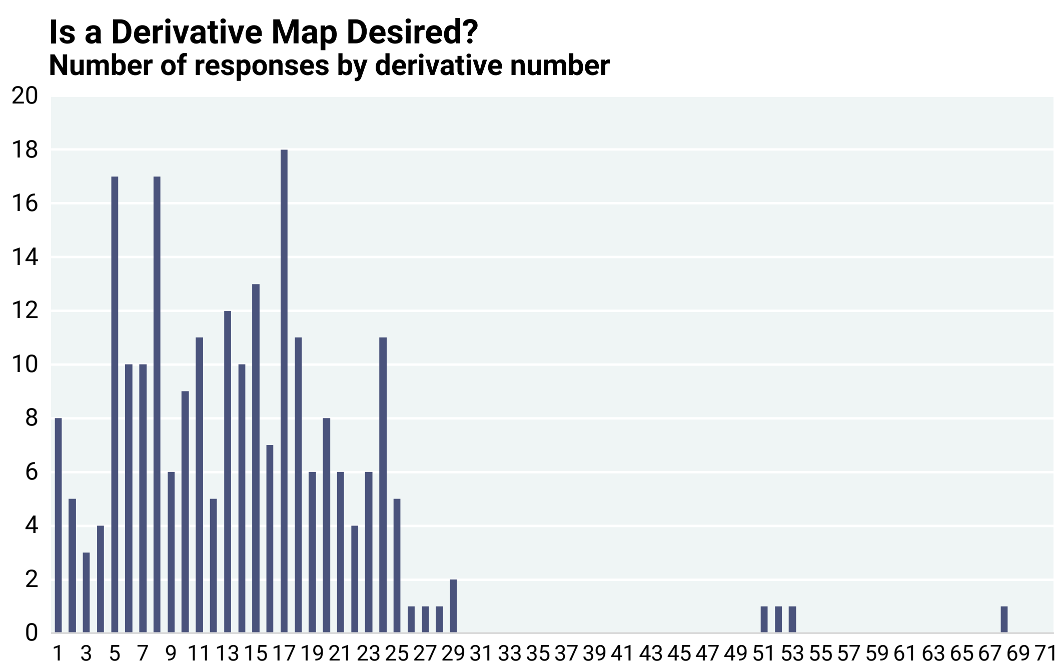
▶ Table of Contents

Figure 5.5.2

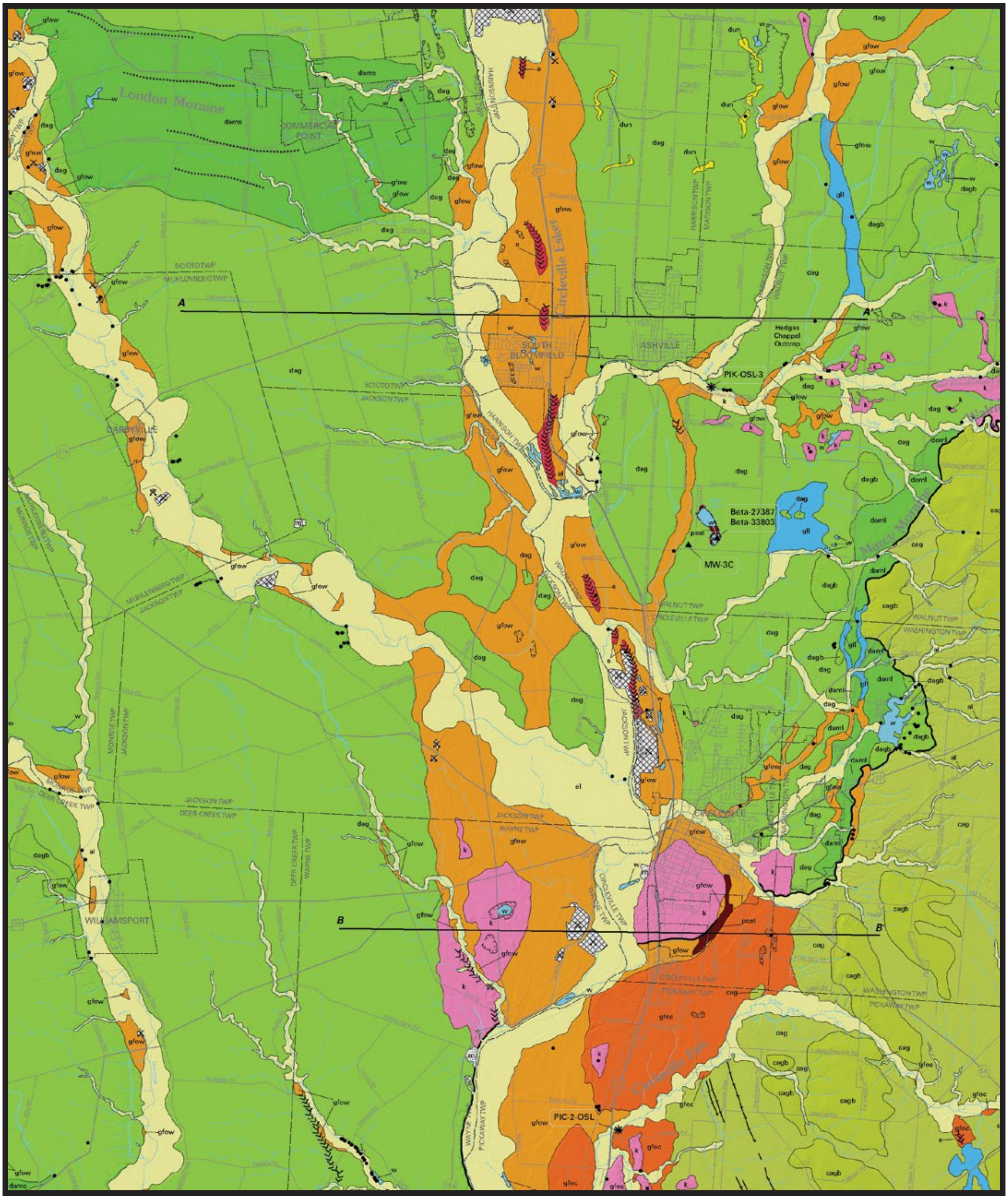


Does the derivative need revision?

Figure 5.5.3



If the derivative does not exist, is it desired in the future.



Portion of: Valachovics, T.R., Nash, T.A., and Norris, T.A., 2023, Quaternary geology of Pickaway County, Ohio: Columbus, Ohio: Department of Natural Resources, Division of Geological Survey Map, QG-2-PIC, scale 1:62,500.

CHAPTER 6: BENEFITS OF GEOLOGICAL MAPPING: QUANTITATIVE ASSESSMENT OF RESPONSES TO STAKEHOLDER QUESTIONNAIRE

Subhash B. Bhagwat (Illinois State Geological Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, Ret.)

ABSTRACT

Of those respondents who provided full information, 62.7% worked in the private sector and 37.1% in the public sector. In the public sector, 57.7% of respondents represented state and local governments, and 20.8% were from educational institutions. Independent geologists formed the largest single responding group in the private sector. About 26.7% of respondents worked in organizations employing up to five persons, 23.8% in organizations with 6 to 50 employees, 13.1% with 51 to 200 employees, and 36.4% worked in larger organizations. The analysis indicates that the size of the respondents' employer had no influence on their benefit assessment.

About 37% of respondents indicated a preference for digital or online access to geological maps. GIS format maps are the most desirable digital product. Derivative maps addressing water resources were of high interest to 25.8% of respondents. Surface topography maps also received a substantial number of responses. As in previous studies, higher resolution maps at scales of 1:24,000 or larger were overwhelmingly preferred by 72% of respondents. 3D maps were not yet available extensively. However, they are likely to receive increased uses in the future.

Input about the monetary assessment of map values and benefits was solicited in various ways, such as time and costs saved in the past five years (median time saved 20%, median cost saved 15%), project specific value per map used (median value $11,162 to $18,375), willingness to pay for a geological map (median of $3,000), long-term value of a map (median value $10,000), and expected high, low, and likely payment for a map (median expected payment $2,883). Respondent's willingness to pay did not seem to depend on the size of their organization.

6.1: INTRODUCTION

As previously explained, a questionnaire was distributed to over 81,000 individuals identified as stakeholders in the use of geological maps because of their affiliation (directly or indirectly) with the geosciences and the likelihood that their professional activity requires and benefits from the use of geological maps and information. A total of 4,779 individuals submitted responses. As seen from the questions in Appendix 2, the objective was to obtain in the words of the stakeholders (1) how the use of geological maps and information benefit them professionally; (2) what significance they see in maps prepared by scientists employed at publicly funded institutions; and (3) how they would quantify those benefits. For the quantification of benefits, the respondents were asked to assess in terms of time and money saved, because maps were readily available to them at little or no cost, and to estimate how much they would pay for a geological map if maps made by state and federal agencies were not available.

A non-controllable outcome of having questionnaires forwarded by societies and associations to their members was that 140 were sent to SGS employees and about 40 to individuals working solely in foreign countries. Questionnaire responses from SGS staff were excluded to avoid conflicts of interest. Responses from individuals working solely in foreign countries were also excluded, because this assessment covers only the U.S. For the latter, some foreign respondents did conduct work in the U.S. and were therefore included. In addition, those USGS employees who responded were not excluded. The USGS is a 9,000-person agency with different scientists within several mission areas (e.g., water, hazards, ecosystems, minerals, etc.) in numerous locations throughout the U.S., all of which are direct beneficiaries of geological maps produced by their own USGS Core Sciences Mission Area, as well as SGS. However, SGS have relatively small staff sizes with overlapping duties for both producing maps and developing derivatives. Therefore, it would be a conflict of interest for SGS staff to assign a value on something that they created.

This chapter first describes the characteristics of the sample of stakeholders who responded followed by the evaluation of stakeholder responses in the sequence in which the questions were asked. Most responses from stakeholders were received in the first four months from August 10, 2020, through December 14, 2020. Some additional responses were received through September 2021. A reminder to responders who had submitted incomplete questionnaires resulted in a small number of additional responses, although the proportion of complete and incomplete responses did not change appreciably (Figure 6.1.1).

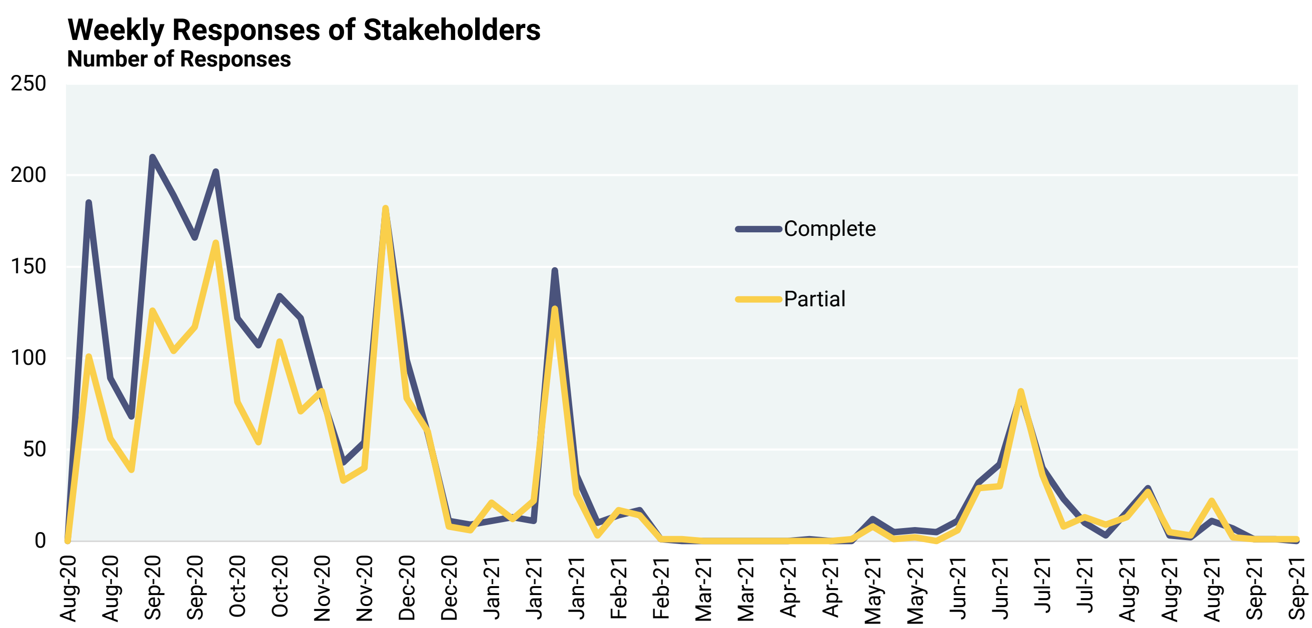
6.2: STAKEHOLDER BACKGROUND

Stakeholders responding to the survey were active in all parts of the U.S. Figure 6.2.1 is a compilation showing in which state the respondents work. As mentioned above, respondents working at SGS were excluded, and this was consistent with their exclusion from all monetary and other evaluations of maps to avoid conflicts of interest. Respondents working in foreign countries were also not included in this figure. The frequency with which states were mentioned are presented. Also, many respondents worked in more than one state, and some in foreign countries also worked in one or more states. The total number of responses (over 10,000) therefore exceeds the number of respondents. All states, including the District of Columbia, are well represented.

The respondents worked in both the private and public sectors (question 1). About 62.9% worked in the private sector and 37.1% in the public sector (Figure 6.2.2).

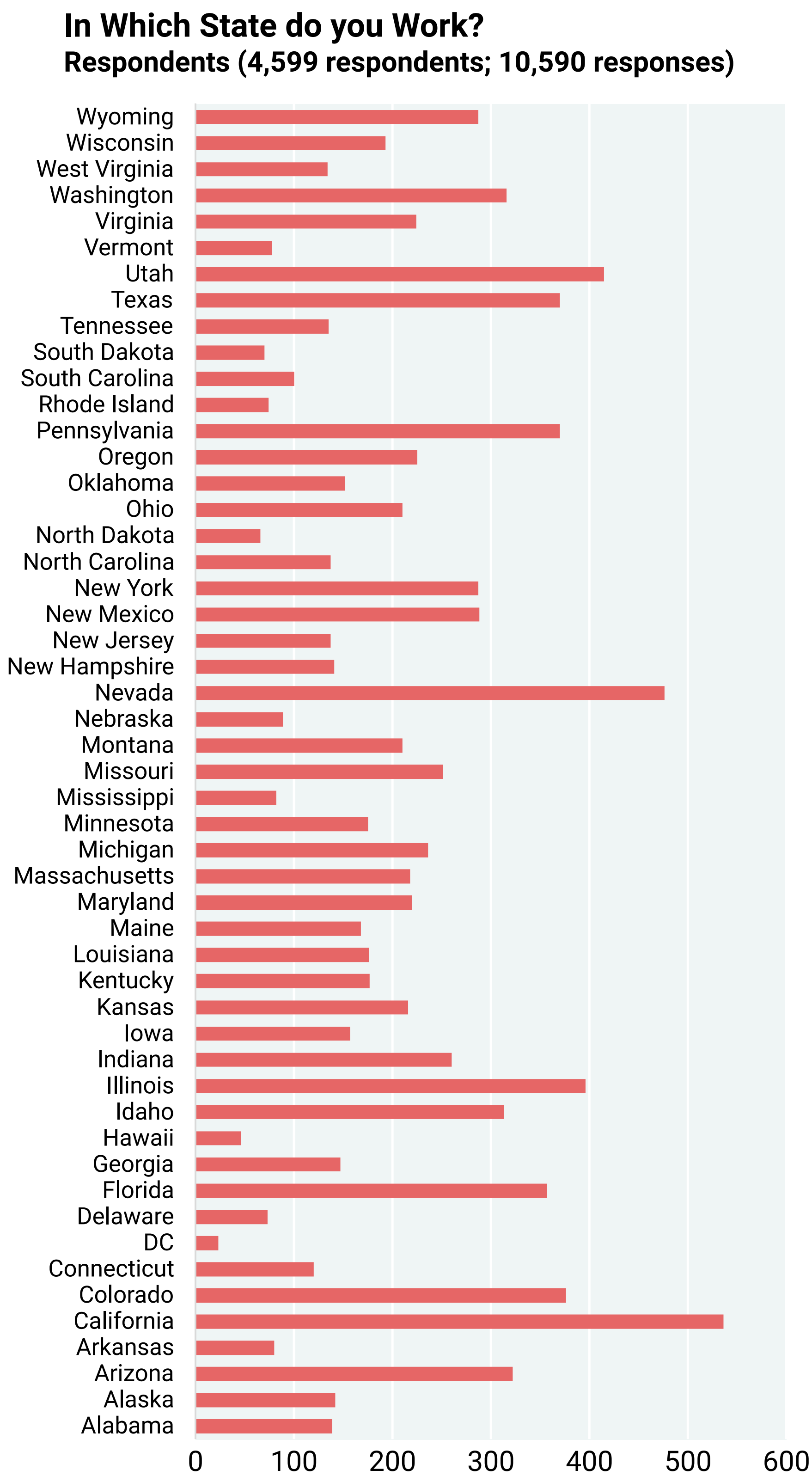
Figures 6.2.3 and 6.2.4 indicate the broad representation of a wide segment of public and private sectors (questions 1A and B). Some of these apparently work in private as well as public sectors. State and local government entities account for 57.7% and educational institutions for 20.8% of public sector responses. In the private sector, 2,527 responders provided 5,171 responses averaging about two responses per person, indicating the overlap of activities among categories (Figure 6.2.4). Large and small mineral

Figure 6.1.1



Weekly responses of stakeholders.

Figure 6.2.1

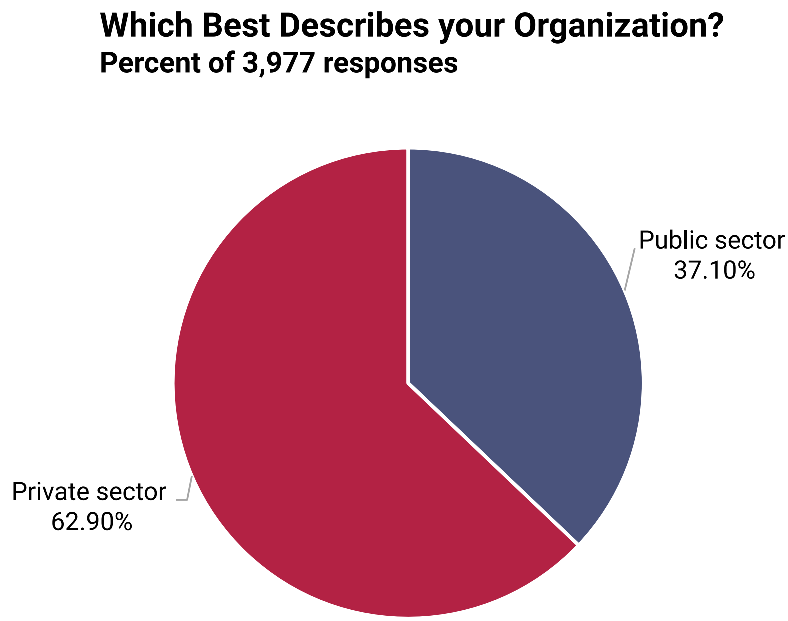


In which state do you work? (name all)

and energy industries account for 25.7% of responses. The largest single group of responses in the private sector are from independent geologists (17%), whose actual areas of work are unknown. The same person may be active in more than one private sector category. For example, mining and water management may be complementary geological activities, or geotechnical investigations may be involved in construction, transportation, or real estate.

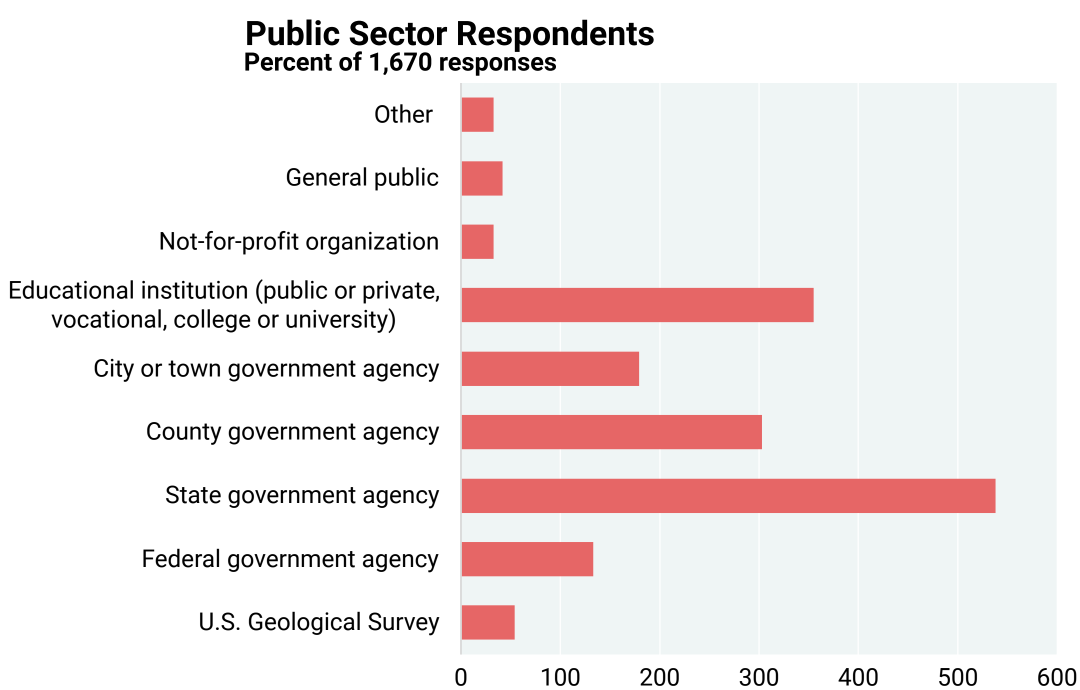
Responders came from all sizes of organizations in terms of employment (question 1C). Employment information was provided by 3,749 respondents. The median number of employees in organizations was 180, whereas the mean number of employees was 2,955. Without the 44 very large organizations that were reported, the mean declines to 2,241. The data show that small and medium-sized organizations are well represented. About 26.7% of respondents work in organizations with up to 5 employees (respondents who stated zero persons employed in their organization are evidently working on their own). About 23.8% of the respondents work in organizations with 6 to 50 employees, and 13.1% with organizations of 51 to 200 employees. The remaining 36.4% of the respondents work with organizations larger than 200 employees (Figure 6.2.5). Sampling this diversity of applications by a variety of users at different levels with different budgets for various projects was an explicit intent of this economic analysis of geological mapping, such that it would be as inclusive as possible and representative of a broad spectrum of economic and user-driven needs. However, the following analysis in this chapter indicates that the assessment of map value is not influenced by the size of the organization using geological maps.

Figure 6.2.2



Public vs Private sector occupation.

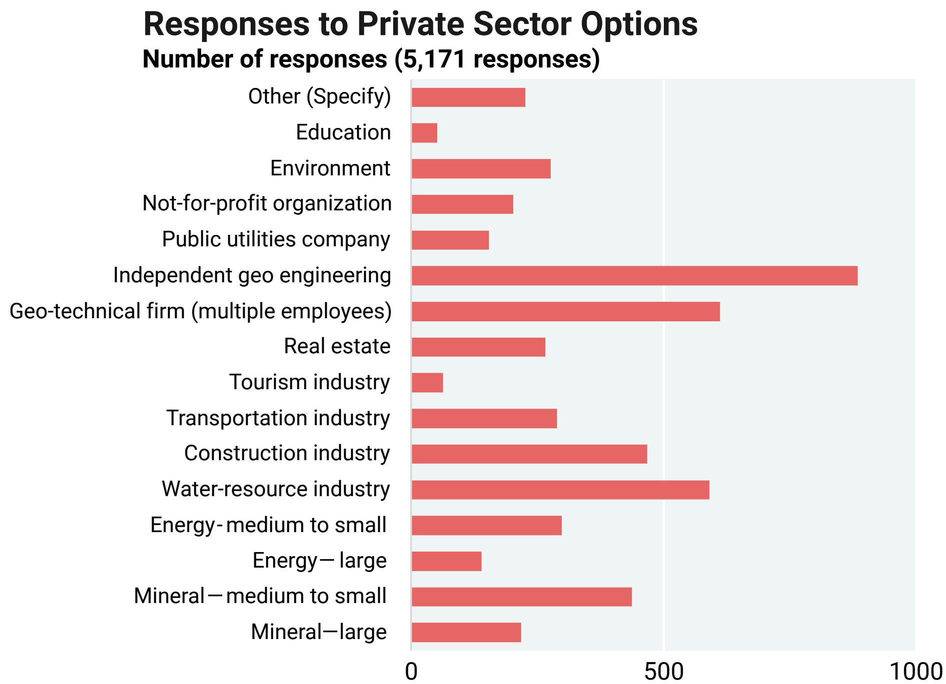
Figure 6.2.3



Sub-categories in public sector responses. (Individual responses in the "Other" category)

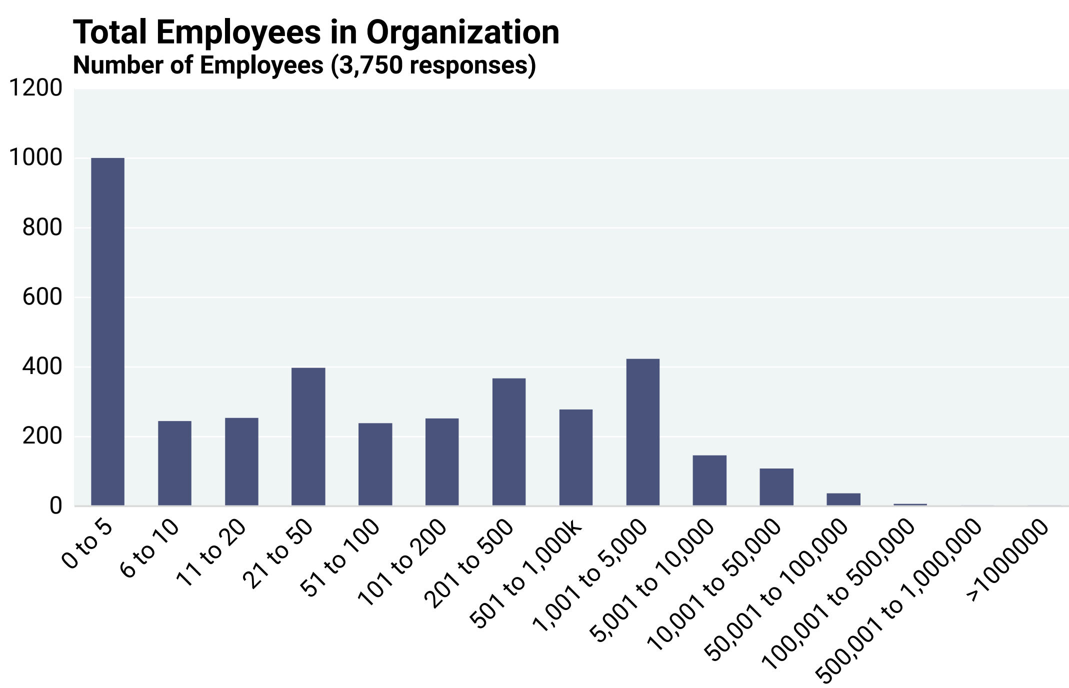
▶ Table of Contents

Figure 6.2.4



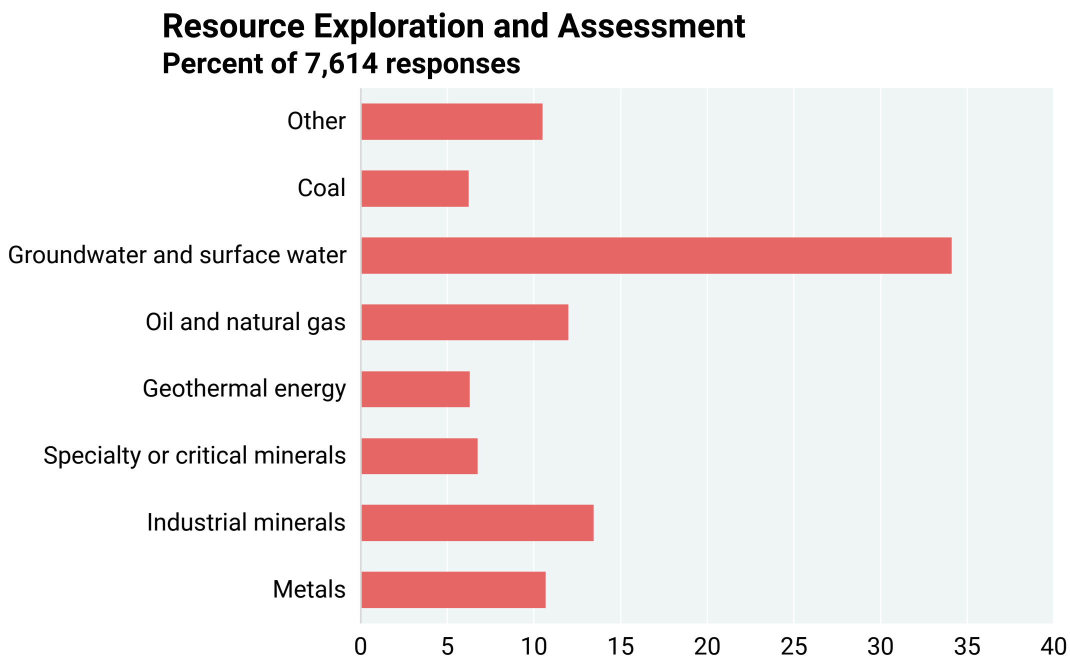
Sub-categories in private sector responses.

Figure 6.2.5



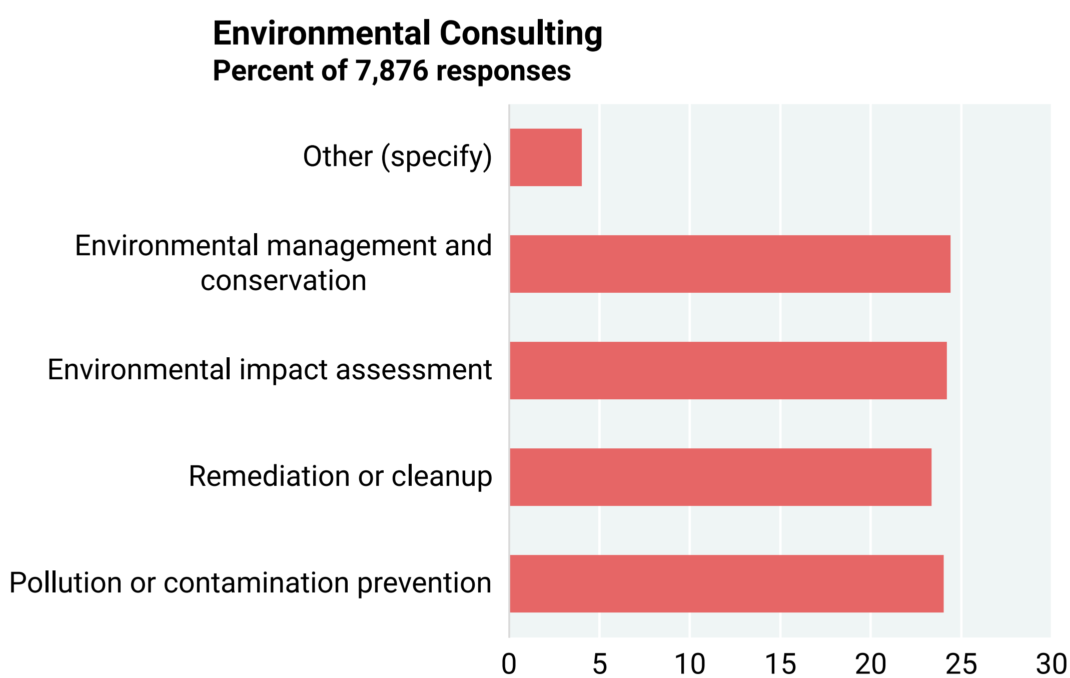
Organization size of stakeholders.

Figure 6.2.6



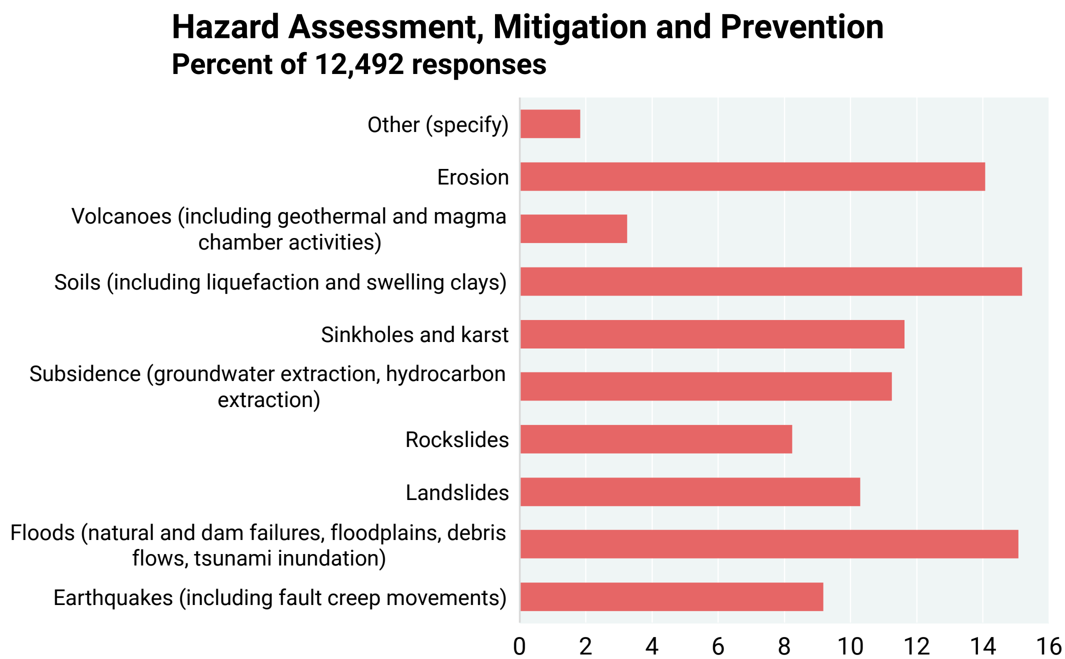
Resources explored/assessed.

Figure 6.2.7



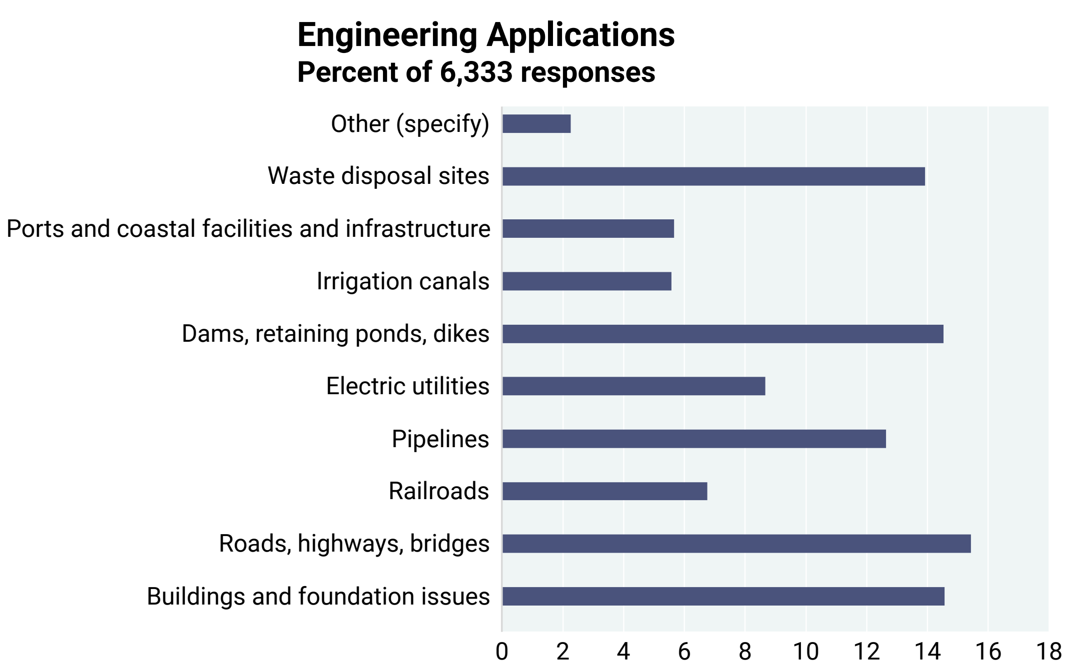
Types of environmental consulting.

Figure 6.2.8



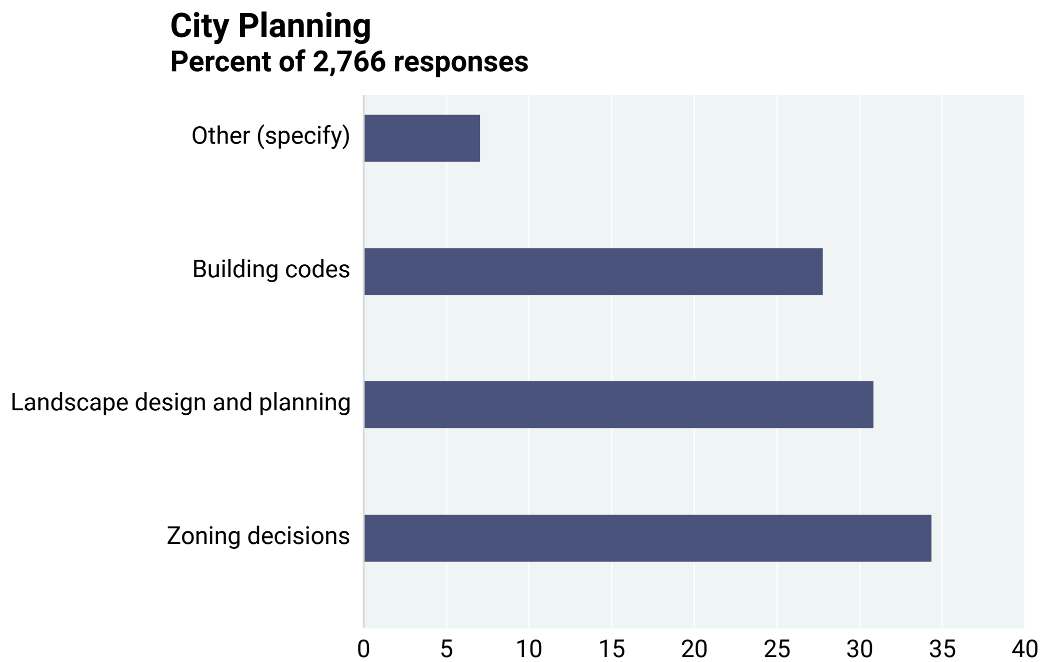
Hazard Assessment, Mitigation or Prevention.

Figure 6.2.9



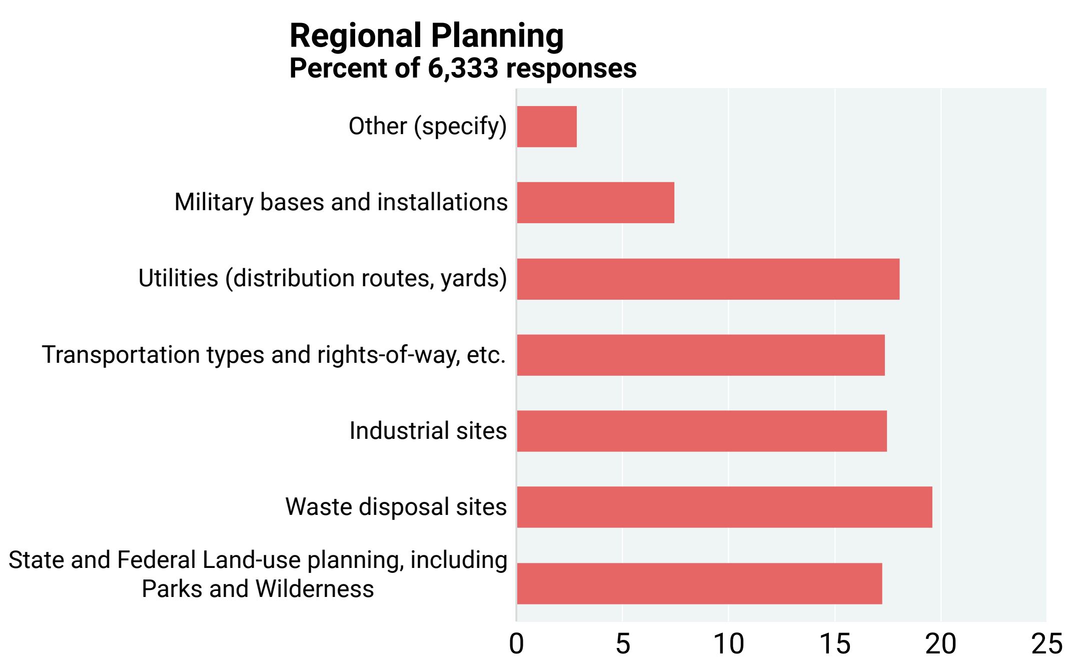
Engineering applications.

FIgure 6.2.10



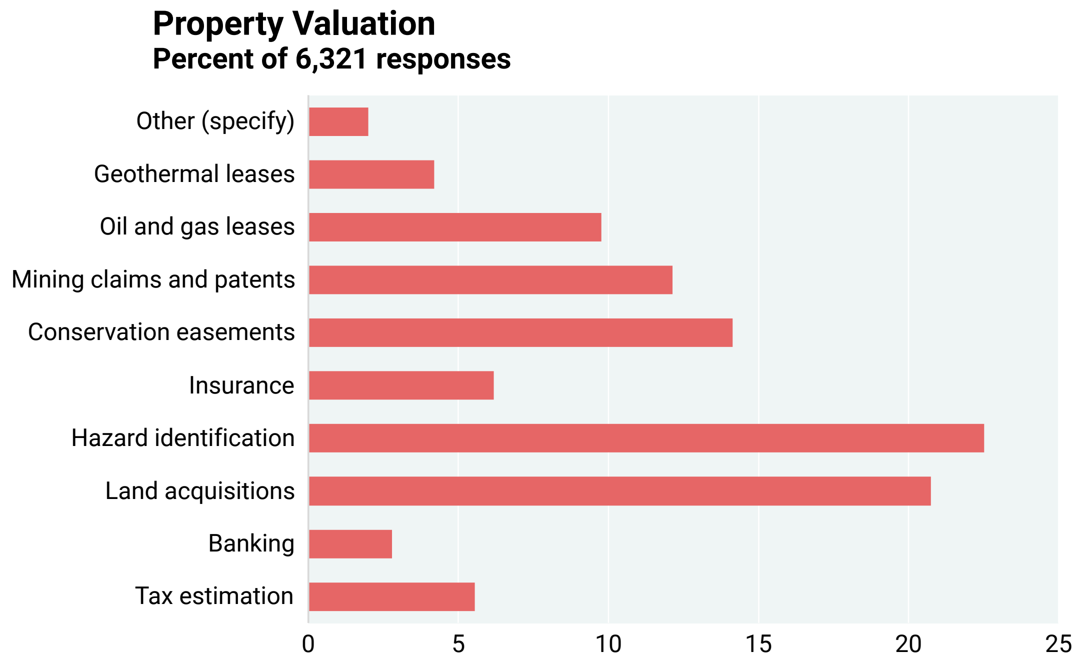
City planning.

Figure 6.2.11



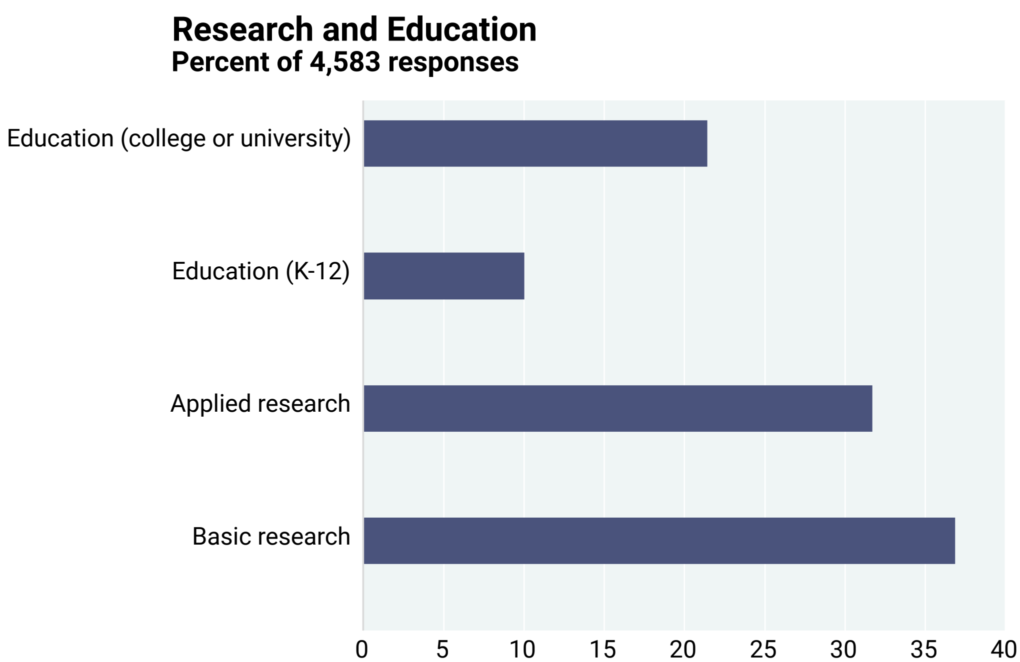
Regional planning.

Figure 6.2.12



Property valuation.

Figure 6.2.13



Research and education.

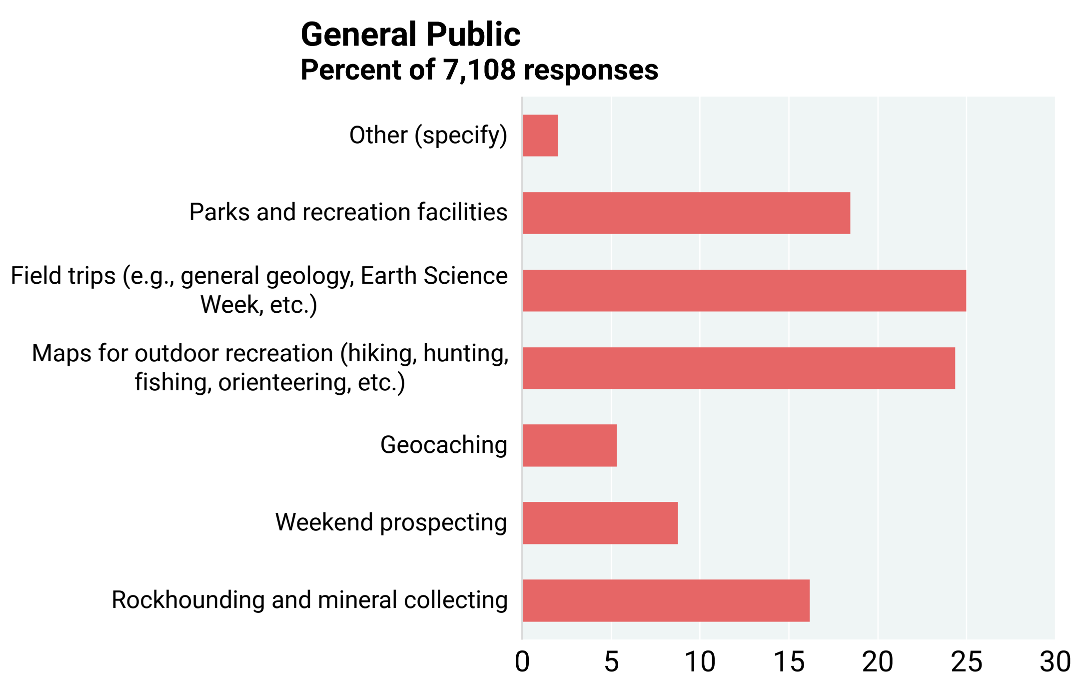
A more detailed assessment of industry responders is depicted in Figures 6.2.6 through 6.2.14 (question 2). In all the graphs, the number of responses is considerably larger than the number of individuals who responded because many are active in multiple areas of application. The data in the graphs indicate the breadth of the U.S. economy for which geological maps are fundamentally important. Regional aggregation of data provides no additional insights into any relationship between number of responses and value assessment. For simplicity, some of the most frequently mentioned areas of application include the following: groundwater and surface water, industrial minerals, pollution prevention, pollution, remediation, flood hazard, soil quality, roads, highways and bridges, dams, retaining ponds, zoning decisions, landscape design and planning, state and federal land-use planning, utility corridors, hazard identification, land acquisitions, basic research, applied research, field trips, and outdoor recreation.

The frequency of choices does not necessarily point to the economic weight of the application in the GDP of the nation (see Chapter 11). Moreover, the economic value of a share in the GDP of a sector may differ from its impact on the environment or public health. For example, industrial minerals are produced in large quantities in all regions of the country but may have a low total value and be a small percentage of the GDP. Yet, their importance for supporting infrastructure is critical. Similarly, the total value of water measured by the price paid by consumers is not high, but its use is vital. Chapter 9 discusses in some detail the economic importance of pollution prevention and remediation.

6.3: STAKEHOLDER PREFERENCES FOR MAP TYPES AND SCALES

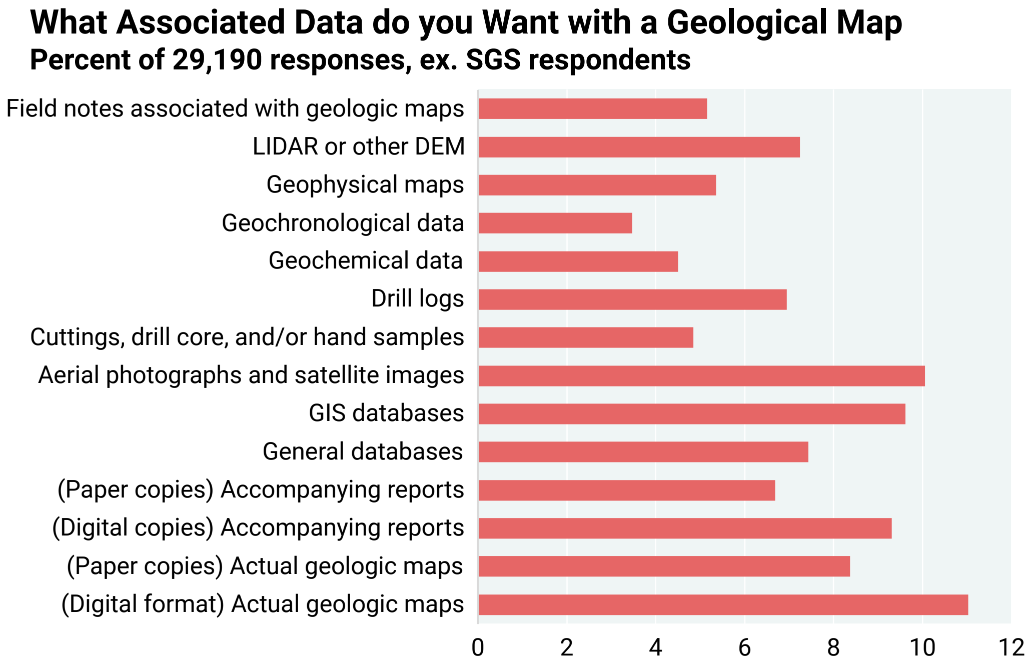
Data provided by SGS and the USGS on web visits indicate that stakeholder preferences regarding the form in which they like to receive geological maps, data, and reports has changed in the past couple of decades. They were asked to express their preferences regarding how they would like to receive this product and what types of products they need (question 4). Respondents were given the choice of selecting multiple ways to obtain geological maps and information.

Figure 6.2.14



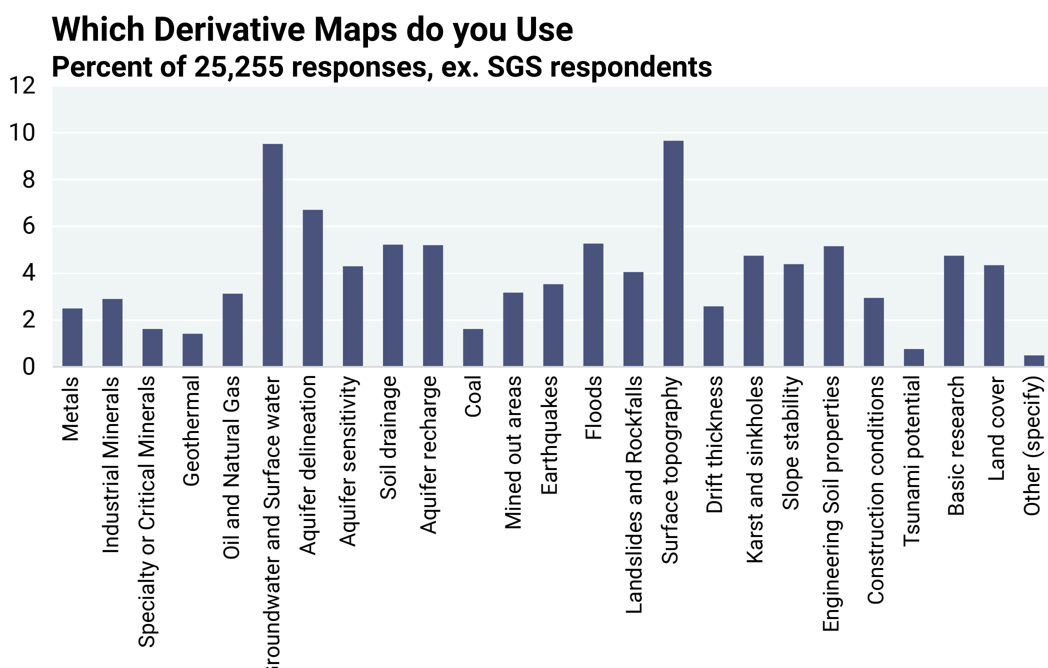
General public.

Figure 6.3.1



Preferred forms of maps and information.

Figure 6.3.2



What types of derivative maps do you use.

Figure 6.3.1 shows the number of times each of the 14 categories was selected by stakeholders. The total number of responses was 28,190. The number of responses far exceeded the number of respondents indicating that each respondent marked multiple choices. In part, this was a result of the choices that were provided. Five of the fourteen choices were digital or online, two were paper form, and the remaining seven were other forms in which geological information was sought by stakeholders. The response statistics reflect the preference for digital or online access of geological information, as this accounts for about 37% of the responses.

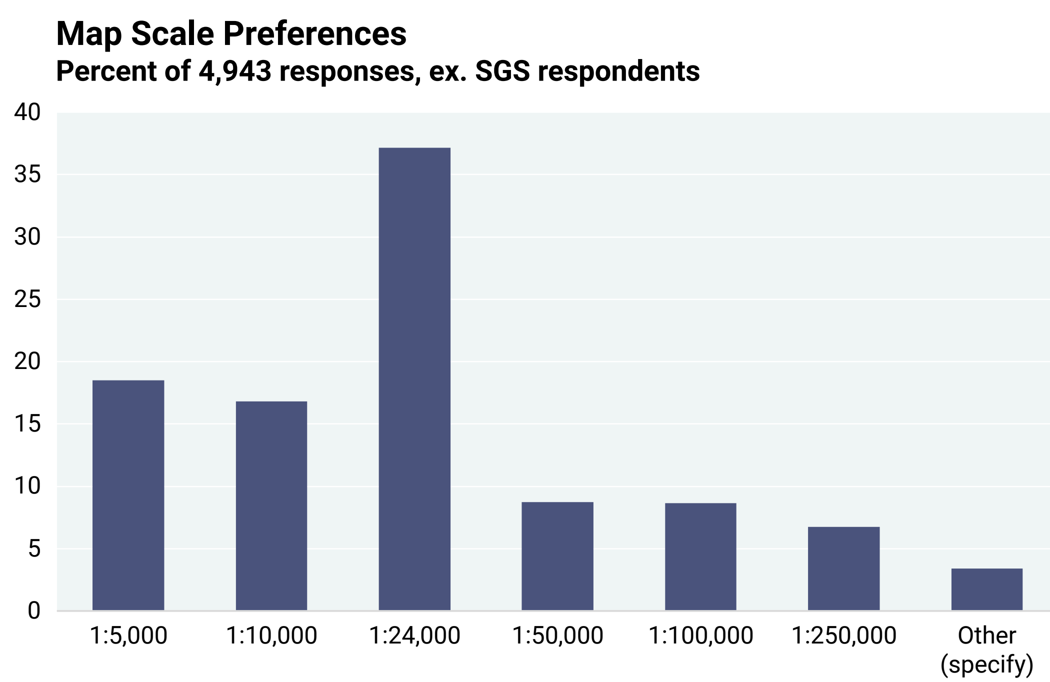
Stakeholders were further asked to provide input on the types of derivative maps that they use (question 5). A total of 25,255 responses were received. Figure 6.3.2 shows the percentages of responses in each category of derivative map. Five derivatives directly concerning water account for 25.8% of the responses. Some other derivatives may also be related to water. Two of the derivatives — surface topography and ground- and surface-water — received high response rates. The need for a derivative map not only motivates its development and production but provides opportunities to project future mapping policies.

Stakeholder needs are best served when maps have required details and specifics (question 12). The total number of responses was 4,943 (Figure 6.3.3). On average, each respondent chose two scales. About 72% of responses indicated the need for maps at the scale of 1:24,000 or larger. This would also suggest that stakeholders may not be looking only at what is available, but primarily at what is desirable.

Stakeholders were also asked in a later query to comment about the direction mapping programs should take. One of the frequent responses was the desire to continue mapping at scales of 1:24,000 or larger. The 1:24,000-scale was the preferred scale in previous cost-benefit assessments in Kentucky and Nevada (Bhagwat and Ipe, 2000; Bhagwat, 2014). This scale is adequately detailed to address most societal issues by the preponderance of stakeholders.

The desirability of digital access to various products of geological mapping varies, as seen in Figure 6.3.4 (question 15). Geological map data, such as in a GIS format, is the most preferred product (commonly ranked as "critically important" in the survey), followed by scanned maps and accompanying reports. Based on stakeholder comments,

Figure 6.3.3



What mapping scale best serves your needs?

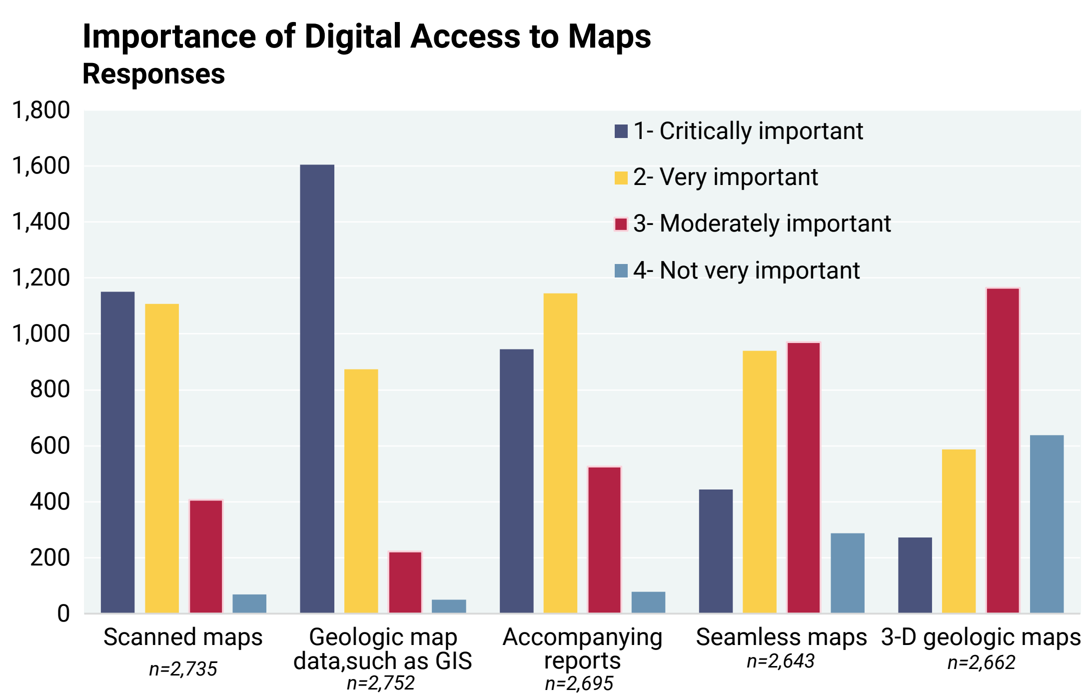
some users appear to prefer creating their own maps and interpreting geological data to fit their needs and purposes. However, digital access to most other geological products is rated "very important" by large numbers of respondents.

The lower overall perceived importance for seamless maps and 3D (or subsurface) maps may reflect lack of familiarity, and particularly their availability, to stakeholders. Although there has been a significant global increase in 3D mapping (and modeling) over the past 20 years (MacCormack et al., 2019), here in the U.S., only a few SGS, as well as the USGS, are engaged in the activity. Seamless mapping is a newly introduced concept that involves the goal of having uniform geology (surface and subsurface) and map standards from map to map and state to state across the country. Both seamless and 3D geological maps can greatly increase their ability to portray a uniform view of the subsurface. However, not until recently (Brock et al., 2021) have these concepts been included in a national strategy for geological mapping. As mentioned in Chapter 4 that presents the $1.99 billion in geological mapping costs for the 1994–2019 project period, 3D mapping and modeling of the subsurface will increase mapping costs because of the added funds required for obtaining subsurface information (e.g., exploration drilling, geophysics, up-to-date water well and geotechnical databases, etc.). However, increased benefits will also be realized as 3D mapping and modeling lead to (1) improved discovery of energy and critical minerals resources; (2) identification of regions with optimum conditions for CO_2 sequestration; (3) better characterization of geothermal potential; (4) a better understanding of geological hazards; and (5) providing a detailed subsurface framework for delineating aquifers, efficient placement of groundwater monitoring wells, and prioritization of areas requiring subsequent groundwater flow modeling.

6.4: QUANTITATIVE ASSESSMENT OF VALUE OF GEOLOGICAL MAPS

The assessment of the value of geological maps is as complex as the assessment of the cost of specific maps as described earlier. Stakeholders were provided different ways of assessing the monetary value of geological maps based on personal expertise and experience about what it takes to generate geological maps, as well as how much time and money may be

Figure 6.3.4



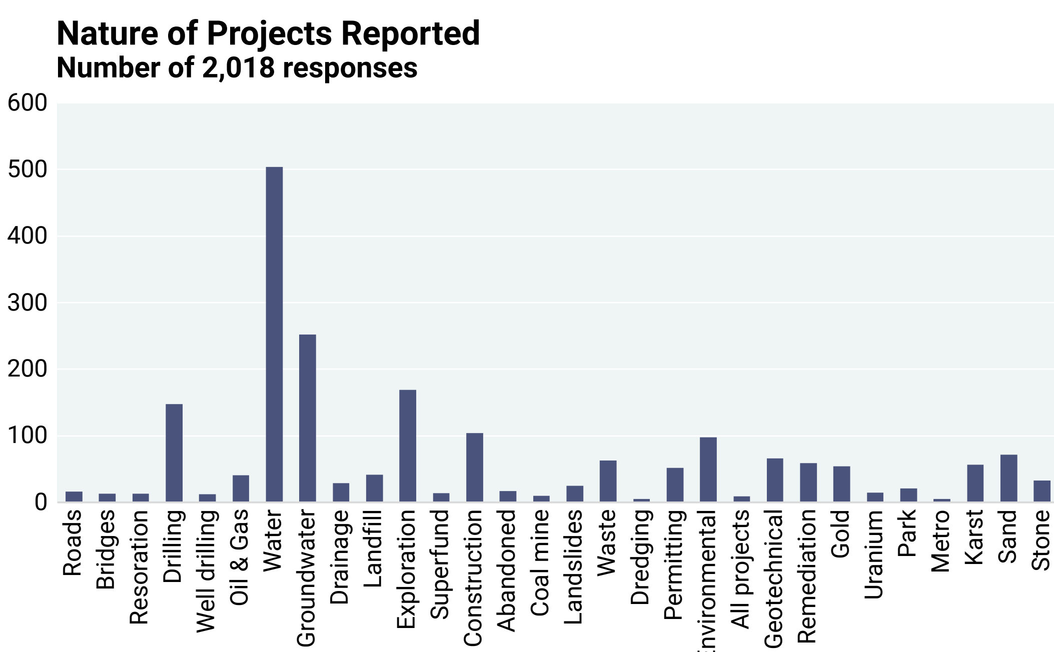
How important is digital access to geologic products?

required to create them if they were not made available from institutions like SGS and the USGS. Value assessments are indeed subjective, because geologists and other users of geological maps do not conduct the same investigations with and without available geological maps to judge their monetary value. Geological maps may also be used multiple times for different projects and over long time periods, adding more uncertainty to the estimation of their value. Furthermore, the monetary value of geological maps as assessed by stakeholders can only be understood as unrelated to any specific type, form, or application, but only as a statement of map value in general. One question to stakeholders involved an assessment of time and money saved over a five-year period in terms of percentages of total project cost and time. Another question asked for project specific savings, and yet another question asked directly what they would willingly pay for a map if it was not available from public institutions. Finally, stakeholders were asked to venture an estimate about what amount they would have paid for one map, if not available from publicly funded institutions. They were asked to state a maximum amount, a minimum amount, and a likely amount per map to accommodate the uncertainty involved in the exercise. The questionnaire was designed to ask geological map value questions in several different ways and elicit responses that would bring out the nuances in map use and could be compared for consistency. The basic assumption in sending the questionnaire to stakeholders was that they have, or should have, some utility for knowledge about geology and could therefore estimate the value of geological maps utilized by their organizations or themselves.

There was a wide range of data from stakeholder respondents, usually with dollar value outliers that may have been overestimates of very large, long-term projects. Therefore, median values are considered more representative than the mean values and are reported as such in the below discussion. Basic summary statistics are shown in Appendix 4, including the mean, median, range, and standard deviation for all data points pertaining to time and cost savings, total project costs, number of maps for projects, willingness to pay, long-term map value, and expected payment for a map.

Estimates of time and money saved during the past five years. Having established that the population represented in the responder group comes from a wide swath of the nation's economy, responders provided an estimate of time and cost

Figure 6.4.1



Nature of projects reported.

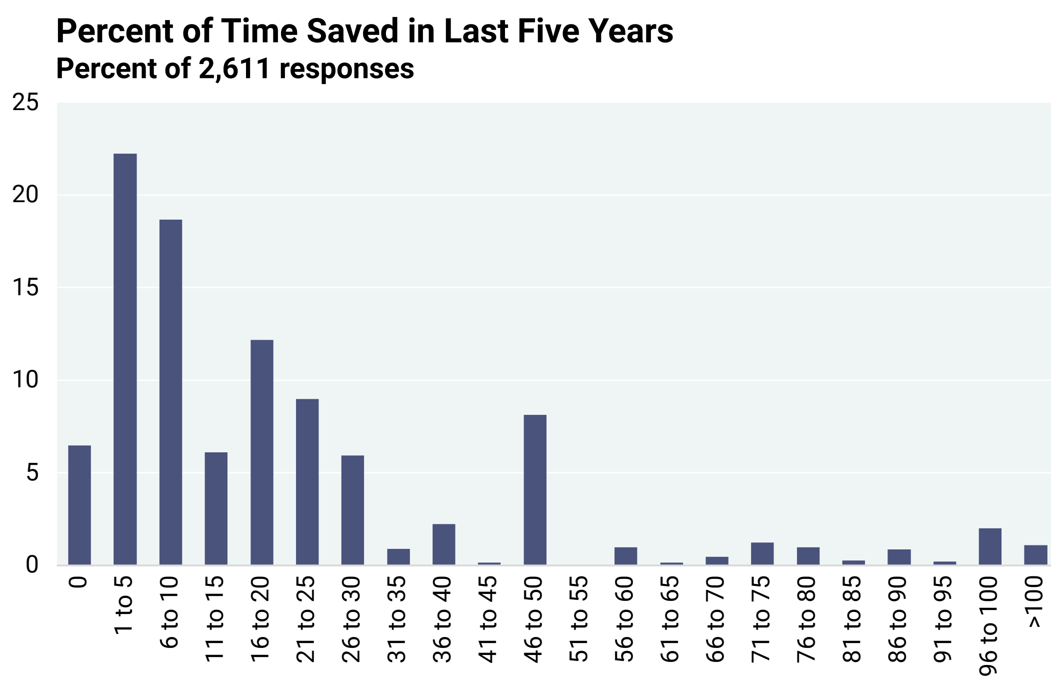
savings in the previous five years attributable to the availability of geological maps prepared by scientists at publicly financed institutions such as SGS and the USGS (question 3). The estimated savings were reported as a percent of total time and money that they would have otherwise spent. Information about the specific number of projects or their budgets was not solicited. However, Figure 6.4.1, based on a random word search to ascertain the nature of reported projects, highlights the breadth of geological mapping applications for various practical uses. As with all estimates provided by the responders in this study, it is understood that they are not based on actual comparisons of time spent and costs incurred with and without the maps because such cases, if existing, would be exceptionally rare.

About 6.5% of responders indicated no time saving (Figure 6.4.2). One major reason why no time was saved could be that geological factors played a small role in their project. The median time saved based on all responses was about 20%. Because of the wording of the question, it is not possible to save more than 100% of the project time. An Interquartile Range* analysis was performed to determine statistical outliers. No low-end outlier was determined. However, 5% of responses with time savings above 67.5% were flagged as high-end outliers.

Figure 6.4.3 is a graphical depiction of estimated cost savings and expectedly shows a pattern like that in Figure 6.4.2. About 6.5% reported no cost savings, 22.2% reported cost savings from 1–5%, and 18.7% reported 6–10% cost savings, which add up to 47.4% under 10% cost savings. The median cost savings reported was 15%, and the average cost savings was 20%. Interquartile Analysis (the spread of the middle half of the distribution) flagged 7% of responses at >67.5% savings as high-end outliers. However, only 1% of responses were >100%. As savings above 100% make no sense, they need to be ignored. Ignoring responses >100% did not affect the median savings.

Project cost increase if maps unavailable. Another question to stakeholders (question 7) had three components – (1) question 7A asked to describe a project and provide a budget, if possible; (2) question 7B requested how much (%) higher the budget would be if maps were unavailable; and (3) question 7C asked how many maps were used for the project. A total of 776 responses included all three numbers — the

Figure 6.4.2



Percent time saved in last five years.

budget, the percent increase in budget without maps, and the number of maps used. Individual responses were used to calculate the dollar amount by which the budget would have increased if maps were not available, and this number was divided by the number of maps used for the project. The result is the "value" attributable to each map. The 776 individual responses were the basis to determine the median per map value.

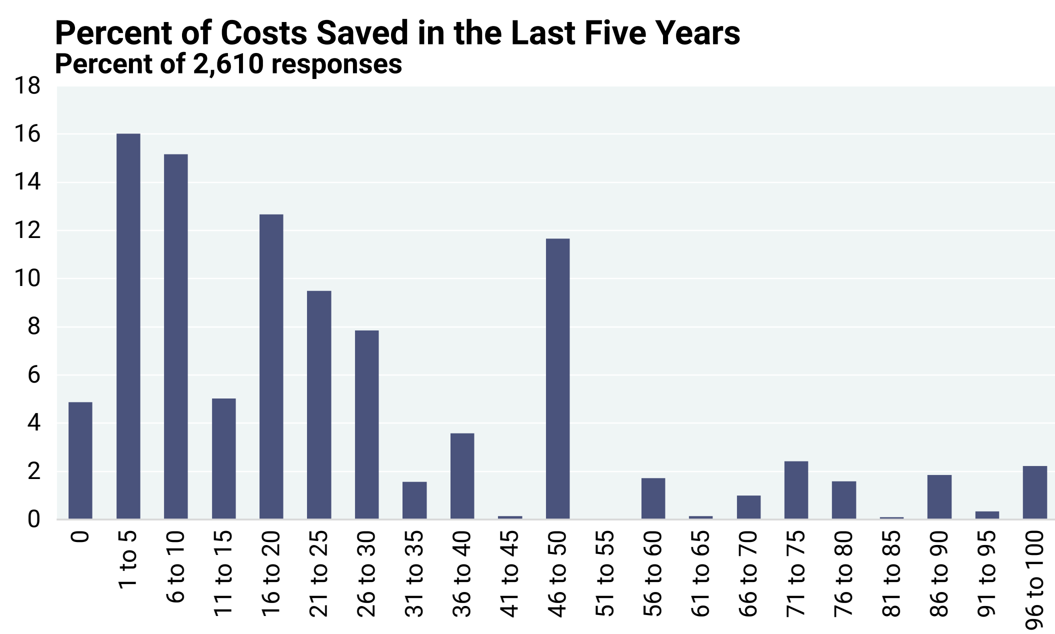
Some responders provided a budget range, while others gave a single dollar figure. Therefore, all calculations were based on the maximum and the minimum budgets reported. The results are shown in the charts below. The median value per map was $11,062 based on minimum project budgets, and $18,275 based on maximum project budgets. The value based on the maximum project budgets ($18,275 per map) is preferred, because budget overruns are not uncommon (Figures 6.4.4 through 6.4.7). Interquartile Analysis flagged high budget outliers above $311,250 or $697,750, respectively, for the minimum budgets and maximum budgets that were reported by the respondents. However, outliers were not excluded, because they had no effect on the calculation of the median value.

Figures 6.4.6 and 6.4.7 show the frequencies with which the budget would increase by a specific percentage and the number of maps used, respectively (question 7B). Interquartile Range Analysis indicated that about 11.6% of the 776 responses were >210% and may be considered high outliers. The median budget increase was 30%.

Willingness to pay for one map. A more direct approach was taken in another question (question 8) to stakeholders in which they were asked what they would willingly pay for having **ONE** map constructed if it was not available from publicly financed institutions. They were asked to select from several price ranges.

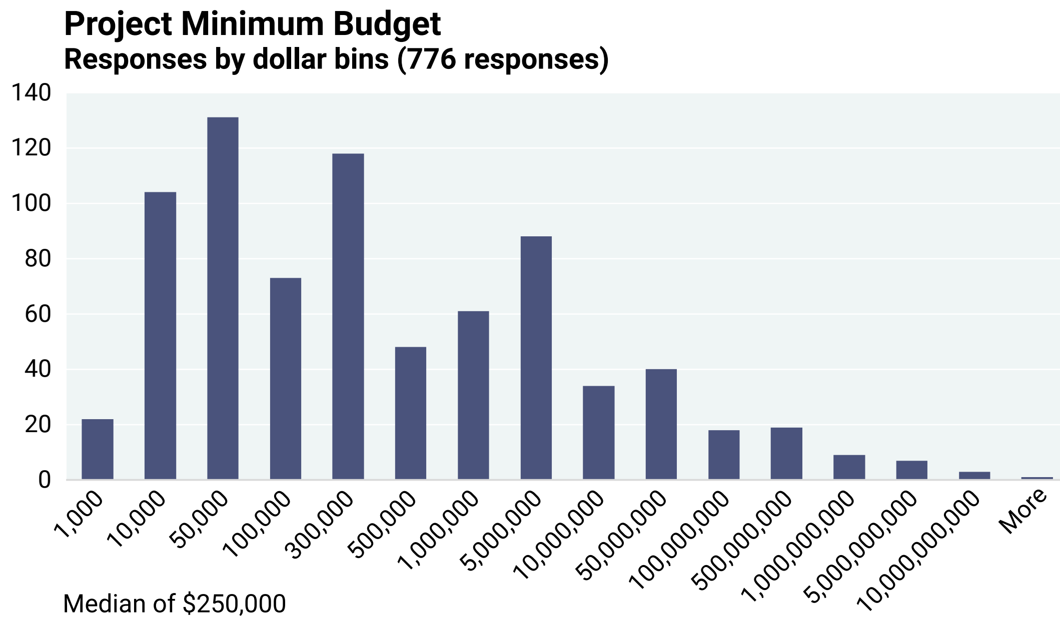
To calculate the price that stakeholders would willingly pay, it was assumed that choices within each price range are uniformly distributed, and each price range is represented by its center value. For example, all responses in the $50,000–$100,000 category were assumed to be equal to $75,000 per map. The responses from 2,178 stakeholders are graphically presented in Figure 6.4.8. The median willingness to pay (WTP) for one map was $3,000.

Figure 6.4.3



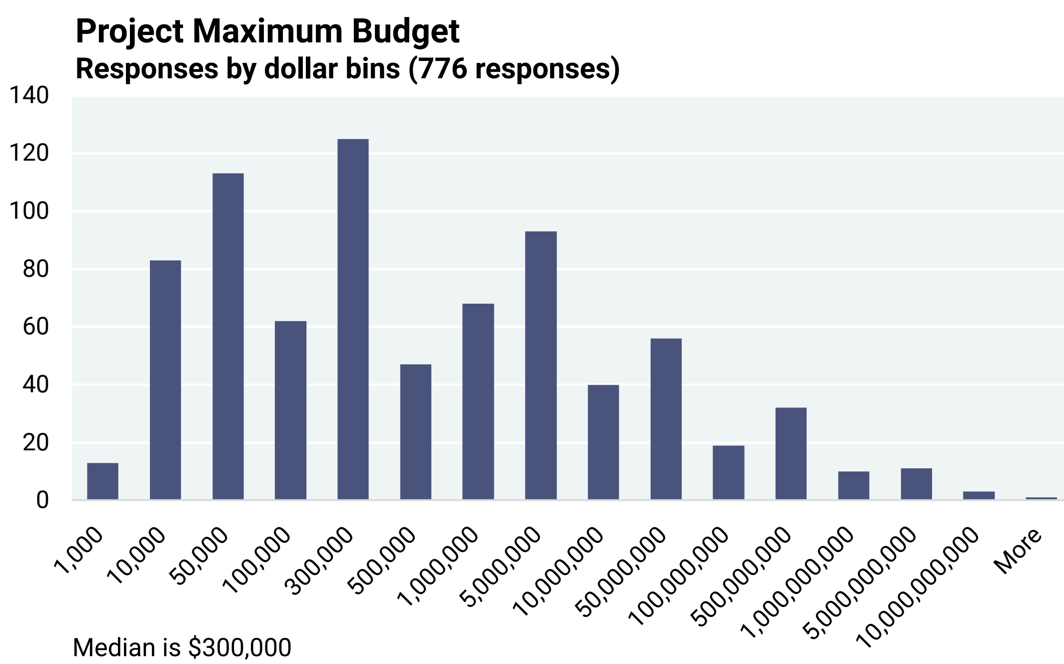
Percent cost saved in last five years.

Figure 6.4.4



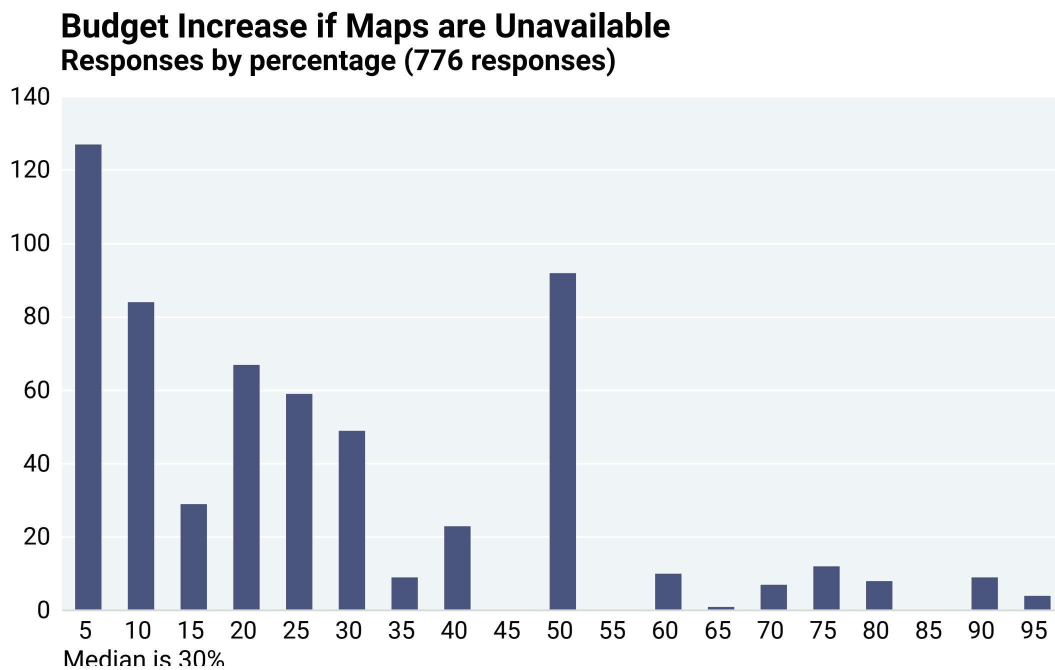
Budget minimums.

Figure 6.4.5



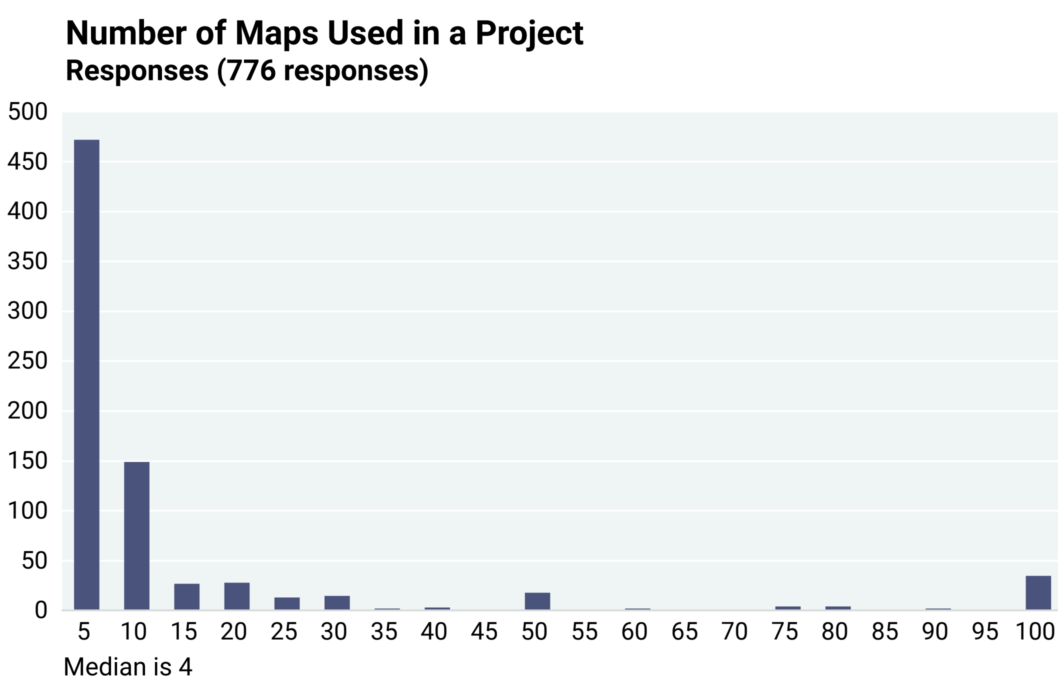
Budget maximums.

Figure 6.4.6



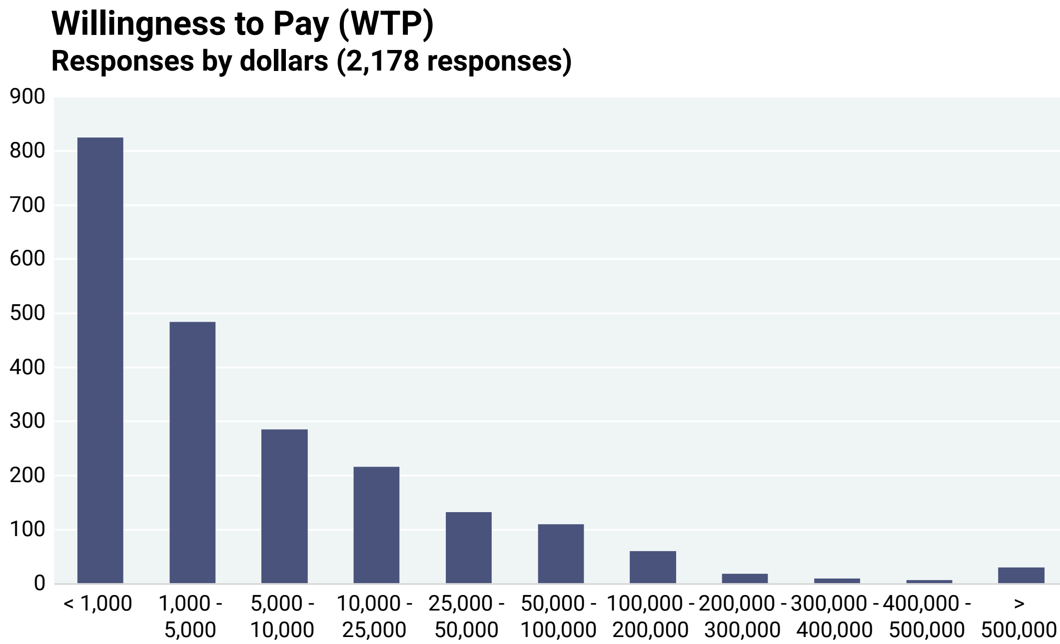
Percent increase in budget without map availability.

Figure 6.4.7

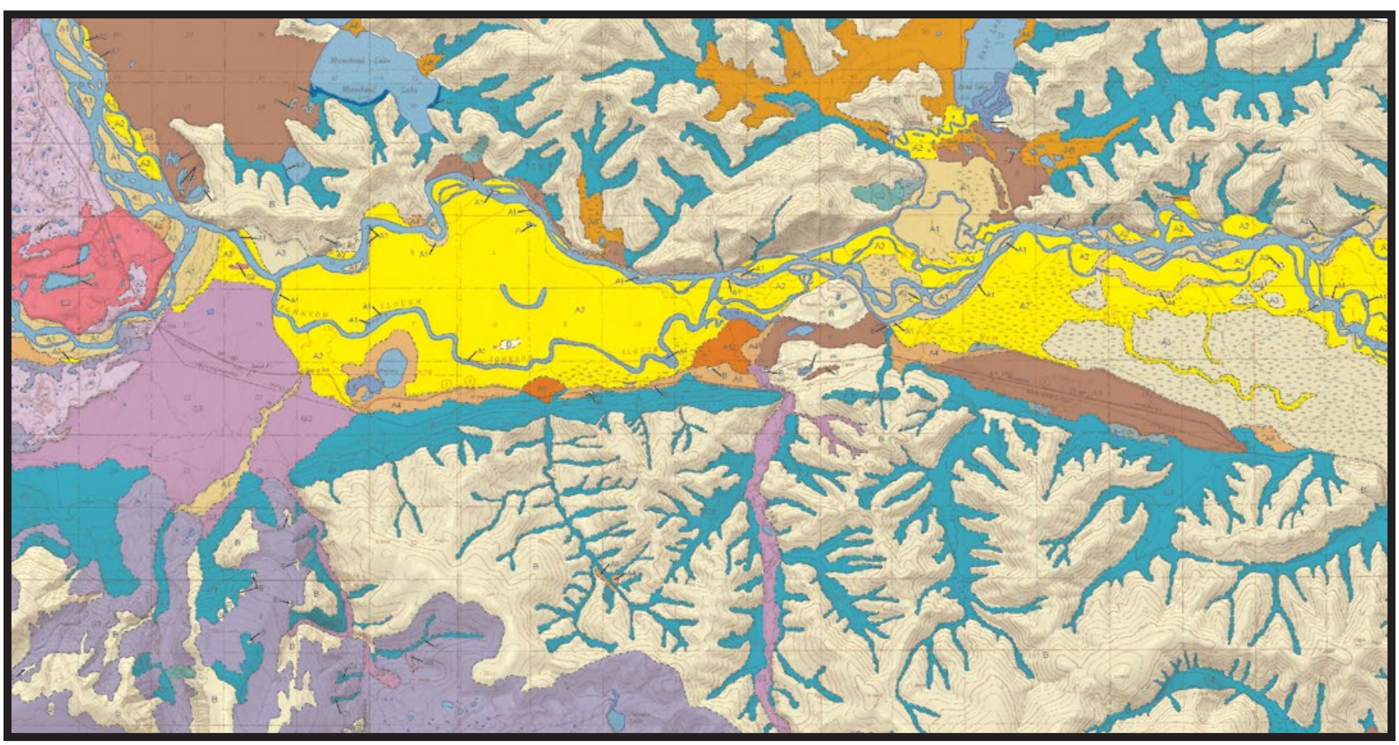


Number of maps used for projects.

Figure 6.4.8



Willingness to pay for ONE map if not publicly available.



Portion of: Reger, R.D. and Hubbard, T.D., 2021, Engineering-Geologic map, Alaska Highway Corridor, Delta Junction, Alaska, to the Canada border: Segment 1 East: Alaska Division of Geological & Geophysical Surveys Professional Report 124, scale 1:63,360.

To test if organizations that employ fewer people were willing to pay less for a map than the larger organizations, responses to employment (question 1C in Appendix 2) and WTP (question 8 in Appendix 2) were filtered as follows:

1. Employment in organizations from which respondents would willingly pay (WTP) <$1,000 for one map;

2. Employment in organizations from which respondents would willingly pay $1,000–$5,000 for one map;

3. Employment in organizations from which respondents would willingly pay $5,000–$10,000 for one map.

The four groups of columns in Figure 6.4.9 represent organizations with an increasing number of employees. The blue column in each group shows how many individuals would willingly pay up to $1,000 for a map. The orange column indicates the number willing to pay $1,000 to $5,000 for one map, and the red column stands for those willing to pay $5,000 to $10,000 for one map.

Figure 6.4.9 data show that most respondents (59%) came from small organizations employing <100 persons. Their number declines with the size of organization, as 3.9% of respondents belonged to the largest organizations with >10,000 employees. Each set of columns shows the distribution of what the respondents would pay for a map. In each set of columns, the blue column shows the smallest willingness to pay:

- Respondents from very large organizations (>10,000 employees) — 44.6% would pay <$1,000 for a map.

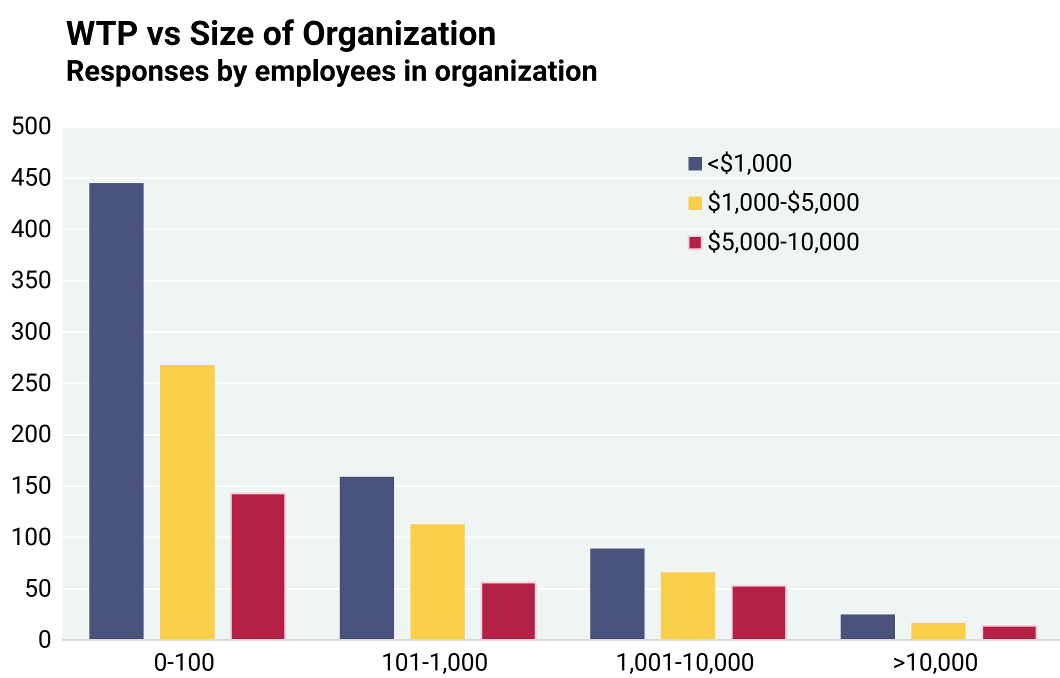
- Respondents from large size organizations (1,001 to 10,000 employees) — 42.8% would pay <$1,000.

- Respondents from medium size organizations (101 to 1,000) — 48.5% would pay <$1,000.

- Respondents from small size organizations (100 or less employees) — 52% would pay <$1,000.

In all company sizes, the highest percentage of respondents would pay <$1,000, and the lowest percentage would pay

Figure 6.4.9



Willingness to pay for a map vs number of employees in organization.

$5,000-$10,000. For those who would pay <$1,000 for a map, an average of 43.7% were from very large and large organizations, whereas an average of 50.3% were from medium and small organizations. It is understandable that a higher percentage of smaller organizations would pay <$1,000 for geological maps than larger organizations. However, percentages are remarkably similar among all four organizational sizes.

After assessing the value of geological maps, the stakeholders were asked to state how confident they felt about their answers on a scale of 0 to 10, ten being the highest certainty (question 9). Their responses are graphically shown in Figure 6.4.10.

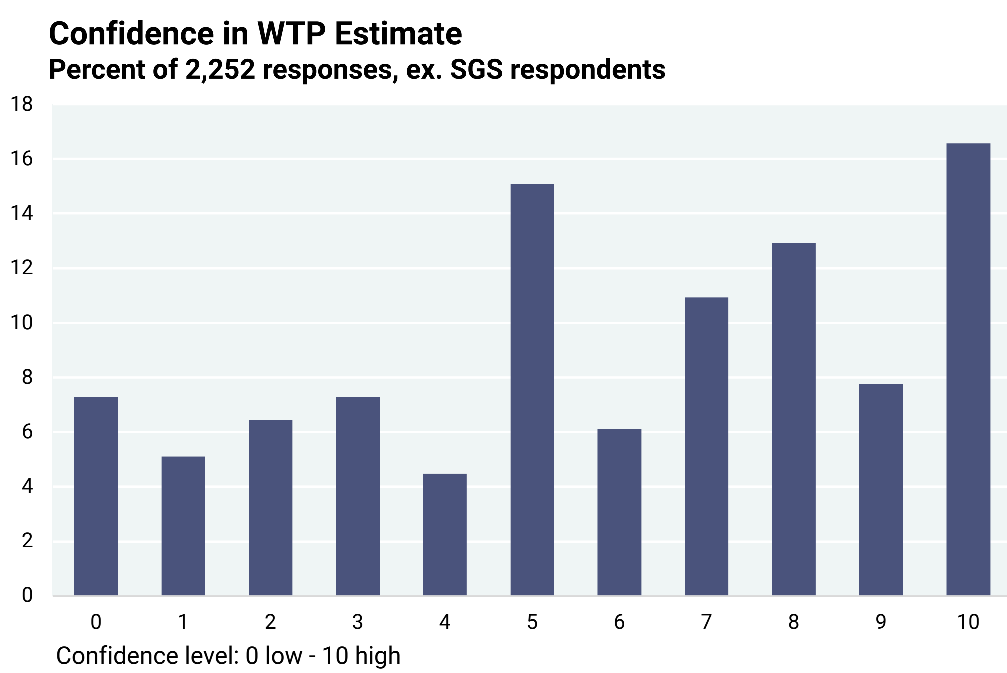
The data in Figure 6.4.10 indicate that stakeholders are generally more confident than not, as 54.3% indicated a confidence level higher than 5, 30.6% responded with a lower than 5 confidence level, and 15.1% indicated a confidence level of 5. The mean confidence level was 5.85. The confidence level trend above level 5 is generally greater, whereas it is largely consistent below level 5.

Long-term value of geological maps. A geological map may be used in more than one project, by more than one person, and over many years. It serves multiple objectives for a long time, delivering benefits to users (question 10). Stakeholders were asked to provide their assessment of the long-term value of geological maps (question 10). Unlike previous queries, no value ranges were provided from which to choose, and stakeholders could state any dollar amount that they felt appropriate. Figure 6.4.11 depicts the same data re-organized into bins of values, which help visualize the probability distribution. Interquartile Analysis indicated that the median long-term value is $10,000, with high outliers above $248,500.

Respondent confidence in their long-term value assessment is understandably lower because they were asked to predict the future, as data in Figure 6.4.12 show. About 41% of respondents, including those with no confidence at all, indicated confidence levels <5, about 39% indicated confidence levels >5, and about 20% indicated 5.

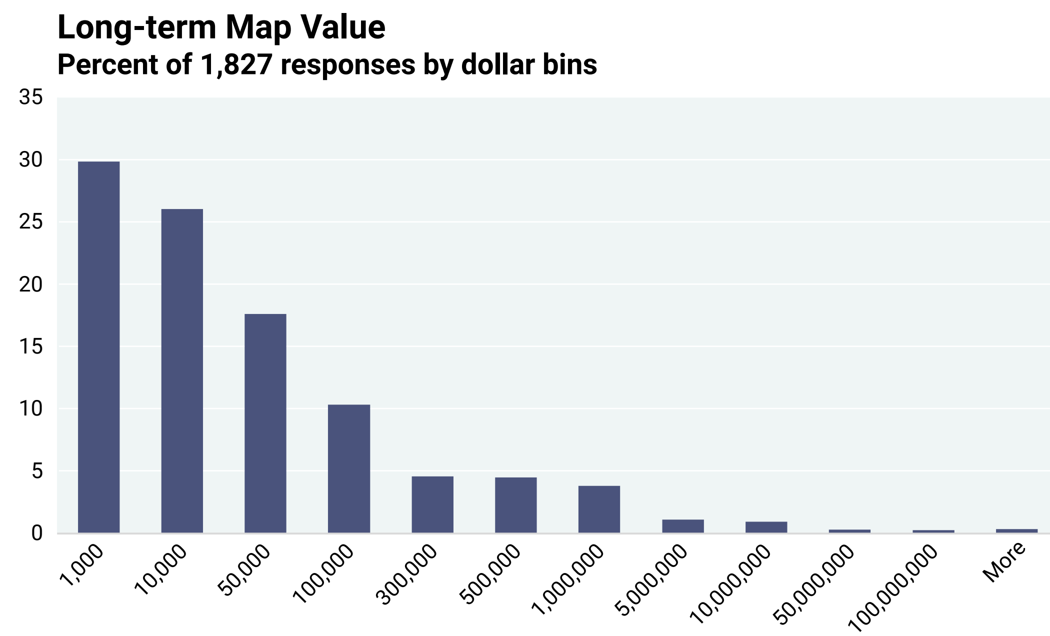
Expected payment for a map. Stakeholders were then asked how much they would typically have to spend to acquire a

Figure 6.4.10



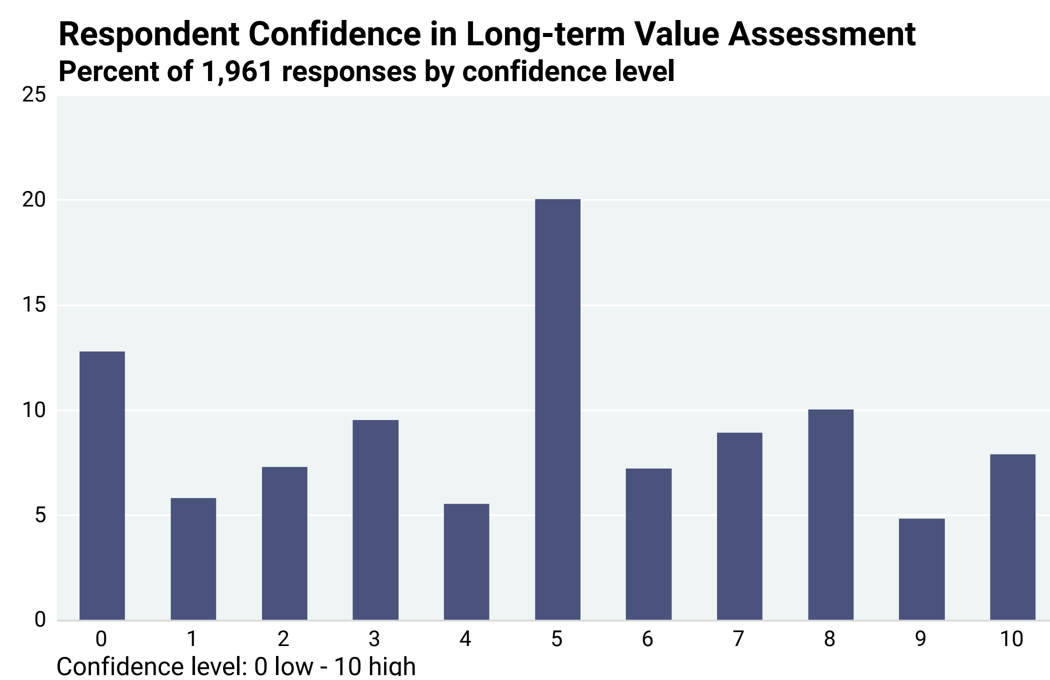
Respondents own assessment of confidence in their value assessment.

Figure 6.4.11



Distribution of long-term map value assessments.

Figure 6.4.12



Confidence level in the assessment of long-term value of geological maps.

map if it were not available publicly (question 17). Previously in question 8, they were provided with broad value ranges from which to choose. In this step, stakeholders were asked to provide a maximum, minimum, and a likely amount they would pay. They were free to quote any dollar value. The likelihood or probability that the "real" value would fall between the minimum and the maximum is assumed to be 100%. However, the exact probability distribution in such cases is unknown. Using the three data points, a simplified triangular probability distribution is used as the most practical approach. A triangular probability distribution is commonly used in risk analysis (Rodger and Petch, 1999). Although a probable or likely estimate is offered, the "expected" value is not necessarily the same. According to Rodger and Petch (1999), the expected value is determined by averaging the maximum, minimum, and likely values:

Expected value = (Maximum + Minimum + Likely)/3.

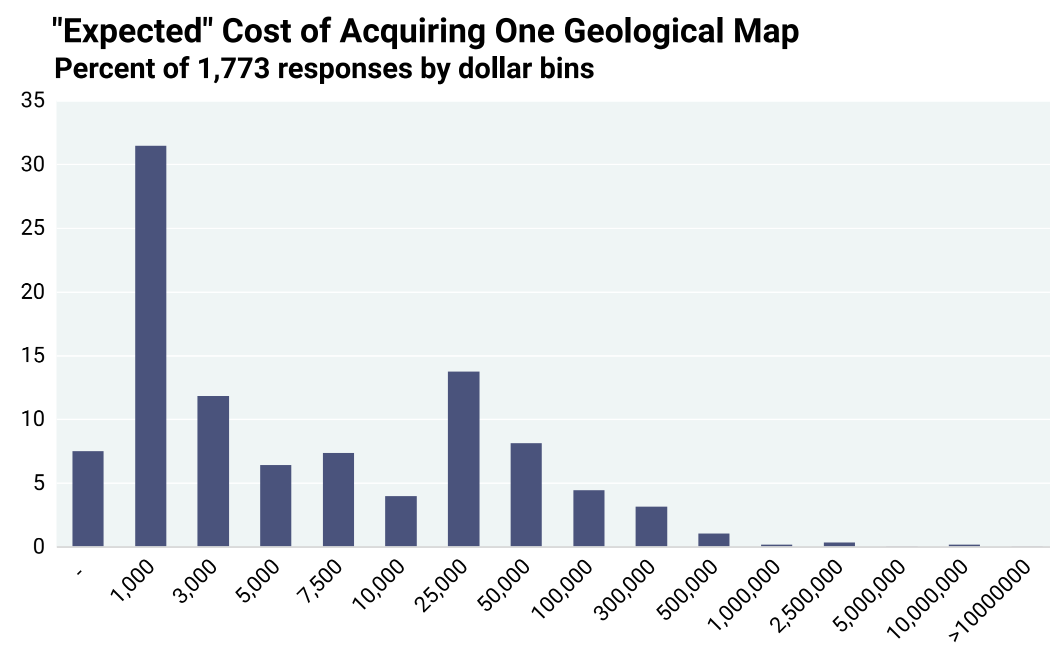
In Figure 6.4.13, the expected values are presented in randomly chosen bin sizes for ease of visualization. About 7.5% assigned $0 value to a map, and 5.2% exceeded $100,000 per map. There were no restrictions imposed on respondents regarding their value assignment.

Using the triangular probability distribution approach, the median expected value of one geological map from the responses of 1,773 stakeholders was $2,883. Values >$37,300 were flagged as high outliers by Interquartile Analysis. This $2,883 number is considered the best data for deriving the most accurate value of an individual use of one geological map, because uncertainty is reduced and respondents guessing is minimized. Chapter 7 will discuss that when cost is factored with demand numbers, this $2,883 median expected payment for one geological map was chosen to represent not only the best data but also the most conservative value.

6.5: SUMMARY OF QUANTITATIVE BENEFITS ASSESSMENT

Table 6.5.1 summarizes the quantitative responses in assessing cost savings and respondent map value perceptions. The foregoing discussion documents that the results from responses to the various queries differed significantly. The

Figure 6.4.13



Expected cost of acquiring a geologic map.

variance is expected, because (1) each query has a different reference point; (2) the responses are estimates and not specific to any type or scale of map; and (3) estimates are not necessarily the result of the actual experience of the respondents. Due to the wide range of data, usually with high-value outliers that may have been overestimates of very large long-term projects, the median values are considered more representative than the mean values. The median values obtained from various questions are tabulated below.

In question 7, respondents were asked to estimate how much more time and money they would have to pay for their project if maps were unavailable. In question 10, they were asked to estimate the long-term value of a map. In both cases they were not asked what they would pay. Their responses to questions 7 and 10 are indicative of map value. In comparison, questions 8 and 17 specifically asked what the respondent would pay for a map. The Table 6.5.1 summary indicates that the median value assessments from question 7, based on the estimated impact on project budget due to map availability, and question 10 based on the long-term value of a map ($11,062 and $10,000) are close to each other and are distinctly higher than the median willingness to pay from questions 8 and 17 ($3,000 and $2,883, respectively). In its extreme case is the "free rider" syndrome, where a consumer knows the value of a public good, such as a park, but expects free, or a very low, entry fee. In general, we expect that a purchase is worth at least as much but preferably more than its price indicates.

An important overarching conclusion is that geological maps have high value as measured from several different perspectives and that these high values involve individual applications of those maps. Moreover, as noted earlier, geological maps are a public good, are not consumed after use, and are typically utilized in many different projects and applications, with overall value accruing significantly through time.

Table 6.5.1. Summary of Quantitative Evaluations by Respondents.

Question 3: Time/Cost saved over 5 years	► Median project time saved — 20%. ► Median project cost saved — 15%.
Question 7: Project cost increase if maps unavailable; responses included maximum and minimum budget statements.	► Median project cost increase — 30%, Median budget size of 776 projects — min. $250,000, max. $300,000. ► Median number of maps used — 4. ► Median value per map — $11,062 - $18,375.
Question 8: WTP for a map if not available (choices of $ bins)	► Median WTP — $3,000.
Question 10: Long-term value of a map	► Median long-term value of a map — $10,000.
Question 17: Expected payment for a map (free to select any amounts)	► Median expected to pay — $2,883. ► (Best data, least uncertainty, and note consistency with question 8).

6.6: REFERENCES

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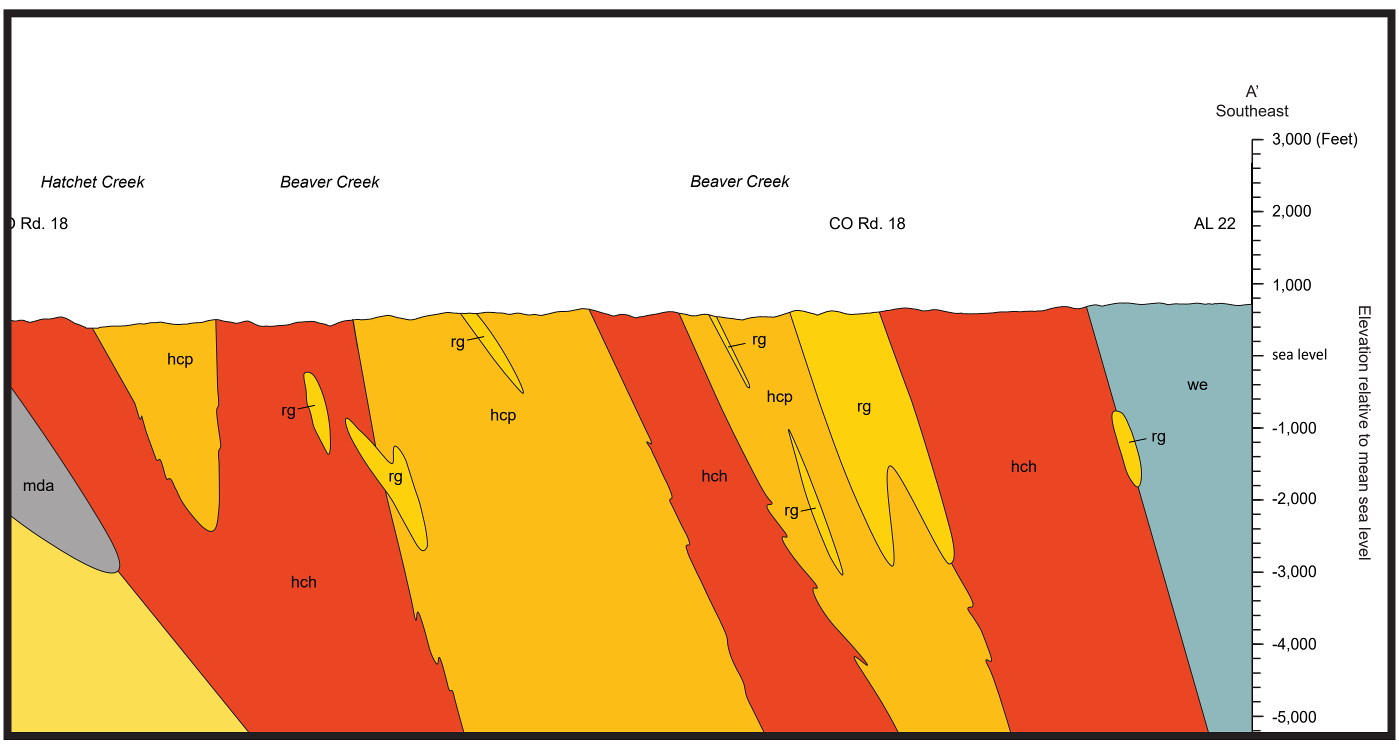
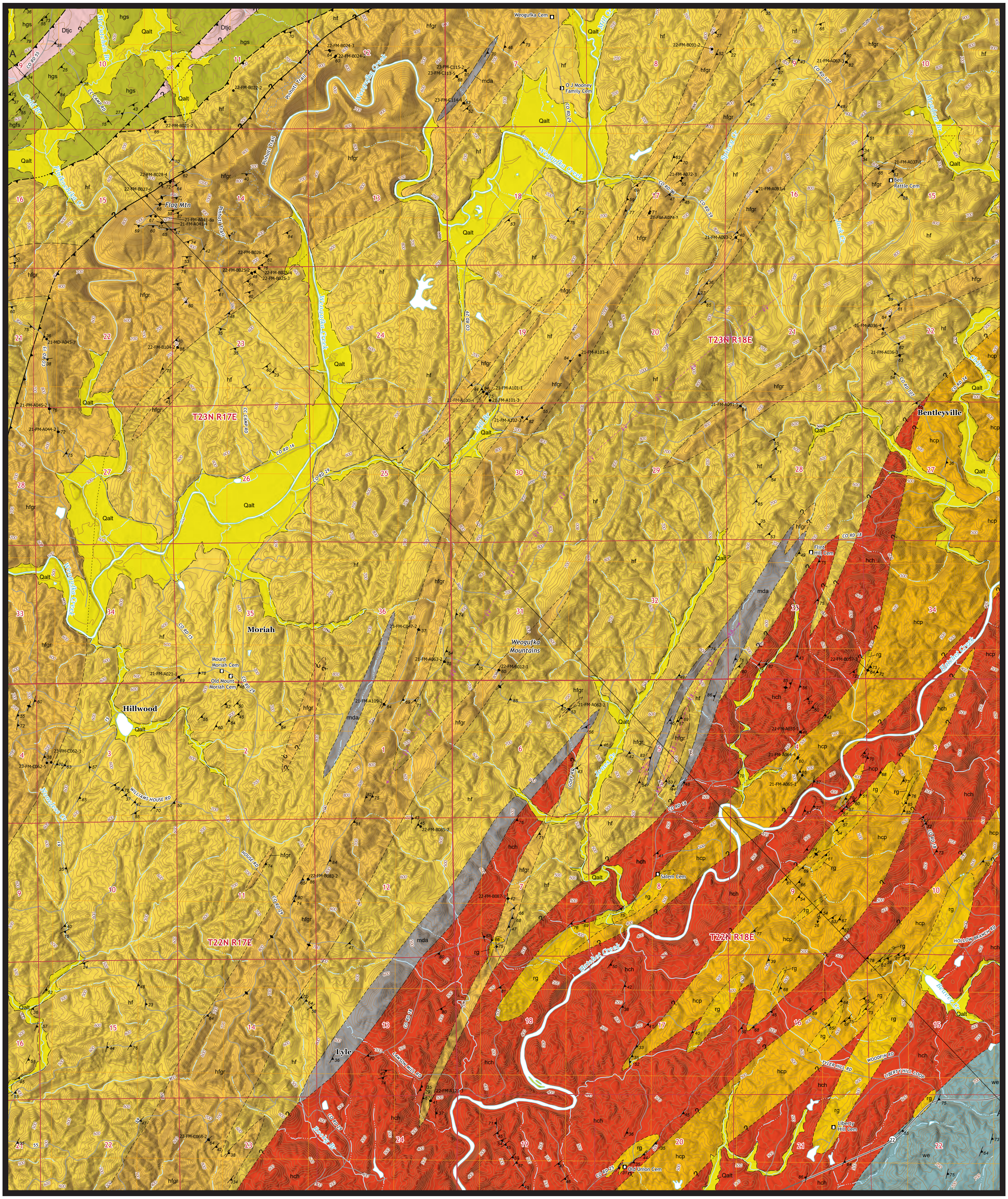


Portion of cross section from: Bollen, E.M. and Whitmore, J.P., 2024, Geologic map and cross section of the Flag Mountain 7.5-Minute quadrangle, Coosa County, Alabama: scale 1:24,000. (Main map projection shown on next page.)



Portion of: Bollen, E.M. and Whitmore, J.P., 2024, Geologic map and cross section of the Flag Mountain 7.5-Minute quadrangle, Coosa County, Alabama: Geological Survey of Alabama, scale 1:24,000.

CHAPTER 7: GEOLOGICAL MAP DEMAND AND ECONOMIC ESTIMATES OF COSTS AND BENEFITS

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ABSTRACT

The demand for geological maps previously has been measured based on map sales. However, a rapid transition began in about 2009 from obtaining geological maps based on map sales to their online web availability. Therefore, for this 1994-2019 study, demand is assessed using information provided by 24 SGS and the USGS on their online views and downloads of geological maps. It is the first attempt to utilize such data for a national cost and benefit economic analysis. There were 4,360,736 geological map downloads and 11,401,967 online map views. For the latter, a conservative 3.32% conversion rate of map views to downloads was applied, and this action provided an additional 378,546 potential downloads. There were also 86,673 maps sold for a grand total of 4,825,955 geological maps downloaded and sold. It was assumed that the other 24 SGS that did not report geological map views, downloads, or sold data, contributed to the overall pool of geological maps, because they received federal funds for mapping and provided a 100% match. Their extrapolated geological maps downloaded and sold resulted in an additional 2,275,768 downloads and 46,383 maps sold for a grand total of 7,148,106. Using the most conservative median amount that respondents expected to pay per map ($2,883), the range of values between the actual maps downloaded and sold with the extrapolated amount are between $13.91 and $20.61 billion. Considering the $1.99 billion cost of producing geological maps during 1994–2019, value estimates range between 6.99 and 10.35 times the expenditure.

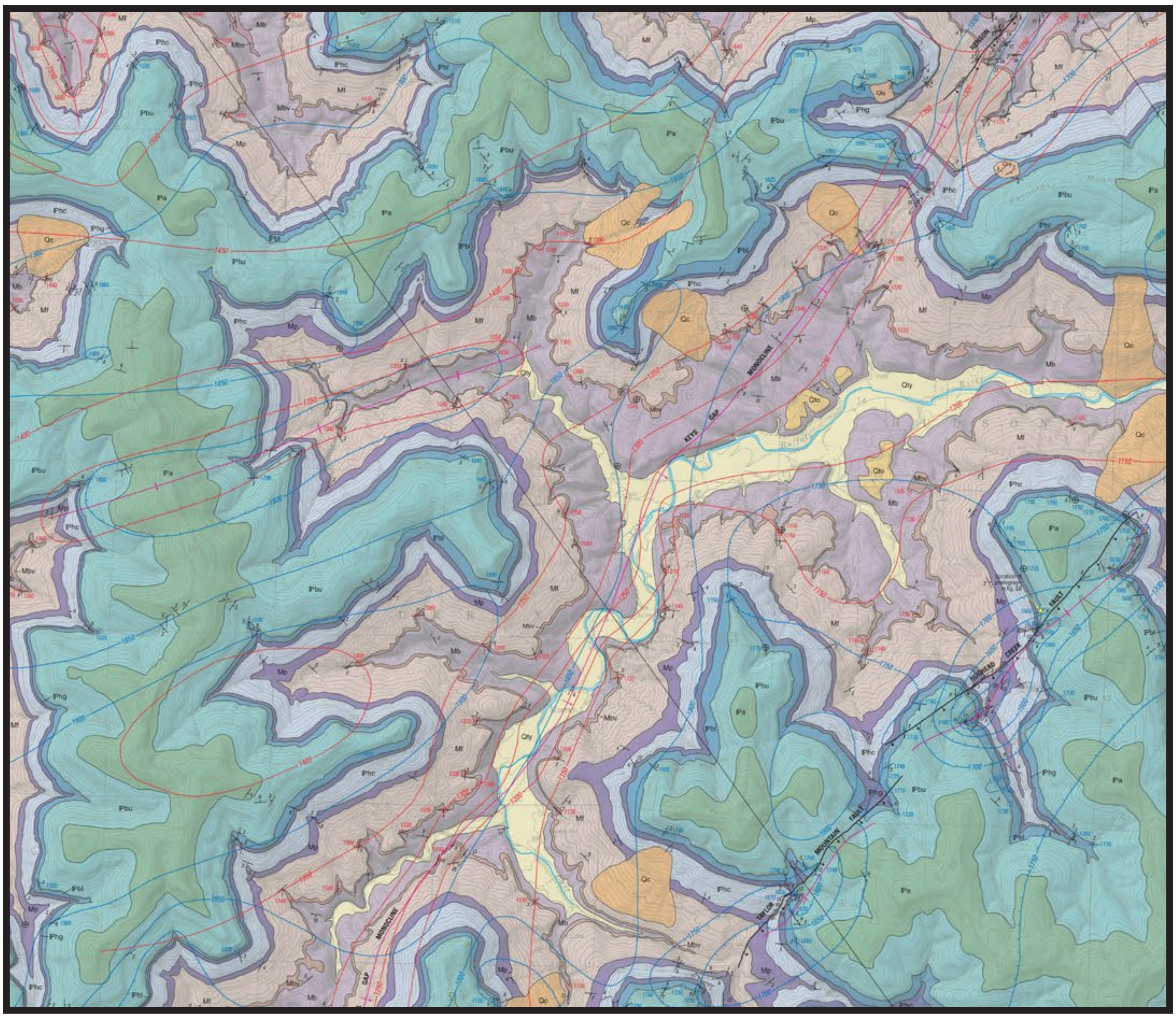
Download action is a very conservative estimate of geological map demand, because websites are designed such that mere "viewing" of a geological map may provide adequate information to the user without downloading it. Total views of 11,401,967, plus the actual downloads and maps sold accounted for 15,849,376 potential transactions. Therefore, the range of values between the actual maps viewed, downloaded, and sold with the extrapolated amount is between $45.69 and $70.15 billion, with maximum value estimates ranging between 22.95 and 35.23 times the expenditure. These maximum values are not realistic but, considering the conservative nature of this entire economic assessment, value estimates would lie somewhere between the 6.99 and 10.35 values and the higher extrapolated values of 22.95 to 35.23.

Adding to the conservative nature of this economic assessment, and factored into the above geological map web view and download numbers, is consideration of the interaction of robots (bots) with web sites. Nine SGS plus the USGS accounted for some bot activity in their reported numbers. For other SGS and years when bots were not identified, web view and download data were reduced by an average of 44.3% for bot activity in line with reported industry data for 2012-2019. This resulted in a significant reduction of geological map views and downloads. The only SGS that uniformly reported bot activity was the Montana Bureau of Mines and Geology, which reported a 14% average of bot activity. This one sampling may be more indicative of reality amongst other SGS. However, this lower bot percentage could not be confirmed with other similar public entities. Therefore, to maintain a conservative approach, the industry reported higher bot rate percentages were used for this study.

7.1: GEOLOGICAL MAP ONLINE VIEWS AND DOWNLOADS

Having arrived at a median value per map in the judgment of stakeholders, an approximation of the total value of all maps, without reference to its type, specific use, or scale, can be reached if the number of maps sold or accessed electronically could be estimated. One procedure for establishing the historical demand for geological maps produced by geological surveys has been based on the number of maps sold. Bhagwat and Ipe (1999), for example, used a total sales volume of 81,000 geological maps in Kentucky to determine a minimum aggregate value of those maps. Likewise, the geological surveys of Spain (Garcia-Cortes et al., 2005) and Nevada (Bhagwat, 2014) estimated the total value of geological maps and data sold on the basis of physical map sales. Similarly, geological map sales remain a good measure of map demand and use. However, the Association of American State Geologists (AASG) has been tracking overall publication sales by SGS, including maps, for decades. Reporting by Bradbury (2021) showed fairly robust sales of all publications over $3 million per year between the mid-1990s and 2008, but beginning in 2009 sales began exhibiting a steady decline that has continued to 2021, when sales resided at just over $500,000. The reason for the decline was the transition from traditional sales to online web availability, whereby most SGS and the USGS have provided maps and other publications to users free of charge, while a few other SGS have charged a low nominal fee.

Based on the transition to online availability, geological maps have become vastly more accessible to view, and if desired, to download to personal computers and other devices. Therefore, the measure of demand during the project period timeframe (1994–2019) has greatly expanded. To report this activity, SGS and the USGS were asked to provide their



Portion of: Hudson, M.R., and Turner, K.J., 2016, Geologic map of the Murray quadrangle, Newton County, Arkansas: USGS Scientific Investigations Map SIM-3360, scale 1:24,000.

information on online views and downloads of geological maps, knowing that (1) reporting would be restricted to the most recent years of the project period because of a lack of early website record keeping capabilities or system changes resulting in lost statistical data; (2) some of the geological surveys, depending on analytical capabilities of their system or operators, could only provide web view statistics; and (3) some geological surveys would be incapable of providing any online web view or download data. Despite these limitations, all SGS and the USGS possess online web view and/or download capabilities, and these activities are direct transactions responding to growing needs for geological information that address specific natural resource, geological hazard, public safety, land-use, and environmental issues.

For the 1994–2019 project period, online web view and/or download statistics were provided by 24 SGS and the USGS. Therefore, web view and download data were not reported by 24 other SGS over the project period. Two states lack an SGS, and four did not respond to inquiries for their online view and download information. The remaining SGS did not/could not provide any statistics and explained that (1) while there were download files, time stamping of those downloads was not available; (2) online view and download data could not be found; (3) there was no mechanism for tracking of clicks without an IT ticket, and the IT department was understaffed; (4) given the different ways/places for accessing files with different formats, data accuracy was questionable; and/or (5) migrating to a new centralized system resulted in loss of older data and lack of more recent data to track newer website traffic. The USGS reported the longest record of online geological map views beginning in 1999 (Table 7.2.1). However, the earliest SGS reporting was from New Jersey in 2004, and the average earliest year of reporting for all SGS was 2011. Therefore, these data are considerably underreported and represent minimum values.

Although not requested to do so, 30 SGSs reported online views and/or downloads post 2019, five of which reported post-2019 data only. There were 31 SGS, plus the USGS, who provided some data, including those data over the post-2019 period. Their websites were visited to explore the means by which they offered download options, and 21 did so through PDFs.

A reliable measure of geological map use and map demand is the action taken by users to download geological maps from these sites. This is bolstered by the business and marketing community widely reporting that download action shows the serious intent of those browsing the web to use or purchase a commodity (Geckoboard website; Saleh, Invesp website, 2020; Burstein, Marketing Sherpa webpage, 2021).

Even among the 31 SGS and the USGS that provided data, the functionality of their websites for users to view and download geological maps varies considerably (Appendix 5). Only three SGS (Kansas, Kentucky, and Missouri) and the USGS have maintained website capability covering some years/portions of years for users to completely view a map without downloading it. Users (1) click on a link, thumbnail image, or a map boundary outline on a statewide location map; (2) access a geological map as a JPEG or other "non downloadable" image; (3) zoom in and out and navigate the online image; and (4) if desired, "screen save" or print the image. According to Hersy (Personal communication, 2023) of WebEx Digital Marketing Agency, the ability to easily access and engage with the image, without downloading it, also constitutes end-user action. Therefore, this online geological map view action is also used as a factor contributing to map demand for this economic study. The data from these four surveys were treated as follows and are shown in detail in Appendix 5:

1. The Kansas Geological Survey's data only applies to the supplemental 2020–2022 information, and their JPEG views are equal to downloads.

2. The Kentucky Geological Survey's view-only JPEG option was operational from 2004–2008, and these views are equal to downloads. During the post-2008 period, options were offered to either view without downloading or directly download maps. However, the number of these views and downloads by these two mechanisms could not be separated easily, and therefore all of their post-2008 map view data were treated similarly to other SGS map view data and subject to applying a conversion rate (as discussed below) of map views to downloads.

3. The Missouri Geological Survey's online views of geological maps were provided beginning in 2014. They confidently reported that 90% of their website map files were JPEGs and therefore equal to downloads. The remaining 10% were treated similarly to other SGS map view data and subject to applying a conversion rate (as discussed below) of those map views to downloads.

4. The USGS has the longest record of map views going back to 1999. However, there has been a transition to viewable JPEG-like images because of the large volume of maps in the National Geologic Map Database (NGMDB). For this economic study, the USGS provided an annual estimate of the percentage of their map holdings that were transitioned to a JPEG-like image equivalent to a download (Appendix 5). The transition began in 2003 with 5% of their holdings, and since 2018 it has been over 20%. Those that were not transitioned were treated similarly to the majority of SGS map view data and subject to applying a conversion rate (as discussed below) of these map views to downloads.

7.2: USGS NATIONAL GEOLOGIC MAP DATABASE WEB VIEWS

Because the NGMDB of the USGS is the recognized, nationwide, comprehensive listing of geoscience maps and reports, a brief discussion of its holdings, operations, and contribution to this economic assessment is warranted. Its current holdings comprise ~40,000 USGS and SGS geological maps among its 109,000+ geoscience publications. Since 1996 when the NGMDB opened its Web site, its Geoscience Catalog interface enabled users to search by various parts of a citation (e.g., author, title, year, publisher, map scale) and by geographic area, geoscience theme, or product format (e.g., paper, digital, GIS). From the search results, users could then select one of the geological maps and view its "Product Description Page" (i.e., "landing page") — that user action constitutes an online view, which continuously has been operational since the 1990s.

The Web statistics data of the NGMDB were provided beginning in 1999 and constitute the earliest reporting of online geological map view statistics in the U.S. (Table 7.2.1 and Appendix 5). Only USGS online views were reported, and it was decided to include all geological map publications that currently include a viewable image of a geological map. It is a conservative estimate of geological map views and usage because the statistics exclude geological map publications for which a viewable image is not yet provided by the NGMDB. It is reasonably assumed that becoming aware of the map publication through the Product Description Page of the NGMDB enabled users to access and use the publication, either directly by viewing it at the NGMDB Page, or by accessing the link to the map publisher, which is provided at each Product Description Page.

In 2003, the NGMDB began to provide some online map viewing capability that, for this report, is considered equivalent to downloading. That capability is found on the "Product Description Pages" (i.e., Web landing pages for individual publications) and in NGMDB's online viewer, "MapView". NGMDB's Web statistics were computed from those Product Description Pages that included a custom map-viewing inset (e.g., see https://ngmdb.usgs.gov/Prodesc/proddesc_113783.htm) that enables users to fully inspect the content of the map. That functionality offers a similar result to a direct download—that is, map content can be viewed and used for many real-world applications.

The maps shown at many PDPs are also accessible through the MapView interface of the NGMDB (https://ngmdb.usgs.gov/mapview/?center=-109.832,51.422&zoom=4). The MapView interface includes a zoom function to view maps from small scale, as shown in the national coverage in Figure 7.2.1 to larger scale (Figure 7.2.2). As an example, Figure 7.2.2 shows in red outline the Heinrich et al. (2010) New Orleans 30 x 60-minute quadrangle at a scale of 1:100,000, produced by the Louisiana Geological Survey. More detail can be seen by zooming in farther. When a red box appears, the full text reference and a thumbnail image of the map is highlighted in the left-hand panel of the interface. Clicking on the thumbnail image, or the “More Info” button, then directs users to the Product Description Pages of the map — that action then is recorded as a "download" because the PDP is accessed, and the map and its explanation can be inspected in full detail. In all cases of Product Description Pages accessed through the NGMDB, download and additional view options for SGS maps were all referred back to their original source to ensure that they were properly credited.

Becoming aware of a map publication through the Product Description Page of the NGMDB enables users to access and use the publications. By this reasoning, year-by-year Web page views for each SGS geological map subsequently were reported by each SGS to the best of their abilities over the project period.

Table 7.2.1.
SGS and USGS geologic map views, downloads, and maps sold — 1994–2019.

Survey	Years	Total Views or DLs	Years	Views = DLs	Years	Views	CR DLs	CR DLs	CR DLs	Years	Direct DLs	Years	Sold
			Bot free		Bot free		2006–19	2006–22	2020–22	Bot free			
			Bot % reduced**		Bot % reduced		CR=3.32%	CR=4.7%	CR=7.2%	Bot % reduced			
AK	2006–19	163,366								2006–19	163,366		
AR	2013–19	2,144,144								2013–19	113,724		
AZ	2011–19	866,746			2011–19	866,746	28,776	40,737	62,406				
CA	2013–19	2,188,847			2013–17	846,209	28,094	39,772	60,927	2018–19	42,373		
CO	2015–19	716,160								2014–19	6,110	2014–19	38,243
FL	2018–19	51,042								2018–19	32,017	2018–19	10
IL	2014–18	181,247								2014–18	181,247	2011–19	4,312
IN	2011–19	1,324,842			2011–18	1,107,819	36,780	52,067	79,763	2019	335	2014–19	800
KS												2000–19	1,423
KY	2004–19	1,062,315	2004–8	326,886	2009–19	735,429	24,416	34,565	52,951			2001–19	12,300
MD	2015–19	116,106								2015–19	116,106	2003–19	3,257
ME	2017–19	46,664								2017–19	46,664		
MO	2014–19	73,403	2014–19	66,063	2014–19	7,340	244	345	528				
MN	2014–19	170,537								2014–19	170,537		
MT*	2015–19	1,304,614								2005–19	1,304,614	2005–19	5,018
NE	2016–19	6,282								2016–19	219		
NH												2010–18	905
NJ	2004–19	1,254,959								2004–19	1,254,959		
NM	2006–19	2,918,137			2006–19	2,918,137	96,882	137,152	210,106				
NV	2016–19	61,864								2016–19	61,864	2009–19	10,682
SC												2018–19	119
SD	2016–19	33,117								2016–19	33,117	2016–19	70
TN												2000–19	9,534
TX	2017–19	6,888								2012–19	4,668		
UT	2012–19	209,959			2012–18	127,929	4,247	6,013	9,211	2019	12,392		
VT	2018–19	23,824			2018–19	23,824	792	1,120	1,715				
WV	2012–19	2,446,034			2012–19	2,446,034	81,208	114,964	176,114				
WY	2018–19	28,664								2018–19	13,838		
USGS	1999–19	2,739,160	2003–19	409,637	1999–19	2,322,500	77,107	109,158	167,220				
TOTALS		20,138,921		802,586		11,401,967	378,546	535,893	820,941		3,558,150		86,673

Black — Views, downloads, and maps sold.

Green — Views are also DLs from SGS that only reported DLs.

Red — Additional DLs from SGS views-only yrs. based on conversion rates (CRs).

*MT conducted bot analysis (% bots), and these figures used instead of Invesp.

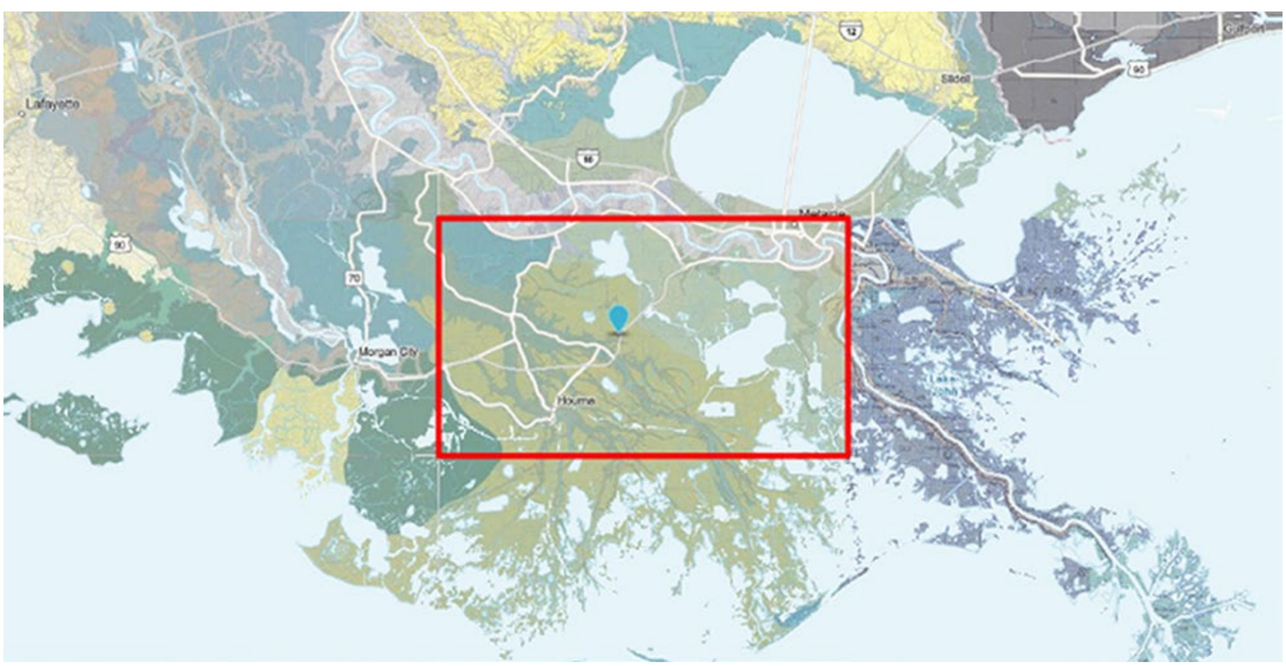
**Bot % reduced — Originally reported view/download numbers reduced by Invesp (2023) industry reporting to account for bots.

Views=DLs	802,586	Views=DLs	802,586	Views=DLs	802,586
CR DLs (3.32%)	378,546	CR DLs (4.7%)	535,893	CR DLs (7.2%)	820,941
Direct DLs	3,558,150	Direct DLs	3,558,150	Direct DLs	3,558,150
Sold	86,673	Sold	86,673	Sold	86,673
TOTAL	4,825,955	TOTAL	4,983,302	TOTAL	5,268,350

Figure 7.2.1

USGS NGMDB MapView showing small-scale coverage of geological maps in the conterminous U.S. https://ngmdb.usgs.gov/mapview/?center=-109.832,51.422&zoom=4 (Accessed March 28, 2022.)

Figure 7.2.2



USGS NGMDB MapView image showing the outline of the New Orleans 30 x 60-minute quadrangle at a scale of 1:100,000, with the full text reference, and a thumbnail image of the actual geological map. https://ngmdb.usgs.gov/mapview/?center=90.369,29.615&zoom=9 (accessed March 28, 2022).

7.3: EFFECT OF ROBOTIC ACTION ON GEOLOGICAL MAP ONLINE VIEWS AND DOWNLOADS

A factor that affects reporting of web statistics, including geological map online view and download data, is the interaction of robots, or "bots", with web sites. Bots are designed to perform specific and repetitive tasks, and they do so automatically, faster, and often more effectively than if humans performed them (Metwalli, 2021). Bots are classified as either "bad bots" or "good bots". According to Karl Triebes, Imperva Senior Vice President and General Manager, and quoted in Security Today (2023), bots have evolved rapidly since 2013, and this technology will evolve at an even greater rate in the next ten years (to 2033) due to generative artificial intelligence.

Bad bots can result in significant economic and productivity loss (Distill, 2016). Imperva (2023) defines them as those that perform automated tasks with malicious intent, including fraud and theft. Imperva (2023) and Metwalli (2021) classified bad bots as (1) hacking that distributes and enables malware and can break networks; (2) scraping data from sites without permission, which includes stealing data, and then reusing it to gain a competitive advantage; (3) scalping, where items of limited availability are obtained and then resold at a higher price; (4) spamming using faulty advertisements to drive web traffic to specific sites; and (5) impersonating, where a user's behavior is mimicked to gain their personal information or steal sensitive data. Bad bots also are used to create distributed denial of service (DDoS) attacks targeted at a network or application. These cyber-attacks are designed to make a machine or network unavailable to users and are done so by overloading systems, thereby preventing legitimate users from access.

SGS and the USGS are within either the government or education sectors of the economy. Imperva (2020) mentioned that from 2014–2019 education averaged 45.7% bad bot traffic, while government averaged 37.5% bad bot traffic. However, for the former, Imperva (2020) highlighted that the reason for doing so was for scraping bots to maliciously search for research papers, class availability, and access to user accounts, and for the latter, to steal business registration listings, whereas other bots were used to interfere with elections and voter registration accounts. Neither of these would apply to viewing or downloading geological maps. In addition to data scraping, bad bot activity also involves hacking, scalping, spamming, and impersonating. Again, the incentive for substantial bad bot activity at SGS would seem to be quite low. Upon inquiry to SGS, there were no known bad bot intrusions into their web sites. However, as a large federal agency, the USGS NGMDB had experienced distributed bad bot denial of service attacks mainly targeting topographic maps.

Metwalli (2021) and Imperva (2023) mentioned that good bots conduct useful functions, and they usually operate with the permission of the website owner. They assist users by indexing and matching their queries with the most applicable websites and pages and ensuring that displayed products are easily discovered by customers. "Crawlers" interact with websites to collect and index data or monitor website performance. "Search engine spiders" are a type of crawler that extracts URLs from the web, and then uses them to download and separate data into searchable indices. Good bots also can be "transactional" if they are designed to move data and provide helpful information by sending notifications, emails, and texts. Based on these activities, geological map databases can benefit from good bots. One SGS website manager mentioned that they have identified search engine crawlers from analyzing http-user agents and "were comfortable with the activity. If the search engines were harvesting our content, then they were pushing people our way, or making it easier for people to get our products". Easy access, distribution, and wide use of geological maps and information over many years are paramount to the mission of geological surveys.

Despite the benefits of good bots, the downside of all bots is that they can skew web statistics and make websites appear more popular than reality. Metwalli (2021) stressed that "being able to intelligently distinguish between traffic generated by legitimate human users, good bots, and bad bots is crucial for making informed business decisions". Therefore, in the marketplace of private goods, web view and download data can be "manufactured" by companies through bots and falsely present a high demand for specific products. In view of such marketing practices, a question can be raised regarding the propriety of using map view and download data as demand for geological maps.

In analyzing this issue, a marketing division may succeed in creating the impression of high demand for outsiders. However, if the same impression is conveyed to the company's own production division, the company could produce more products than could be sold. Therefore, it is safe to assume that this deceitful practice is likely to be uncommon and essentially non-existent among geological surveys embedded within governmental agencies and public educational institutions.

Estimating demand for geological maps from web view and download data must also consider that geological maps are a public good that are given away or sold at nominal cost that covers printing, mailing, and website maintenance costs. Therefore, there is no market for geological maps, nor an incentive for SGS or the USGS to create robotic activity to “manufacture” demand data, because they have nothing to sell.

In recent years, sales of printed geological maps by SGS and the USGS have markedly declined. However, there is no known reason to assume that geological maps are not needed or used to the same extent as before. On the contrary, more and more economic sectors require them, and simultaneously, online visits to map databases of SGS and the USGS have risen exponentially (Appendix 5). This indicates that ease of access has allowed many map users to switch from paper copies to digital versions. One way to estimate geological map usage is to count map downloads, and some SGS maintain that ability as discussed above. However, when download data are not available, estimates of “conversion rates” can determine how many web site visitors performed a meaningful transaction and downloaded maps. Conversion rates for geological maps used in the present study ranged from 3.32% to 7.2% based on download data monitored and reported by nine SGS for multiple years of map views and downloads as discussed in detail below.

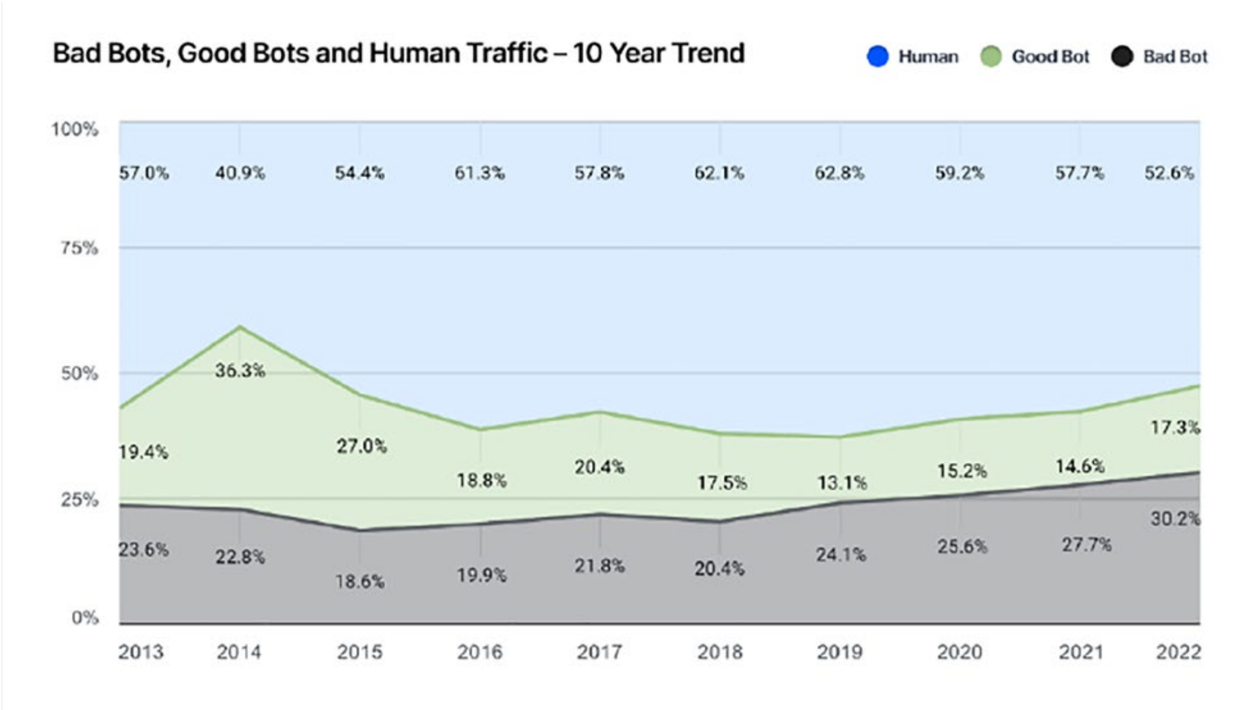
The following procedure was followed to account for SGS and USGS bot activity regarding geological map web view and download data, with full realization that all bots can never be identified. Although bot traffic accounted for nearly 40% of all internet traffic in 2020, Knecht (2020) reported (see also Imperva, 2023) that much is yet to be learned in distinguishing bots from humans.

- Nine SGS plus the USGS were able to account for bot activity in their geological map web view and/or download numbers, saying that their data were either “bot free” or very minimal. For example, the Utah Geological Survey mentioned that they “don't get much bot activity on the geological map portal (at least that we can identify and track). Our stats are pretty consistent month to month, so when there is a spike in views or downloads, we try to identify the source. It is usually easy to find where the unusual traffic is coming from and why and it is almost never bot-related”. The California Geological Survey reported that only their download data was bot free.

- Other SGS either did not have the capacity to evaluate bot activity or did not report on their degree of bot activity. Their raw website view and download data were adjusted to account for bots based on annually reported industry findings for (1) a 10-year (2013–2022) trend in bad bots, good bots, and human traffic (Imperva, 2023; Figure 7.3.1), and (2) 2012 data (Imperva, 2013) showing that bots accounted for 51% of web traffic (49% human traffic). Bot data from industry sources are not available prior to 2012. Therefore, between 2004 and 2011 (years for which SGS and USGS data were provided), web view and download data by SGS and the USGS were adjusted based on the average (44.3%) of Imperva’s 2012–2019 bad bot, good bot, and human traffic data (Figure 7.3.1). This resulted in a significant reduction of geological map views and downloads.

The only SGS that uniformly kept track and reported bot activity (2006–23) on their website (Table 7.3.1) was the Montana Bureau of Mines and Geology (personal communication, Luke Buckley, Data Scientist, July 14, 2023). From 2006–2019, bot activity ranged from 7–22%, with an average of 14%. The 2020–2023 data averaged 23.5% bot activity. There was a 16% overall 2006–2023 average. This one sampling shows bot activity less than one-half of the industry average reported by Imperva (2023), and it may be more indicative of reality amongst other SGS. However, this study could not confirm the Montana lower bot rate activity despite consultations with several high-profile university map libraries, all of which could not offer any perspectives on the effects of bots on their websites. Therefore, to maintain a conservative approach to this economic assessment, the Imperva higher bot rate percentages were used for this study.

Figure 7.3.1



Bad bots, good bots, and human traffic, 2013-23 (Imperva, 2023).

Table 7.3.1.

2006–23 MBMG Data Center, standard vs. mobile analytics (including bot analysis), July 14, 2023.

	Person			Bot			Summary		
Calendar Year	**Desktop**	**Mobile**	**Totals**	**Desktop**	**Mobile**	**Totals**	**Total-Activity**	**Mobile-Percentage**	**Bot-Percentage**
2006	1,696,104	5	1,696,109	217,986	14	218,000	1,914,109	0%	11%
2007	7,240,114	270	7,240,384	1,196,566	58	1,196,624	8,437,008	0%	14%
2008	9,140,647	3,404	9,144,051	1,979,946	858	1,980,804	11,124,855	0%	18%
2009	8,172,842	14,629	8,187,471	2,360,435	1,000	2,361,435	10,548,906	0%	22%
2010	10,685,686	54,158	10,739,844	2,278,472	1,700	2,280,172	13,020,016	0%	18%
2011	10,997,605	186,907	11,184,512	2,182,391	5,234	2,187,625	13,372,137	1%	16%
2012	10,634,183	346,985	10,981,168	1,623,363	20,399	1,643,762	12,624,930	3%	13%
2013	12,578,252	729,107	13,307,359	1,250,801	133,900	1,384,701	14,692,060	6%	9%
2014	17,465,648	1,368,938	18,834,586	1,331,064	45,620	1,376,684	20,211,270	7%	7%
2015	17,997,020	1,366,903	19,363,923	2,729,403	98,842	2,828,245	22,192,168	7%	13%
2016	22,195,108	1,538,079	23,733,187	2,639,930	141,192	2,781,122	26,514,309	6%	10%
2017	26,514,183	2,454,370	28,968,553	5,450,883	184,410	5,635,293	34,603,846	8%	16%
2018	25,942,197	2,868,112	28,810,309	5,215,499	441,557	5,657,056	34,467,365	10%	16%
2019	26,845,420	3,768,422	30,613,842	4,589,716	713,359	5,303,075	35,916,917	12%	15%
2020	30,252,941	3,717,971	33,970,912	8,783,171	1,039,395	9,822,566	43,793,478	11%	22%
2021	35,166,551	4,936,637	40,103,188	10,106,529	1,236,276	11,342,805	51,445,993	12%	22%
2022	38,567,452	4,141,065	42,708,517	15,438,708	2,662,787	18,101,495	60,810,012	11%	30%
2023	34,680,864	3,979,479	38,660,343	8,279,030	1,417,639	9,696,669	48,357,012	11%	20%
Averages	**19,265,157**	**1,748,636**	**21,013,792**	**4,314,105**	**452,458**	**4,766,563**	**25,780,355**	**6%**	**16%**

7.4: ESTABLISHING INDUSTRY STANDARD CONVERSION RATE

According to Waite (Personal communication, 2022) of WebFX Digital Marketing Agency, it was legitimate to use the percentage of geological map downloads resulting from views as a conversion rate, because the views resulted in an action. Saleh (2020) reported that different goals, like downloading a lookbook versus adding a product to a cart or filling a form, can dictate the conversion rate. The average conversion rate of e-commerce websites in 2020 was 2.86% (2.63% in the U.S. and 4.31% globally). Daniel Burstein, Senior Director for Content and Marketing, Marketing Sherpa and MECLABS Institute (2021) distinguished conversion rates depending on examples from several industry sectors, including (1) software-as-a-service (5.1% who signed up for a free trial); (2) health food (13.4% who spent >5 seconds on a site); (3) clothing (5.2% who purchased clothing from an e-commerce site); (4) marketing agencies (4% who booked an estimation call, and 4–8% who optimized their websites); (5) real estate (49.3% who called, messaged, or asked for directions); (6) tourism (7–24% who booked a tour); (7) music education (10% who filled out a call-back form); (8) dating services (1.58% who navigated to an order received page); (9) sports/lifestyle blogging (3.78% who made a purchase, and 15.69% who downloaded an e-book); (10) business to business publishing (61% who clicked on outbound links for help); (11) gaming (32% who started playing cards); and (12) the casino business (26.5% who clicked to an online casino). A public sector study by Whang (2007) at Western Michigan University calculated a conversion rate of 10.5% based on the percentage of clicks on a library web advertisement to the number of orders derived from that advertisement from faculty seeking new electronic media for teaching and research.

Conversion rates commonly are used to determine the percentage of website visitors that turn into customers. They reflect those interactions between websites, consumer choices, and who may eventually complete desired actions (Whang, 2007; Ayanso and Yoogalingam, 2014; McDowell et al., 2016). Downloading a map constitutes such actions. Table 7.4.1 shows the online view, download, and maps sold contributions of the 28 SGS and the USGS that provided 1994–2019 data, nine of which provided both online view and download data in the same years. A conversion factor was used to help determine the percentage of their online viewers that downloaded a map.

Table 7.4.1.
SGS and the USGS Contributing Data on Geological Map Online Views, Downloads, and Maps Sold.

Survey 1994–2019 Data	**Online Views**	**Down-loads**	**Maps Sold**
AK		X	
AR	X	X	
AZ	X		
CA	X	X	
CO	X	X	X
FL		X	X
IL		X	X
IN	X	X	X
KS			X
KY	X		X
MD		X	X
ME		X	
MO	X		
MN		X	
MT		X	X
NE	X	X	
NH			X
NJ		X	
NM	X		
NV	X	X	X
SC			X
SD		X	X
TN			X
TX	X	X	
UT	X	X	
VT	X		
WV	X	X	
WY	X	X	
USGS	X		

Table 7.4.2.

National conversion rate: 2012–22			
State	**Years**	**Views**	**Downloads**
Arkansas	2013–21	2,436,067	201,765
California	2018–21	2,229,919	127,747
Colorado	2015–21	1,038,206	11,447
Indiana	2019–22	606,196	4,795
Nebraska	2016–21	7,691	254
Texas	2017–21	610,955	12,395
Utah	2019–21	230,423	45,628
W. Virginia	2012–21	2,886,358	54,882
Wyoming	2018–21	91,879	17,803
TOTALS	**52 Years**	**10,137,694**	**476,716**
Conversion Rate			**4.70%**

SGS providing years of both views and DLs

Table 7.4.3.

National conversion rate: 2012–19			
State	**Years**	**Views**	**Downloads**
Arkansas	2013–19	2,144,144	113,724
California	2018–19	1,342,638	42,373
Colorado	2015–19	716,160	6,072
Indiana	2019	217,023	335
Nebraska	2016–19	6,282	219
Texas	2017–19	6,888	3,398
Utah	2019	82,030	12,392
W. Virginia	2012–19	2,446,034	44,737
Wyoming	2018–19	28,644	8,648
TOTALS	**33 Years**	**6,989,843**	**231,898**
Conversion Rate			**3.32%**
SGS providing years of both views and DLs			

Table 7.4.4.

National conversion rate: 2020–22			
State	**Years**	**Views**	**Downloads**
Arkansas	2020–21	291,923	88,041
California	2020–21	887,281	85,374
Colorado	2020–21	322,046	5,375
Indiana	2020–22	669,244	7,717
Nebraska	2020–21	1,409	35
Texas	2020–21	604,067	7,727
Utah	2020–21	148,393	33,236
W. Virginia	2020–21	440,324	10,145
Wyoming	2020–21	63,235	9,155
TOTALS	**19 Years**	**3,427,922**	**246,805**
Conversion Rate			**7.20%**
SGS providing years of both views and DLs			

For completeness, three conversion rates (Tables 7.4.2., 7.4.3, and 7.4.4) were calculated based on the geological map view and download numbers provided by the nine SGS for the:

- 1994–2022 overall project period (4.7%) with 2012–2022 data — 4.7% conversion rate.
- 1994–2019 project period with 2012–2019 data — 3.32% conversion rate.
- 2020–2022 period of supplemental data acquisition — 7.2% conversion rate.

This simple calculation shows the highly significant increase in online geological map downloads since 2019. Although not analyzed in the stakeholder questionnaire or reported by SGS or the USGS, several factors are most likely responsible for this trend:

- Improvements in website technology allowing for easier access to geological maps.
- Increasing number of geological maps being made available for viewing and downloading.
- Increased overall demand for geological maps.

All three conversion rates are discussed in detail below.

Direct download data, similar to total sales volume, allows for a reasonable determination of the minimum aggregate value of geological maps. Table 7.2.1 shows a total of 3,558,150 directly downloaded geological maps over the 1994–2019 project period, plus 802,586 online views equivalent to downloads, for a total of 4,360,736 downloads. However, this is a minimum value because not all states reported their download numbers, and even for those that did, the earliest reported downloads occurred in 2004, and this was only for the New Jersey Geological Survey. All other states reported their first downloads later. Knowing that data would be sparse, and there was a higher likelihood of data retention for 2020–2022, online view and download data for these years were also provided by some SGS. However, 2022 data were not complete, as SGS information was only accepted through March 2022. USGS information was complete for 2022. The 2020–2022 recent data were included in the development of the overall 4.7% national conversion rate and used to further show the ongoing increase in online accessibility and downloading of geological maps beyond the 26-year project period.

The nine SGS that reported both online view and download data had 3 to 10 years of reporting, including data for 2020–2022. A total of 52 years of reporting from these nine SGS was used to calculate the average national conversion rate of 4.7% (Table 7.4.2). For those SGS that provided just online view data, or online view data for years prior to providing download data, the 4.7% national conversion rate was used to estimate that their 11,401,967 online views resulted in 535,983 additional potential downloads. However, for this study, the most conservative 3.32% conversion rate, covering just the 1994–2019 project years, was used, and this calculation reduced the additional potential downloads to 378,546 (Table 7.2.1).

For those nine SGS that reported both online views and downloads of geological maps, yearly conversion rates were calculated, and there are some observable general trends.

- Eight SGS (Arkansas, California, Colorado, Indiana, Texas, Utah, West Virginia, and Wyoming) displayed increasing downloads over their reporting periods. Download numbers for Nebraska were small (~42/year) and fairly constant.

- Three SGS (Texas, Utah, and Wyoming) displayed increasing online views over their reporting period, while Arkansas and Nebraska showed decreasing views, and California and West Virginia displayed fluctuating up and down view numbers.

SGS in Wyoming and Texas both showed that the number of their downloads increased over time. However, their number of online views increased at a far greater rate than downloads, presumably either because map users in those states became more comfortable with searching and just viewing geological maps, or the reporting method changed due to operation of a new system.

In addition to the nine SGS mentioned above, the Alaska Division of Geological & Geophysical Surveys reported a relatively steady increase in downloads of both geological maps and data between 2006 and 2021 (Appendix 5). Noteworthy was their increase of downloads from 2014–2021. According to Alaska's Jennifer Athey (personal communication), considerable effort was spent from 2012–2014 building and deploying web maps and applications with the intent to increase accessibility and distribution of their products.

The nine SGS that reported both online view and download data had 1 to 8 years of reporting from 2012-2019 (covering the latter portion of the study period), and this accounted for 33 cumulative years of reported online view and download data that were used to calculate the average conversion rate of 3.32% (Table 7.4.3). There were 19 cumulative years of data reported for 2020–2022 (Table 7.4.4). For this period, there were 3,427,922 online views and 246,805 downloads, which yielded a conversion rate of 7.2%. Therefore, there was an obvious trend of downloading greater percentages of geological maps post 2019. Also, 33.8% of all online views from 2012–2022, and 51.8% of all downloads, were reported post 2019 as well. All these data show increased activity over time of downloading geological maps.

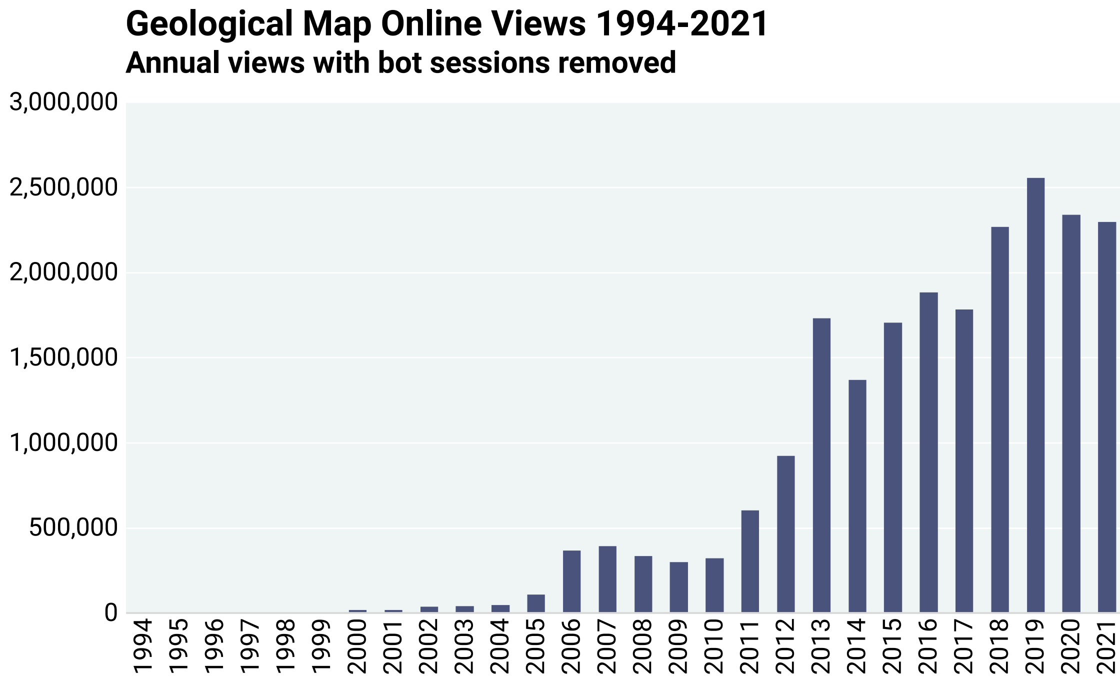
Table 7.4.5.
Summary SGS and USGS geologic map views, downloads, and maps sold — 2020–2022.

Survey	Views	Downloads	Sold
		CR=7.2%	
AK	98,894	98,894	
AR	291,923	88,041	
AZ	190,747	13,734	
CA	887,221	85,374	
CO	322,046	5,375	14,195
FL	21,349	21,349	7
IL	98,469	90,300	381
IN	389,173	4,460	20
KS	11,332	11,332	32
KY	101,466	7,306	117
MD	57,771	57,771	44
ME	54,142	54,182	
MO	4,137	298	
MN	48,384	48,834	
MT	122,991	122,991	249
NE	1,409	35	
NH	471	471	63
NJ	177,101	177,101	
NM	371,673	26,760	
NV	29,501	29,501	1,192
NY	2,684	2,684	
OK	19,447	1,400	
SC			211
SD	3,299	35,838	52
TN			68
TX	604,067	7,727	
UT	148,393	33,236	
VT	30,825	2,219	
WI	6,347	6,347	
WV	440,324	10,145	
WY	63,235	9,155	
USGS	1,042,759	285,829	
TOTALS	**5,641,580**	**1,338,689**	**16,631**

Black — Views, downloads, and maps sold.
Views and downloads include bot adjustments.
Green — Views are also DLs from SGS that only reported DLs.
Red — Additional DLs from SGS views-only years based on the 7.2% CR.

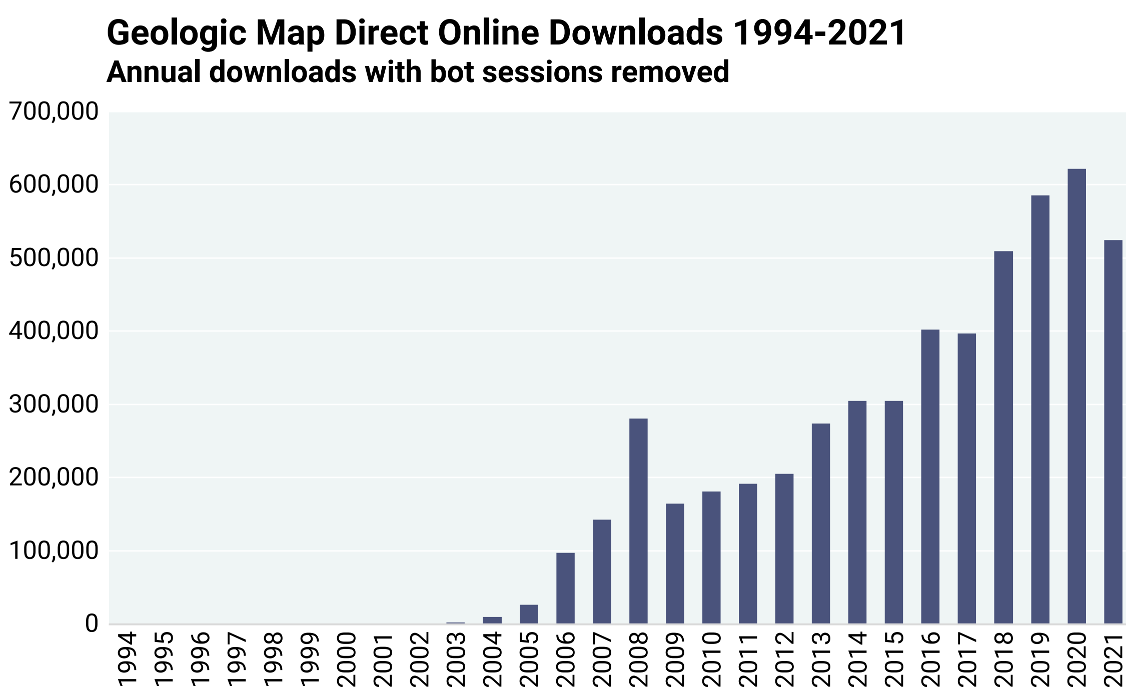
Thirty-one SGS and the NGMDB of the USGS reported their online view and download data beyond the 1994–2019 project period (Table 7.4.5). Although cost data were not obtained

Figure 7.4.1



Geologic map online views from 1994 to 2021.

Figure 7.4.2



Geologic map direct online downloads from 1994 to 2021.

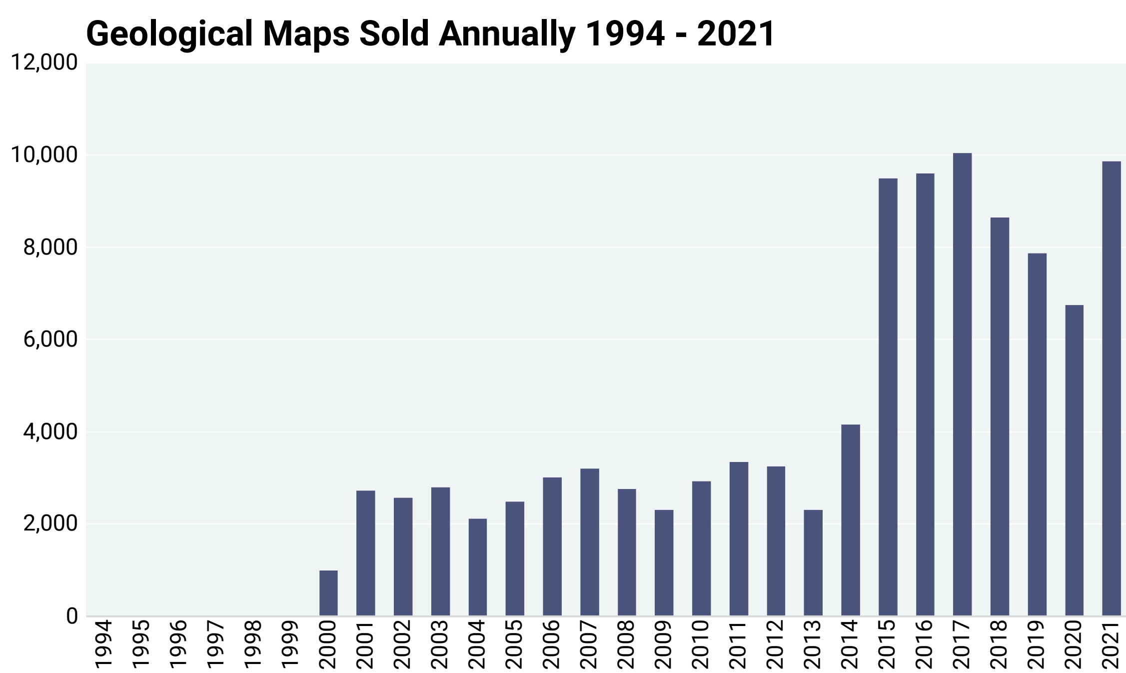
for these later years, these data show the continued trend in online viewing and downloading of geological maps. Data from 2020 to 2022 showed 5,641,580 additional online views and 1,338,689 downloads. The download numbers include the 7.2% conversation rate of online views-only data for SGS from Arizona, Kentucky, Missouri, New Mexico, Oklahoma, Vermont, and some of the USGS data. There were also 16,631 geological maps sold during this period. Therefore, there were an additional 1,355,320 transactions that resulted in geological maps being directly or indirectly downloaded and sold over this most recent period. In graphic form, Figures 7.4.1 and 7.4.2 show the trend of online map views (from 2002) and downloads (from 2004) to 2021.

7.5: GEOLOGICAL MAPS SOLD

Adding to the demand numbers from geological map downloads, a small sample set of 13 SGS (only 25% of the SGS) provided information on the number of geological maps that were sold over the project period. While total SGS publication sales have been tracked annually by the AASG (Bradbury, 2021), geological map sales numbers, as a subset of overall publications, were not tracked or widely recorded. Figure 7.5.1 shows geological maps sales from 2000–2014 averaging about 2,700/year and then from 2015–2021 about 8,900/year. However, we do know that the number of maps sold was more robust than our incomplete data that began in 2000. Therefore, the number of 86,673 maps sold as reported here is very much a minimum value, but still contributes to the overall geological map demand numbers. Also, this study did not obtain a price for estimating the dollar value for maps sold. These sales primarily constitute paper maps that were distributed at the cost of printing or copying. Even if the cost was $10/map, the dollar value would only be $866,730, or roughly <1/2000ths of the total $1.99 billion of total costs reported by SGS and the USGS, and thereby not have any noticeable effect on cost and benefit ratios. In addition, because the total maps sold was so small (1.8%) in comparison with the total of geological maps accessed electronically, it was unnecessary to include any generated revenues from map sales into cost considerations for this report.

While geological map sales data contribute to the overall demand and aggregate value of geological maps, the number of maps sold is ~2% of map downloads. However, the

Figure 7.5.1



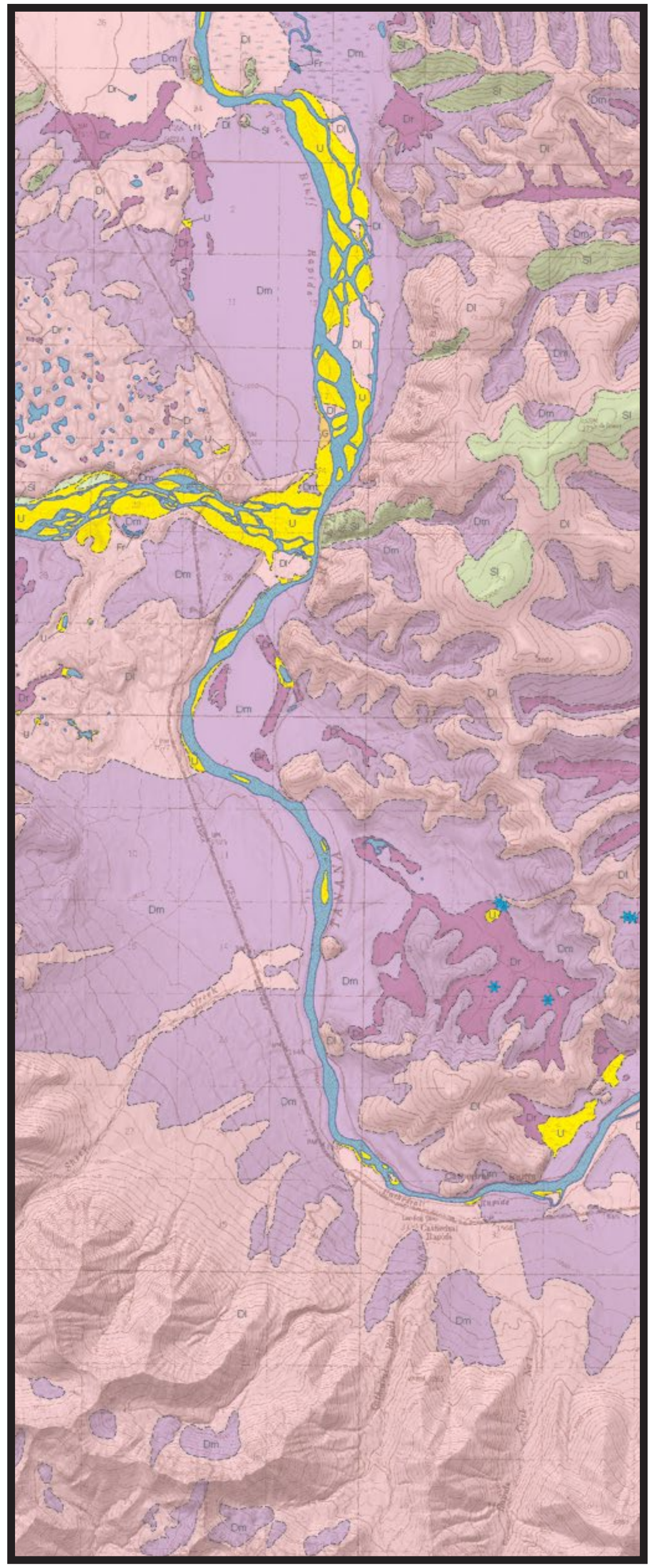
Geologic maps sold from 1994 to 2021.

exception to minimal national geological map sales is that reported by the Colorado Geological Survey (38,243). This SGS accounts for over 45% of the reported national total of map sales through 2019, with a significant increase in sales beginning in 2015. According to Karen Berry, retired Colorado State Geologist (personal communication), geological map sales were large, because they included their state-wide map of expansive soils, and builders were required by law to provide buyers of new homes with a copy of the publication.

Those same 13 SGS also provided information showing that 16,631 geological maps were sold in 2020, 2021, and a portion of 2022 (Table 7.4.5), and maps sold constitute ~1.2% of map downloads. Again, the Colorado Geological Survey dominated with 85% (14,195 geologic maps) of those map sales.

7.6: GEOLOGICAL MAP DOWNLOAD EXTRAPOLATION SCENARIO

Mentioned above was that only 24 SGS supplied online view and/or download data for the 1994–2019 project period, and that these actions primarily occurred over the second half of the project period, with full realization that online map views and download data were not available, under reported, or not reported for much of the first half of the project period. Therefore, map view and download numbers are very conservative. However, adding to this conservative assessment was realization that data were not reported at all from 24 other SGS. It is reasonable to assume that except for the lack of a SGS in Hawaii and Georgia, these 24 other SGS have been producing and disseminating geological maps. An extrapolation of potential online views and downloads can be made by evaluating the "robustness" of these 24 SGS (Table 7.6.1) based on their overall cost of mapping reported for this study and graphically portrayed on Figure 4.1.2. These 24 SGS have all been receiving funding from various sources for mapping, and it is a requirement of the USGS STATEMAP program that this federal funding be matched at 100%. The primary source of funding to SGS for geological mapping was through the USGS STATEMAP program, as discussed in Chapter 2.



Portion of: Reger, R.D., and Hubbard, T.D., 2021, Interpretive permafrost map, Alaska Highway Corridor, Delta Junction, Alaska, to the Canada Border: Segment 2 West, Alaska Division of Geological and Geophysical Surveys, scale 1:63,360.

Table 7.6.1.
Geological mapping costs for 24 SGS that provided 1994–2019 online view/download data and 24 SGS that could not (HI and GA lack an SGS).

State	Views/DLs 1994–2019 Costs	No submission 1994–2019 Costs	
AL		6,425,561	
AK	14,770,782		
AR	3,720,135		
AZ	13,034,041		
CA	57,936,379		
CO	15,145,010		
CT		1,974,085	
DE		4,934,394	
FL	8,246,423		
IN	13,512,791		
IA		9,308,781	
ID		26,040,294	
IL	22,946,327		
KS		8,688,672	
KY	12,293,866		
LA		5,637,015	
ME	6,659,837		
MD	12,634,275		
MA		3,962,414	
MN	$37,011,168		
MI		4,396,235	
MS		8,030,667	
MO	10,934,641		
MT	10,685,861		
NE	7,171,859		
NV	13,452,556		
NH		3,391,412	
NJ	8,487,522		
NM	15,509,989		
NY		7,705,667	
NC		11,141,202	
ND		1,154,567	
OH		11,043,467	
OK		6,202,821	
OR		11,496,721	
PA		11,525,298	
RI		432,163	
SC		11,359,456	
SD	7,649,523		
TN		2,855,117	
TX	7,994,684		
UT	27,743,808		
VT	4,551,053		
VA		15,598,345	
WV	27,757,845		
WA		12,630,058	
WI		9,718,098	
WY	5,795,167		
TOTAL SGS	**365,645,542**	**195,652,510**	**561,298,052**
% of Total	**65.14%**	**34.86%**	**100%**

*Includes all Federal, state, local, and private sources

Table 7.6.2 shows that the 24 SGS that provided geological map view and/or download data accounted for 65.14% of the total SGS costs, and the 24 SGS that did not/could not provide these data provided for 34.86%. Table 7.6.2 compares Table 7.2.1 map download/sales data with extrapolated download and maps sold data from those 24 SGS that did not/could not provide online view/download or maps sold data. This table shows (1) Table 7.2.1 data; (2) Table 7.2.1 data extrapolated to include SGS only data (thereby deletes USGS data) from those 24 states; and (3) Table 7.2.1 data extrapolated to include the 24 SGS data plus USGS data. It assumes the most conservative 1994–2019 conversion rate of map views to downloads of 3.32%, and it also extrapolates map sales data. Most importantly, it assumes that the 24 SGS that did not/could not provide any online view and/or download data had a high likelihood of contributing to it overall. The result would have been an additional 2,275,768 downloads and 46,383 maps sold for a total of 7,148,106 downloads/maps sold.

Table 7.6.2.
Total map downloads/sales comparing Table 7.2.1 with extrapolated download data from 24 SGS that did not/could not provide online view/download data, or maps sold.

Views=DLs	CR DLs (3.32%)	Direct DLs	Maps sold	Totals
Table 7.2.1 data of the 24 SGS plus USGS **that provided** online views/downloads.				
802,586	**378,546**	**3,558,150**	**86,673**	**4,825,955**
Table 7.2.1 data, minus USGS data, and extrapolated to include the 24 other SGS that **did not** provide online views/downloads.				
603,238	**462,756**	**5,462,312**	**133,056**	**6,661,362**
Table 7.2.1 data extrapolated to include information from those 24 other SGS + USGS data (views=DLs and 3.32% CR DLs).				
1,012,875	**539,863**	**5,462,312**	**133,056**	**7,148,106**

7.7: DATA SYNTHESIS

For the nine SGS that provided both online and download data, conversion rates were calculated for the (1) 52 cumulative years of reported online view and download data covering the 2012 — 2022 period; (2) 33 cumulative years of reported online view and download data covering just the 2012–2019 period; and (3) 19 years of cumulative reported data for 2020–2022 (Tables 7.4.2, 7.4.3, and 7.4.4). For the entire 1994–2022 period, there were 10,137,694 online views and 476,716 downloads, yielding a conversion rate of 4.7%. Covering the 2012–2019 project period were 6,989,843 online views and 231,898 downloads, which yielded a conversion rate of 3.32%. For the 2020–2022 post-project period, there were 3,427,922 online views and 246,805 downloads that yielded a conversion rate of 7.2%.

In summary, Table 7.2.1 shows:

- 3,558,150 direct downloads of geological maps plus 802,586 online views equivalent to downloads for a total of 4,360,736. The 3.32% conversion rate estimate of 11,401,967 online views resulted in an additional 378,546 potential downloads for the 1994–2019 project period.
- The 4.7% conversion rate estimate of 11,401,967 online views resulted in an additional 535,893 potential downloads for the extended 1994–2022 period.
- 86,673 SGS maps sold (primarily paper maps that were distributed at the cost of printing or copying).
- Using the 4.7% conversion rate, covering the 1994 to 2022 period, results in 4,983,302 total maps downloaded and sold.
- Using the 3.32% conversion rate, covering the actual 1994 to 2019 project period, results in 4,825,955 total maps downloaded and sold. This number is the most conservative, and the one used for a minimum cost/benefit estimation.

In graphic form, Figures 7.4.1, 7.4.2, and 7.5.1 portray geological map online views, online downloads, and maps sold per year from the first recorded capturing of this information through 2021, the most recent year of complete SGS data. The three graphs show a noticeable uptick of national demand for geological maps beginning in 2013. This coincides with improved technological capabilities of both the SGS and the USGS providing more easily accessible geological maps, as well as the ability of the users to navigate websites and discover, view, download, and purchase the maps.

Based on this exercise, the total transactions that resulted in geological maps being directly or indirectly downloaded and sold during the 1994–2019 project period (Table 7.2.1) is very much a minimum figure for two reasons:

1. Download activity was reported by SGS primarily over the second half of the 1994–2019 project period, with full realization that map view, download, and map sold data were not available, under reported, or not reported for much of the first half of the project period.
2. Online map view, download, and map-sold data were not provided by 24 SGS for the 1994–2019 reporting period of this study.

Finally, adding to the conservative nature of this economic assessment and factored into all the above geological map web view and download numbers is consideration of the interaction of robots (bots) with web sites. Nine SGS plus the USGS accounted for some bot activity in their reported numbers. For other SGS and years when bots were not, or could not be, identified, web view and download data were reduced by an average of 44.3% to account for bot activity, and this percentage is in line with industry data. This resulted in a significant reduction of the original geological map view and download numbers provided by SGS and the USGS. The only SGS that uniformly reported bot activity was the Montana Bureau of Mines and Geology, which reported a 14% average of bot activity over the project period. This one sampling may be more indicative of reality amongst other SGS. However, this lower bot percentage could not be confirmed with other similar public entities. Therefore, to maintain a conservative approach, the industry reported higher bot rate percentages were used for this study.

7.8: ECONOMIC ESTIMATES OF COSTS AND BENEFITS

To help account for the 24 SGS that did not report any map view, download, or maps sold data, Tables 7.6.1 and 7.6.2 were developed with the assumption that they had a high likelihood of contributing to the overall download data, if they could have reported it. Online views equal to downloads (i.e., as discussed in Section 7.1 where SGS and the USGS provide users with full capability to completely view a map, zoom in and out, and navigate an online image), direct downloads, online views converted to downloads (using the 3.32% most conservative 1994–2019 conversion rate), and maps sold were calculated. The result was an additional 2,275,768 downloads and 46,383 maps sold for a total of 7,148,106 downloads/maps sold. Using the median amount that respondents expected to pay per map in responses to question 17 as the basis ($2,883), the cumulative range of values between the actual maps downloaded and sold (4,825,955 as shown in Tables 7.2.1 and 7.6.2) with the extrapolated amounts (7,148,106 as shown in Table 7.6.2) would be between $13.91 and $20.61 billion. In comparison, the cost of producing the geological maps during 1994–2019 was $1.99 billion. The value estimates thus range between 6.99 and 10.35 times the expenditure.

There has been emphasis on the download action to constitute a transaction, and that perspective provides the most conservative estimation of geological map demand. However, websites are designed such that the mere “viewing” of a geological map may provide adequate information to the user without downloading it. Table 7.2.1 shows that once the adjustment for bots was made, total views (without conversion rate adjustments) were 11,401,967, views equal to downloads were 802,586, actual downloads were 3,558,150, and there were 86,673 maps sold, for a total of 15,849,376 actual plus potential transactions. Again, using the median amount that respondents expected to pay per map in responses to question 17 as the basis ($2,883), the cumulative range of values between the actual maps viewed, downloaded, and sold (15,849,376 as shown in Table 7.2.1) with an extrapolated amount as discussed above (24,331,250) would be between $45.69 and $70.15 billion. Therefore, maximum value estimates range between 22.95 and 35.23 times the expenditure. It is safe to assume that these maximum values are not realistic. However, it is also reasonable to assume that, considering the conservative nature of this entire economic assessment, value estimates would lie somewhere between the 6.99 and 10.35 values and the higher extrapolated values of 22.95 to 35.23.

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► Table of Contents

CHAPTER 8: REGIONAL VARIATIONS IN COSTS AND BENEFITS OF GEOLOGICAL MAPPING

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ABSTRACT

This chapter examines regional variations in the economic analysis of geological maps in the U.S. through separate analyses of the stakeholder survey and historical expenditure data. Respondents to the stakeholder survey indicated that geological maps provided a positive net benefit across six designated regions of the country. Public and private sectors generally valued the maps similarly, with private stakeholders placing a slightly higher value in some regions. Responses revealed a high percentage of positive long-term value (71% to 87%) from both sectors. Additionally, the average perceived cost savings by stakeholders were estimated to range from $11,000 to $30,000, with the Intermountain West region having the highest savings and the South-Central region the lowest.

A second analysis confirmed a trend: the more complex a geological map (finer scale), the higher the expense of production. Limitations include potential under-reporting of map data and the time gap between funding allocation and map production. The estimated average map cost ranged from $42,000 to $123,000 for detailed to intermediate scale maps, with the Southeast region having the lowest costs and the Pacific Rim region the highest.

Finally, projected map costs were compared to actual documented geological map costs using two examples: (1) 2019 Illinois State Geological Survey (ISGS) large-scale costs, and (2) 2019 U.S. Geological Survey (USGS) average large-scale costs for all State Geological Surveys (SGS) that received USGS funding for mapping. The statistical data on mapping costs provided by the ISGS and USGS both align with the projected regional historical map cost analysis reported in this chapter. This consistency reinforces a general trend in map production costs. Overall, the chapter highlights the value of geological maps while acknowledging the importance of considering variations in cost related to either the region or map complexity.

8.1: INTRODUCTION

In this chapter, we recognize that geological and economic conditions in the United States show regional variations. To analyze the extent of the variability, the country was divided into six regions as shown in Figure 8.1.1.

The stakeholder survey was not intended to ask stakeholders about mapping costs. Mapping costs were instead documented by the U.S. Geological Survey (USGS) and State Geological Surveys (SGS) each year from 1994 to 2019. However, it was noticed that the wording of two of the questions in the stakeholder questionnaire, question 16 and question 17 (Appendix 2), had the potential for being interpreted as asking for mapping cost estimates. Therefore, in sections 8.2 and 8.3, the responses to question 17 were assumed to be their estimates of mapping costs and were compared to the stated benefits in response to question 10.

This chapter reviews results in four major sections. In section 8.2, the cost and benefit comparisons of both the private and public sectors are discussed for each of the six regions based on the responses to the stakeholder survey questions (Appendix 2). In section 8.3, the public and private sector data are used from the stakeholder survey to compare how responses to questions about mapping benefits vary by region, which is displayed by visual graphs and charts. In section 8.4, an approach was employed to assess the cost of mapping that differs from the methods used in other chapters of this study, as well as the first two sections of this chapter. As Chapter 4 shows, individual SGS reported their mapping expenditures incurred during 1994 to 2019 from federal, state, and other sources (Appendix 1). In section 8.4, expenditures reported by the USGS and SGS are used. In addition, data from the USGS on the number of geological maps produced annually for representative states from each of the six regions are also used to determine the average cost of producing a geological map. However, the cost per map was not compared with the benefits of maps. Lastly, in section 8.5, the true geological mapping costs from the Illinois State Geological Survey (ISGS) and the USGS were compared to the results from section 8.4.

8.2: DETERMINATION OF COSTS AND BENEFITS

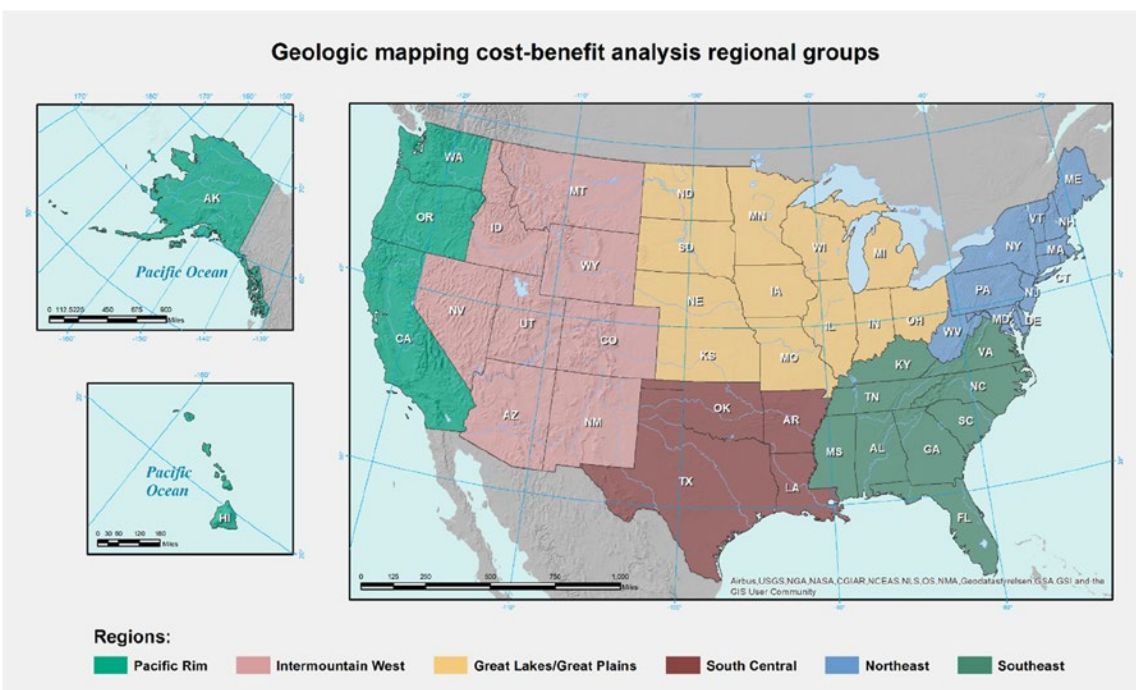
The one question posed to stakeholders that appeared closest to a benefit was question 10 that asked, "Considering that your willingness to pay (WTP) for geological maps for a project may be different from their value over a longer period, in your judgment, what would be this long-term value of those geologic maps?" Data interpreted as 'long-term value' was best for calculating a stream of dollars spread over a length of time. Using these datasets required making several significant assumptions. First, it was assumed that the values collected in the questionnaire represent a value at 'Time-Zero' or present-year dollars. There was no extra data indicating number of years of value. By assuming the data derived from the questionnaire is in present year dollars, no calculations were required for a net present value based on future years.

The cost of producing geological maps is complicated and requires making assumptions about the data that were collected for this analysis. The first assumption is that the questions and answers of the questionnaire to stakeholders should be viewed from the perspective of the respondents. The purpose of the study was to collect information and data from respondents to ascertain the costs and benefits of creating and using geological maps, respectively.

There are two questions related to costs and benefits if maps are unavailable. Question 10 deals with long-term map benefits in the estimation of stakeholders. We note that wording of questions 16 and 17 (Appendix 2) offered the possibility of being interpreted differently than intended. The intent was to elicit stakeholders to estimate the value of geological maps. The question, however, may be interpreted as asking for the cost of a geological map. The questions were worded as follows:

- Question 16 states: How do you obtain geological maps if these are not available from public or private institutions?

Figure 8.1.1



Regional grouping of states used to assess commonalities/differences regarding the costs and benefits of geological mapping.

- Question 17 relates back to question 16 and states: How much would you typically spend for a map in the above case?

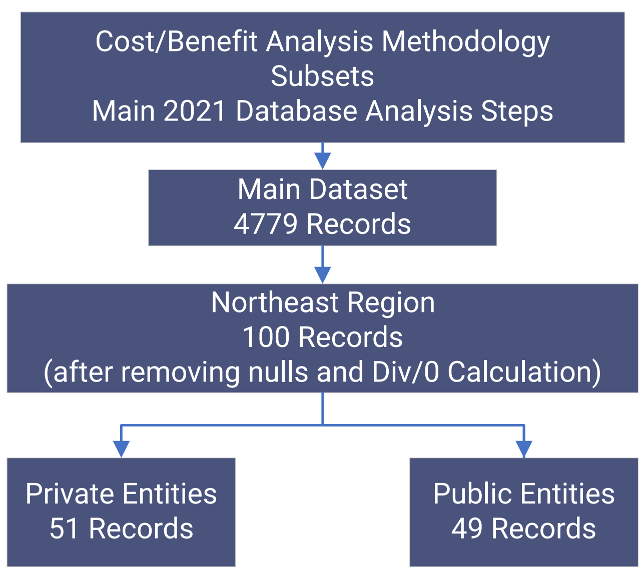
To account for the alternative interpretation, we assumed that respondents were stating their estimates of mapping costs in response to question 17. We used responses stated to be the most likely amounts. In many regions, there were several very high values reported for question 10. High values could reflect the nature of the geology that was mapped. Large-scale maps with complex geology will have greater costs of production than those maps that cover areas with simpler geology. The range of responses also indicates that respondents have a range of experience and work in widely different specialties and regions.

Questionnaire Response Analysis of Cost and Benefit Values: To accurately calculate either a cost or benefit from the current dataset of questionnaire responses, one must have a reasonable number of data points. Figure 8.2.1, for example, shows the data subsets that are created for the Northeast region, separated by geography and public/private ownership in an Access database. Data from Access databases were filtered by query to remove those records that did not have values for state, private, and public fields. The remaining regions are similarly calculated and were used to create Excel spreadsheets. These spreadsheets are located in Appendix 6.

The assumption is that the respondent's best estimates represent the cost and benefits for the purpose of calculating net benefit divided by net cost of data from the regional queries, as shown on the spreadsheets. Two new columns are added to each spreadsheet, one for cost/benefit values and one for net cost values — net benefit. Only the net-benefit analysis is presented here. The values for cost-benefit analysis are then used to analyze which projects are of higher value than other projects. Negative values are highlighted in red; positive values are in white. A spreadsheet was generated for each private/public scenario for each geographic region, and all are included in this report (Appendix 6).

Cost-Benefit Data Analysis: Table 8.2.1 shows the tabulation of net results (as gleaned from questions 10 and 17), positive or negative, by region, and by private and public groups. The net result is obtained by subtraction of each respondent's stated costs (question 17) from benefits (question 10). The

Figure 8.2.1



The total combined number of responses with cost benefit data for each industry (private and public) across the U.S. This response data was broken down regionally for analysis. Certain industries are very regionally dependent, if isolated, while other industries apply to multiple regions. This is an example from the Northeast region.

▶ Table of Contents

percentage of positive results by region and organization type was examined for any potential correlation. The only potential correlation identified was that all calculated cost-benefit values show a high percentage of positive values.

The regional net positive results (public and private) ranged from a high of 86.8% to a low of 71.4%. About 13% to 28% of respondents indicated a negative outcome (i.e., costs higher than benefits). Furthermore, only the Pacific Rim region had a higher percent positive net result value for the public sector as compared to the private sector value, albeit by a small margin. This may indicate that, overall, private respondents placed a higher value on geological maps in most regions than did public organizations. This can be correlated to the overall involvement in commercial applications or private sector versus public interest applications by public sector entities. Further analysis requires identifying in each region what types of industries may contribute to high cost-benefit values.

Table 8.2.1 indicates that 71-to-84% of respondents stated that long-term benefits (question 10) were higher than costs (question 17). Table 8.2.1 also indicates that 12 records in the report show the responses to question 10. The median response to question 10 indicated that the long-term map benefit was $10,000 per map. In other words, 71-to-84% of respondents stated that mapping costs (question 17 responses) were lower than the long-term map value.

Table 8.2.1

Overview of the Economic Analysis. The table consists of each regional sector from the questionnaire responses and the sector derivatives. This includes the total number of responses received, the number of responses that were referenced as positive values (benefits), the number of responses that were referenced as negative values (costs), the overall percentage of positive (benefit) responses, the mean cost/benefit (C/B) ratio, and trimmed mean (trim mean) C/B ratio (set to 30%). All calculations and data derived in the cost-benefit analysis are present in Appendix 6.

Region	# Records	# Positive Values (Benefits)	# Negative Values (Costs)	% Positive Values (Benefits)	Mean C/B Ratio	Trim mean (30%) C/B Ratio
Northeast Public	49	37	12	75.6	1312.56	2.68
Northeast Private	51	39	12	76.5	13154.52	23.46
Southeast Public	28	20	8	71.4	208.70	13.01
Southeast Private	36	29	7	80.6	229.80	11.74
Great Lakes/Great Plain Public	76	64	12	84.2	19596.45	7.24
Great Lakes/Great Plain Private	83	70	13	84.3	5494.74	10.02
South-Central Public	9	7	2	77.7	1125.69	18.72
South-Central Private	23	18	5	78.3	763.78	3.82
Intermountain West Public	63	48	15	76.2	265688.16	7.75
Intermountain West Private	96	77	19	80.2	210.94	7.41
Pacific Rim Public	38	33	5	86.8	289.96	21.58
Pacific Rim Private	74	62	12	83.8	807.09	9.59

*Trim mean is a variation of the mean that excludes a certain percentage (30% in this case) of extreme values from both ends of the data set. This is done to account for outliers (unusual but valid data points) that might skew the regular mean. Both the mean and trimmed mean are included in Table 8.2.1 for comparison between the mean C/B ratio values due to these differences.

8.3: VISUAL OVERVIEW OF THE REGIONAL ECONOMIC ANALYSIS OF COSTS AND BENEFITS

In this section, the regional results from the net benefits in public and private sectors are presented. As stated earlier in the introduction of this chapter, benefits are stakeholder responses to question 10 and costs are their responses to question 17. Because both responses were stated in 2020 dollars, inflation adjustment is not necessary. The total number of industry records and the represented region used in the cost-benefit analysis (Table 8.2.1) are displayed in Figure 8.3.1.

Box and whisker plots were chosen to analyze each of the six regions to help identify and display both the positive and negative results presented in the datasets of the economic analysis of costs and benefits. Additional line charts comparing the industries and the number of records for each region, for both public and private sectors, were also included with the box and whisker plots. Examples of graphs portraying box and whisker plots and the combined number of data responses for each industry are displayed in Figures 8.3.2 and 8.3.3 from the Northeast region and Figures 8.3.4 and 8.3.5 from the South-Central region, and in the other four regions as shown on Figures A7.1 through A7.12 in Appendix 7. Box and whisker plots are an effective method for graphically displaying the median, lower/upper quartiles, and lower/upper extremes of the cost-benefit datasets, thus showing the distribution and variability. Each box and whisker plot also has a corresponding diagram of the number of responses based on both the private sector and public sector from each region. A positive value for X on the box and whisker plots means that, on average, benefits are higher than mapping costs as shown on Figure 8.3.2 from the Northeast region. Negative values for X mean that mapping costs are higher than the benefits from its use as portrayed from the South-Central region on Figure 8.3.4. For the 10 box and whisker charts displayed as Figures 8.3.2, 8.3.4 and in Appendix 7, there are 20 calculations, only one of which (South-Central region) shows a negative value for X. The lowest positive value for X is about $13,000 and the highest positive value for X is about $43,000. However, as mentioned earlier, extremes are not taken into consideration in these plots due to graphical limitations, but they are still valid estimates from respondents.

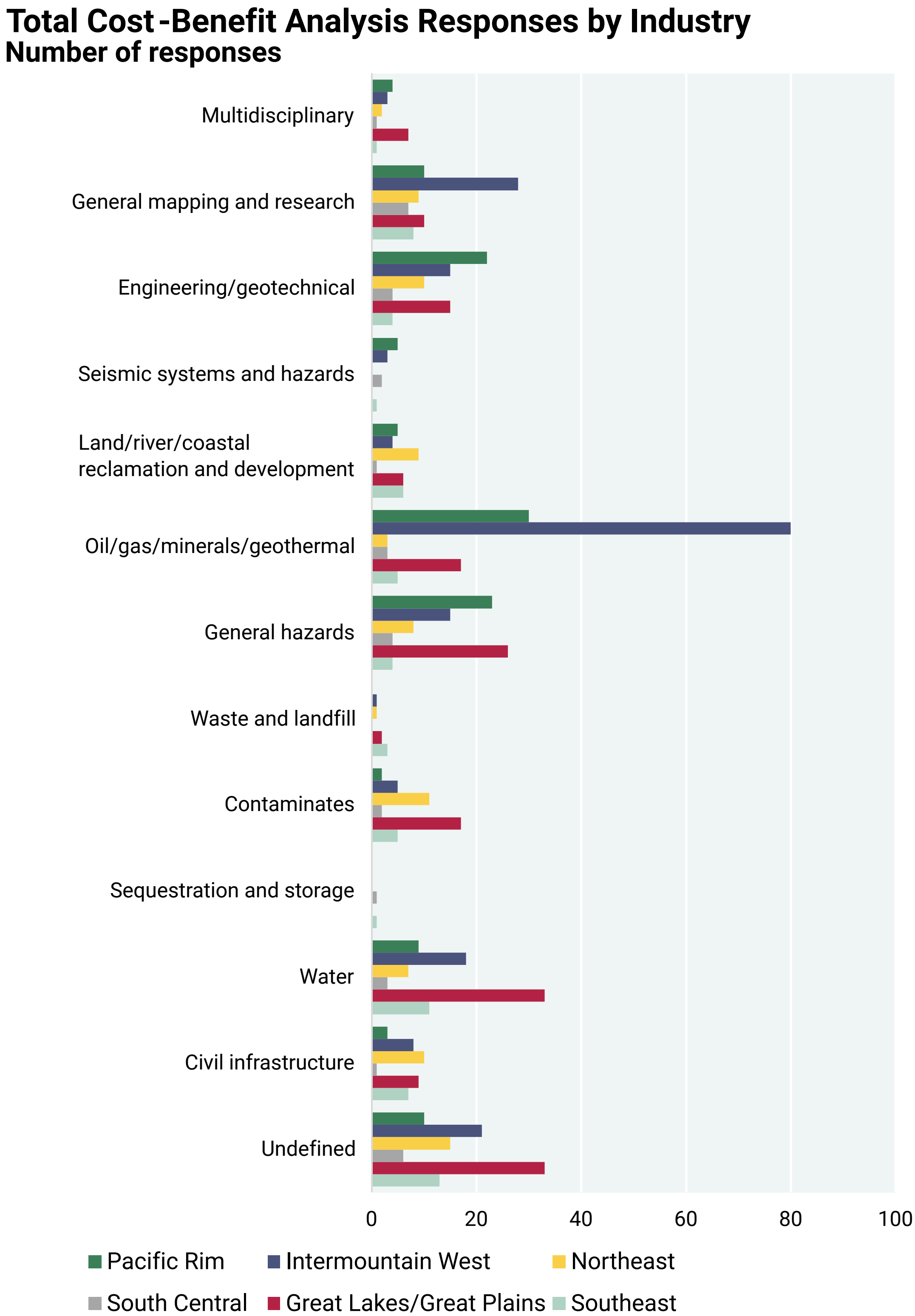
All data used in the visual overview of this section are derived from the questionnaire dataset, as discussed in section 8.2. The questionnaire and the cost-benefit analysis datasets are in Appendix 2 and Appendix 6, respectively.

The cost-benefit values are represented by the net-costs and the net-benefits. These net-costs and net-benefits, as mentioned in section 8.1, are based on questions 10, 16, and 17. Responses to both questions 16 and 17 are correlated to each other and are interpreted as 'best estimate' costs. However, question 10 responses are interpreted as determining a 'best estimate' of benefits.

The box and whisker plots derived from calculations do have limitations in that certain regions and organizations have small numbers of responses. Another limitation is the number of outliers in the dataset, as mentioned previously. To help provide a good graphical display of the regional data, each plot was set to show the upper quartile, lower quartile, the mean line, and mean marker. The quartile calculations were derived based on an inclusive median due to the variability in the datasets. All outliers were excluded from the plots. Any cost values greater than $400,000 were interpreted as extreme due to graphical limitations for this section. While these registered values are unusually high or low, they are real in the judgment of the respondents. Tables of these extreme values follow the regional box and whisker plots (Appendix 7, Tables A7.1 through A7.10). Tables 8.3.1 and 8.3.2, again from the Northeast region, serve as examples.

Breaking down the regional dataset even further, some regions had enough data for independent industries to be represented graphically (e.g., the oil/gas/mineral/geothermal industries in the Intermountain West region). However, many other industries (depending on region) did not have an adequate number of responses for values to be represented graphically (e.g., industries in the South-Central region). If adequate response data were available, graphs of industries follow the main regional graphs and tables.

Figure 8.3.1



The combined number of data responses for each industry (private and public) used in the cost-benefit analysis of the South-Central region.

NORTHEAST REGION

Table 8.3.1

Positive benefit values (question 10) from private industry sectors determined to be extremes and excluded from the box and whisker plots. The extreme values offset any visible graphics.

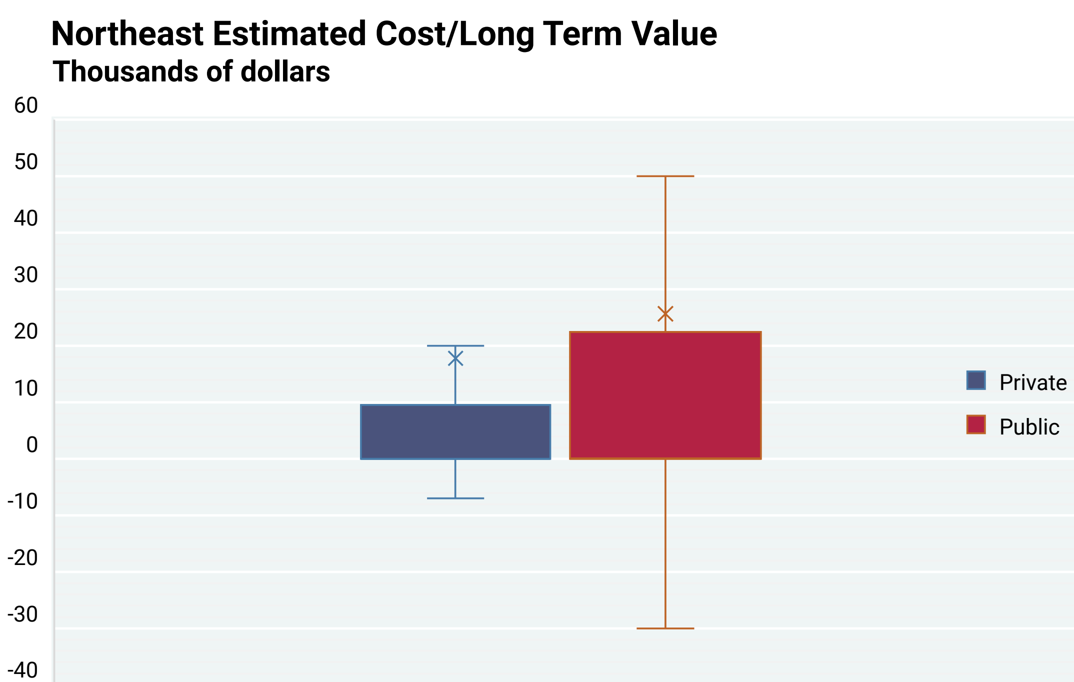
Responder ID	Northeast Private Industry	Extremes
3665	Civil infrastructure	$19,999,950
3044	Land/river/coastal reclamation and development	$480,000
618	Engineering/geotechnical	$499,900
647	Multidiscipline	$950,000
3652	Unknown	$999,500

Table 8.3.2

Positive benefit values (question 10) from public sectors determined to be extremes and excluded from the box and whisker plots. The extreme values offset any visible graphics.

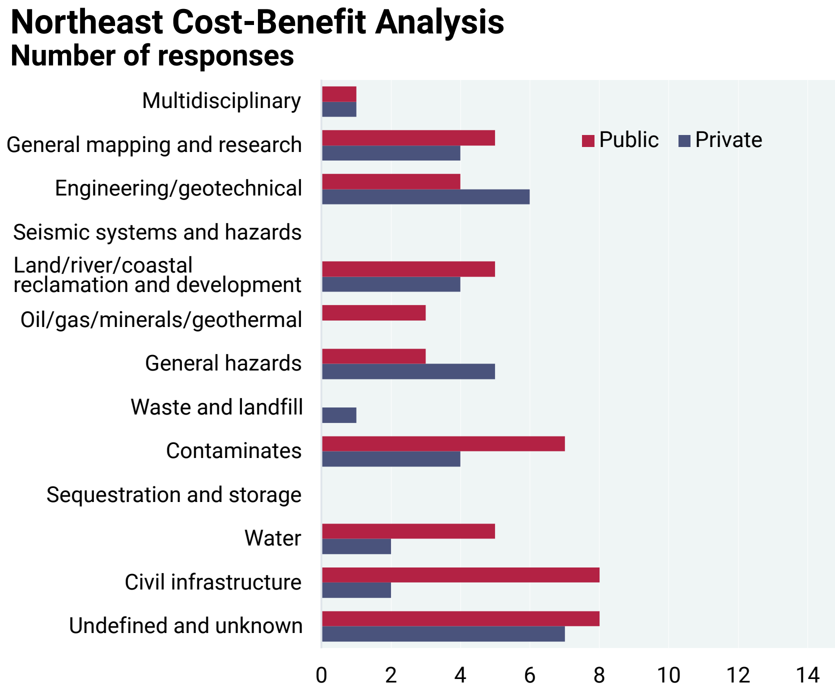
Responder ID	Northeast Public Industry	Extremes
3019	Contaminates	$799,985
4484	Land/river/coastal reclamation and development	$450,000
3124	Engineering/geotechnical	$992,500

Figure 8.3.2



Graphical display of the lower/upper quartiles, the lower/upper extremes, and the mean of the (net cost - net benefit) for both the private and public industry in the Northeast region. Positive values represent a net benefit, while negative values represent a net cost.

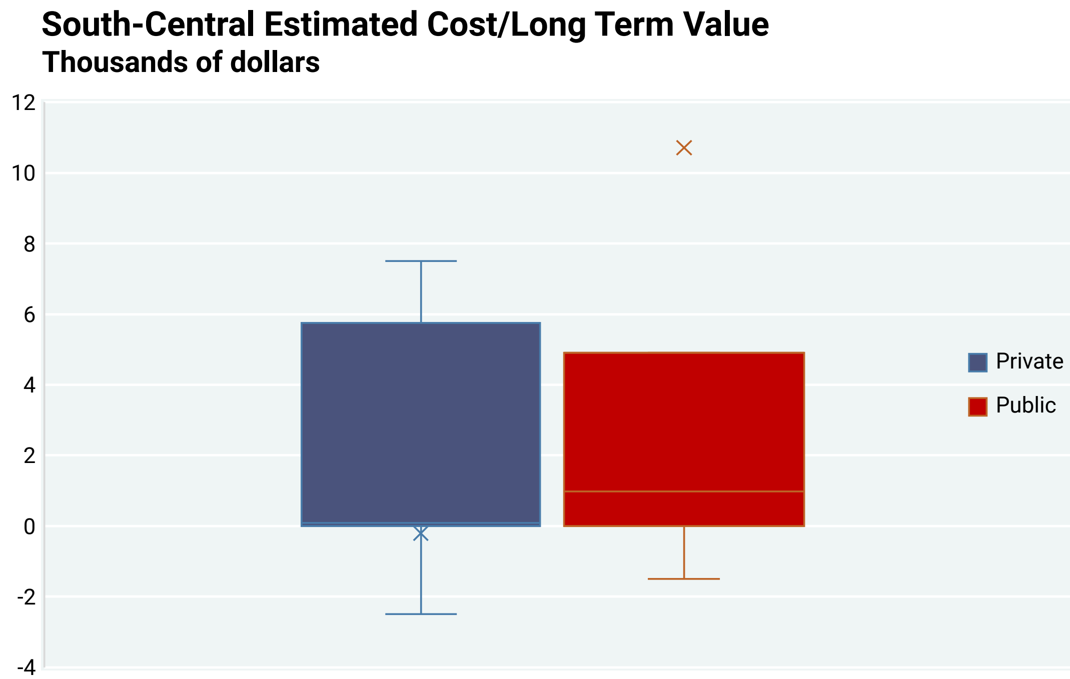
Figure 8.3.3



The combined number of data responses for each industry (private and public) used in the cost-benefit analysis of the Northeast region.

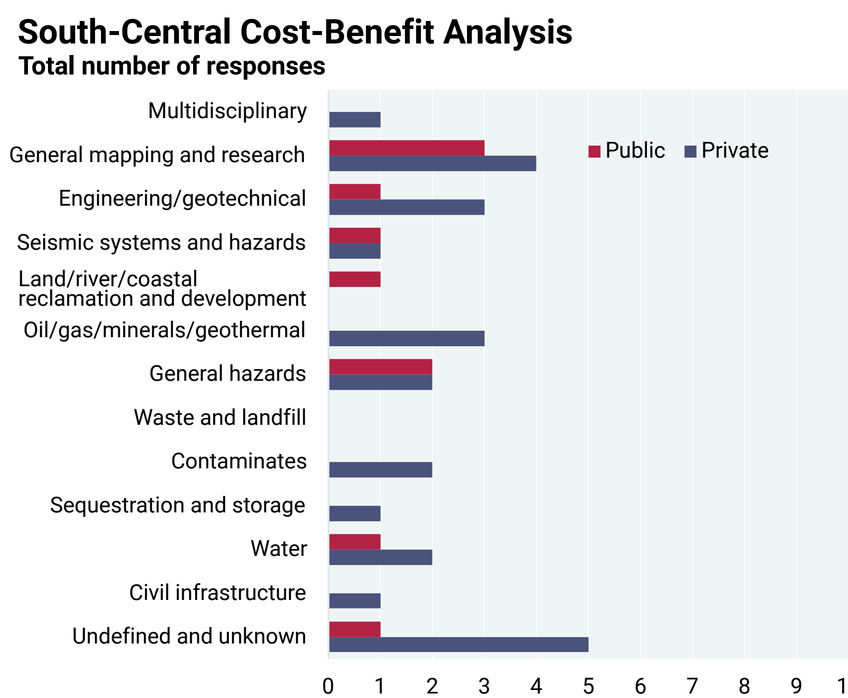
SOUTH-CENTRAL REGION

Figure 8.3.4



Graphical display of the lower/ upper quartiles, the lower/upper extremes, and the mean of the (net cost - net benefit) for both the private and public industries in the South Central region. Positive values represent a net benefit, while negative values represent a net cost.

Figure 8.3.5



The combined number of data responses for each industry (private and public) used in the cost-benefit analysis of the South-Central region.

8.4: REGIONAL HISTORICAL DATA, ANALYSIS, AND INTERPRETATIONS

The analysis in this section is based on mapping expenditure data from SGS and the USGS obtained for the study and used in previous chapters. It also uses separate data obtained specifically from the USGS for the approximate number of maps constructed annually during that same 1994 to 2019 period for six regional examples. The two datasets are used to determine the average cost per map. We do not calculate net benefits, net losses, or cost-to-benefit ratios in this section. After the discussion of the financial data in the Overview of Regional Historical Data, all state cost data and estimated map costs are adjusted to the 2020 inflation rate for the remainder of this section.

Overview of Regional Historical Data: The 1994–2019 state mapping expenditure data (abbreviated as "state cost data") from SGS and the USGS were acquired through the first questionnaire distribution (discussed in Chapter 2 "Data Acquisition — Cost Information" and documented in Appendix 6). For the analysis that this section presents, the state cost data are broken up into six regions: Northeast, Southeast, Great Lakes/Great Plains, South-Central, Intermountain West, and Pacific Rim (Figure 8.1.1). The SGS cost data is further grouped into three sections of funding per state: (1) funding provided by the federal government, (2) funding provided by state government, and (3) other funding by third parties. "Other" parties may consist of local government agencies or private industries that provided funding for geological mapping. The analysis in this section was limited to geological maps ranging in scale from 24K to 100K to account for greater geological complexities.

By regionalizing the states, this study identifies similar trends and differences with potential significant implications. Figures A7.13 through A7.24 in Appendix 7 were constructed to display the regional historical funding, based purely on the non-inflation adjusted data acquired in this study. The figures include line diagrams of the regional funding from the 1994 to 2019 period and clustered columns of total funding for geological mapping in each state within a region

However, to address inflation over the 25-year period of data acquired for this study, the state cost data were adjusted to 2020 dollars, as illustrated in Figures 8.4.1 through 8.4.12 and discussed below under the heading "National CPI Inflation Adjustment to Historical Regional Data." The cost data adjusted to 2020 dollars, based on 25 years of inflation, are used for the remainder of the analysis in this section.

The state cost data spreadsheets, however, do not have any information on the number of maps constructed during the 1994 to 2019 period. To contextualize the valuations of the state cost data, map information for specific state examples from each region was gathered through a separate inquiry, with assistance of representatives from the USGS National Geologic Map Database (NGMDB) and the NGMDB MapView interface, as discussed further in "Extraction of Map Estimates from the USGS National Geologic Map Database."

Box and whisker plots were then created to display estimated costs per map, based on the 2020 inflation adjusted state cost data and the map numbers gathered from the NGMDB MapView for the regional examples. The box and whisker plots were plotted with an (X) symbol representing the mean marker, a mean line, as well as outliers represented by dots with their independent estimated cost values. Along with the box and whisker plots, additional line graphs and clustered columns are referenced to specific state cost data, which are further discussed in the section "Six Regional Map Cost Examples Adjusted to 2020 Inflation Rate." Figures 8.4.13 through 8.4.16 from Tennessee serve as examples of the projected map cost box, whisker plots, and the line graphs. The other five regions are included in Appendix 7 as Figures A7.25 through A7.44. The adjusted state cost data and estimated map costs for each regional example are displayed in Tables 8.4.1 through 8.4.6.

National CPI Inflation Adjustment to Historical Regional Data: To address the need to account for the value of the U.S. dollar over time, the 2020 national consumer price index (CPI) inflation adjustment that was used in previous Chapters was also applied to the regional analysis in this section. The Bureau of Labor Statistics (BLS) provides all the U.S. national CPI data online, which were used to determine the 2020 inflation adjustment. Figures 8.4.1 through 8.4.12, as well as Figures A7.25 through A7.44 in Appendix 7 are comparisons of historical funding with inflation adjusted funding for each of the six regions through line graphs, bar charts, and box and whisker plots.

Missing Information and Questions: The state expenditure Excel spreadsheet for geological mapping from SGS and the USGS is very significant; however, it leaves out important information about the number of maps produced. The SGS and the USGS did not provide any information on the number of geological maps published or produced each year throughout the 1994 to 2019 study period. The lack of such data raises two important questions:

Question 1: How many geological maps were constructed per year per region?

Question 2: What is the average cost of a geological map, based on regional data?

Although these two questions seem relatively simple, obtaining discrete answers was challenging. A solution to question 1 was addressed by gathering map information for regional examples, with assistance from NGMDB representatives of the USGS, using the NGMDB's MapView interface. For a solution to question 2, the map data (number of maps) gathered using the NGMDB MapView interface were integrated with the state financial data to estimate the cost for producing geological maps. Estimated costs are displayed using box and whisker plots, line diagrams, and bar charts as shown on Figures 8.4.13 through 8.4.16 as well as A7.25 through A7.44 in Appendix 7. However, some assumptions had to be made, and the numerical estimates vary due to the range of data. Nonetheless, even considering that all SGS have not provided all their geological maps for inclusion in the NGMDB, a trend is apparent showing that an increase in the complexity of a geological map (or the finer the scale of a geological map) produced results in a higher production cost.

Extraction of Map Estimates from the USGS National Geologic Map Database: In 1992, the U.S. Government authorized the National Geologic Mapping Act, which created the National Cooperative Geologic Mapping Program (NCGMP), as described in Chapter 1. This program was created to fund geological mapping across the entire country and to address the construction of the NGMDB to serve as a national catalog and archive of geological maps and related information for the U.S. The USGS administers both the NCGMP and NGMDB in collaboration with SGS. The NGMDB Catalog contains citations for greater than 110,000 geoscience publications addressing a wide range of topics and themes, such as natural resources and geologic hazards. Because of the complex nature, format, and layout of geoscience publications, which are available from more than 600 publishers cataloged in the NGMDB, it is not straightforward to directly query the NGMDB Catalog to confidently identify all publications that contain geological maps. To address this concern, a related NGMDB resource was accessed, the "MapView" interface, which provides access to the subset of publications in the NGMDB Catalog that have been visually inspected and determined to include high-quality geological maps. As mentioned previously, the statistics presented herein for the number of geological maps published by each agency are, therefore, somewhat conservative.

Projections of Map Estimates to Provide Estimated Map Cost: After discussions with USGS NGMDB representatives, the following data were provided for this regional analysis. These data consist of the estimated number of maps for specific SGS examples within each of the six regions that were published within the 1994–2019 timespan. This is based on the conservative representation derived from the MapView interface. All of the financial data acquired for section 8.4 were through SGS and the USGS cost sheet datasets on the total funding provided for geological mapping, as discussed in Chapter 4 (see also Appendix 1). The simplest method of projecting the cost range of geological maps was by tallying the total funding of a region and dividing it by the estimated number of maps produced for each region, demonstrated below in Equation 8.4.1.

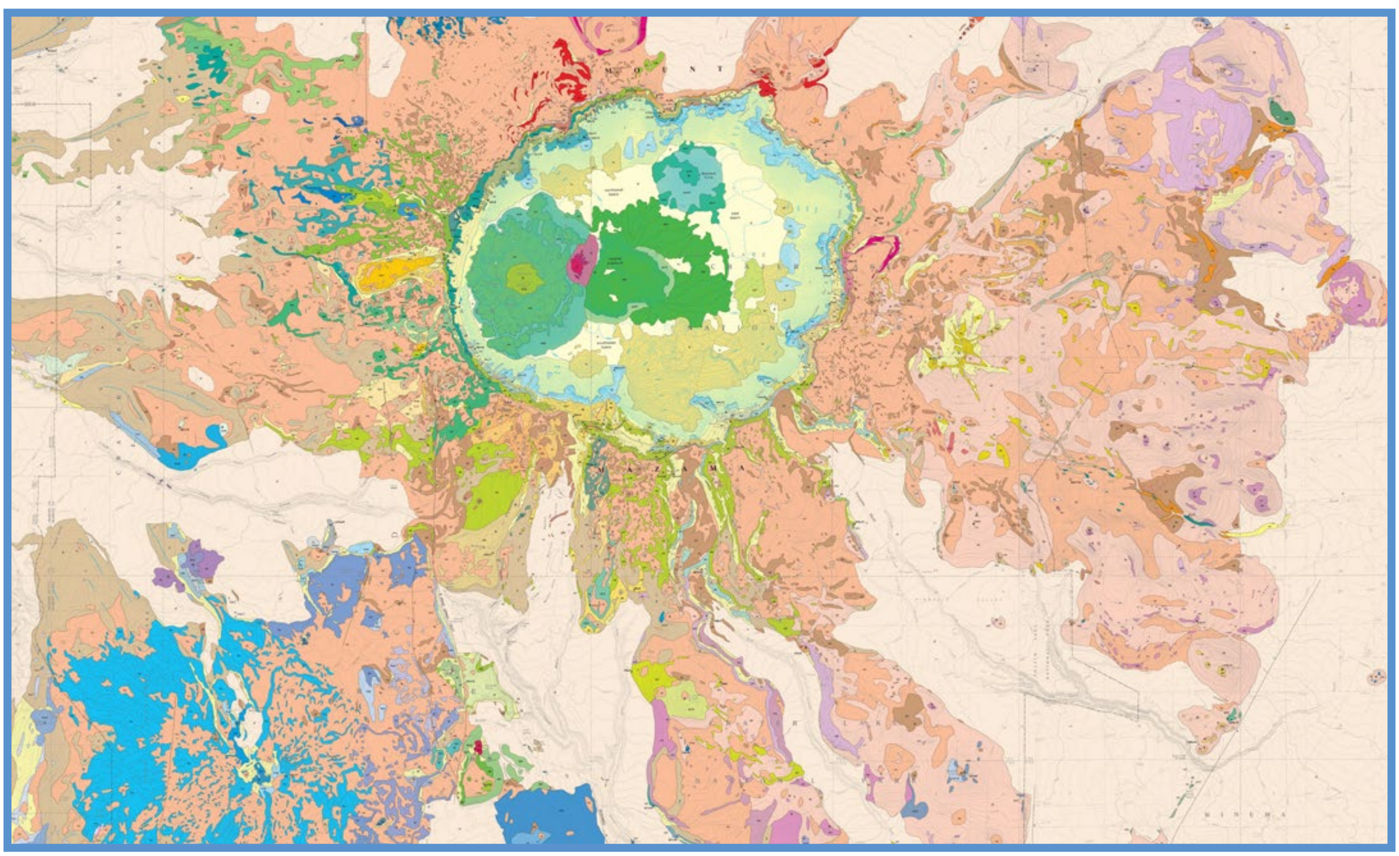
$$\text{Equation 8.4.1 Projected Map Cost} = \frac{\text{Total Funding}}{\text{Number of Maps}}$$

Due to under-reporting of the number of geological maps, changes in funding per year, changes in funding sources, and differences between states (e.g., size, population, bedrock vs. surficial geology and its associated complexity), analyses of each SGS could not be addressed. In addition, the NGMDB is continuously updated with new geological maps replacing older versions across all regions of the U.S. Therefore, for each of the six regions of the U.S., one state with adequate completeness of data was selected to serve as a representative example for that region.

The completeness of the provided data from these regional state examples has allowed for independent estimates of projected map costs for each year between 1994 through 2019. One caveat that should be addressed is the delay between when an SGS was awarded funding from the federal government and the time for that map to be produced. For the SGS, the time between the funding award and the map production was generally between one to two years. For each regional example, the data are provided below, as well as three separate box and whisker plots. The examples consist of Maine for the Northeast region, Tennessee for the Southeast region, Illinois for the Great Lakes/Great Plains region, Arkansas for the South-Central region, Utah for the Intermountain West region, and Washington for the Pacific Rim region.

Tables 8.4.1 through 8.4.6 document funding received each year over the number of maps produced each year. Both a one-year and a two-year gap was recognized between the time that funding was awarded and when geological maps were produced. To compensate for the time gap, additional data were included: the 1993 awarded funding, and the number of maps published in 2020 and 2021. It should be mentioned that there is most likely an additional time gap between when the Federal Act began to when the funding was distributed for its purpose. The 2-year gap diagram likely provides the most accurate and realistic projection of map costs, though this is open to interpretation. In the box and whisker diagrams showing Tennessee as an example (Figures 8.4.15 and 8.4.16) and in Figures A7.27, A7.28, A7.31, A7.32 A7.35, A7.36, A7.39, A7.40, A7.43, and A7.44 in Appendix 7, the 'X' represents the median value, while the middle line of each box indicates the mean. All of the regional examples were adjusted to the 2020 national inflation rate. Lastly, it is important to also note that while certain map costs are categorized and graphed as outliers due to the cost extremities, specialized maps may have unusually high costs that are outside the norms.

With increasing prices of goods, products, and costs, as exemplified by the annual CPI, the costs of producing any geological map will also increase. However, funding provided for geological mapping by both federal and state governments has not always been able to meet the increasing inflation nor the growing needs for geological maps by the public and by private industries.



Portion of: Bacon, C.R., Ramsey, D.W., and Dutton, D.R., 2008, Geologic map of Mount Mazama and Crater Lake caldera, Oregon, USGS Scientific Investigations Map SIM-2832, scale 1:24,000.

► Table of Contents

NORTHEAST REGIONAL EXAMPLE

Table 8.4.1

Estimated map cost of Maine of the Northeast region of the U.S. These data include the total funding provided from the NCGMP for the state, the number of maps published each year, and three estimated map costs based on no gap, one-year gap, and two-year gap between when the funds were awarded and the time a map was published. The total funding incorporates the 2020 national inflation adjustment.

Projected Map Cost of Maine after Inflation Adjustment					
Funding Year	Adjusted Funding	Maps Published	No Gap	1-Year Gap	2-Year Gap
1993	$31,697.08	No Data	$-	$31,697.08	$31,697.08
1994	$117,978.16	1	$117,978.16	$117,978.16	$9,831.51
1995	$150,353.89	1	$150,353.89	$12,529.49	$10,023.59
1996	$163,773.72	12	$13,647.81	$10,918.25	$163,773.72
1997	$81,420.72	15	$5,428.05	$81,420.72	$2,714.02
1998	$133,945.78	1	$133,945.78	$4,464.86	$133,945.78
1999	$164,872.51	30	$5,495.75	$164,872.51	$41,218.13
2000	$207,748.50	1	$207,748.50	$51,937.13	$34,624.75
2001	$213,032.03	4	$53,258.01	$35,505.34	$16,387.08
2002	$262,203.07	6	$43,700.51	$20,169.47	$52,440.61
2003	$294,328.27	13	$22,640.64	$58,865.65	$98,109.42
2004	$395,834.76	5	$79,166.95	$131,944.92	$197,917.38
2005	$209,030.30	3	$69,676.77	$104,515.15	$23,225.59
2006	$222,263.70	2	$111,131.85	$24,695.97	$10,102.90
2007	$333,981.93	9	$37,109.10	$15,181.00	$25,690.92
2008	$341,412.20	22	$15,518.74	$26,262.48	$24,386.59
2009	$346,618.07	13	$26,662.93	$24,758.43	$21,663.63
2010	$363,022.96	14	$25,930.21	$22,688.93	$15,783.61
2011	$326,264.82	16	$20,391.55	$14,185.43	$29,660.44
2012	$242,909.92	23	$10,561.30	$22,082.72	$12,784.73
2013	$358,587.81	11	$32,598.89	$18,873.04	$39,843.09
2014	$190,195.92	19	$10,010.31	$21,132.88	$9,056.95
2015	$237,950.42	9	$26,438.94	$11,330.97	$59,487.60
2016	$268,620.23	21	$12,791.44	$67,155.06	$22,385.02
2017	$282,953.61	4	$70,738.40	$23,579.47	$31,439.29
2018	$312,575.11	12	$26,047.93	$34,730.57	$20,838.34
2019	$358,222.75	9	$39,802.53	$23,881.52	$51,174.68
2020	No Data	15	No Data		
2021		7			

SOUTHEAST REGIONAL EXAMPLE

Table 8.4.2

Estimated map cost of Tennessee of the Southeast region of the U.S. These data include the total funding provided from the NCGMP for the state, the number of maps published each year, and three estimated map costs based on no gap, one-year gap, and two-year gap between when the funds were awarded and the time a map was published. The markings of #DIV/0! only represent that a solution for the data cannot be divided by "zero." The zero represents no maps being published that year. The total incorporated the 2020 national inflation adjustment.

Projected Map Cost of Tennessee after Inflation Adjustment

Funding Year	Adjusted Funding	Maps Published	No Gap	1-Year Gap	2-Year Gap
1993	$-	No Data	$-	$-	$-
1994	$51,549.21	1	$51,549.21	$51,549.21	$17,183.07
1995	$41,611.16	1	$41,611.16	$13,870.39	$41,611.16
1996	$37,839.75	3	$12,613.25	$37,839.75	$18,919.87
1997	$-	1	$-	$-	#DIV/0!
1998	$50,072.05	2	$25,036.02	#DIV/0!	$50,072.05
1999	$51,766.03	0	#DIV/0!	$51,766.03	$25,883.01
2000	$83,674.76	1	$83,674.76	$41,837.38	$27,891.59
2001	$148,015.04	2	$74,007.52	$49,338.35	$148,015.04
2002	$109,326.55	3	$36,442.18	$109,326.55	$54,663.28
2003	$112,189.06	1	$112,189.06	$56,094.53	$112,189.06
2004	$88,038.45	2	$44,019.22	$88,038.45	$44,019.22
2005	$26,134.16	1	$26,134.16	$13,067.08	$6,533.54
2006	$129,266.74	2	$64,633.37	$32,316.68	$32,316.68
2007	$132,757.37	4	$33,189.34	$33,189.34	$44,252.46
2008	$111,212.64	4	$27,803.16	$37,070.88	$22,242.53
2009	$167,533.00	3	$55,844.33	$33,506.60	$33,506.60
2010	$98,635.34	5	$19,727.07	$19,727.07	$32,878.45
2011	$143,857.55	5	$28,771.51	$47,952.52	$20,551.08
2012	$124,380.76	3	$41,460.25	$17,768.68	$41,460.25
2013	$149,156.42	7	$21,308.06	$49,718.81	$29,831.28
2014	$144,674.18	3	$48,224.73	$28,934.84	$36,168.55
2015	$164,595.44	5	$32,919.09	$41,148.86	$82,297.72
2016	$156,978.13	4	$39,244.53	$78,489.07	$31,395.63
2017	$165,512.22	2	$82,756.11	$33,102.44	$55,170.74
2018	$156,873.75	5	$31,374.75	$52,291.25	$26,145.62
2019	$161,326.34	3	$53,775.45	$26,887.72	$80,663.17
2020	No Data	6	No Data		
2021		2			

GREAT LAKES/GREAT PLAINS REGIONAL EXAMPLE

Table 8.4.3

Estimated map cost of Illinois of the Great Lakes/Great Plains region of the U.S. These data include the total funding provided from the NCGMP for the state, the number of maps published each year, and three estimated map costs based on no gap, one-year gap, and two-year gap between when the funds were awarded and the time a map was published. The total funding incorporates the 2020 national inflation adjustment.

Projected Map Cost of Illinois After Inflation					
Funding Year	**Adjusted Funding**	**Maps Published**	**No Gap**	**1-Year Gap**	**2-Year Gap**
1993	$567,109.93	No Data	$-	$283,554.97	$283,554.97
1994	$535,037.49	2	$267,518.75	$267,518.75	$267,518.75
1995	$320,946.74	2	$160,473.37	$160,473.37	$53,491.12
1996	$581,679.68	2	$290,839.84	$96,946.61	$290,839.84
1997	$490,190.17	6	$81,698.36	$245,095.09	$81,698.36
1998	$1,209,295.30	2	$604,647.65	$201,549.22	$172,756.47
1999	$432,812.63	6	$72,135.44	$61,830.38	$61,830.38
2000	$626,671.27	7	$89,524.47	$89,524.47	$56,970.12
2001	$681,710.82	7	$97,387.26	$61,973.71	$227,236.94
2002	$772,930.17	11	$70,266.38	$257,643.39	$51,528.68
2003	$905,039.65	3	$301,679.88	$60,335.98	$56,564.98
2004	$971,218.14	15	$64,747.88	$60,701.13	$194,243.63
2005	$928,181.42	16	$58,011.34	$185,636.28	$37,127.26
2006	$970,676.99	5	$194,135.40	$38,827.08	$60,667.31
2007	$883,129.55	25	$35,325.18	$55,195.60	$88,312.96
2008	$756,598.99	16	$47,287.44	$75,659.90	$42,033.28
2009	$803,565.38	10	$80,356.54	$44,642.52	$100,445.67
2010	$834,932.98	18	$46,385.17	$104,366.62	$75,903.00
2011	$695,167.32	8	$86,895.92	$63,197.03	$53,474.41
2012	$550,519.85	11	$50,047.26	$42,347.68	$68,814.98
2013	$712,278.21	13	$54,790.63	$89,034.78	$89,034.78
2014	$673,761.43	8	$84,220.18	$84,220.18	$112,293.57
2015	$577,015.65	8	$72,126.96	$96,169.27	$72,126.96
2016	$592,260.43	6	$98,710.07	$74,032.55	$84,608.63
2017	$691,577.17	8	$86,447.15	$98,796.74	$76,841.91
2018	$579,857.09	7	$82,836.73	$64,428.57	$72,482.14
2019	$650,488.25	9	$72,276.47	$81,311.03	#DIV/0!
2020	No Data	8	No Data		
2021		0			

SOUTH-CENTRAL REGIONAL EXAMPLE

Table 8.4.4

Estimated map cost of Arkansas of the South-Central region of the U.S. These data include the total funding provided from the NCGMP for the state, the number of maps published each year, and three estimated map costs based on no gap, one-year gap, and two-year gap between when the funds were awarded and the time a map was published. The markings of #DIV/0! only represent that a solution for the data cannot be divided by "zero." The zero represents no maps published that year. The total funding incorporated the 2020 national inflation adjustment.

Projected Map Cost of Arkansas After Inflation					
Funding Year	Adjusted Funding	Maps Published	No Gap	1-Year Gap	2-Year Gap
1993	$-	No Data	$-	$-	$-
1994	$-	6	$-	$-	#DIV/0!
1995	$98,432.68	2	$49,216.34	#DIV/0!	$24,608.17
1996	$37,290.99	0	#DIV/0!	$9,322.75	$7,458.20
1997	$134,097.08	4	$33,524.27	$26,819.42	$22,349.51
1998	$127,862.10	5	$25,572.42	$21,310.35	$11,623.83
1999	$117,624.66	6	$19,604.11	$10,693.15	$10,693.15
2000	$119,563.83	11	$10,869.44	$10,869.44	$13,284.87
2001	$133,422.22	11	$12,129.29	$14,824.69	$10,263.25
2002	$147,425.85	9	$16,380.65	$11,340.45	$14,742.59
2003	$138,308.07	13	$10,639.08	$13,830.81	$34,577.02
2004	$175,436.83	10	$17,543.68	$43,859.21	$12,531.20
2005	$167,056.89	4	$41,764.22	$11,932.63	$7,593.49
2006	$222,492.96	14	$15,892.35	$10,113.32	$13,905.81
2007	$182,298.78	22	$8,286.31	$11,393.67	$20,255.42
2008	$249,506.40	16	$15,594.15	$27,722.93	$62,376.60
2009	$155,137.24	9	$17,237.47	$38,784.31	$25,856.21
2010	$161,695.70	4	$40,423.93	$26,949.28	$40,423.93
2011	$166,316.24	6	$27,719.37	$41,579.06	$83,158.12
2012	$152,961.07	4	$38,240.27	$76,480.53	$76,480.53
2013	$134,152.83	2	$67,076.41	$67,076.41	$44,717.61
2014	$158,127.86	2	$79,063.93	$52,709.29	$158,127.86
2015	$124,142.86	3	$41,380.95	$124,142.86	$62,071.43
2016	$125,081.36	1	$125,081.36	$62,540.68	$62,540.68
2017	$149,641.40	2	$74,820.70	$74,820.70	$74,820.70
2018	$146,471.83	2	$73,235.92	$73,235.92	$146,471.83
2019	$132,523.33	2	$66,261.66	$132,523.33	$132,523.33
2020	No Data	1	No Data		
2021		1			

INTERMOUNTAIN WEST REGIONAL EXAMPLE

Table 8.4.5

Estimated map cost of Utah of the Intermountain West region of the U.S. These data include the total funding provided from the NCGMP for the state, the number of maps published each year, and three estimated map costs based on no gap, one-year gap, and two-year gap between when the funds were awarded and the time a map was published. The total funding incorporates the 2020 national inflation adjustment.

Projected Map Cost of Utah After Inflation					
Funding Year	Adjusted Funding	Maps Published	No Gap	1-Year Gap	2-Year Gap
1993	$112,882.49	No Data	$-	$4,907.93	$10,262.04
1994	$507,171.11	23	$22,050.92	$46,106.46	$56,352.35
1995	$471,819.41	11	$42,892.67	$52,424.38	$21,446.34
1996	$744,956.90	9	$82,772.99	$33,861.68	$372,478.45
1997	$904,328.63	22	$41,105.85	$452,164.32	$113,041.08
1998	$907,171.70	2	$453,585.85	$113,396.46	$100,796.86
1999	$875,943.36	8	$109,492.92	$97,327.04	$87,594.34
2000	$788,172.31	9	$87,574.70	$78,817.23	$34,268.36
2001	$879,121.97	10	$87,912.20	$38,222.69	$73,260.16
2002	$1,024,804.53	23	$44,556.72	$85,400.38	$64,050.28
2003	$1,190,805.15	12	$99,233.76	$74,425.32	$74,425.32
2004	$1,108,309.80	16	$69,269.36	$69,269.36	$79,164.99
2005	$961,883.07	16	$60,117.69	$68,705.93	$50,625.42
2006	$884,885.03	14	$63,206.07	$46,572.90	$46,572.90
2007	$962,882.50	19	$50,678.03	$50,678.03	$43,767.39
2008	$951,300.97	19	$50,068.47	$43,240.95	$52,850.05
2009	$1,082,128.59	22	$49,187.66	$60,118.26	$135,266.07
2010	$1,057,214.82	18	$58,734.16	$132,151.85	$81,324.22
2011	$1,250,286.54	8	$156,285.82	$96,175.89	$73,546.27
2012	$1,756,779.62	13	$135,136.89	$103,339.98	$195,197.74
2013	$1,557,477.20	17	$91,616.31	$173,053.02	$155,747.72
2014	$1,368,284.32	9	$152,031.59	$136,828.43	$105,252.64
2015	$1,485,669.85	10	$148,566.99	$114,282.30	$135,060.90
2016	$1,423,378.45	13	$109,490.65	$129,398.04	$79,076.58
2017	$1,401,808.17	11	$127,437.11	$77,878.23	$82,459.30
2018	$1,654,499.35	18	$91,916.63	$97,323.49	$330,899.87
2019	$1,398,770.02	17	$82,280.59	$279,754.00	$233,128.34
2020	No Data	5	No Data		
2021		6			

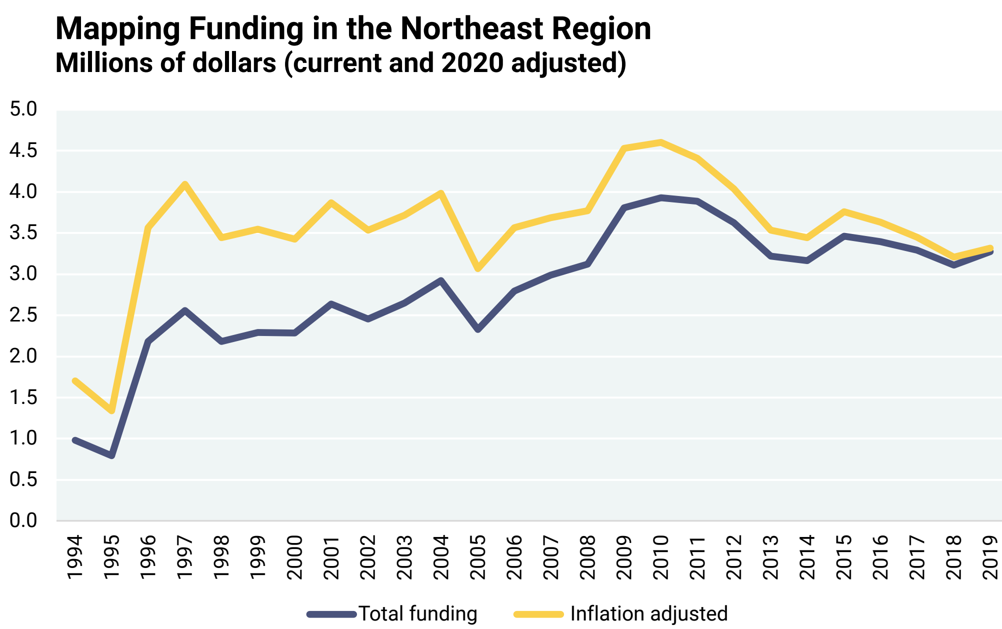
PACIFIC RIM REGIONAL EXAMPLE

Table 8.4.6

Estimated map cost of Washington of the Pacific Rim region of the U.S. These data include the total funding provided from the NCGMP for the state, the number of maps published each year, and three estimated map costs based on no gap, one-year gap, and two-year gap between when the funds were awarded and the time a map was published. The markings of #DIV/0! only represent that a solution for the data cannot be divided by "zero." The zero represents no maps published that year. The total incorporated the 2020 national inflation adjustment.

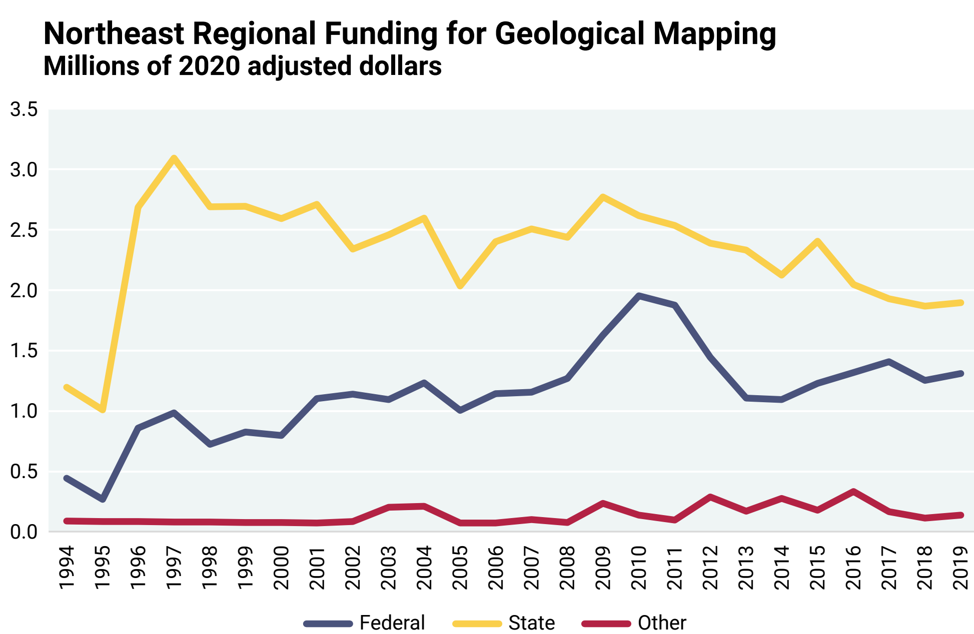
Projected Map Cost of Washington After Inflation					
Funding Year	Adjusted Funding	Maps Published	No Gap	1-Year Gap	2-Year Gap
1993	$94,068.74	No Data	$-	$13,438.39	$94,068.74
1994	$110,316.98	7	$15,759.57	$110,316.98	$55,158.49
1995	$107,514.14	1	$107,514.14	$53,757.07	$21,502.83
1996	$420,585.89	2	$210,292.94	$84,117.18	$140,195.30
1997	$492,000.97	5	$98,400.19	$164,000.32	$123,000.24
1998	$481,343.06	3	$160,447.69	$120,335.76	$120,335.76
1999	$458,890.83	4	$114,722.71	$114,722.71	#DIV/0!
2000	$396,676.88	4	$99,169.22	#DIV/0!	$79,335.38
2001	$394,099.61	0	#DIV/0!	$78,819.92	$24,631.23
2002	$509,032.67	5	$101,806.53	$31,814.54	$50,903.27
2003	$636,761.33	16	$39,797.58	$63,676.13	$70,751.26
2004	$784,625.03	10	$78,462.50	$87,180.56	$196,156.26
2005	$797,153.63	9	$88,572.63	$199,288.41	$265,717.88
2006	$595,019.03	4	$148,754.76	$198,339.68	#DIV/0!
2007	$591,392.64	3	$197,130.88	#DIV/0!	$49,282.72
2008	$545,305.27	0	#DIV/0!	$45,442.11	$136,326.32
2009	$536,339.91	12	$44,694.99	$134,084.98	$268,169.95
2010	$568,671.39	4	$142,167.85	$284,335.70	$113,734.28
2011	$583,179.85	2	$291,589.92	$116,635.97	$194,393.28
2012	$504,566.30	5	$100,913.26	$168,188.77	$126,141.57
2013	$526,517.26	3	$175,505.75	$131,629.31	$175,505.75
2014	$415,133.80	4	$103,783.45	$138,377.93	$138,377.93
2015	$400,281.70	3	$133,427.23	$133,427.23	$200,140.85
2016	$406,577.94	3	$135,525.98	$203,288.97	$203,288.97
2017	$502,541.74	2	$251,270.87	$251,270.87	$251,270.87
2018	$502,897.43	2	$251,448.71	$251,448.71	$125,724.36
2019	$757,454.17	2	$378,727.09	$189,363.54	$189,363.54
2020	No Data	4	No Data		
2021		4			

Figure 8.4.1



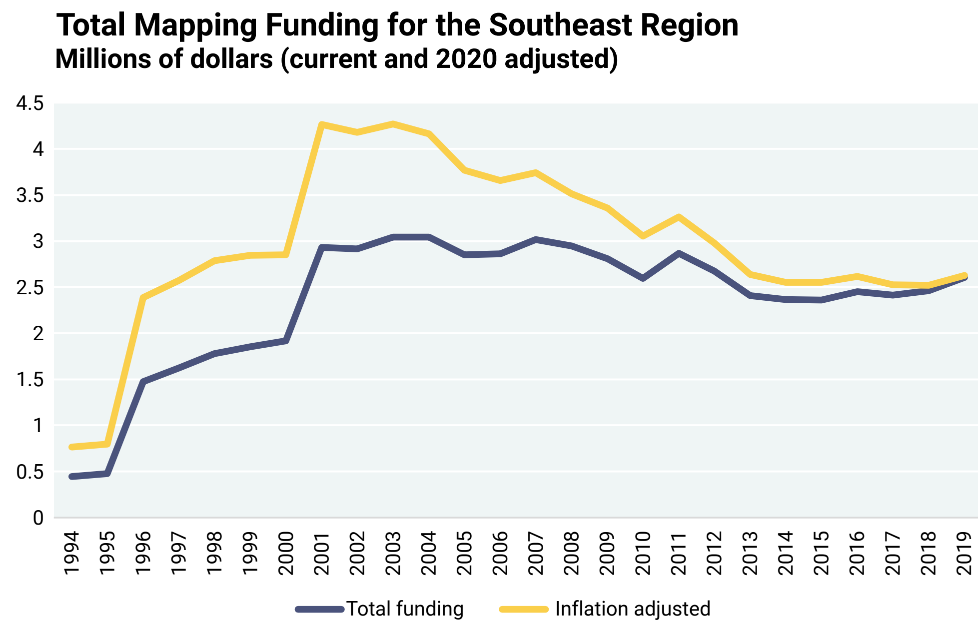
Comparison of both the 1994-2019 total map funding and the 2020 inflation adjustment of the Northeast region..

Figure 8.4.2



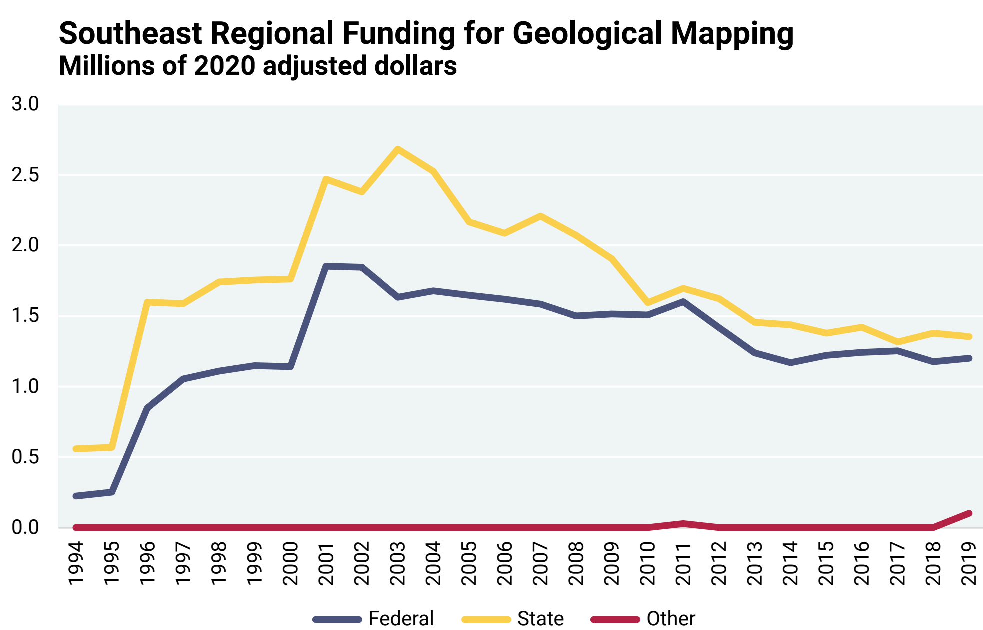
Total funding provided by federal, state, and other entities to Northeast region with the 2020 inflation adjustment.

Figure 8.4.3



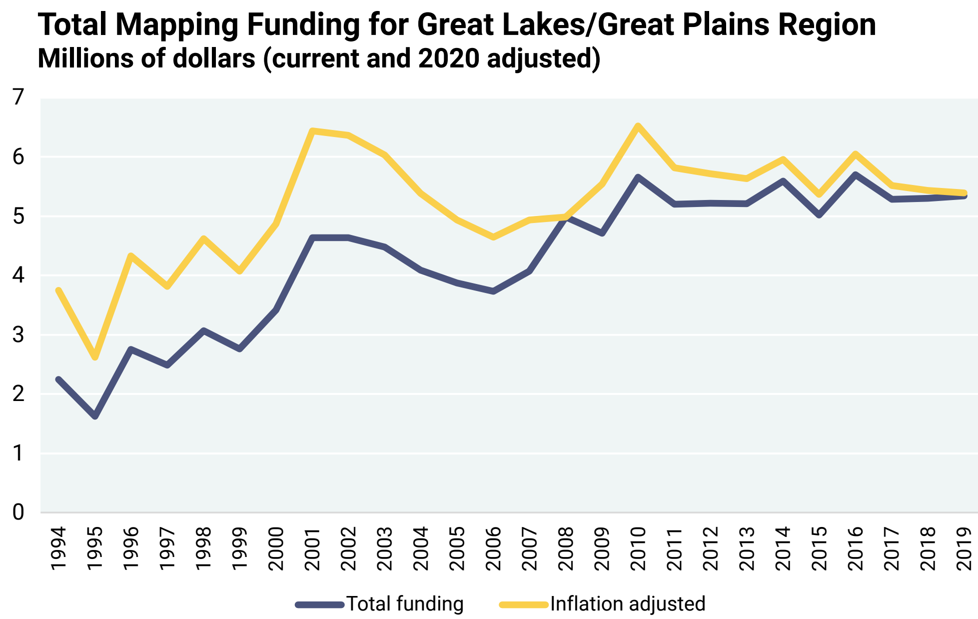
Comparison of both the 1994 - 2019 total map funding and the 2020 inflation adjustment of the Southeast region.

Figure 8.4.4



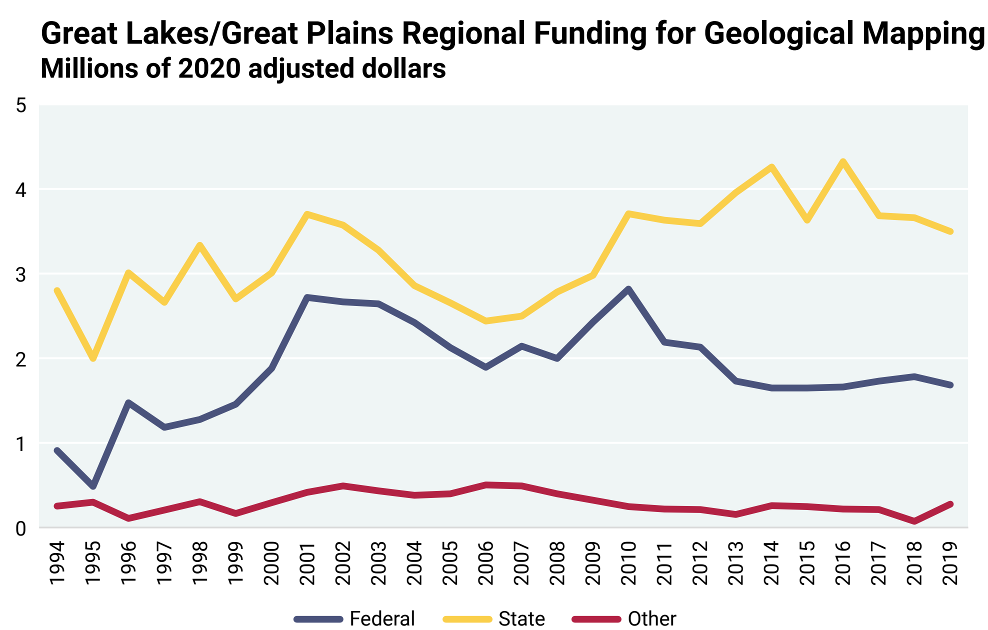
Total funding provided by federal, state, and other entities to Southeast region with the 2020 inflation adjustment.

Figure 8.4.5



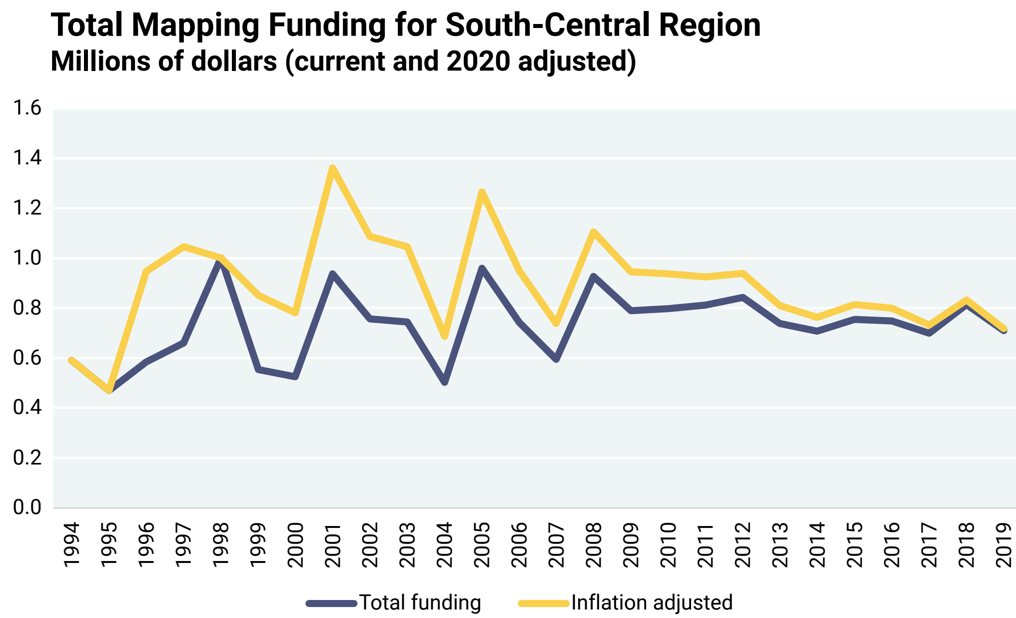
Comparison of both the 1994 - 2019 total map funding and the 2020 inflation adjustment of the Great Lakes/Great Plains region.

Figure 8.4.6



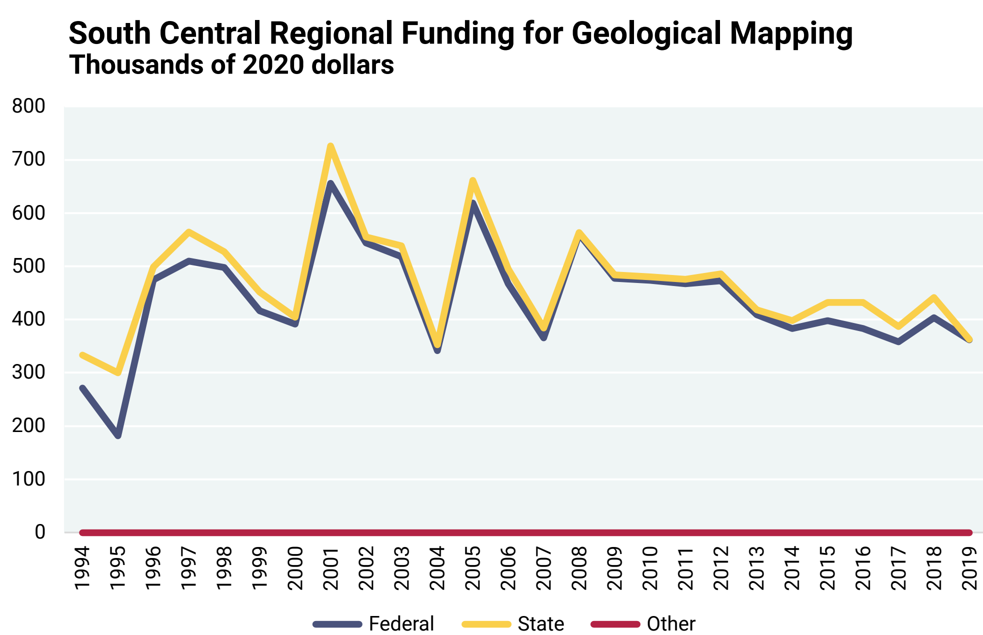
Total funding provided by federal, state, and other entities to Great Lakes/Great Plains region with the 2020 inflation adjustment.

Figure 8.4.7



Comparison of both the 1994-2019 total map funding and the 2020 inflation adjustment of the South-Central region.

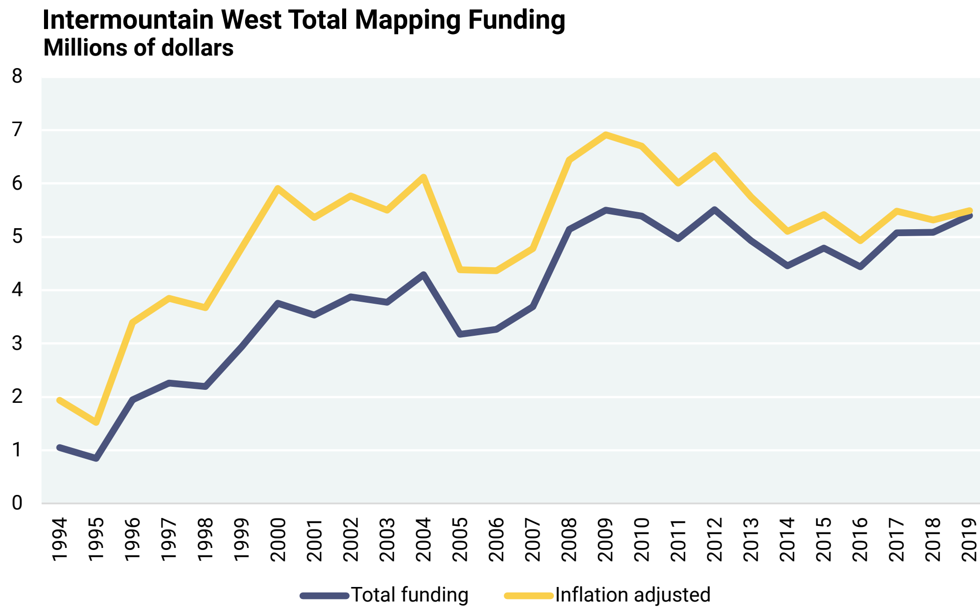
Figure 8.4.8



Total funding provided by federal, state, and other entities to South-Central region with the 2020 inflation adjustment.

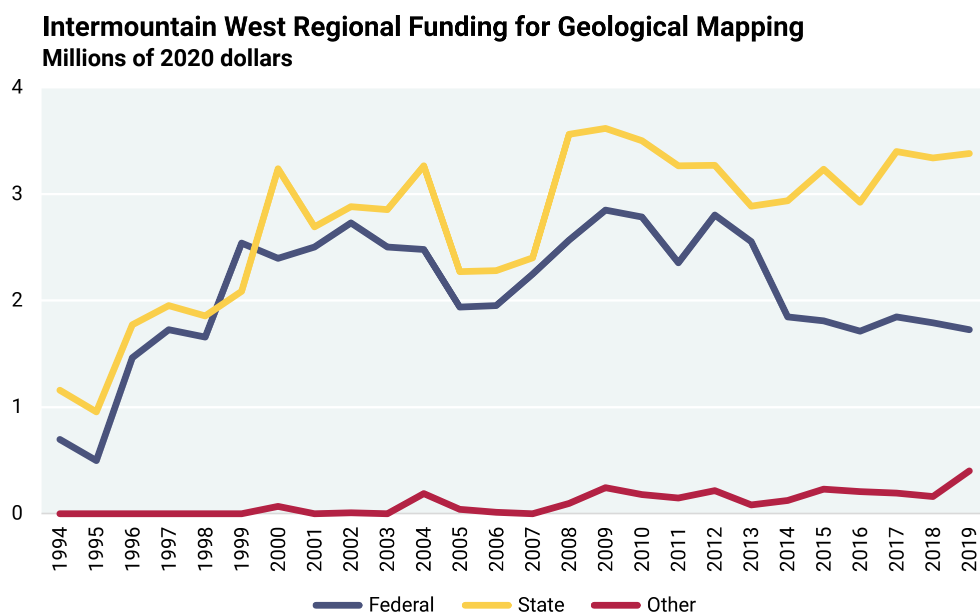
▶ Table of Contents

Figure 8.4.9



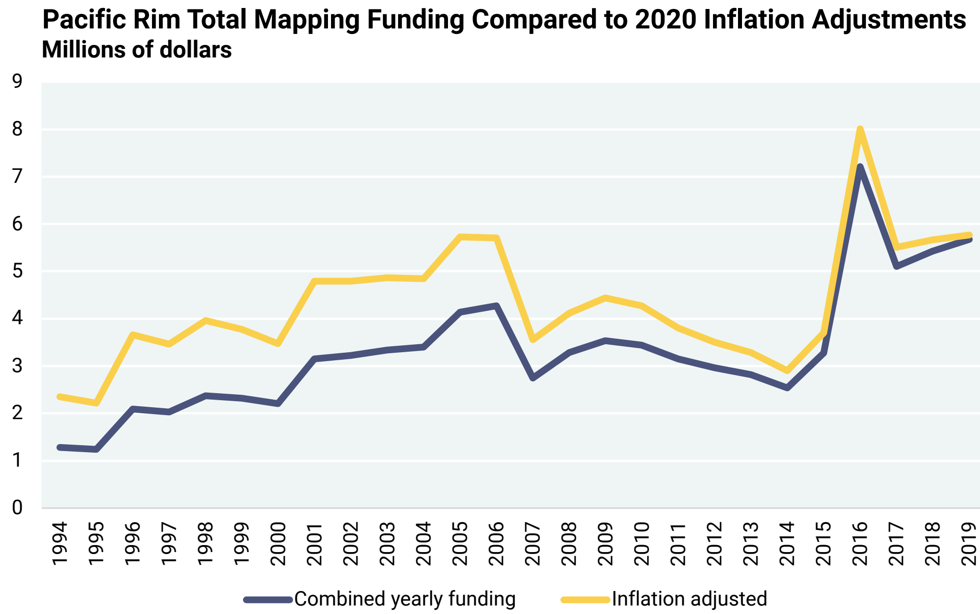
Comparison of both the 1994-2019 total map funding and the 2020 inflation adjustment of the Intermountain West region.

Figure 8.4.10



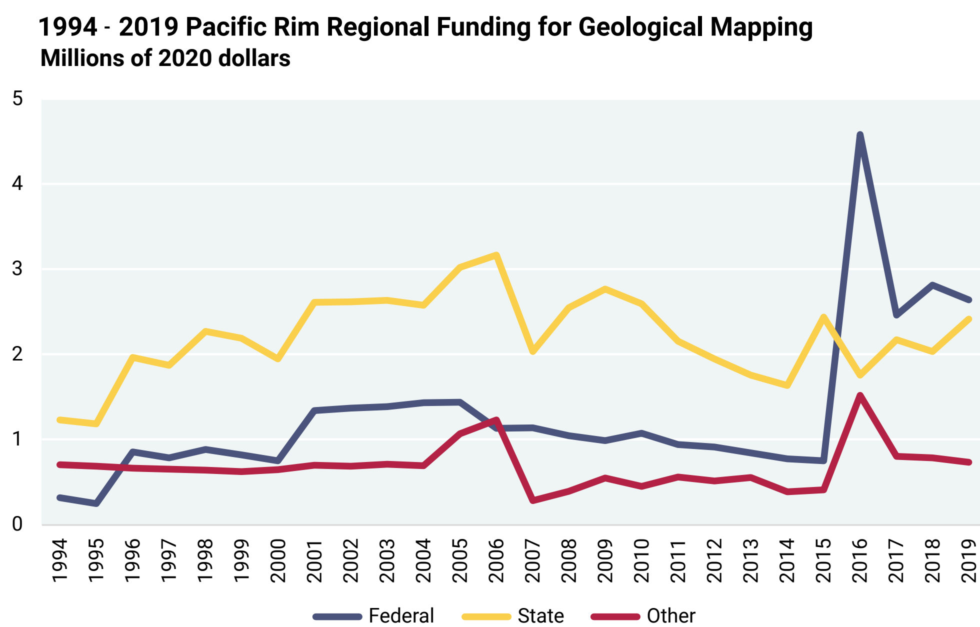
Total funding provided by federal, state, and other entities to Intermountain West region with the 2020 inflation adjustment.

Figure 8.4.11



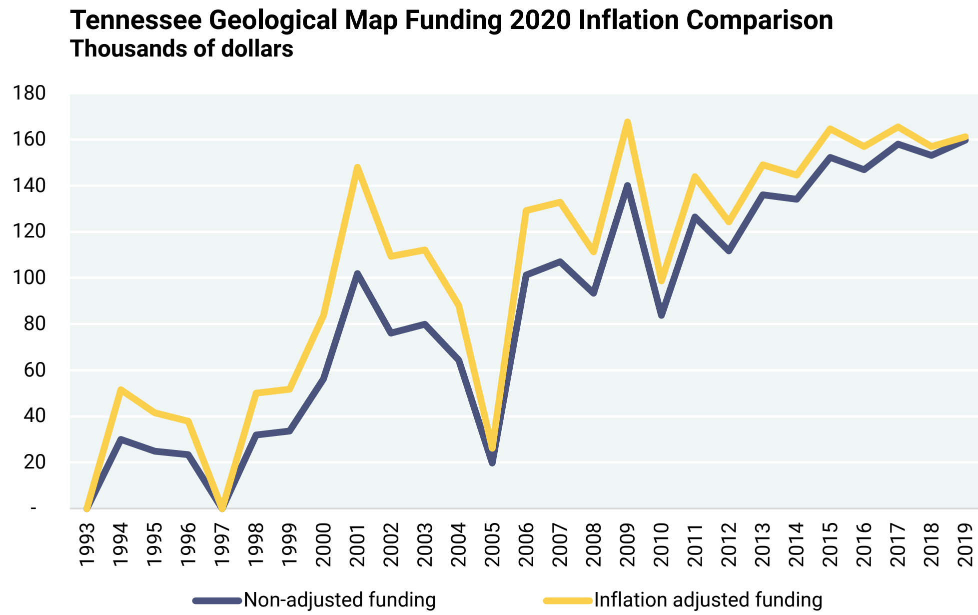
Comparison of both the 1994-2019 total map funding and the 2020 inflation adjustment of the Pacific Rim region.

Figure 8.4.12



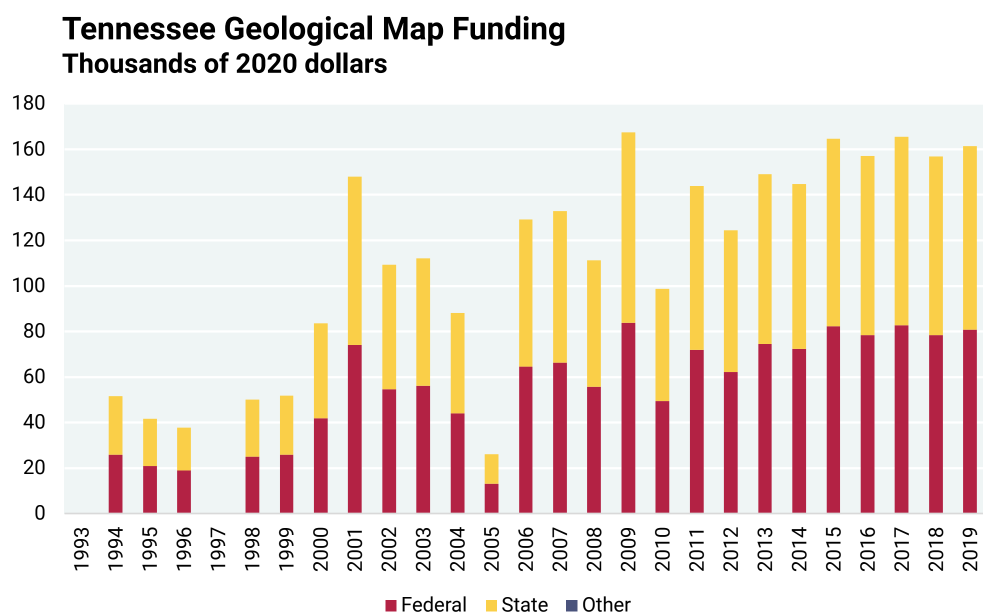
Total funding provided by federal, state, and other entities to Pacific Rim region with the 2020 inflation adjustment.

Figure 8.4.13



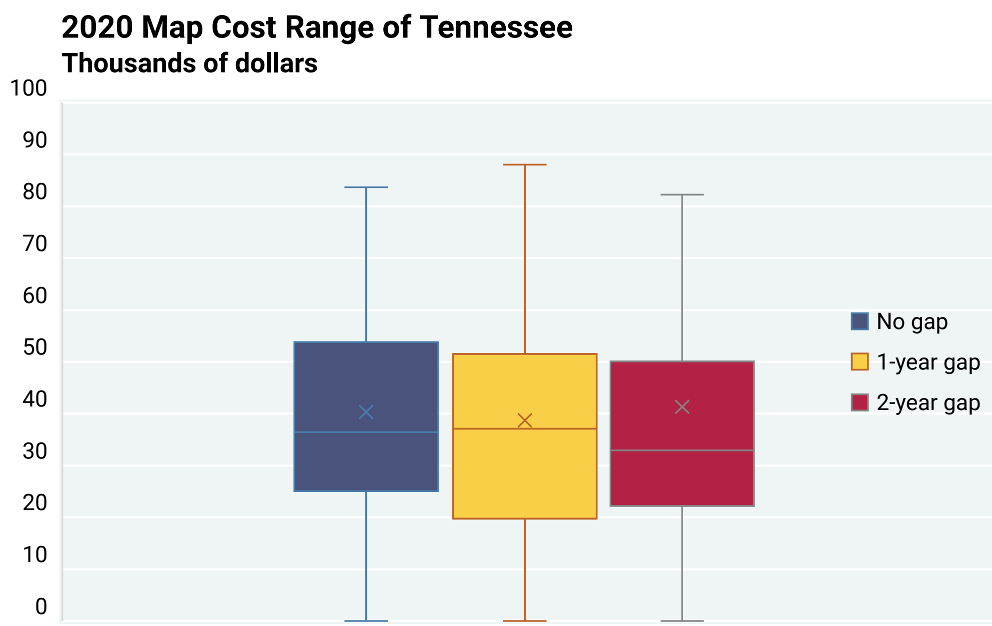
Compilation of 1994-2019 geological mapping Tennessee compared to the 2020 adjusted inflation.

Figure 8.4.14



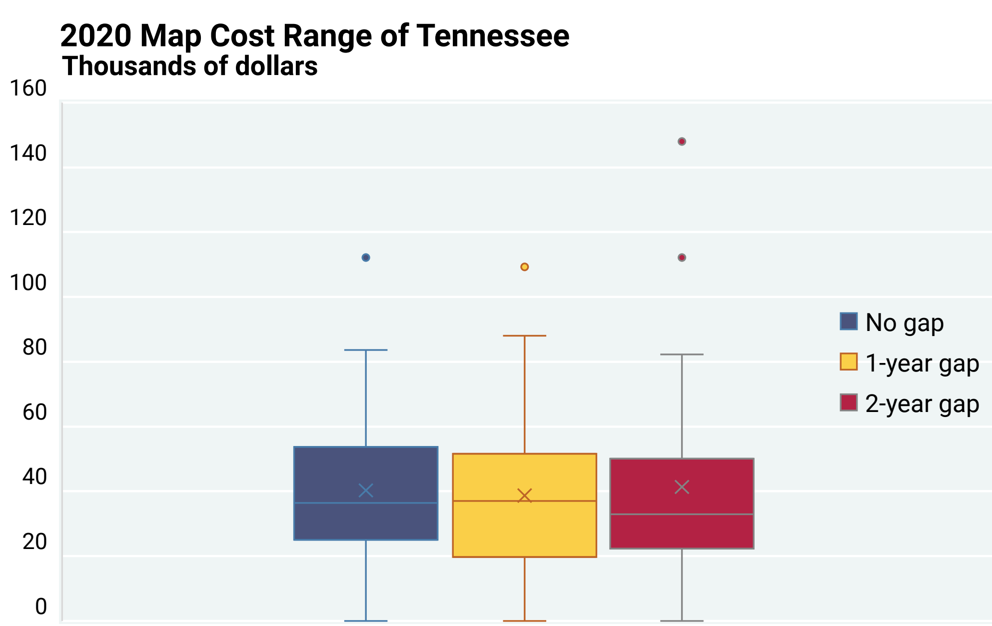
Total funding provided by federal, state, and other entities to Tennessee with the 2020 inflation adjustment.

Figure 8.4.15



Inflation adjusted map cost of Tennessee, without outliers

Figure 8.4.16



Inflation adjusted map cost of Tennessee, including outliers

Note Regarding Separate USGS Cost Spreadsheet: The USGS also provided funding levels for geological mapping conducted by the FEDMAP component of NCGMP from 1994–2019. However, this regional analysis was limited to just the SGS data due to the difficulty of regionalizing maps produced by the USGS, which commonly maps across state boundaries and does not separate costs based on individual states. Therefore, there is no justification to apply USGS data to the state regional mapping estimates.

Summary of Results: Four tables are displayed below that summarize the results from this regional analysis. Table 8.4.7 is a comparison of examples from the representative state of each region for the highest and lowest year of funding to the funding awarded in 2019. First, it is important to note that only two regional examples, Tennessee (Southeast) and Utah (Intermountain West), received their highest funding awards within the 3-years (2017–2019) immediately prior to 2020. For the remaining four regional examples, the highest funding award dates occurred between the years 1998 and 2008, 12+ years prior to 2020. Tennessee had the most consistent increase of funding awards since the 1993 to 1997 period, when they received no awards for geological mapping (Table 8.4.2). Utah had the second most consistent funding since 1993, when the state also did not receive any awards for geological mapping. Table 8.4.8 shows the difference between the peak awards of representative states from each region to the 2019 award. Table 8.4.9 is a comparison of the highest and lowest number of geological maps published and the corresponding year from representative states from each region. Finally, Table 8.4.10 portrays the estimated average cost for producing a geological map in 2020 for each regional state example. Each table is followed by a short review that explains the summarized findings.

As a reminder, the NGMA and NCGMP of 1992 were not implemented until 1993. Numerous SGS may not have had the ability to meet the requirements of the act (e.g., 1:1 match with state funds) at that time to receive a funding award. Table 8.4.7 shows that the SGS with the highest yearly combined awards received from state and federal sources within the regional examples are Utah (Intermountain West) at $1,645,991.24 (2018) and Illinois (Great Lakes/Great Plains) at $1,285,042.31 (1998). While Utah had a relatively consistent increase of funding awards since 1993, Illinois had a large decrease of funding since 1998. The states with the lowest total funding awards from the regional examples are Tennessee (Southeast) and Arkansas (South-Central). Neither of these two regional examples received any funding award during the initial year of the NCGMP (1993), and Arkansas also received no funding in 1994 (Table 8.4.4). The total funding awards received for both Tennessee and Arkansas represent only a fraction of the overall funding received by the remaining regional examples.

Table 8.4.7

Comparison of the highest, lowest, and 2019 funding awarded for geological mapping between 1993 and 2019. The state cost data are from the state mapping expenditures Excel spreadsheets filled out by SGS and incorporated the 2020 inflation adjustment.

Regional Example: Comparison of Funding for Geological Mapping Awarded from 1993 to 2019						
Region	**State**	**2019 Funding**	**Highest year**	**Highest Funding**	**Lowest Year**	**Lowest Funding**
Northeast	Maine	$360,586.25	2004	$402,672.29	1993	$31,965.50
Southeast	Tennessee	$163,097.95	2017	$168,322.11	1993/1997	$-
Great Lakes/Great Plains	Illinois	$657,708.77	1998	$1,285,042.31	1995	$339,812.07
South-Central	Arkansas	$133,978.64	2008	$253,858.56	1994	$-
Intermountain West	Utah	$1,403,329.86	2018	$1,645,991.24	1993	$109,596.00
Pacific Rim	Washington	$759,923.39	2005	$770,357.60	1993	$91,330.00

Table 8.4.8 compares the highest funding award to the funding awarded in 2019 for the representative SGS from each region. The table also includes the percentage of change between the funding of the two awards and the net dollar difference. For each regional example, there was a negative differential between the funding awards and highest funding awards received in 2019. The last column, highlighted in red, lists the net difference in the dollars between the highest funding award and the 2019 award. A negative net difference represents a decrease in funding.

Table 8.4.8

Comparison of the highest, lowest, and 2019 funding awarded for geological mapping between 1993 and 2019. The state cost data are from the state mapping expenditures Excel spreadsheets filled out by SGS and incorporating the 2020 inflation adjustment.

Regional Example: Difference of Peak Funding Year to 2019 Funding					
Region	**State**	**Peak Funding**	**2019 Funding**	**% Difference**	**Net Difference**
Northeast	Maine	$402,672.29	$360,586.25	-11.7%	$(42,086.04)
Southeast	Tennessee	$168,322.11	$163,097.95	-3.2%	$(5,224.16)
Great Lakes/Great Plains	Illinois	$1,285,042.31	$657,708.77	-95.4%	$(627,333.54)
South-Central	Arkansas	$253,858.56	$133,978.64	-89.5%	$(119,879.92)
Intermountain West	Utah	$1,645,991.24	$1,403,329.86	-17.3%	$(242,661.38)
Pacific Rim	Washington	$770,357.60	$759,923.39	-1.4%	$(10,434.21)

Table 8.4.9 compares the years with the highest and lowest publishing of geological maps for the representative SGS in each region. The table also includes the estimated number of maps produced for the corresponding publication year. It is expected that the geological maps will be published 1-to-2 years after a SGS receives the funding award for production of the maps. However, this expectation is not absolute. The number of maps produced may fluctuate based on available resources, accessibility, technical requirements, unanticipated geological complexity, funding still available, number of employees, and any special requests or events (e.g., natural disaster) to meet public needs in each state.

Table 8.4.9

Comparison of the highest, lowest, and 2019 funding awarded for geological mapping between 1993 and 2019. The state cost data are from the state mapping expenditures Excel spreadsheets filled out by SGS and incorporated the 2020 inflation adjustment.

Regional Example: Highest and Lowest Map Production Year Within 1994–2021					
Region	**State**	**Highest Map Year**	**# of Maps**	**Lowest Map Year**	**# of Maps**
Northeast	Maine	1999	30	1994/1995/2000	1
Southeast	Tennessee	2013	7	1999	0
Great Lakes/Great Plains	Illinois	2007	25	2021	0
South-Central	Arkansas	2007	22	1996	0
Intermountain West	Utah	1994	23	1998	2
Pacific Rim	Washington	2003	16	2001/2008	0

*Note: To project a two-year gap between the year the funding is awarded and the year the map is completed, additional data for maps was needed for 2020 and 2021.

The information in Table 8.4.10 is the projected average cost for producing a geological map for each regional example. The average costs are derived from the box and whisker plots of the projected map costs. The time lag between when a SGS receives a funding award and when the corresponding maps are completed typically range between 1 to 2 years. The three columns in the table list the average costs for producing a map, arranged by no time gap, a 1-year gap, and a 2-year gap.

Table 8.4.10

The projected average cost for producing a geological map in 2020 for the six regional state examples. These examples are used as the basis of the overall region (e.g., access to commonalities and both geographical and geological similarities/differences, regarding geological map making).

Regional Example: 2020 Projected Average Cost for Geological Map Making				
Region	**State**	**No Gap**	**1-Year Gap**	**2-Year Gap**
Northeast	Maine	$51,102.53	$44,005.69	$44,502.14
Southeast	Tennessee	$40,987.84	$39,348.23	$42,013.96
Great Lakes/Great Plains	Illinois	$131,234.06	$118,355.65	$110,144.86
South-Central	Arkansas	$36,322.00	$98,902.93	$44,231.98
Intermountain West	Utah	$95,508.26	$98,902.93	$103,810.22
Pacific Rim	Washington	$129,713.14	$121,048.40	$122,654.97

Discussion: It is important to note that the diagrams in Figures A7.25 to A7.44 in Appendix 7, and the summation of results in Tables 8.4.7 to 8.4.10, are projections of the range of costs affiliated with geological map making. All estimations and projections were derived from the data provided by SGS on their individual cost spreadsheets (Appendix 1).

There are multiple caveats and assumptions made that could affect the validity of these estimated values. Even so, these results display the high variation in potential costs of geological maps as illustrated best in the box and whisker diagrams. As the scale changes and the complexity of a map increases, the cost also increases. Federal and state government-funded maps can only be seen as a public good due to the complexity and high costs associated with them. Most private entities will not produce or release geological maps anywhere close to the extent of SGS and the USGS, because of natural differences in objectives between private versus public investments.

This chapter provides an overview of the stakeholder questionnaire and SGS/USGS cost spreadsheets gathered for this study of the economic analysis of geological mapping. By separately analyzing the two datasheets using different methods, a traditional cost-benefit analysis of the stakeholder responses from the questionnaire, and a regional analysis of the SGS cost spreadsheet, key factors were discovered for assessing the costs and benefits of geological maps.

SGS and the USGS provided historical cost data (Appendix 1) furnished by the federal government, state government, and other entities from 1994 to 2019 for the sole purpose of producing geological maps. The historical data unadjusted for inflation are presented in Appendix 7 as Figures A7–13 through A7–24. The historical cost data were then adjusted to account for national inflation through 2020 and are displayed in lined graphs for comparison (Figures 8.4.1 through 8.4.12). The historical data also incorporated additional data (e.g., number of maps produced per region per year from 1994–2020) to help estimate and project current and future costs of the product (geological maps). Figures A7.25 through A7.44 in Appendix 7 are box and whisker plots and line charts, constructed to graphically portray the variation of costs required for producing a geological map across six different regions of the U.S. in 2020. Although the costs to generate a geological map vary, the financial value of producing a geological map is still extremely high. When the importance of producing a geological map outweighs the high costs of producing the map, especially for public safety, national security, and economic development, the U.S. government has commonly recognized the benefit of investing in geological maps.

8.5: COMPARISON OF PROJECTED GEOLOGICAL MAP COSTS TO DOCUMENTED COSTS

To compare and validate the projected range of regional geological mapping costs calculated in this analysis, documented fiscal-year budget data for creating geological maps were provided by the USGS and one SGS, the Illinois State Geological Survey (ISGS).

Table 8.5.1 provides the breakdown of the documented costs for six geological maps that were published by the ISGS in 2019 and funded by combined federal and state funding. Of the six geological maps, three were bedrock maps, while the other three were surficial maps. The budgets for the two different map types are further broken down by funding categories, such as drilling, salaries, travel costs, and associated fees, etc. Cost differences were largely based on the complexity of each geological map and the requirements for constructing it. The individual costs for each ISGS geological map are not provided, but rather the overall costs of the six maps. The cost per map was obtained by dividing the total costs for each mapping type (surficial and bedrock) by the number of maps constructed with each method.

Table 8.5.1

The documented budget data from the ISGS for 2019, obtained through personal communications (Berg, 2024).

Fiscal Year 2019 Illinois State Geological Survey Mapping Costs		
Projects:	**3 Surficial Maps**	**3 Bedrock Maps**
Description	**Costs**	**Costs**
Salary Expenses	$46,879.00	$82,079.00
Affiliated Costs	$17,166.00	$22,801.00
Transportation	$2,646.00	$2,352.00
Daily Expenditures	$2,920.00	$7,136.00
Drilling	$25,542.00	$13,302.00
Analytical Equipment	$19,632.00	-
Supplies	$278.00	$337.00
Final Costs	$135,774.00	$151,048.00
2019 Average Cost/Map	$45,258.00	$50,349.33
2020 Inflation Cost/Map	$46,833.41	$52,101.97

The funding in Table 8.5.1 is the amount received in 2019. To comply with this overall report, based on 2020 inflation-adjusted dollar values, required adjusting the 2019 average map cost to account for the 2020 average inflation rate. The results are displayed in Table 8.5.2. The overall average costs of making a geological map were determined to be $49,467.70. These ISGS costs are just an example from one state. It must be recognized that costs for geological mapping can vary considerably depending on several factors, including:

- The surrounding environment and geological complexity,
- Equipment requirements,
- Drilling and other means to acquire data,
- Number of employees and their skill levels, and
- Access to study areas.

Table 8.5.2

ISGS NCGMP Mapping Budget 2019. The table consists of both projects (Berg, personal communication, 2024).

National Cooperative Geologic Mapping Program					
STATEMAP Mapping Budget: Illinois Fiscal Year 2019 (Inflation adjusted to 2020)					
Project #	**Map Type**	**Number of Maps**	**USGS Funding**	**ISGS Match**	**Average Cost/Map**
Project 1	**Surficial**	3	$67,288.00	$68,486.00	$45,258.00
Project 2	**Bedrock**	3	$75,296.00	$75,752.00	$50,349.33
Combined	**Both**	6	$142,584.00	$144,238.00	$47,803.67

2020 Inflation Adjusted Average Geological Map Cost: $49,467.70

The 2019 ISGS costs for producing the six geological maps discussed above falls within the projected range of costs ($42,000 to $123,000) for producing a geological map in 2020, as reported in this chapter. The average costs of the three bedrock maps, adjusted for 2020 inflation, were $52,102. Similarly, the average cost of the three surficial maps, adjusted for 2020 inflation, was $46,833. Drilling at the sites was a major cost factor in the field expenses for these maps. The average cost for all six maps combined, after 2020 inflation adjustments, was $49,467.70 (Table 8.5.2).

The NCGMP of the USGS was contacted directly to examine their 2019 costs for all SGS that received USGS funding for large-scale geological mapping (Shelton, personal communication, 2024). Although the USGS data are not state-specific, the total costs associated with individual maps can still be compared to the overall cost range in this report, since the funding comes from a combination of their STATEMAP program and the matching SGS funds. We can also compare these USGS map costs to the above ISGS map costs. A total of 158, 7.5-minute quadrangle (1:24,000 scale) geological maps were constructed in 2019 (Shelton, personal communication, 2024). A few maps also were created at smaller scales (e.g., 1:100,000), but these were minimal and have negligible impact on the summary statistics. Therefore, they were excluded from this comparison for consistency. The USGS provided the total costs for each of the map types (Table 8.5.3). The average cost for the 158 geological maps at 1:24k scale in 2019 was $53,495 for bedrock maps and $56,153 for surficial maps.

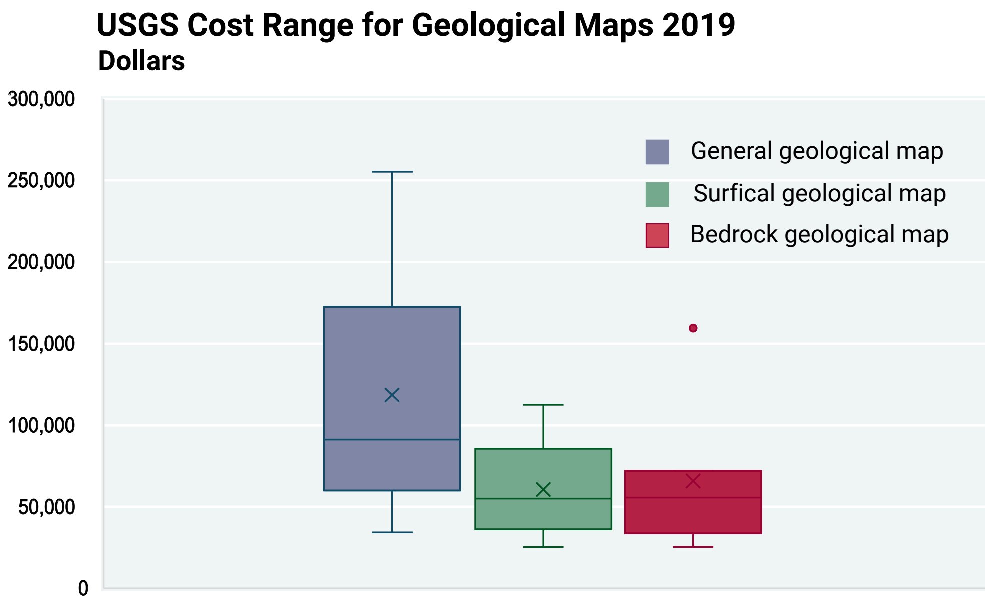
Table 8.5.3

2019 USGS Geological Mapping Cost Summary. The summary statistics consist of 158, 7.5-min quadrangle geological maps at 1:24K scale (Shelton, personal communication, 2024). All cost data were inflation adjusted to 2020.

National Cooperative Geologic Mapping Program				
Map Type	**Average Cost**	**Median Cost**	**Minimum Cost**	**Maximum Cost**
General	$77,345.46	$65,455.84	$34,418.12	$255,510.00
Bedrock	$53,494.65	$55,791.41	$25,325.04	$159,466.22
Surficial	$56,152.93	$53,759.91	$25,325.04	$112,678.34

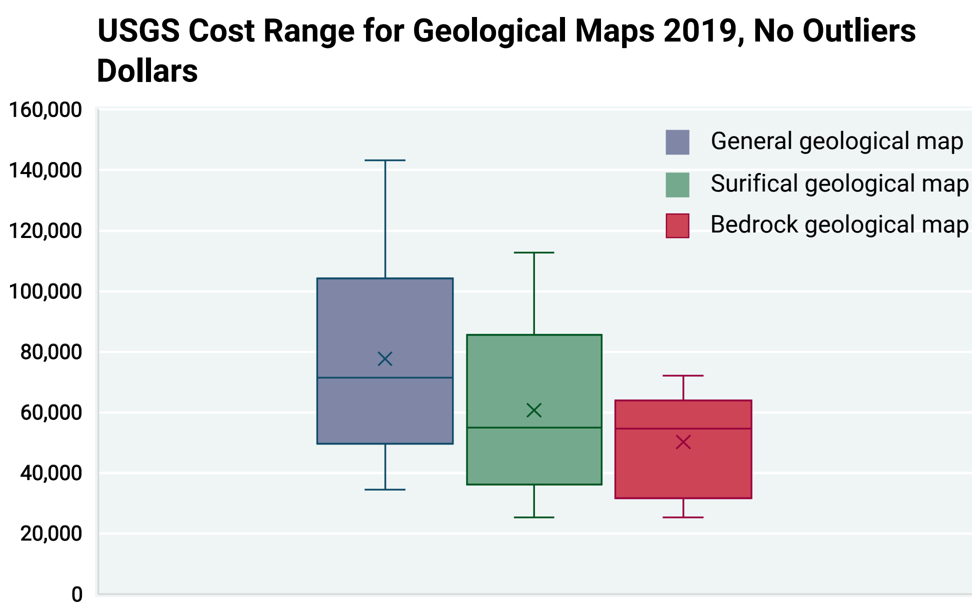
To further validate the high end of the cost range, two additional box and whisker plots were created using only the inflation-adjusted USGS data for 7.5-minute quadrangle maps at 1:24,000 scale (Figures 8.5.1 – 8.5.2). Figure 8.5.1 includes the mapping cost outliers, while Figure 8.5.2 excludes them. The statistical data on mapping costs provided by the USGS aligns with the average map-cost range derived from both the ISGS map cost data and the regional historical map-cost analysis reported in this chapter. This consistency suggests a common trend across the range of map costs and suggests a relatively high level of certainty in these findings.

Figure 8.5.1



Box and whisker plots of the 2019 USGS map cost range of all 158 geological maps produced by USGS. The true costs were provided by combining both the federal mapping funds and matching state mapping funds for each quadrangle map. This includes outliers that are true map costs . All cost data was adjusted to the 2020 inflation.

Figure 8.5.2



Box and whisker plots of the 2019 USGS map cost range of all 158 geological maps produced by USGS, excluding the outlier map costs. The true map costs were provided by combining both the federal mapping funds and matching state mapping funds for each quadrangle map and outliers were omitted. All cost data was adjusted to the 2020 inflation.

8.6: CONCLUSIONS

The data acquired for this national study consists of two closely related datasets, specifically the questionnaire data (Appendix 2) that primarily addresses the assessment of benefits of geological maps linked to stakeholders and the spreadsheets that address state and federal cost data by SGS and the USGS (Appendix 1) for producing geological maps.

The NCGMP of the USGS was contacted directly to examine their 2019 mapping costs. Although the USGS data are not state-specific, the total costs associated with individual maps can still be compared to the overall cost range in this report, since the funding comes from a combination of their STATEMAP program and the matching SGS funds. We can also compare these USGS map costs to the ISGS map costs. A total of 158, 7.5-minute quadrangle geological maps were constructed in 2019 at a scale of 1:24,000. The average cost of producing bedrock maps at this scale was $53,495 compared to $56,153 for surficial maps.

Two key questions were discussed in the overview of this chapter *(1) How many geological maps were constructed per year per region; and (2) What is the average cost of a geological map, based on regional data*. Question 1 can only be applied to the state costs dataset, which is discussed in section 8.4. Question 2, on the other hand, can be intermingled between the results of both the questionnaire and cost spreadsheets; it is a question that is addressed through several approaches discussed in this report. The goal is to categorize and give a U.S. dollar value to the cost and quantify the benefits of a geological map. Chapters 3 through 7, 9, and 10 include empirical analyses and assessments of the questionnaire and cost datasets, U.S. EPA data, and values estimated by respondents. This chapter incorporates analyses of both datasets, including the stakeholder responses and SGS spreadsheets of state expenditures for geological mapping.

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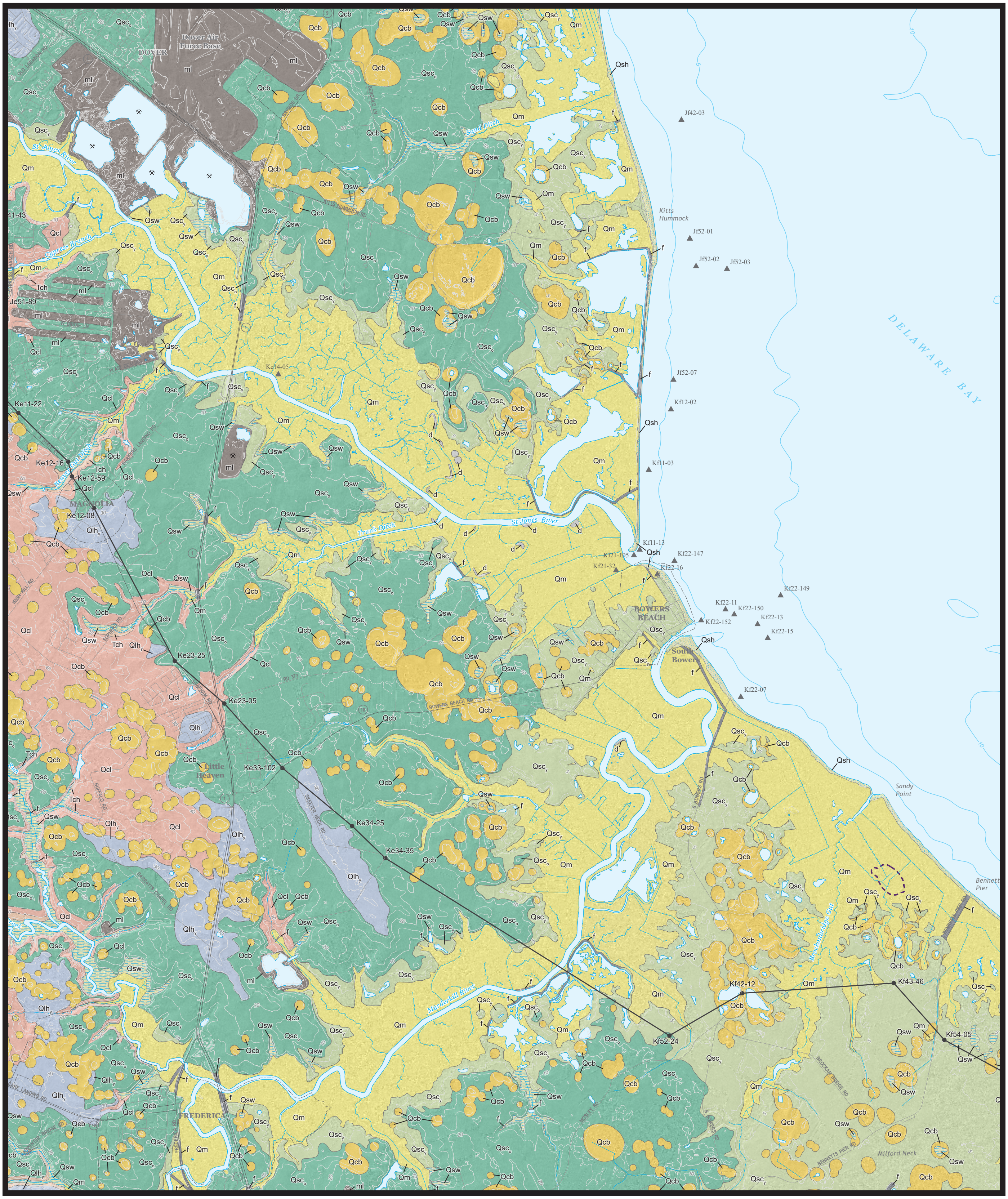

Portion of: Tomlinson, J.L, and Ramsey, K.W., 2024, Geologic map of the Frederica and Bennetts Pier quadrangles, Delaware: Delaware Geological Survey GM28, scale 1:12,000.

CHAPTER 9: QUANTITATIVE VALUE ASSESSMENT FROM INDEPENDENT EPA DATA

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ABSTRACT

Another means for assessing the value of nationwide geological mapping is based on the rationale that contamination mitigation costs, resulting primarily from waste disposal and industrial sites, could be minimized significantly or even avoided had geological information been available and used prior to the potentially detrimental land-use activity. Using this model, quantifiable benefits were potential savings from funds spent by the U.S. Environmental Protection Agency (USEPA) and private parties from 1994 to 2019 associated with their SuperFund program to clean up some of the nation's most contaminated land (1,883 sites listed). The USEPA reported total inflation adjusted costs in 2020 dollars of $86,227,531,539. The cost of geological mapping for the 26-year (1994–2019) period was $1.99 billion. Assuming that 5% of the $86.23 billion costs could have been avoided had geological maps at a meaningful scale been available and used to initially locate waste disposal and/or industrial sites (often many years prior to designation as SuperFund sites) in areas with less vulnerability to contamination of land and/or water, that would be a cost savings of $4.3 billion and yield a cost benefit ratio of 2:1. If 10% could have been saved, the cost savings would have been $8.6 billion with a cost benefit ratio increase to 4:1. It is impossible to determine how much of these costs could have been avoided. However, it is instructive to envision that a 2.3% reduction in the $86.23 billion clean-up expenditure would have paid for the entire $1.99 billion geological mapping outlay from 1994 to 2019.

9.1: SUPERFUND SITE COSTS

Avoiding costs, and explicitly using them as a measure of benefits, are well documented in the literature. For example, Lizzuo et al. (2019) reported that the Arizona Geological Survey saved Arizonans over $30 million in cost avoidance over a 12-month period, a 30 to 1 ratio relative to its state funding. Chiavacci et al. (2020) reported on the health benefits from using geological data to communicate radon risk potential, and this equated to potential avoidance of Kentucky residents to harmful radon exposure, with a net value of $3.4 to $8.5 million (2016 dollars).

Table 5.5.1. in Chapter 5 lists 73 maps that can be derived from geological maps. Among those are aquifer sensitivity (i.e., pollution potential), groundwater quality, landfill suitability, and geology for land use, all of which can help delineate regions and potential sites where waste disposal and certain industrial activities can have a high potential for contaminating land and water (e.g., Hughes, 1972; Berg et al., 1989). The premise is that by avoiding potentially sensitive areas through geological mapping, municipal, county, and industrial planners can avoid or at least minimize future contamination issues, while taking advantage of land areas where potential contamination would be less of an issue. Although geological mapping at a detailed scale has not been widespread enough to significantly reduce these contamination issues in a country as large as the U.S., this cost avoidance scenario presents the case for the potential benefits of geological mapping in future years. An early assessment of the value of geological mapping, and an example of the above cost-avoidance scenario, was reported by Bhagwat and Berg in 1992. It was based on the rationale that future contamination mitigation costs, resulting primarily from waste disposal and industrial sites, could be minimized or even avoided had geological information been available and used prior to the potentially detrimental land-use activity. For this two-county analysis, cost amounts were direct contractual funds for the geological mapping activity as well as state matching funds. A reliable, quantifiable benefit was the savings from funds spent by the Illinois Environmental Protection Agency to document, investigate the extent of contamination, and take mitigative remedial action. There were nine SuperFund sites within the study area. It was assumed that geological knowledge would not have prevented all mitigation costs.

However, some avoidable costs could have been significantly reduced had geology been considered prior to development of the sites that resulted in contamination often decades later. Secondly, it was assumed that the effectiveness of existing environmental regulations played a role in cost reduction, and if regulations were 100% efficient, geological mapping may have been unnecessary. However, the latter can never be attained. To account for these factors, overall benefits were reduced 50%, 75%, and 90%, and this still resulted in cost benefit ratios of 1:23.5 to 1:54.5, 1:11.7 to 1:27.2, and 1:4.7 to 1:10.9, respectively.

The present study obtained considerable benefits data derived from the >4,700 responses to the stakeholder questionnaire. However, the above methodological approach provides another means for assessing the value of nationwide geological mapping. For the 1994–2019 project period, SGS and the USGS reported that their overall geological mapping costs in 2020 dollars were $1.99 billion. Using the model of Bhagwat and Berg (1992), another reliable, quantifiable benefit were funds spent by the U.S. Environmental Protection Agency (USEPA) and responsible private parties associated with the SuperFund program. Both maintain responsibility for cleaning up some of the nation's most contaminated land while responding to environmental emergencies, oil spills, and natural disasters (USEPA, 2022a). While the annual accomplishments of the program and associated remedial costs since 2004 are reported online (USEPA, 2022b), costs prior to 2004 were not available, and funded amounts as reported in the literature were inconsistent with one another and with the USEPA website. Therefore, the USEPA was contacted directly to provide uniform 1994–2019 SuperFund programmatic costs (Personal communication — William Dalebout, USEPA, Budget Planning and Evaluation Branch, January 2022). As noted by the USEPA's William Dalebout in providing the information, they concentrated on a "more comprehensive pull of expenditures under the Superfund umbrella (e.g., remedial, removal, etc.) and in so doing corrected for some of the overlapping/double counted costs that occurred when summing values from the website (e.g., amounts to states, while reported separately, are accounted for within construction and pre-construction amounts already)".

The cost numbers include direct USEPA Superfund expenditures, as well as private party commitments for site investigations and cleanup. USEPA expenditures included:

1. Transactions associated with response functions such as clean-up (remediation, removal, etc.) and excludes management and support costs, as well as costs for enforcement activities.

2. Both intramural costs (e.g., payroll, travel, etc.) and extramural costs (e.g., contracts, interagency agreements, cooperative agreements, etc.).

3. All fund types, including those that were congressionally appropriated, reimbursable allocations (e.g., special accounts), from the American Recovery and Reinvestment Act of 2009 (ARRA), and from Homeland Security Supplemental funds.

Private party commitments included:

1. Estimated amounts that parties spent on future site investigations and cleanup. The actual amounts spent were unknown.

2. Cash out payments to the USEPA that went into special accounts that the Agency used for government-performed cleanup.

3. Cost recovery that went either into site-specific special accounts for future government-performed cleanup or back to the SuperFund Trust Fund to clean up orphan sites.

As provided by the USEPA, Table 9.1.1 shows their total expenditures in nominal dollars of $29,943,391,516 and private party commitments of $34,686,400,000 for a total of $64,811,791,516 dedicated to SuperFund cleanup and associated activities. It also shows the inflation adjusted costs in 2020 dollars of $86,227,531,539.

Table 9.1.1.
USEPA SuperFund Total Expenditures and Private Part Commitments (in nominal and inflation-adjusted dollars).

Expenditures		Private Party Commitments								
Fiscal Year	Expenditures	Fiscal Year	Estimated Value of PRP Response (Includes Work & Cashouts)	Value of Cost Recovery Settlements	Total Value of PRP Commitments (Work & CR)	Expenditures	Total Value of PRP Commitments (Work & CR)	TOTALS Non-inflation Adjusted	CPI Multiplier	2020 $ Total
1994	$1,163,599,838	1994	$1,765,500,000	$197,000,000	$1,962,500,000	$1,163,599,838	$1,962,500,000	**$3,126,099,838**	1.761133603	$5,505,479,471.02
1995	$1,183,977,848	1995	$1,127,500,000	$241,000,000	$1,368,500,000	$1,183,977,848	$1,368,500,000	**$2,552,477,848**	1.712598425	$4,371,369,542.77
1996	$1,143,179,595	1996	$849,100,000	$300,500,000	$1,149,600,000	$1,143,179,595	$1,149,600,000	**$2,292,779,595**	1.663479924	$3,813,992,825.75
1997	$1,172,641,322	1997	$781,400,000	$293,100,000	$1,074,500,000	$1,172,641,322	$1,074,500,000	**$2,247,141,322**	1.626168224	$3,654,229,813.04
1998	$1,120,537,399	1998	$878,800,000	$329,300,000	$1,208,100,000	$1,120,537,399	$1,208,100,000	**$2,328,637,399**	1.601226994	$3,728,677,061.42
1999	$1,268,343,652	1999	$777,200,000	$323,700,000	$1,100,900,000	$1,268,343,652	$1,100,900,000	**$2,369,243,652**	1.566626651	$3,711,720,246.54
2000	$1,285,494,967	2000	$801,500,000	$201,000,000	$1,002,500,000	$1,285,494,967	$1,002,500,000	**$2,287,994,967**	1.515679443	$3,467,866,936.14
2001	$1,153,636,857	2001	$2,046,200,000	$295,300,000	$2,341,500,000	$1,153,636,857	$2,341,500,000	**$3,495,136,857**	1.473743648	$5,150,935,740.16
2002	$1,133,219,268	2002	$853,400,000	$288,800,000	$1,142,200,000	$1,133,219,268	$1,142,200,000	**$2,275,419,268**	1.450806003	$3,301,191,934.35
2003	$1,172,108,933	2003	$895,700,000	$223,300,000	$1,119,000,000	$1,172,108,933	$1,119,000,000	**$2,291,108,933**	1.418478261	$3,249,888,214.18
2004	$1,199,965,139	2004	$568,900,000	$142,000,000	$710,900,000	$1,199,965,139	$710,900,000	**$1,910,865,139**	1.38168343	$2,640,210,700.45
2005	$1,119,215,990	2005	$752,800,000	$217,900,000	$970,700,000	$1,119,215,990	$970,700,000	**$2,089,915,990**	1.33640553	$2,792,975,286.14
2006	$1,071,916,061	2006	$391,300,000	$163,800,000	$555,100,000	$1,071,916,061	$555,100,000	**$1,627,016,061**	1.294642857	$2,106,404,721.49
2007	$1,102,673,843	2007	$687,500,000	$252,200,000	$939,700,000	$1,102,673,843	$939,700,000	**$2,042,373,843**	1.259044863	$2,571,440,294.81
2008	$1,095,152,002	2008	$1,574,700,000	$232,000,000	$1,806,700,000	$1,095,152,002	$1,806,700,000	**$2,901,852,002**	1.21226196	$3,517,804,795.19
2009	$1,242,578,995	2009	$1,995,000,000	$371,000,000	$2,366,000,000	$1,242,578,995	$2,366,000,000	**$3,608,578,995**	1.216783217	$4,390,858,357.38
2010	$1,375,339,807	2010	$1,411,100,000	$154,500,000	$1,565,600,000	$1,375,339,807	$1,565,600,000	**$2,940,939,807**	1.196698762	$3,519,419,025.80
2011	$1,389,148,645	2011	$3,009,400,000	$298,600,000	$3,308,000,000	$1,389,148,645	$3,308,000,000	**$4,697,148,645**	1.160515785	$5,451,115,146.19
2012	$1,283,302,077	2012	$657,300,000	$172,100,000	$829,400,000	$1,283,302,077	$829,400,000	**$2,112,702,077**	1.136759582	$2,401,634,329.74
2013	$1,125,464,992	2013	$1,242,500,000	$292,300,000	$1,534,800,000	$1,125,464,992	$1,534,800,000	**$2,660,264,992**	1.120171674	$2,979,953,489.37
2014	$984,164,784	2014	$453,600,000	$57,700,000	$511,300,000	$984,164,784	$511,300,000	**$1,495,464,784**	1.102661597	$1,648,991,587.26
2015	$960,160,088	2015	$1,975,300,000	$512,200,000	$2,487,500,000	$960,160,088	$2,487,500,000	**$3,447,660,088**	1.101265823	$3,796,790,223.57
2016	$1,048,964,011	2016	$1,002,300,000	$55,300,000	$1,057,600,000	$1,048,964,011	$1,057,600,000	**$2,106,564,011**	1.0875	$2,290,888,362.39
2017	$1,071,370,870	2017	$1,227,100,000	$142,600,000	$1,369,700,000	$1,071,370,870	$1,369,700,000	**$2,441,070,870**	1.064871481	$2,599,426,752.61
2018	$1,025,793,306	2018	$452,900,000	$80,000,000	$532,900,000	$1,025,793,306	$532,900,000	**$1,558,693,306**	1.039426523	$1,620,147,164.28
2019	$1,051,441,228	2019	$570,400,000	$282,800,000	$853,200,000	$1,051,441,228	$853,200,000	**$1,904,641,228**	1.020727415	$1,944,119,516.84
						$29,943,391,516	$34,868,400,000	**$64,811,791,516**		$86,227,531,538.88
										Total 1994–2019 in 2020$

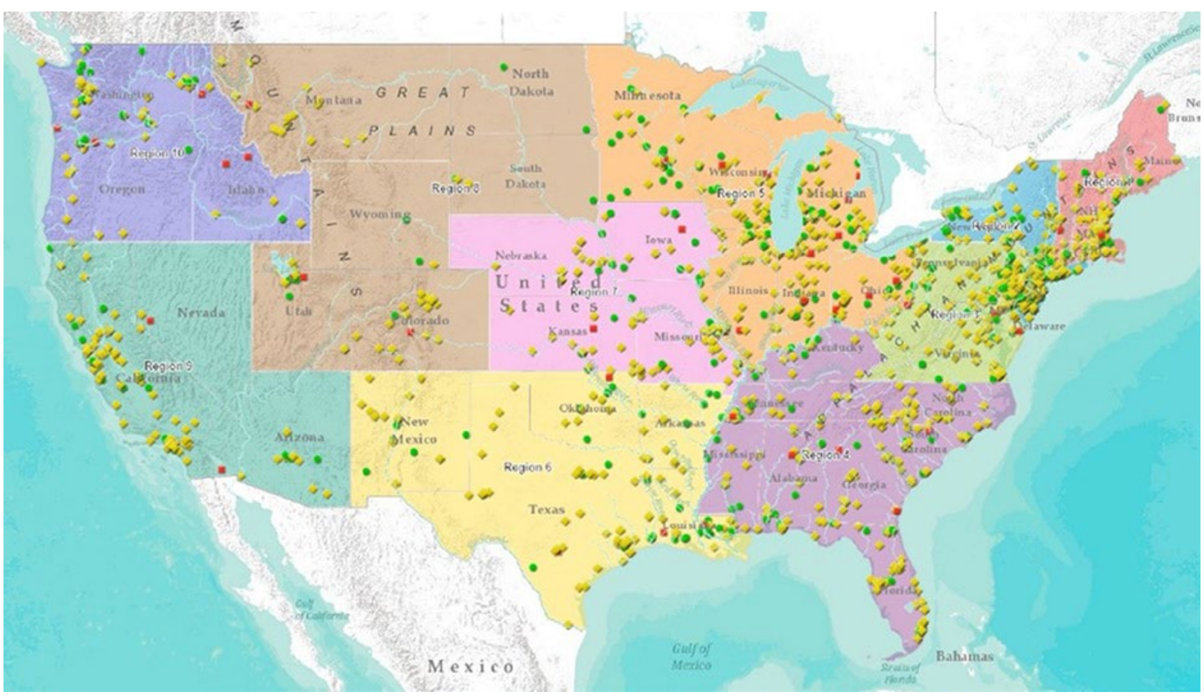
9.2: LINKING SUPERFUND COSTS TO GEOLOGICAL MAPPING

As a means of linking SuperFund costs to geological mapping, the USEPA operates an interactive map (Figure 9.2.1) providing specific latitudinal and longitudinal information of the 1,883 National Priorities List (NPL) or SuperFund sites (USEPA, 2022c) reported in 2022, including all those that are deleted, existing, and proposed. Another website provides tables of more state-specific information about those sites (USEPA, 2022d). These websites were used to evaluate if SuperFund sites resided within geological map boundaries using the rationale that contamination mitigation costs could have been minimized or even avoided had geological information been available and used prior to the potentially detrimental land-use activity.

The absence or presence of geological maps in association with SuperFund sites was ascertained using the Interactive Map View function of the USGS National Geologic Map Database (NGMDB) (USGS, 2022). In the absence of geological maps placed in the NGMDB by SGS, or to supplement maps found in the NGMDB with additional maps, websites of SGS were viewed as well. Evaluation of SuperFund site placement within a geological map boundary was restricted to geological maps at scales larger (i.e., finer scale) than 1:250,000, and preferably 1:100,000 or greater. An environmental assessment, or an evaluation of the contamination potential of any site-specific location, cannot be conducted effectively on small-scale maps. For states with 100% of its geological mapping coverage within the NGMDB, or where all of the state's SuperFund sites were found to have been within an NGMDB geological map coverage, SGS web sites were not consulted.

Following very careful comparing of latitudes and longitudes within geological map boundaries of SuperFund sites, it was determined that 1,384 sites, or about 74%, were contained within geological maps at scales larger than 1:250,000, and about 75% of those were within geological maps at scales greater than 1:100,000. It was not surprising that the largest states of Alaska, Texas, and California would not have conducted much of their mapping at larger scales. Only 35 SuperFund sites in Texas and California out of a total of 184 were located within the larger-scale maps. However, and surprisingly, 8 of 10 sites in Alaska were located in regions

Figure 9.2.1



U.S. EPA Superfund National Priorities List (NPL) sites (USEPA 2022c). Yellow dots are existing sites. Green dots are deleted sites. Red dots are proposed sites (Accessed Feb. 10, 2022). States are color coded based on numbered USEPA regions, which do not reflect the regions defined in this cost-benefit analysis (see Figure 8.1.1).

of more detailed mapping. States completely covered by larger-scale geological maps include the smaller states of Massachusetts, Connecticut, Rhode Island, and New Jersey, as well as the larger states of Florida, Kentucky, Ohio, North Dakota, and Washington. Maine, Montana, and Louisiana are close to full coverage.

9.3: PERSPECTIVES ON MAPPING COSTS, PERCEIVED VALUES, AND SUPERFUND CLEAN-UP COSTS

The $1.99 billion cost (2020 dollars) of geological mapping throughout the U.S. for the 26-year (1994–2019) period was accompanied by an inflation adjusted $86.23 billion of SuperFund clean-up and remediation costs by the USEPA and private parties. Assuming that 5% of those costs could have been avoided had geological maps at a meaningful scale been available and used to initially locate waste disposal and/or industrial sites (often many years prior to designation as SuperFund sites) in areas with less potential to contaminate land and water, that would be a cost savings of $4.3 billion and yield a cost benefit ratio of 2:1. If 10% could have been saved, the cost savings would have been $8.6 billion with a cost benefit ratio increase to 4:1. Although it is impossible to determine how much of the costs could have been avoided, it is instructive to envision that a 2.3% reduction in the $86.23 billion clean-up expenditure would have paid for the entire $1.99 billion mapping expenditure.

This SuperFund analysis presents a cost avoidance scenario showing potential savings had geological maps been available and used prior to the siting of these high-pollution sites. It supplements previously discussed (Chapters 4 through 7) input from stakeholders and map generating agencies that provided data on geological mapping expenditures, stakeholders willingness to pay for one geological map, and how they assess map value, all of which show very positive benefits over costs. Stakeholders indicated that they would willingly pay $2,883 to $3,000 for one geological map, but they assessed its value to be $10,000 to $11,062 per map. Using the median amount that respondents expected to pay per map as the basis ($2,883), the cumulative range of values between the actual maps downloaded and sold (4,825,955 as shown in Tables 7.2.1 and 7.6.2) with the extrapolated amounts (7,148,106 as shown in Table 7.6.2) would be between $13.91 and $20.61 billion. The most conservative value estimates thus range between 6.99 and 10.35 times the expenditure. Finally, the data on maps sold or downloaded from the computerized databases serve to constrain the cumulative total amount stakeholders would willingly pay as well as their total map-value assessment. The overall results show not only that geological maps provide critical, essential knowledge for every activity in the country's economy and civic life, but also that all indicators show the creation of geological maps to be a highly rewarding function of public spending.

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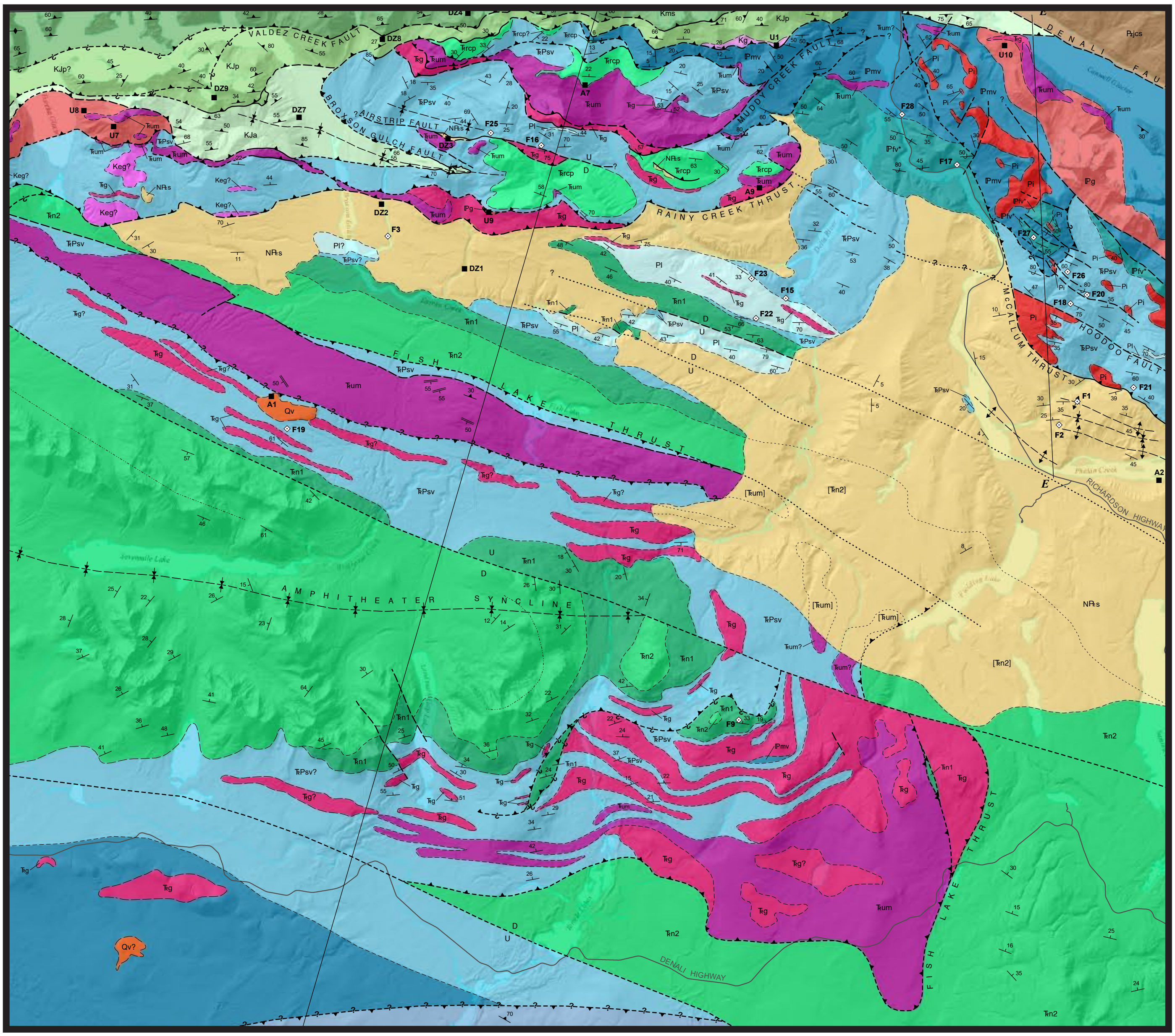

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CHAPTER 10: QUALITATIVE ASSESSMENT OF VALUE OF GEOLOGICAL MAPS BY STAKEHOLDERS

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ABSTRACT

Geological maps offer a wide array of uses that benefit stakeholders in ways that can be difficult to quantify. Therefore, stakeholders were asked in text format to describe how maps benefit their industry or organization. About 58.4% of respondents (2,689 out of 4,599) provided explanations of what benefits they received from map use. Benefits of map use were described by respondents working in various fields from their own perspectives. Several commonalities emerged from the responses that included the following: (1) providing regional context to project area; (2) identifying and exploring for resources; (3) helping with regulatory compliance; (4) identifying hazards; (5) enhancing accuracy of decisions; (6) lending credibility to work; (7) communicating effectively; (8) educating students and officials; and (9) saving time and money.

10.1: STAKEHOLDER QUALITATIVE RESPONSES

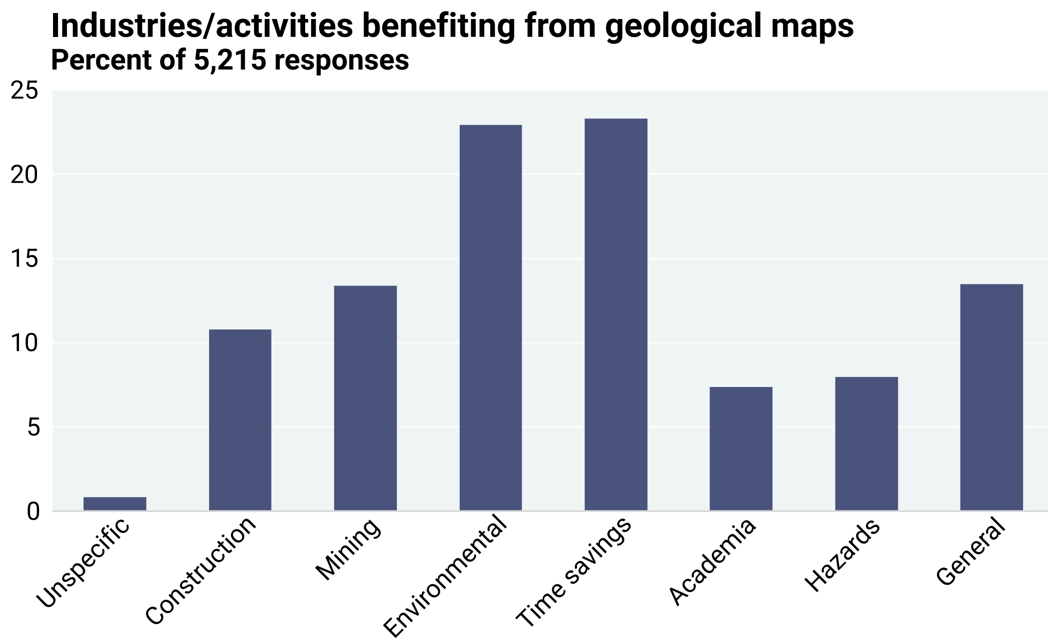
Geological maps offer a wide array of uses that benefit stakeholders in ways that can be difficult to quantify. Therefore, stakeholders were asked to describe how maps benefit their industry or organization (question 6). About 58.4% of respondents (2,689 out of 4,599) provided explanations of what benefits they received from map use. Many respondents work in multiple industries. As a result of their diverse activities, the actual number of responses was 5,215. A simplified list of search words or phrases provided an overview of the responses received and the industries that benefited from map use (Figure 10.1.1). Time saving is the single largest benefit that was cited. By inference, it can be concluded that cost savings are also a major benefit. This conclusion was reinforced in Chapter 6, which describes actual estimates by respondents of time and cost savings (in the previous five years the median value was 20% for time savings and 15% in cost savings) attributable to the availability of publicly financed geological maps prepared by State Geological Surveys (SGS) and the U.S. Geological Survey (USGS). Benefits in conducting environmental work are cited by an almost equal number of respondents. A detailed reading of a sample of about 200 responses provided better insight into how geological maps benefit users, as summarized below:

- Identify resources.
- Provide regional geological context.
- Aid construction safety.
- Save time.
- Save cost.
- Aid grant writing.
- Assist exploration planning.
- Help regulatory compliance.
- Hazard identification.
- Aquifer recharge planning.
- Assist environmental work.
- Communication with the public.
- Educate students.

A criterion for assessing the quality of the geological maps produced by SGS and the USGS is the stakeholder trust in these publicly funded independent institutions, and if use of their maps helps improve the quality/accuracy of their decisions (question 19). Close to 89% of respondents reported a “notable” or “extreme” improvement in the quality of their decisions if they use maps from SGS and the USGS (Figure 10.1.2).

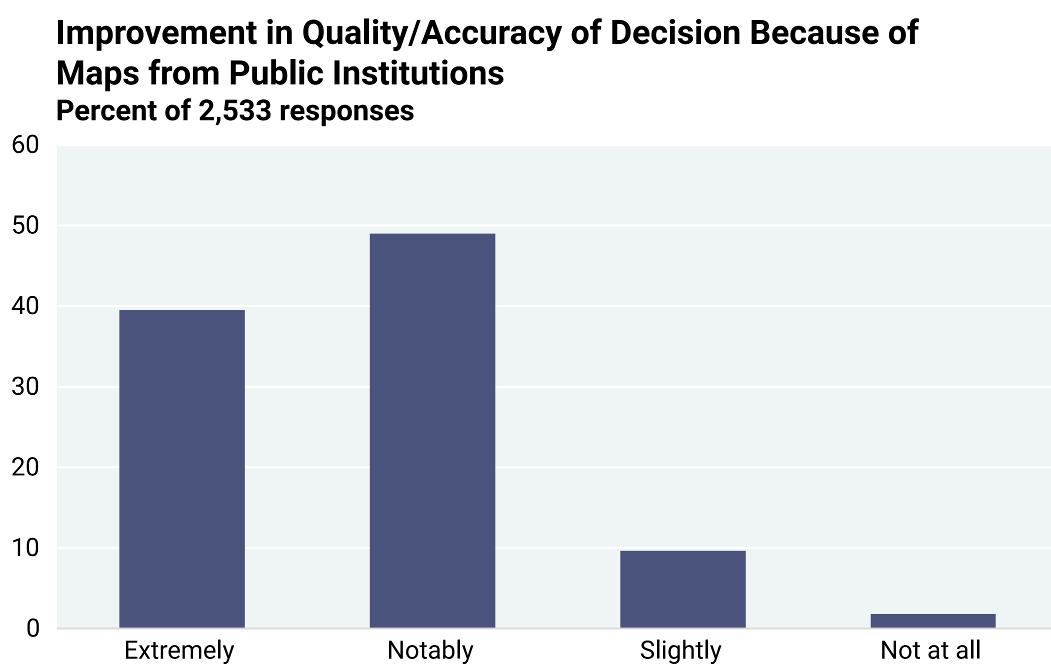
Figure 10.1.3 shows the application areas in which geological maps help improve the quality/accuracy of decisions. A closer reading of responses in each of the categories in Figure 10.1.3 provides greater insight. The following bullet points, based on extensive reading of specific responses,

Figure 10.1.1



How do geological maps benefit your organization/industry

Figure 10.1.2



How maps from SGS and USGS improve work quality/accuracy of users.

summarize comments within several broad topical areas as shown on Table 10.1.1.

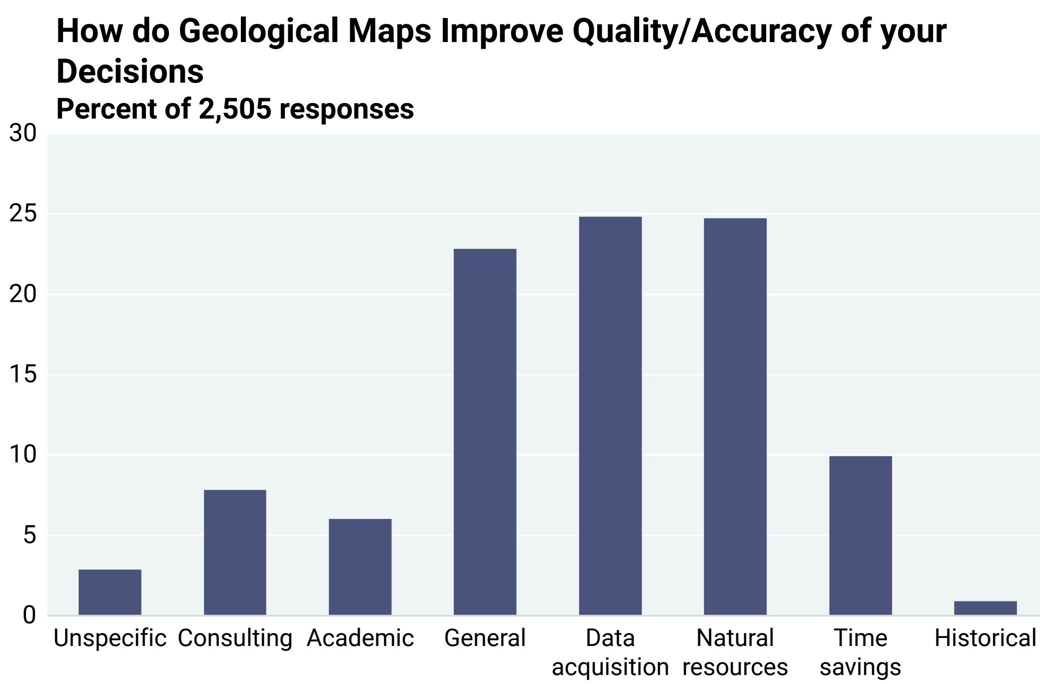
The quality and accuracy of the work by map users/stakeholders are vitally important. Commonly, however, as in courts of law and compliance issues, the work submitted by project managers must appear credible. The independent geological expertise of public institutions substantiates the credibility of the work of the users (question 20). Stakeholders were asked to respond to the credibility aspect by selecting one of the four descriptions provided to them and explain their choices. Figure 10.1.4a is a breakdown of 1,616 narrative responses, whereas Figure 10.1.4b is a breakdown of all responses regardless of whether they provided a narrative about their choices. Out of the 2,484 respondents, 82.6% reported that the credibility of their work was “notably” or “extremely” substantiated through use of SGS and USGS geological maps.

To further explain how credibility of stakeholder work benefits from the use of geological maps prepared by SGS and the USGS, 1,616 respondents provided comments. Table 10.1.1 shows a representative sample of responses.

Asked to describe “how” quality and accuracy of their work is influenced by the availability of geological maps, stakeholder responses were very diverse and difficult to analyze electronically. Individual responses had to be read and manually summarized. A total of 2,302 narrative responses to question 21 were provided regarding how the quality of their projects have been affected. Individual reading of the narratives provided a better sense of stakeholder views. Stakeholders described their experiences in many ways depending upon the nature of their project. However, the dominant and recurring descriptions could be summarized as follows:

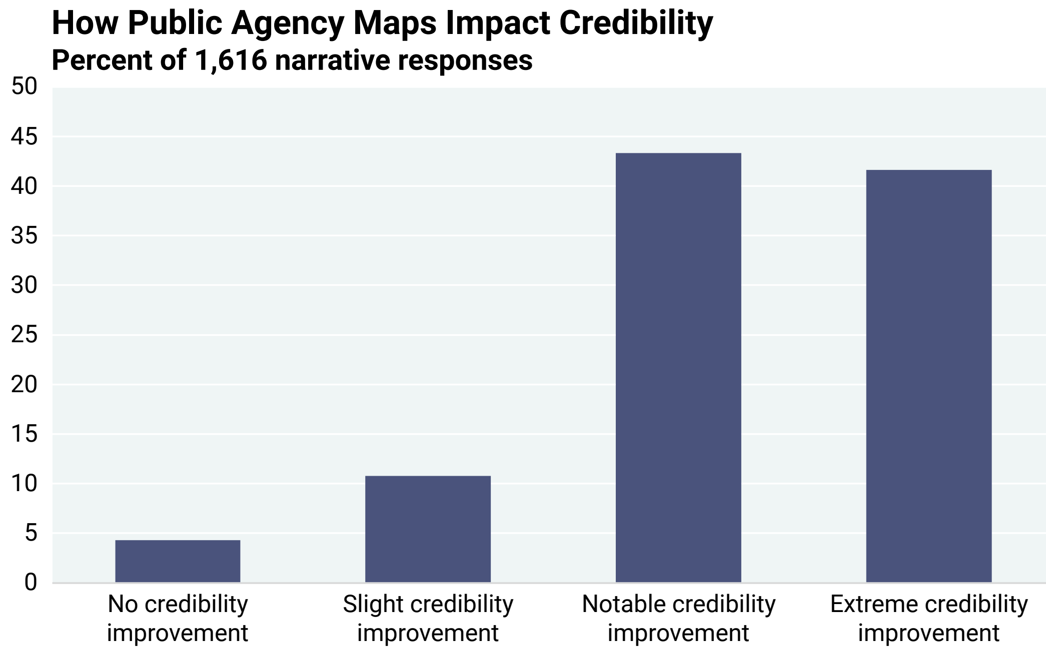
> Without regard to the sector, nature, and size of projects, the project sponsors are unable and/or unwilling to support the research needed to place the geology of the project area in the context of the regional geology for financial as well as time reasons. The contextualization of local geology with regional geology is critical for high-quality project planning and execution. It is therefore crucial to be able to rely on the quality of the regional geological information. The mission of publicly funded agencies is to create quality

Figure 10.1.3



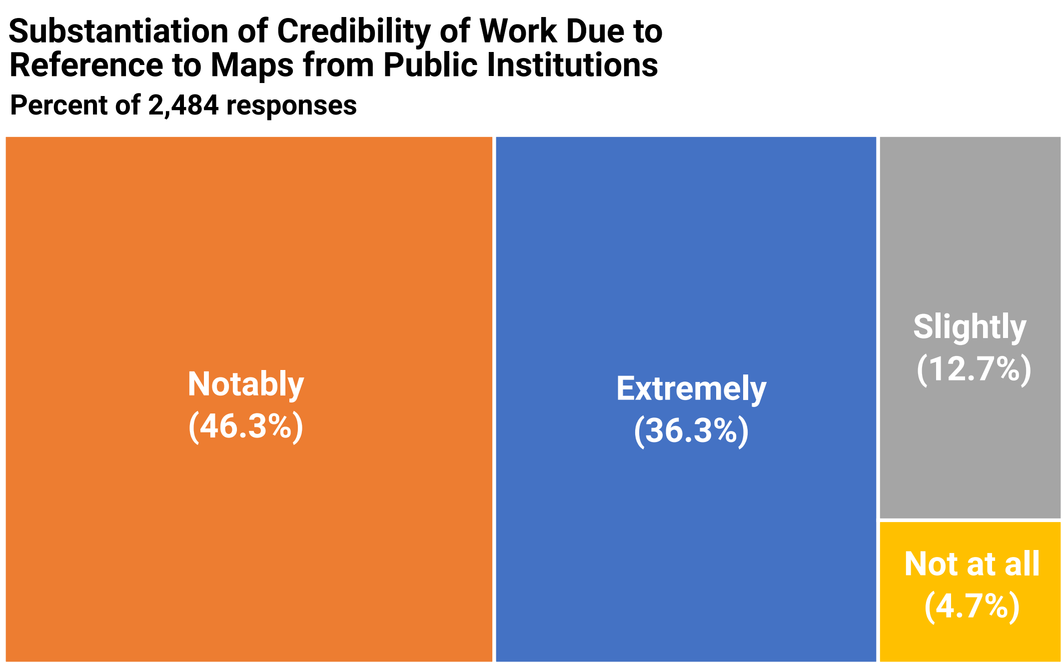
How do geologic maps improve the quality/accuracy of decisions.

Figure 10.1.4a



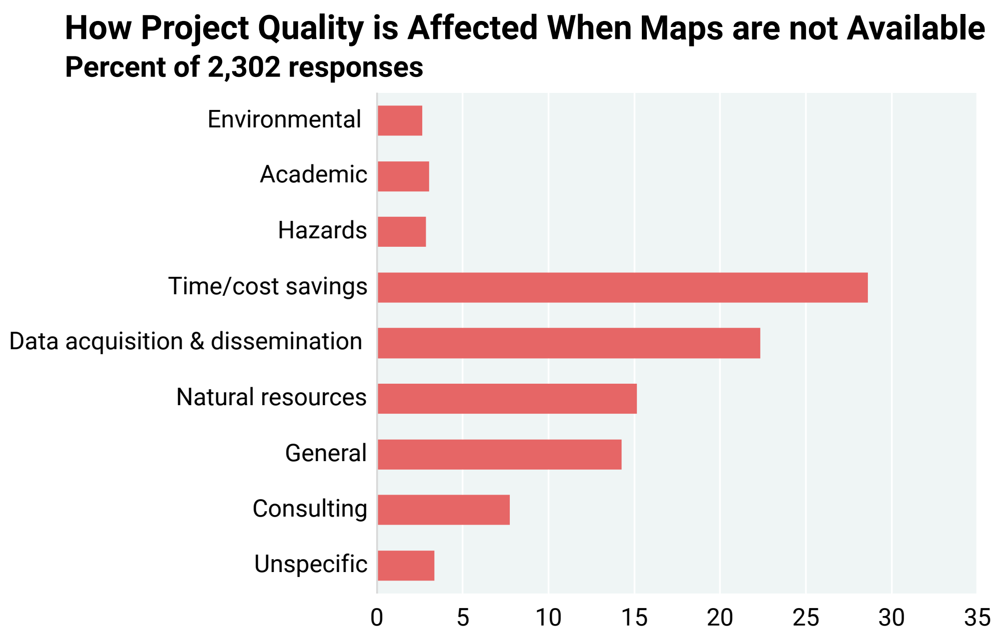
Substantiation of credibility of work (Breakdown of narratives).

Figure 10.1.4b



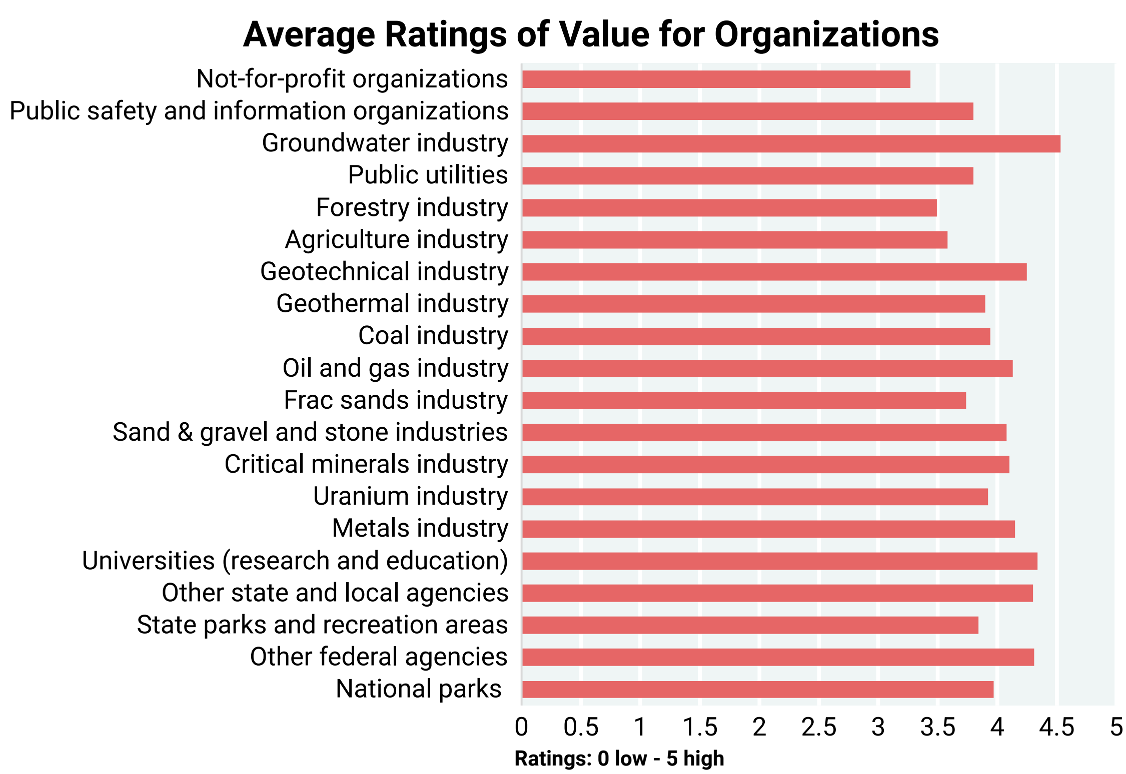
Substantiation of credibility of work (Breakdown of all responses).

Figure 10.1.5



How project quality is affected when maps are not available (Responses by sector).

Figure 10.1.6



Value of maps for various public and private entities in the judgment of responders on a scale of 1 to 5, with 5 indicating the highest perceived value.

> geological maps. They employ expert geologists who produce the maps and revise them over time as newer knowledge and/or technologies become available. High quality project planning needs the maps generated by them.

Qualitative assessments of geological maps may vary depending on who is using the maps and to which business or organization they belong. Stakeholders were asked for their assessment regarding the value of the geological maps produced by the publicly funded institutions for 20 different public and private entities and industries on a scale of 1 to 5, with 5 as the highest rating (question 22). These are assessments by the stakeholders for institutions and organizations for which they are not necessarily working. For all entities, the stakeholder assessments of the value of geological maps are in the upper half of the rating scale, between 3.3 and 4.5. (Figure 10.1.6)

Table 10.1.1.
Summary of the qualitative narrative assessments of benefits of maps by stakeholders.

Question 6: How do geologic maps and information benefit your organization or industry?

- Identify resources.
- Provide regional geologic context.
- Aid construction safety.
- Save time.
- Save cost.
- Aid grant writing.
- Assist exploration planning.
- Help regulatory compliance.
- Hazard identification.
- Aquifer recharge planning.
- Assist environmental work.
- Communication with public.
- Educate students.

Question 19B: How do geologic maps and the accompanying reports obtained from public institutions improve the quality and accuracy of your decisions?

CONSULTING:
- Clients can see results.
- Decisions are substantiated visually.
- Help verify field observations.
- They enhance information for decision making.
- Their accuracy helps in litigations.
- Their high quality improves our quality.
- Increases trust in our work.
- Reference to public maps required for compliance work.
- They help fill information gaps attributable to our investigative limitations.

ACADEMIC:
- Academic uses are mainly in areas of research and teaching.
- Most academic institutions have little or no resources to conduct their own mapping.
- Accurate maps available from SGS and USGS determine the quality of teaching and research in academic institutions.

GENERAL:
- Maps provide an overview of regional geology and a context to specific projects.
- Maps are the basis of all projects.
- Maps aid in all planning.

DATA ACQUISITION:
- The large amount of available regional data provide basis for site specific data gathering operations.
- The high-data quality of maps can be trusted because they are from trusted and independent geologists.
- Regulatory agencies have no way of collecting their own data and must rely on available maps.

NATURAL RESOURCES:

- Exploration and development of natural resources require accurate information to select targets and execute programs.
- Publicly available and reliable geologic maps are fundamental to resource development.

TIME SAVINGS:

- Almost all respondents stated that availability of accurate maps from trusted sources save them a great deal of time and money.

Question 20: How does map use substantiate credibility of your work?

- Provides us with a creditable reference.
- Surveys are well respected and well known for the quality of their work.
- Gives academic credibility.
- On numerous occasions, our clients have noted that they appreciate our use of SGS or USGS produced maps.
- Research reported by these institutions carries more weight than the same information obtained during project work.
- These maps are constructed by knowledgeable individuals whose work is reviewed by peers and experts.
- This information is of high value due in part to modern technology and the time and effort put into the project.
- Adds "outside expert" credibility.
- Clients understand the value of a report that includes peer reviewed research and comparisons from renowned institutions.
- Helps drive home the point by respected offices.
- They provide peer-reviewed maps created by knowledgeable professionals.
- Having maps and data from USGS, for example, provides level of expertise and peer review that will hold up in court.
- Information from these sources is used to confirm field observations.
- Regulatory agencies respect these resources.
- In most times, the most accurate information available before conducting our own site investigations.
- Public peer-reviewed maps validate much of the assessment.
- Peer-reviewed data adds to credibility.
- These maps are universally recognized by the public, regulators, and the courts.
- The information provided is accurate.
- Increases client trust.
- Regulatory agencies value and trust the reports prepared by public sources more than the work that we do.
- Agencies responsible for approving mine design requires that geologic statements be verified from a reliable source.
- Review of geologic maps at the federal and state level have rigor.
- Use of non-proprietary data is essential in maintaining the shareability and transparency.
- Site-specific data combined with regional data from a peer-reviewed report/map provides credibility.
- USGS and other federal and state geologic maps are very accurate.
- Public data are used as the first level of QC when we receive data from a client.
- Federal, state, and academic institutions provide professional services typically not influenced by project funding constraints.
- More experienced mappers are non- or less- biased.
- By providing information that I would not otherwise have.
- Project saves time and clients' money.
- Helps to minimize the possible appearance of biases.

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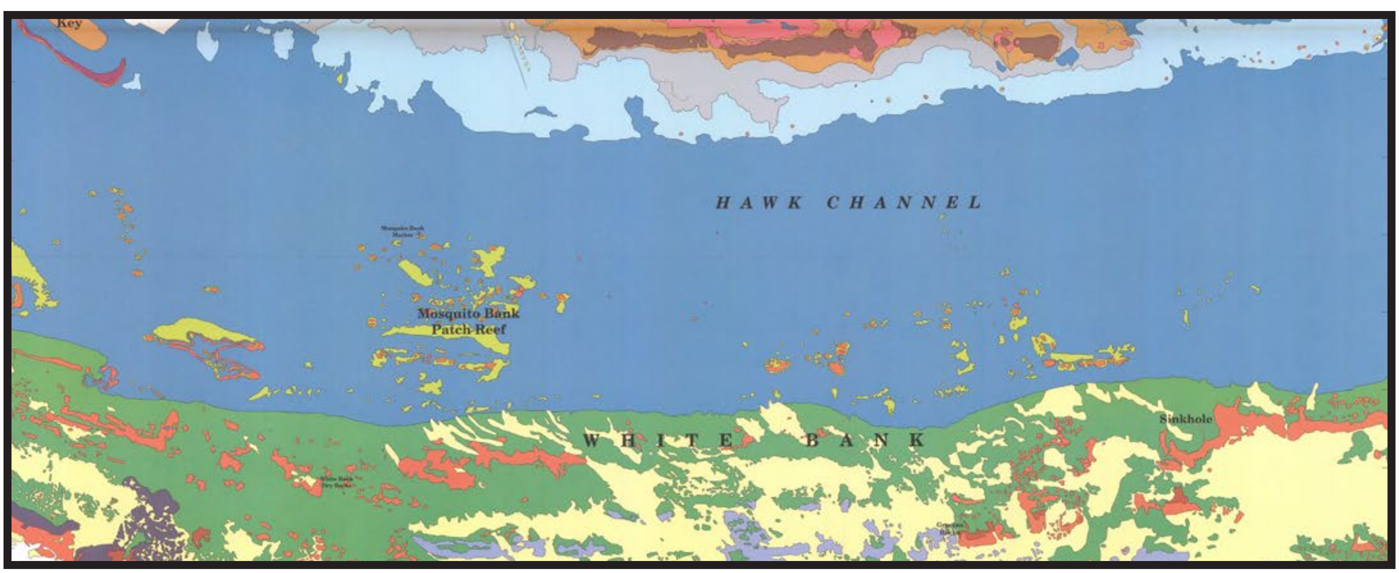
Question 21: Give an example of how the quality of your project is affected when geological mapping is not available.

"Without regard to the sector, nature and size of projects, the project sponsors are unable and/or unwilling to support the research needed to place the geology of the project area in the context of the regional geology for financial as well as time reasons. The contextualization of local geology with regional geology is critical for high-quality project planning and execution. It is therefore crucial to be able to rely on the quality of the regional geological information. Publicly funded agencies' missions are to create quality geological maps. They employ expert geologists who create the maps and revise them over time as newer knowledge and/or technologies become available. High-quality project planning needs the maps created by them."

Question 22: Value of maps for various public and private entities in the judgment of responders. (Scale of 1: low — 5: high)

- National parks 4.0.
- Other federal agencies 4.3.
- State parks and recreation areas 3.9.
- Other state and local agencies 4.3.
- Universities (research and education) 4.3.
- Metals industry 4.2.
- Uranium industry 3.9.
- Critical minerals industry 4.1.
- Sand & gravel and stone industries 4.1.
- Frac sands industry 3.8.
- Oil and gas industry 4.1.
- Coal industry 4.0.
- Geothermal industry 3.9.
- Geotechnical industry 4.3.
- Agriculture industry 3.6.
- Forestry industry 3.5.
- Public utilities 3.8.
- Groundwater industry 4.5.
- Public safety and information organizations 3.8.
- Not-for-profit organizations 3.3.



Portion of: Lidz, B.H., Shinn, E.A., Hansen, M.E., Halley, R.B., Harris, M.W., Locker, S.D., and Hine, A.C., 1997, Maps showing sedimentary and biological environments, depth to Pleistocene bedrock, and Holocene sediment and reef thickness from Molasses Reef to Elbow Reef, Key Largo, South Florida: U.S. Geological Survey Map Series 2505, scale 1:24,000.

CHAPTER 11: AN ECONOMIC MODEL OF GENERAL GEOLOGICAL MAP APPLICATIONS

Christopher Keane (American Geosciences Institute) and Richard Bernknopf (American Geosciences Institute)

ABSTRACT

Geological maps are intermediate public goods that provide information on the surface and near subsurface geology for various applications in different economic sectors. The value of a geological map is inseparable from the expertise used to interpret the map information for a given economic problem. Also, this leads to the critical issue of sufficiency in decision making and the level of investment in an activity. In the case of geological maps, it is rational to only invest up to the needed sufficiency of data collection and interpretation. However, as more detailed mapping is substantially more expensive, the level of sufficiency can be controlled by the available capital. Thus, traditional willingness-to-pay approaches can be problematic in this assessment, and we note that capacity-to-invest may be a more appropriate view. The econometric model indicates that the economic sector and map application are factors for whether the public good form of the geological map is sufficient in most cases. This exercise was not conducted to create a predictive model for value return on geological maps, but rather to understand their position in the economy. As we see from the results, applications in real estate tend to have higher total value than the use in most resource industries, which may differ from assumed conventional views. This study delineates the role and position of geological maps in the U.S. economy and provides insights for future development and investment decisions.

11.1: INTRODUCTION

General geological maps (GGM) are a component of the information infrastructure of the U.S. and are viewed as a public good. Here, we evaluate how users of geological maps behave explicitly among map applications in a variety of sectors in the U.S. economy. GGMs contain information on the surface and near subsurface structure, lithology, and other properties, and can be utilized across a spectrum of scales in a wide variety of applications. Geological maps of a given scale can be generalized if an application needs a broader view and operate as a starting point for investigations requiring fine detail.

A wide variety of economic sectors either directly use or utilize the information derived from geological maps, and those uses continue to evolve with the economy. New energy sources, more mobility, and digitization have necessitated changes to the way geological maps are used, distributed, and developed, leading to the need for new development investments. Long-term demands for fossil fuels and related assets are phasing out of the economy, but issues such as the energy transition and its impacts on mineral resource demands and maturing network technology is leading to social changes, such as the acceptance of the remote workplace that have exposed new types of infrastructure asset demands (https://www.mckinsey.com/industries/private-equity-and-principal-investors/our-insights/infrastructure-investing-will-never-be-the-same).

The U.S. and many state agencies provide geological information that has become the standard of accuracy and quality. Specifically, geological maps produced by SGS and the USGS are viewed as highly reliable by 99% and 98%, respectively, of geoscience data users in 2017 (Keane and Mars, 2018). Privately developed and contract maps are viewed as reliable by only 40% of users and are almost exclusively used in the absence of coverage by SGS or USGS products (Keane and Mars, 2018).

However, this study is asking what is the value of a geological map? Given the nature of the place of geological map usage in the economic value chain, we view it as more appropriate to ascertain how to estimate the value of the GGM input in the economy as an intermediate good as its place within the economy. As a result of the survey done for this study, it appears that the market is dynamic and has changed from the historic context in which geological maps were traditionally utilized by the resource industries to a more diverse range of applications.

In this chapter, we investigate the uses of geological map information to reduce costs and uncertainty for economic sectors that are likely to use the map as an intermediate input to a production process. We provide a case for providing geological map information as a public good. Our primary interest is with geological maps that we define as general information at the 1:24,000 scale or broader and are predominately developed using public funds. Then, we develop and estimate the latent demand[1] for a range of economic sectors in the U.S. that use scientific information. The latent demand or capacity to invest (CTI) in geological maps is based on how valuable the map can be as an input in the production of a good or service, private or public. In our empirical analysis, the *CTI* is the dependent variable that we seek to estimate as a function of explanatory variables, while these explanatory variables are economic measures that rely on the informativeness of the science for development activities and for regulatory decisions and actions.

The analysis presented in this chapter represents one of the four approaches taken in the report to analyze the value of GGMs compared to those described in Chapters 6, 7, 8, and 9. It employs the application of an economic model that incorporates the survey conducted for this study. An econometric model is developed to estimate three investment categories of increasing cost to the user of geological mapping as a function of map-use scale, economic sector of application, and the economic dominance of a specific sector in a geographic region.

11.2: GEOLOGICAL MAPS AS AN INTERMEDIATE GOOD

A key consideration in the economic valuation of a geological map is that it behaves as an intermediate good in a value chain. In economic terms, geological maps are used in decision making as an intermediate economic good (Bernknopf et al., 2020). This means that the scientific data contained in the map are one component of a larger value chain that results in the production of a final good or service demanded by society.

A geological map contains scientific data, but the economic value of scientific data is in its interpretation by competent individuals to support decisions based on that distilled new knowledge (Bernknopf et al., 1993). Without the value of skilled interpretation, the value of the map is limited to the physical product materials and production effort. However, with skilled interpretation, which can only be enabled by using the map, the effective economic value becomes far greater, and thus the value of the map is inseparable from the interpretation effort (Bernknopf et al., 1997).

In an example of the value of map information as an intermediate good, Bernknopf et al. (2007) estimated the value of a geological map in the traditional use of mineral exploration. The results of the study demonstrated that the GGM informs the search for Canadian copper deposits. The value of the map is derived as information used by the private sector in the initial search for targets of mineralization. The map contributes to identifying favorable places for detailed industry analysis of the potential monetary return of investment for resource extraction. The study was validated by mineral exploration firms in the industry.

11.3: MATERIALS AND METHOD

As an intermediate good, the value of a geological map is intrinsically linked to the analysis that it facilitates. Figure 11.3.1 is a schematic view of the value dependencies for geological maps. An economic opportunity, regulatory responsibility, or another purpose can generate the need for understanding the physical characteristics of the land surface and resources in the subsurface. The necessity for this understanding is driven by a geological problem that needs to be addressed to facilitate the economic solution.

Geological maps are a core asset applied toward the solution. A trained geoscientist will apply the information derived from the geological map and, if needed, other supplemental data can provide an analysis that addresses the geological problem. Hence, the geological information reduces the decision uncertainty involved in the economic activity.

Assuming rational economic behavior, users will be willing to pay for a geological analysis, of which the geological map is a required enabler. In the models that we develop, the value of geological analysis is the intermediate good that is recognized in the decision-making process. That is, the geological map is the combination of field data and scientific interpretation that provides a critical input for the analysis of a societal decision.

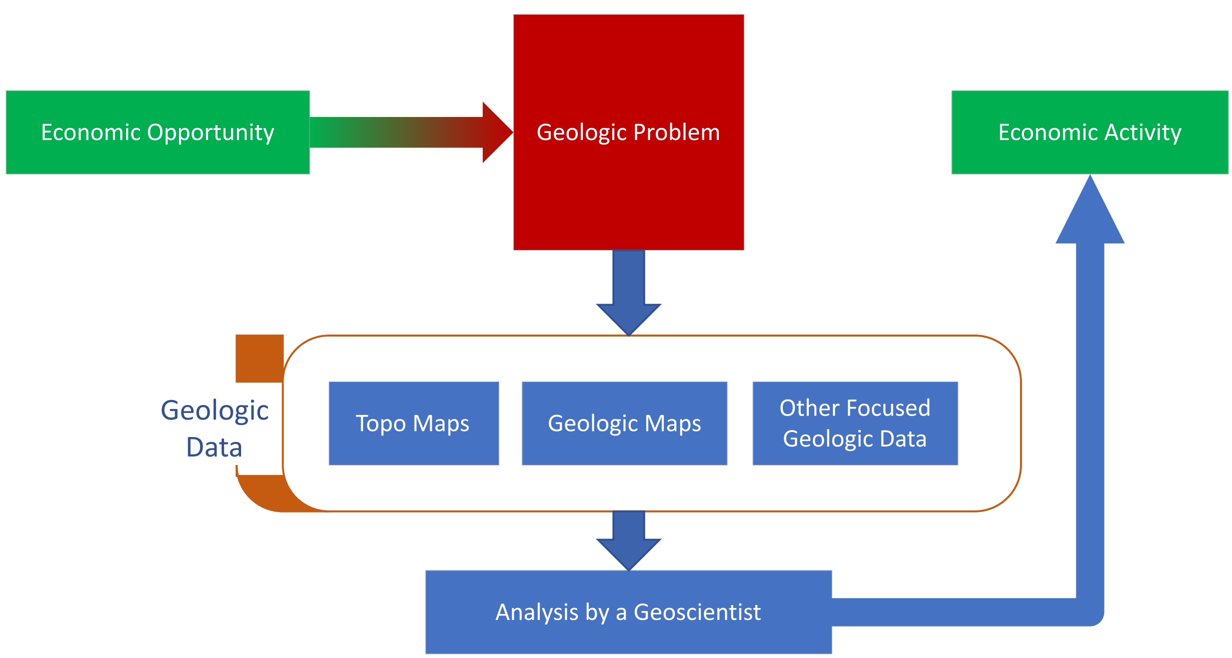
[1] **A demand which the consumer is unable to satisfy, usually for lack of purchasing power** (https://www.kamcity.com/kamwords/demand-latent/).

To conduct an evaluation of the economic impact of a geological map (Figure 11.3.1), an econometric model is used to identify relationships between variables within the model (Gujarati, 1988). An econometric model is the quantitative analysis of actual economic phenomena based on the concurrent development of theory and observation that are related by appropriate methods of inference (Goldberger, 1964). Econometrics can be further defined as the social science in which the tools of economic theory, mathematics, and statistical inference are applied in the analysis of economic phenomena (Theil, 1971). These definitions suggest that there is a connection between underlying behavioral models and the modern practice of econometrics (Greene, 2012). Applied econometric methods are used to estimate the correlation between user behavior and a suite of user characteristics to analyze the need for policy changes, impacts on markets, testing theories, and for forecasting (Greene, 2012). Here, we apply an econometric model represented as a discrete choice of classes of investment by users of geological map information (Maddala, 1983) against seemingly independent factors that lead to specific decisions.

Geological maps are produced at several scales. Some, such as 1:24,000, are mostly produced by public institutions. Larger scale (i.e., finer scale) maps of small areas and locations are more likely to be produced by entities for specific projects, commonly related to activities in the private sector. We seek to understand the relationship between examples of current map applications and how working at scales generated by public institutions and employed by private entities intersect. Map requirements are likely developed on a project-specific basis, and some combination of both types of maps improve economic efficiency. Through this approach, we attempt to determine whether there are dependencies on sectors and aggregate economic activity that may drive map usage trends, or likewise may represent the greatest utility relative to the perceived value of or the capacity to invest in the geological analysis for decision making on a specific project.

Econometric models are based on statistical regression analysis. The regression model in this chapter is a quantification of the relationship between the dependent variable of user behavior and a set of explanatory factors of user characteristics that can affect the behavior. In other words, in a regression analysis, we try to understand the statistical

Figure 11.3.1



Conceptual framework for valuation of geologic map information.

relationship between a main variable (dependent variable) such as the demand for GGMs and other factors (independent variables) such as map scale and map use in economic sectors. The dependent variable is influenced by chance, whereas the other factors are treated as fixed values that we collect in repeated samples. The econometric model is used to test the hypothesis that there exists a significant statistical relationship between the dependent and independent variables. The intent is to estimate the mean of the dependent variable in terms of the known values of the independent variables (Gujarati, 1988).

The goal of the econometric model is to uncover the causal connections between economic behaviors and the data collected for the independent variables (Greene, 2012). It is also necessary to incorporate stochastic elements. As a result, the observed variation in data can be attributed to two factors:

1. Differences in the variables that are specifically included in the model.

2. The randomness of human behavior along with countless minor influences that are not explicitly considered. (Greene, 2012).

11.4: THE GEOLOGICAL MAP: DOES MAP MEET REQUIREMENTS OF A PUBLIC GOOD AND AN INTERMEDIATE INFORMATIONAL GOOD?

The geological map is defined as (1) a public good and (2) an intermediate good in a value chain in the production of final consumption of economic goods and services. Discussion of the public-good attributes of information involves a distinction between general and specific information. A frequent argument is that general information is a public good, whereas specific information is a private good (Bernknopf et al., 1993). There is the presumption that general information possesses more of the characteristics of a public good, having a lack of exclusion possibilities (anyone can use the information) and a lack of congestion costs (there is no cost of competition in the use of the information).

A public good has two key characteristics: (1) it is impossible, or inefficient, to exclude anyone (nonrival in consumption) from consuming the good once it is produced; the availability to other users is not diminished, and (2) the production of the good is characterized by jointness of supply. Jointness is defined as a physical quality of a good, which allows its consumption by one user to cause no reduction in the amount consumed, at the same time, by others (Musgrave, 1959). Public informational goods are nonrival in consumption. That is, any one individual's consumption of the map does not reduce the consumption by others.

Geological information can be both general and specific and thus has a different market scope. A GGM contains general information that is constructed from scientific data at a scale and of sufficient informational scope that is valuable in a wide range of land use and land-management decisions such as highway route selection, waste repository siting, and development impacts. Geological maps also are valuable for a long period of time, given the slow rate of decay of its usefulness and that newer products do not supersede the existing information, but rather add new dimensionality. On the other hand, specific information is much more localized and has a lower probability of utility in further application. The collection and use of site-specific geological information for determining the economic feasibility of siting and constructing a multistory office building in an urban center would be of little use in road planning unless the road is to be constructed in the same location as the proposed building. As the information becomes more specific, the number of users becomes smaller.

GGMs also exhibit nonrival consumption. Broader-scale geological mapping enables a wider range of users to use the information over a large area. The approach of broad-scale mapping does not intrinsically lead to legal exclusion of others from making use of the map information unless it is possible to use and enforce developer patents and copyrights. Such rules for exclusion are necessary for the private sector to have the incentive to produce geological map information. Without the imposition of user restrictions, individuals can obtain map information by not paying (a "free ride") for the information. A private sector producer could not recover the cost of production and would not provide the good. Implementation of an exclusion scheme is difficult in the case of regional geological map information because the range of potential users is large and dispersed; thus there is no way to implement a payment scheme. As information becomes more general, there is a larger group of potential beneficiaries, and there is less likelihood that exclusion is feasible. Therefore, production of geological maps by public agencies emerges due to the excessive cost for private production of broad-scale maps, and the user's incentive to invest only in fine-scale maps for narrow spatial and application purposes. In addition, public goods become cheaper to provide as more people use them. In the case of GGMs, most of the costs come upfront when collecting and interpreting the data. The costs of giving these maps to more people, like printing or digital distribution, are relatively low.

For example, making a GGM of Loudoun County, Virginia, at the scale of 1:100,000 cost about $1.16 million in 1993 dollars to gather and analyze the data upfront (Bernknopf et al., 1993). But once the map was published in 1992, it cost about $8.44 per copy to print and distribute physical copies. To download from the USGS map archive, there is no cost. So, it does not make sense to limit who can use the map after following its release, because it is efficient or less costly to share it with more people.

The jointness of supply condition of a public good also is fulfilled. That is, a map used by one individual does not reduce the value or utility for other users of the map. The per map production and distribution costs of regional geological map information per single use approaches zero over time as uses accumulate, whereas the actual per unit cost of application to the user is almost entirely in the interpretation enabled by the map in economic and policy applications. The value of a GGM is derived by combining the data and scientific interpretation as an input (intermediate good) in a management or development process to produce a consumption good.

The GGM can be interpreted as a forecast derived from geological data applied in the production of final goods and services (Arrow, 1996). In the valuation process, the geological map is an input factor that influences production and management decisions indirectly rather than a market good that affects consumer utility directly, so scientific information is one component of a larger value chain that can be used to forecast economic outcomes. However, this second distinction of geological map information can limit access to users with fewer resources to participate if there is a limitation, cost or logistical, in access to the necessary expertise to produce the interpretations needed for an application.

The level of expertise needed for a geological map can vary depending on the complexity of the geology and the specific economic application. When it comes to making informed decisions based on scientific interpretation, there is a point at which the information gathered is sufficient to make a practical decision. This sufficiency is related to the scale, detail, or breadth of the analysis (including having adequate data). Similarly, when private entities create geological maps, they tend to focus efforts on their needs.

While the scientific sufficiency of a geological map is crucial, private companies must consider the return on investment (ROI) when deciding how detailed required maps should be and if that entails generating new maps separate from existing public geological maps. A market solution can lead to economic inefficiencies in production if the private capacity to invest is constrained by a decision to produce maps only if ROI ≥ 0. If the return on investment is negative in terms of the cost of science competence required by the problem, it is unlikely that a company will produce a new map. Better capitalized organizations are more likely to be able to invest in generating more comprehensive maps when the ROI is positive, both in terms of data collection and scientific analysis, as their capacity to invest will be higher, but the decision to take action will still be dependent on the expected ROI.

When a firm does invest in producing a geological map, to protect the investment in a competitive market, map creators commonly restrict access to their map through licensing agreements. Importantly, the creation of a private geological map does not prevent other entities, either public or private, from generating their own maps for the same area. This situation creates a challenge in the market, because there is limited incentive to produce comprehensive maps for large areas or for purposes beyond what a specific firm needs that is not adequately addressed by existing public maps. Consequently, it is commonly more efficient for the public sector to provide high-quality geological information to a wide range of users in a fair and equitable manner.

11.5: ECONOMIC MODELS FOR VALUING GEOLOGICAL MAPS

To assess the value of an intermediate public good for individuals, economists rely on two main approaches: revealed preference (RP) and stated preference (SP) models, both aimed at assigning a monetary value to the good. RP methods involve studying consumer behavior to estimate the marginal value of the good. This approach identifies how people act in real-life situations to determine the worth of the intermediate public good (Freeman, 2003). On the other hand, SP techniques also aim to gauge changes in well-being and estimate the prices individuals are willing to pay for goods. However, SP differs from RP analyses, because it does not rely on directly observed market behaviors or monetary transactions to determine value but, instead, it gathers information through surveys and hypothetical scenarios to understand preferences and willingness to pay (WTP).

RP models use Benefit-Cost Analysis (BCA) that systematically categorizes the benefits and costs to estimate the net benefits, and this includes the proposed geological map information compared to a baseline information case. We assume there is existing geological map information available that is older that would represent an outdated scientific interpretation. To do this, RP models gather scientific and technical data related to the geography and geology in question. These data are crucial for understanding how the geological map influences decision-making. Monetary values are assigned to these benefits and costs through specific case studies, forming the foundation for what is known as the "Value of Information."

SP models, on the other hand, involve surveys of current and potential users of geological map data. These surveys aim to gauge the WTP by users for access to improved information. Questions in these surveys may revolve around the potential savings users expect from reduced time, labor, and informed decision making. These surveys can take various forms, such as face-to-face interviews, telephone interviews, online surveys, mail surveys, or some combination. SP techniques depend on asking individuals hypothetical questions to create a hypothetical market (Pearce et al., 2002).

In SP models, the economic value is determined by the responses to these survey questions, which provide an estimate of how much individuals are willing to pay to access an intermediate public good (like geological map information) that directly impacts their well-being. This WTP is a measure of how much someone is willing to spend to improve the state of a particular good compared to leaving it as is, essentially capturing the value they place on this improvement (Freeman, 2003).

SP techniques can be controversial for economic valuation, because survey respondents put themselves into hypothetical situations and potentially react differently than in real transactions (Freeman, 2003). In these types of circumstances, there is evidence that consumers tend to overestimate the value of the good or service being evaluated (Freeman, 2003). WTP surveys are effective but costly. However, if a WTP survey is undertaken, considerable attention is needed to eliminate bias from the survey to preserve the credibility of the results. Several potential sources of bias exist in these kinds of studies. The surveys can ask users to estimate the benefits they would experience from updated GGMs that do not actually exist. Answers to such hypothetical questions may present a problem known as hypothetical bias. Furthermore, since map users are able to benefit from new mapping, there may be a strategic bias in which individuals may report a higher level of expected benefits from new development projects to influence any decisions regarding the project (Bernknopf et al., 2020).

The intended outcome of this study is to evaluate the WTP for a geological map by the map-user market as a measure of its value to society and the economy. The core dataset is from a survey based on a SP model, and this econometric analysis is limited to the results of the survey. Survey responses included a variety of variables, including scale, economic sector, location, and data on value ranges. Use of the WTP by the respondents posed challenges for developing an economic model to identify the factors impacting decisions on the level of investing in acquiring map information. Consistent definitions of spatial extent and cost basis required identifying an effective WTP proxy metric, which for this model, broke between the medium and small-scale maps generally produced by public entities and the detailed scale that are more likely produced by private mapping efforts. The survey responses are not independently observed actual market transactions related to the acquisition of geological maps, but rather cost statements or value assessments for a mix of existing, potential, and declined activities. A range of responses were received, which may reflect some variation by respondents in the interpretation of the questions and descriptions of project scope.

The survey responses did shed light on behavioral thinking about the role of geological maps in solving economic issues. Some respondents reported on direct nominal acquisition costs of geological maps for use in their projects. Others reported on values representing the totality of the intermediate good, including the geological analysis leveraging the maps. With the discussion of use of multiple map scales, varied spatial extents, and similar factors, for the purposes of the economic analysis, we recognize the sufficiency issue in geological analysis, and thus the response may better reflect a capacity to invest than a traditional willingness to pay.

In any problem-solving process, there is a threshold of information sufficiency to make a confident decision. This information, in the case of geological maps, is an integrated combination of data, analysis, and scale. There is likely a continuous probability curve representing certainty of a correct decision based on data and analytic intensity applied to the solution for geological mapping, scale, and detail of the map.

Given that many geological-economic problems represent costs such as direct application of the information or liabilities that need to be offset (such as meeting environmental regulations or engineering standards), there is a disincentive to overinvest in the analysis. In scenarios of sufficient capital to address a cost-centric problem, the reported value will represent a willingness to invest. Likewise, if the capital available is limited, as would be expected in most real-world situations, the actual value reported on data and analytic input reflects the capacity to invest from which point there will be a defined certainty of a correct solution decision.

11.6: AN ECONOMETRIC MODEL OF MAP APPLICATIONS

This project assessed the value of geological mapping through multiple methodologies. The approach in this chapter, utilizing an econometric model, is focused on understanding the importance of geological maps as a significant input factor in a production process in an economy and what might be influencing it in that role. The model is meant to reveal general structural trends and is not a precise predictive tool or one that provides nuanced estimates of the exact magnitude of influence of the independent variables.

Our interest is estimation and the analysis of a specific model to ascertain the influence of factors for deciding the mapping investment for a given problem. As mentioned previously, the responses reflected the actual use of geological maps, which does not necessarily reflect a traditional willingness to pay, but likely limitations on a capacity to invest that yields a defined certainty level. Within narratives in the responses, we see examples of descriptions of work abandoned because of inability to invest enough to obtain informational sufficiency. As such, the economic value of the map information informs value-added production costs of a final consumptive good or government policy choice.

In this analysis, we assume that geological map users are competent and apply appropriate scales, based on the nature of the problem to solve and the ability to have funds to acquire the data and interpret the data to produce the needed geological maps. Furthermore, we assume that public institutions produce public good maps and likewise preferentially use them.

11.7: TRANSFORMATION OF DATA FOR ECONOMETRIC ANALYSIS

The survey responses provided a wide set of variables for consideration in performing an econometric analysis. One characteristic of many of the survey responses was individual fields of a given response could contain multiple discrete answers, such as scales of maps used. Additionally, individual respondents were not always clear in their answers whether the responses reflected the activities of a specific project or that of the whole of the responding entity, an observation supported by reviewing associated narrative response fields. To facilitate analysis, responses were "unrolled" such that for each response, a new data row was created representing each possible perturbation reflected in the multivalued response fields. Though this approach negatively impacts the statistical strength of the analysis, it also reduces the relational power between variable values given the imprecision of the original responses. For the sake of analysis, each of these unrolled data rows was recognized as a distinct observation in the dataset.

For the economic analysis, we filtered the unrolled dataset to only consider complete responses in which no fields of data were missing. This filter yields an analytic dataset of 2,937 responses. Each response had data covering a range of factors, including location (by state), map scale used, dollar value brackets for the activity, economic sector of the activity including state and local government, federal government, real estate industry, energy and mining industries, education, and professional services.

11.8: MODEL VARIABLES

To assess the factors that influence the demand for geological maps, we have utilized the survey WTP responses as discussed in Chapters 6 and 10 to undertake an econometric analysis. Demand for geological information is represented as the capacity to invest (CTI) in the production of geological

▶ Table of Contents

map information from public, private, or both sectors. However, a latent demand exists in the form of a consumer's CTI for map production that is based on the SP responses explained in Chapters 6 and 7.

Our analysis also assumes that those who participated in the survey are the best sample of individuals to assess the CTI for geological maps. The survey is not comprehensive in coverage of all users of geological maps, and we have assumed users not represented in the survey sample have preferences aligned with the respondents of the survey as otherwise may be limited, as explained in Chapters 2 and 6.

As the primary point of the overall study is the estimation of the economic value of geological maps by consumers, we considered an econometric analysis that would represent an approximation of the consumer decision process in paying for geological maps — namely whether they are using pre-existing maps or generating new maps, or some potential combination of both.

We conducted an econometric analysis to establish an economic variable of mapping choice behavior. Survey respondents indicated a WTP for each map, with response options binned as:

- < $1,000
- $1,000–$5,000
- $5,000–$10,000
- $10,000–$25,000
- $25,000–$50,000
- $50,000–$100,000
- $100,000–$200,000
- $200,000–$300,000
- $300,000–$400,000
- $400,000 and higher

We analyzed the distribution of responses and found distinct populations in the low end ($5,000 or less) and the high end ($25,000 or larger). We have assumed that these WTP levels are indicative of behavior toward the mapping needs of the respondents.

The dependent variable in the model implies that a latent demand is associated with the CTI for an input cost of geological map information to produce a final good. The CTI in the econometric model is represented by three options derived by the indicated WTP from the survey as clustered into three probable cost-behavioral brackets:

Off-the-Shelf: For responses with a survey response to WTP of $5,000 or less, we classified the response as choosing an off-the-shelf map, as this expense might cover nominal acquisition costs of public maps or commercially available data through a vendor but is distinctly insufficient for original mapping of any material extent. About 40% of the responses were in this value range of $5,000 or less.

Custom Maps: These data are for responses with valuations that are $25,000 or larger, which is a cost scope that can represent material professional investment of time and resources, likely more than 25% of a professional FTE. We expect these responses involve either active augmentation of existing geological maps and/or the development of new maps at standard or site-specific scales. About 20% of responses were in this value range of $25,000 or more.

Transitional Mapping: These observations are projects that reported values between $5000 and $25,000, representing an intensive investment in the geological data component, but not likely to the level of extensive custom mapping. We hypothesize that many of these responses are of either large spatial extent with multiple analysts and/or required the selection of additional mapping detail to address specific issues to ensure scientific sufficiency for the problem.

The independent variables utilized in this econometric model included reported classification of the use of a map scale, the economic sector reported for the application, and the per capita GDP attributed to each of the reported sectors.

Map Use Scale: Each response indicated the map scales used in their response — 1:5000, 10,000, 24,000, 100,000, and 500,000. Each map scale represents an application space, and the map scale was coded as local scale (1:5000 and 1:10,000), general utility scale (1:24,000 or smaller), and cross scale if they indicated use of maps within both bins. As few public maps are generated at greater than 1:24,000 scale, local scale and cross scale responses are likely indicative of at least some private mapping.

Economic Sector: Responses indicated the economic sectors of application: state/local government, federal government, real estate, education, energy, mining, transportation, and professional services.

Per Capita Sectoral GDP: An additional economic factor used in the econometric model captures a measure of the economic dominance of a specific sector in a geographic region. We characterize this explanatory variable as a per capita sectoral GDP, i.e., the associated GDP component of the economic sector normalized by the population of the region. As described in Chapter 8, the regional variation in the economic responses to the survey were limited, inferring that geological map values have little specific regional dependency overall, but that does not indicate if the proportional economic activity, which varies by region, might be a factor. For example, real estate is not as large an economic driver in Nevada compared to Maryland because of differences in population density, but mining is a bigger part of Nevada's economic activity than in Maryland because of the availability of extractive resources.

11.9: ECONOMETRIC ANALYSIS

The econometric analysis is initiated with a statement of a theoretical proposition. In the developed model, our hypothesis is: Geological map information is economically valuable to public and private economic decisions.

Geological map information is derived from publicly observable phenomena, as it is intrinsically a public good since the fundamentals of a map are non-rivalrous and non-exclusionary. Geological map information should be provided as a public good because of the many uses of general information and the inefficiency to exclude anyone (nonrival in consumption) from consuming the product as a market good.

The concept of multiple regression constitutes the underlying platform for our multinomial choice model. A multinomial choice model assumes that individual behavior is to choose among more than two choices and seeks to make the choice that provides the greatest utility. As defined above, the application is the decision-maker's choice among three investment alternatives of increasing levels of user investment for geological map information. These choices define a ranking of the CTI for geological information. The three classes of investment in producing reliable geological map information include: (1) off-the-shelf maps provided mostly by SGS and USGS or public data vendors (least costly); (2) transitional map projects that combine public sector maps and user staff/contractors (some cost to user); and (3) custom mapping that uses internal staff and/or contractors (costliest).

A multinomial logistic model is employed to estimate the probability of user type to invest in geological information by imposing the logistic distribution on the qualitative choice (Greene, 2012). Estimation of the parameters of the chosen model is the chance that a user is in one of the three categories of CTI for a geological map, which reflects the amount invested in a map application as an input in the form of an informational intermediate good. The model uses the CTI as the dependent variable and uses the survey questions on map scale use (MSU), economic sector of application (ES), and our calculated per capita GDP of the application sector for 2019, the year of the survey (GDP) as a measure of potential aggregate available capital in a sector.
The model at national scale is:

$$\text{Capacity To Invest } (\mathit{CTI}) = \text{Map Scale Use } (\mathit{MSU}) + \text{Economic Sector } (\mathit{ES}) + \text{Per Capita Sectoral GDP } (\mathit{GDP}) + e \quad (1)$$

where e is a statistical error term.

Table 11.9.1 presents the estimated parameters and model verification through statistical inference. These estimates provide empirical evidence that aligns with the economic theory, reinforcing the idea that a geological map qualifies as a public good (Gujarati, 1988).

To arrive at these estimates, we employed an ordered logistic regression model using the unrolled survey responses comprising 58,191 observations from the year 2019. The verification of our model hinges on assessing whether it aligns with the expectations set by the theory under examination. We subject the results to statistical inference tests to determine their credibility, significance, and to rule out the possibility that they are merely the result of random data sampling.

Results are shown for variable coefficients, standard errors, and inference statistics in Table 11.9.1. The Z-statistic tests if the effect of the variable (coefficient) has no effect ($Z = 0$). A larger absolute Z value is indicative of an effect. The sign of the coefficients indicates whether that variable increases the probability of making a specific decision on CTI (positive coefficient) or increases uncertainty (negative coefficient). The $P > |z|$ statistic is a measure of the probability of the predictive influence of the z value.

Table 11.9.1. National Scale Ordered Discrete Choice Model of Three Categories of the Capacity to Invest in Geological Map Information

	Coefficient	Standard Error	z—value	P > |z|	Confidence Interval [0.025—0.975]
Local Scale (≤10"K")	−0.3096	0.021	−14.534	0.0	−0.351–0.268
Regional Scale (24K)	0.4372	0.011	40.605	0.0	0.416–0.458
State Local Govt	0.0985	0.074	1.324	0.185	−0.047–0.244
Federal Govt	−0.0212	0.023	−0.915	0.36	−0.067–0.024
Real Estate	−0.041	0.117	−0.351	0.725	-0.27–0.188
Education	−0.0581	0.04	−1.465	0.143	−0.136–0.02
Energy	0.0833	0.039	2.153	0.031	0.007–0.159
Mining	−0.0324	0.041	−0.796	0.426	−0.112–0.047
Professional Services	−0.0959	0.023	−4.238	0.0	−0.14–0.052
geopercapita	−7.37E-05	2.01E-05	−3.66	0.0	0.0–3.42E-05

Log-Likelihood: −60238
AIC[2] : 1.21E+05
BIC: 1.21E+05
Number of Observations: 58,191
Degrees of freedom Residuals: 58,179
Degrees of Model: 12

The model in equation 1 establishes national level relationships between map-use characteristics and the choice of mapping used: off-the-shelf, transitional, or custom. Inspection of Table 11.9.1 revealed that map scale use for local or district only criteria had extreme predictive power relative to the multiscale use default in the categorial framing of the independent variable. As the CTI bins were defined on expectations of using available maps (off-the-shelf) to custom maps that are more likely local in scale, this relationship appears rational. Site-specific information from local scale (10,000), which is more likely to have a specific application, has a negative and significant impact on CTI. This phenomenon may be due to the limitation of land use to an individual project. On the other hand, district scale geological maps (1:24,000) have the opposite effect. By design, a broader geological map contains more general information and is of greater use to more users in specific economic sectors. This variable is positive and significant in predicting the specific CTI in maps in both private (e.g., locating investment focus by comparing regional location options) and public (e.g., regulation of land use and land cover for economic development) sector applications.

Specific economic sectors had varied predictive value of the geological map input factor in predicting the three CTI mapping options. For example, professional services associated with the application of extant geological maps is negative and significant as expected, predictive z value = 0.0 as seen in Table 11.9.1. Given the important position of the professional services sector in the application of geology, this finding is not unexpected. Currently, 41% of all geoscientists in the U.S. are employed in the professional services sector, and their work is focused on applying appropriate professional knowledge to the problem. Based on this professional knowledge, the geoscience includes an expected rationale for right sizing of the geological mapping needs, but these needs are also unlikely to be capitalized to produce custom maps of any major scale.

The energy sector exhibited a significant and positive relationship with CTI that would be due to the geographic constraint of resources and the infrastructure needed for exploration, production, and distribution, yielding a p-value of 0.031, and thus significantly different at the 95% confidence level. Additionally, the energy sector relies more heavily on subsurface geophysical data, coupled with depressed domestic onshore exploration demand during the time of the survey. This is not true for the mining sector (i.e., minerals industry). Not only is the minerals industry in active exploration activities, but the inherent nature of its work is also more site specific except for regional evaluation that can focus on identifying exploration targets, which yields a non-significant probability of 0.426.

Governments are, for the most part, users of public good maps. Federal users rely on SGS and USGS maps and are unlikely to invest their own resources, resulting in a probability of 0.36. While in the case of state governments and local governments, institutions also would use district maps from federal and state map producers, with a non-significant probability of 0.185. Real estate users are unlikely to produce their own maps due to the specific nature of investments with non-significant probability of 0.725. Educational institutions are likely to use off-the-shelf maps for instruction and site-specific information for specific research projects with low, but not fully significant probability of 0.143.

The final independent variable, ***Per Capita Sectoral GDP*** (GDP) is negative and highly significant, with a probability of 0.0. This relationship is due to the types of industries and land uses that dominate the national landscape. To reiterate, the model represents a national level set of results, and regional responses vary.

The econometric model indicates that the application scale and wealth of the application sector are drivers for a capacity to invest. Problems that are rationally recognized as needing custom mapping make a better argument for increased capital investment. Likewise, sectors with great economic power are also likely to face less friction on investment to meet the sufficiency needs, especially in problems requiring finer scale mapping information.

11.10: RESULTS: USE OF GEOLOGICAL MAPS IS MEASURABLY RATIONAL

With the driving mechanism of the economic activity related to the application sectors, we extended our analysis to evaluate how the economic value of each sector can be expressed by the various levels of investment by that sector in geological mapping. This is propelled partly by existing biases within the geological community related to the importance of the resource sectors in the overall demand and economic return for geological maps.

Using the GDP component of each sector, as provided by the US Bureau of Economic Analysis for 2019, we identified the sectoral contribution to per capita GDP. Then, analyzing the actual survey response rates by economic sector and whether the project used off-the-shelf, transitional, or custom mapping, the allocation of each mapping type was calculated for the sectoral GDP. We assume that the proportion of map types (off-the-shelf, transitional, and custom) would apply to the economic sector nationally, regardless of the scale of activity within that sector in 2019.

Table 11.10.1 shows the results of this analysis and especially the value recognized that is clearly the public good in the off-the-shelf category, representing 54.7% of the GDP-weighted value of all geological mapping, and for projects that likely included all or some publicly produced geological maps, representing 75.6% of the economic value, or $19,243 per person for 2019.

Table 11.10.1. Sector Per-Capita Allocated by Rate of Map-Scale Use Profile

	Off the Shelf	Transi-tional	Custom
Mining	$131.52	$133.47	$94.01
Energy	$256.63	$190.34	$134.03
Real Estate	$4,781.26	$1,218.54	$2,196.20
Construction	$1,193.58	$674.08	$1,006.34
Professional	$1,432.67	$1,033.70	$687.64
Transportation	$754.53	$354.74	$395.72
Education	$569.16	$257.33	$47.50
State/Local	$3,485.42	$1,216.62	$1,056.96
Federal	$1,316.90	$242.95	$607.15

A further point of discussion is the distinct regional applications of geological maps. Using this same approach, we analyzed the data to look for regional dependency on the scale-value proposition. We examined the ratio of use of local (and likely custom) maps to regional (and likely off-the-shelf) in the responses for each region and compared those to the ratio of use of local (and likely custom) maps to the sum of known regional and cross-scale maps, which will include the publicly produced maps.

This second ratio focuses on the level of use of solely custom mapping to the utilization of the public good. Table 11.10.2 shows the results of this analysis. In general, public good maps are used 8-to-12 times more frequently than custom maps in most regions. However, there are two notable regions where this trend deviates. The South Central, which is dominated by energy sector responses, has distinctly higher rates of custom map use, likely reflecting the nature of the applications, namely focused on engineering and environmental site assessments for energy infrastructure such as wells and pipeline footings. Similarly, the use of custom maps in the Northeast versus strictly off-the-shelf maps is inverted, indicating a much higher use of custom mapping. A likely driver of this phenomenon is the large demand for geological maps in real estate, and when coupled with the high property values in the Northeast, capital for more local geological mapping may be available, especially with numerous building codes to address issues such as radon or the redevelopment of industrial brownfields that necessitate greater geological detail for assessment.

Table 11.10.2. Regional Applications of Geological Maps

Region	Local:Regional	Custom Usage
Great Lakes/Great Plains	0.14	0.04
Intermountain West	0.22	0.07
Northeast	1.43	0.27
Pacific Rim	0.13	0.04
South Central	0.64	0.20
Southeast	0.21	0.06

Table 11.10.3 presents data on how geoscience-influenced sectors intersect regionally, represented as a percentage of the regional GDP for 2019. Using the identified sectors in the econometric model as reported sectors of application of geological maps, the regional contribution to GDP from the U.S. Bureau of Economic Analysis of those sectors was evaluated against the total regional GDP that is calculated as a first-order estimate of potential economic influence of geoscience by region in the U.S. For instance, in the Great Lakes region, geological maps are used in sectors impacting just under 34% of the GDP, whereas in the Mountain West, it affects over 43%. While the specific applications of geoscience can differ widely, many sectors within these regional economies derive significant benefits from geological maps.

Table 11.10.3. 2019 Regional Percentages of GDP Impacted by Geoscience.

Calculated from U.S. Bureau of Economic Analysis data

Region	% of GDP Geoscience Impacted
Great Lakes/Great Plains	33.7%
Intermountain West	43.2%
Northeast	37.8%
Pacific Rim	37.3%
South Central	40.6%
Southeast	38.4%

11.11: SUMMARY

Geological maps are an integrated product of scientific data, analysis, and interpretation. The information value can be considered non-separable among these components that are used to create the value of a geological map. The data and the science provide an intermediate public good. SGS and the USGS provide the intermediate public good to public agencies and private economic sectors.

Based on the characteristics of an informational intermediate good, geological maps have their greatest economic value if produced as a public responsibility to provide accurate and informative information to maximize the number of uses and users as possible. Furthermore, geological maps as a public good is not an endpoint but rather an intermediate good of production that supports economic sectors and is useful in regulatory and land status decisions.

Geological map sufficiency is based on the adequacy of the map and the scientific competence of the map maker to address the economic decision problem at hand in the application. As reported, the market for maps indicates that geological maps produced by the SGS and USGS provide sufficient detail, reliability, and consistency to make actionable and supportable decisions. While scientific sufficiency of geological maps is critical, a private capacity to invest to produce a map comparable to the public good map has a limiting threshold that is based on the required return on investment for a particular firm.

A range of logistic multinomial regressions were estimated and tested to establish the capacity to pay for a geological map. The statistical analysis of the CTI affirmed national consistency using a full, but sparse dataset. Aggregate behaviors of respondents were generally very consistent across all regions of the U.S. We found regional differences, such as the demand for finer scale mapping in the Northeast U.S. for issues such as radon requirements in the real estate sector. Additionally, we found that lower sector per-capita values are more likely to use the less costly off-the-shelf maps.

The econometric model identified behavioral relationships in the stated preference dataset. However, there are limitations to the analysis. In conducting a range of model regressions, various model runs generated identity matrices. There were also models containing internal perfect correlation between independent variables, which was problematic. Also, there were models that exhibited instability from data sparseness. Additional model runs are available upon request.

We have developed a macroeconomic model that rationalizes the production of sufficient geoscience as a public good by both SGS and the USGS. The capacity to invest demonstrates how the size of economic entities influences the availability of geological information and equal access to a fundamental part of the U.S. data infrastructure. Finally, further research on the value of geoscience information at the Congressional district level would provide significant support for the public sector supply of geological map information.

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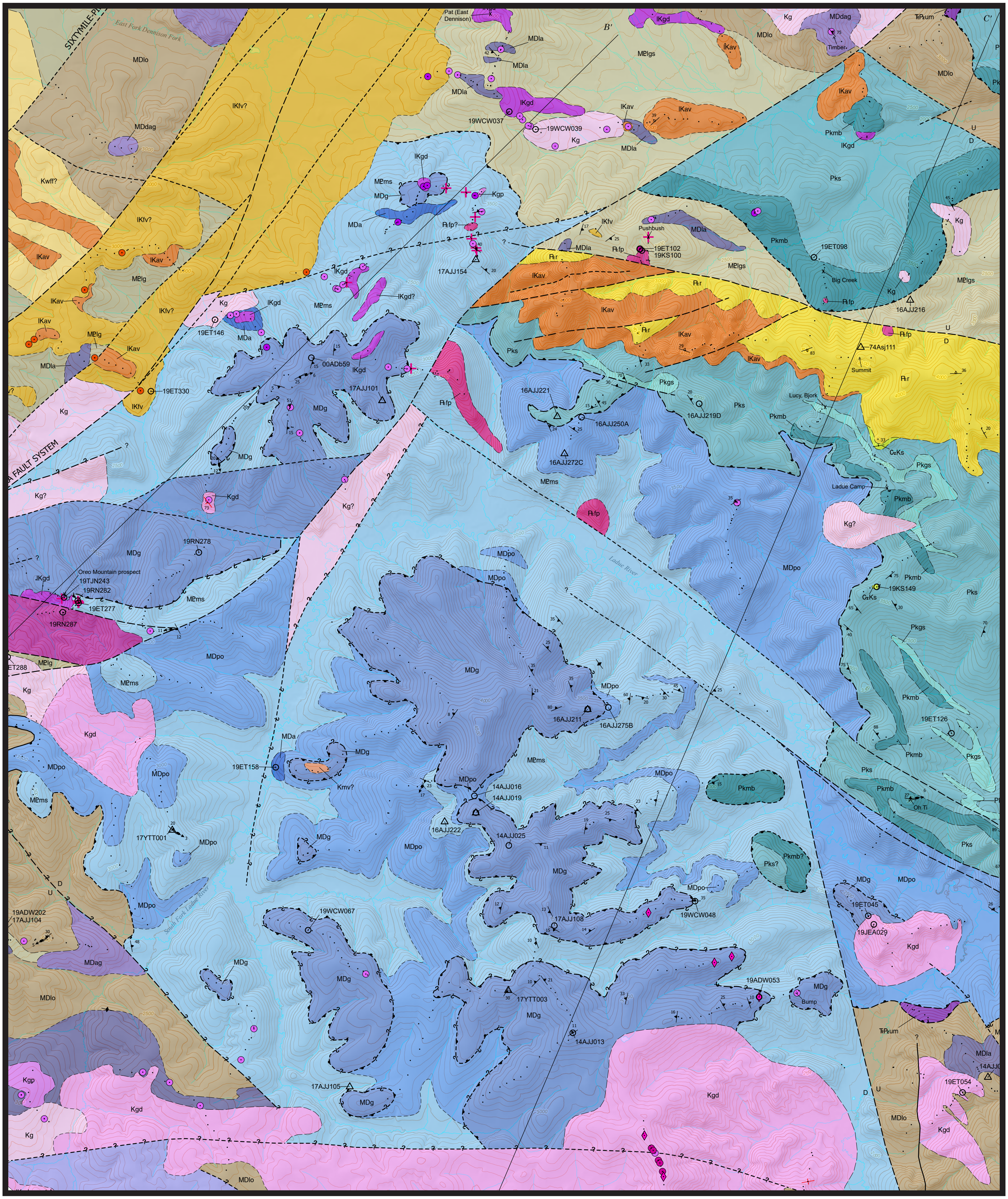

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CHAPTER 12: STAKEHOLDER INPUT ABOUT FUTURE GEOLOGICAL MAPPING

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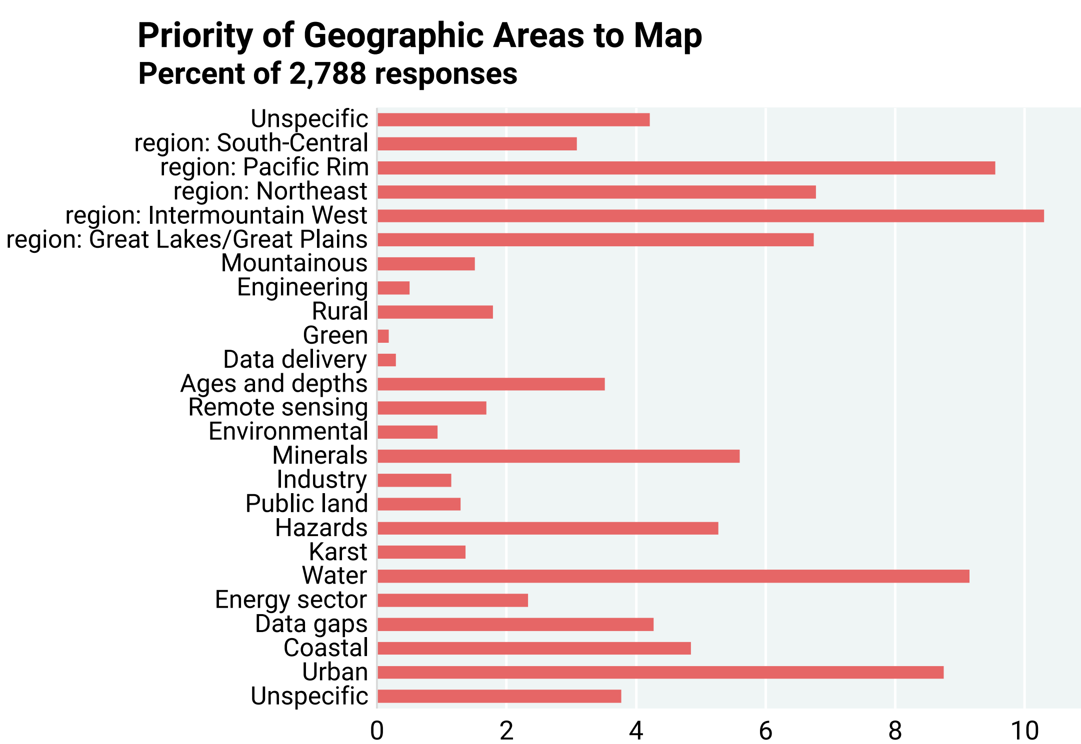
ABSTRACT

Stakeholders asked to list priority geographical areas for future mapping indicated that it was useful in some cases to focus on geological phenomena such as karst or a commodity like water and minerals, which occur in many locations. Other stakeholders identified the Intermountain West, Great Lakes, and Pacific Rim regions for priority mapping. An important desired national focus was on urban areas. Mapping technologies have been changing, as have map applications. Stakeholders provided input on how mapping should evolve in the future, with digital maps and online access as the most frequently expressed priorities. Another suggestion included the need for revision of older maps. Some respondents also provided general input about various aspects of the questionnaire, saying for example that it was too long. Promotion of mapping skills at universities was reported as a future need. Collaboration with private industry and data coordination between various agencies at state and federal levels was suggested for improved efficiency. Finally, it was recommended that there should be a universal system of symbols and colors on geological maps representative of different lithologic types.

Figure 12.1.1



Geographic priorities for future geologic mapping.

12.1: STAKEHOLDER INPUT

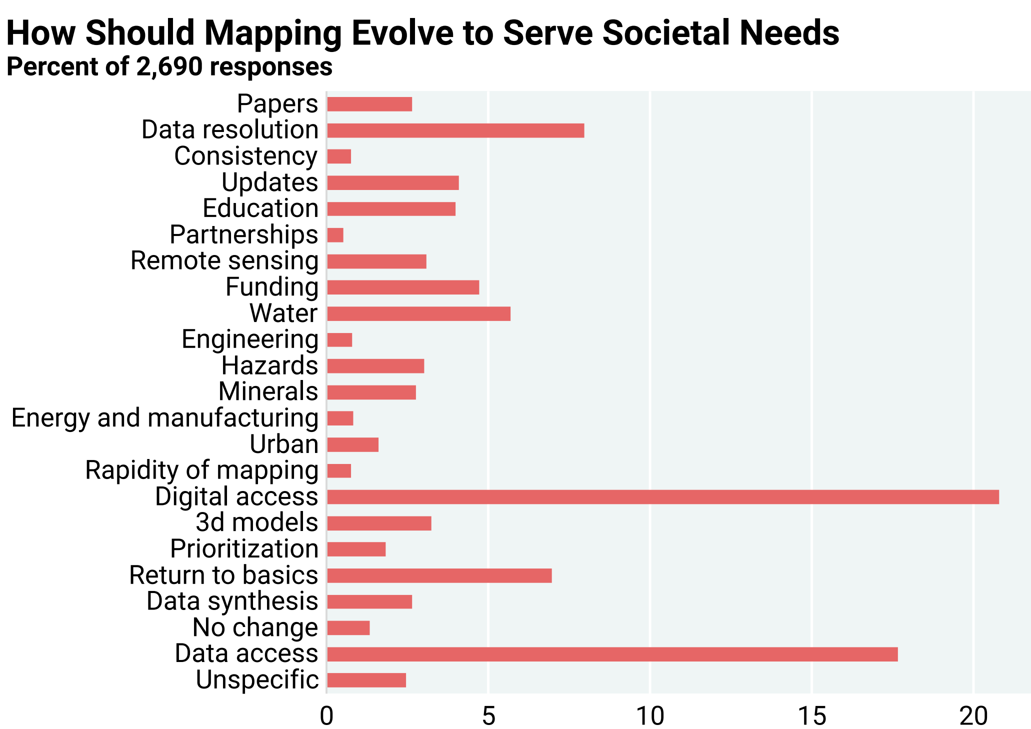
The stakeholder survey primarily focused on assessing how geological maps are used, what benefits they offer, and how map users judge their benefits both qualitatively and quantitatively. However, question 23 in the survey asked stakeholders to list priority geographic areas that should be mapped in the future. As publicly funded agencies that generate geological maps, it is necessary to direct future mapping efforts in accordance with user priorities. Figure 12.1.1 graphically presents their responses.

Stakeholders had a clear perspective of priorities as indicated by the small number (3.8%) of "unspecific" responses out of a total of 2,788. Their responses indicate that it is useful, in some cases, to focus on geological phenomena such as karst or a commodity like water and minerals, which occur in many locations. Accordingly, Figure 12.1.1 shows frequent reference to water, karst, hazards, and minerals in general. In addition, certain regions, such as the Intermountain West, the Great Lakes region, and the Pacific Rim have been identified for priority mapping. An important desired national focus is urban areas. Many stakeholders point out that adequate maps are not available in urban areas, where high-value construction takes place, flood hazards exist, and the use of accurate geological information is highly beneficial.

With advances in technology, as well as changing societal approaches to material consumption and environmental impacts of human activities, it is important to learn the views of map users on how future mapping should evolve (question 24). As Figure 12.1.2 shows, 1,516 respondents provided 2,690 suggestions. About 24.0% desired to see more digital and 3D models in the future. Online access to data is another preference by many, as shown in 17.7% of the responses.

Finally, 505 stakeholders (as summarized below) provided additional input in response to question 25, which asked for additional comments. The length of the survey was found to be too long by several respondents. Likewise, the difficulty assessing the monetary value of maps was highlighted. However, most respondents also realized that the diversity of geological maps and their applications made it inherently difficult to assign a value to maps in general. Continuous revision of maps was pointed out as essential, especially by respondents whose narratives referred to their many years

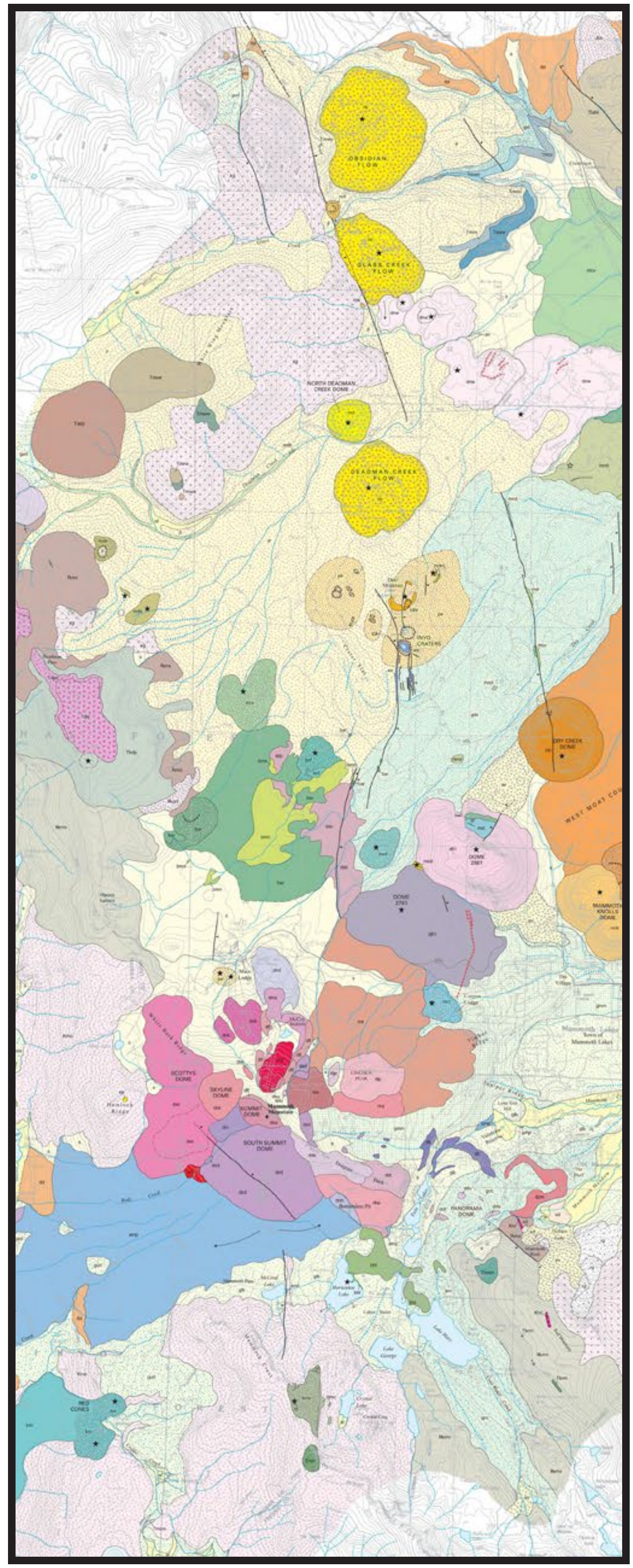
Figure 12.1.2



How future mapping should evolve.

of experience. In addition, several respondents found map accuracy to be lacking, which in their opinion is the result of a lack of emphasis on mapping skills in colleges and universities. In this context, a few commented that older maps were more accurate in some cases than newer ones and recommended that old data and map versions be preserved and made available online. Some important recommendations are summarized below:

- Map revisions are extremely important.
- Coordination and bringing together databases available at various agencies are needed.
- Simplification of map downloading is desirable.
- Collaboration with private industry for geological data in exchange for tax breaks is desirable.
- Mapping skills are not being adequately nurtured at universities.
- Increase communication with local authorities and educate them about map use.
- Reach out to schools.
- Preserve old maps and data, make them available online, and build on it.
- Make sure that State Geological Surveys and the U.S. Geological Survey do not intend to charge more for maps.
- A universal system of symbology and colors to represent different lithologic types on geologic maps would be most appreciated!
- Introduce quality controls in mapping with field verifications.



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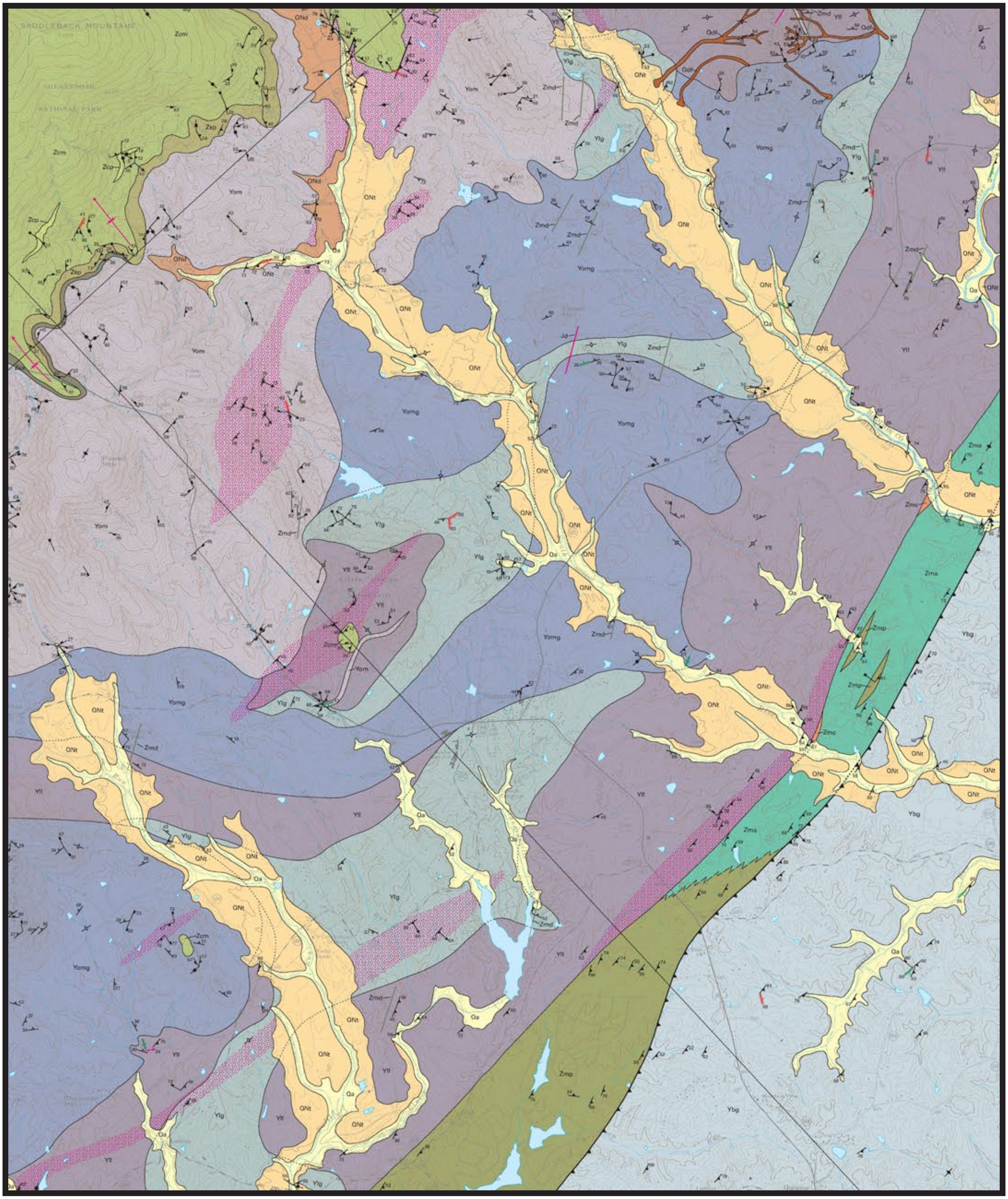

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CHAPTER 13: LESSONS LEARNED AND SUGGESTIONS FOR FUTURE ANALYSES

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ABSTRACT

Although significant effort went into developing the cost sheet and stakeholder questionnaire, important lessons were learned that could benefit future studies. For example, the time and effort needed for State Geological Surveys (SGS) and the U.S. Geological Survey (USGS) to complete the cost sheets were significantly underestimated. Although federal funding through the National Cooperative Geologic Mapping Program was relatively easy to track, other sources of funding were more challenging to tally. Partitioning annual funding was challenging as many of the responses included funding spanning multiple years. Cost reporting was also not consistent over the 26-year period, with the earlier years posing the greatest challenge. Reported costs for geological mapping should therefore be considered a minimum but probably are not significantly lower than actual. Two major omissions on the cost sheet included requests for: (1) the number of geological maps produced at various scales relative to funds allocated, which precluded estimates on the average cost of generating a geological map at a specific scale; and (2) the number of maps sold or downloaded. Some of these data were obtained later, which extended the time needed for the study. The stakeholder questionnaire was comprehensive to capture the many user groups and applications of geological maps for the entire nation. However, many considered it to be too long with too many questions. Also, some respondents worked in many parts of the United States or in more than one sector, so it was not easy to apply answers to an individual state, region, or sector. Other complications included the possible lack of knowledge by some respondents of the complex processes required to generate geological maps coupled with the long-standing tradition of such maps existing as a public good. Thus, estimating the willingness to pay for a geological map was difficult for some respondents, which is compatible with the wide range in estimates. Narratives were requested on eight questions to help clarify responses, but 14,000 individual descriptions led to a lengthy process of evaluating these results.

Lessons learned from this study may enable future, more robust economic analyses of geological mapping. Major elements for any such study include: (1) cost information from SGS and the USGS; (2) sampling the many sectors of society that use and benefit from geological maps; (3) crafting a questionnaire on perceived benefits broad enough to apply to diverse sectors yet short enough to facilitate completion; and (4) obtaining data on geological map demand and use. Although cost sheets should be kept simple and focused on costs to allow for timely completion, they could include data on the number of maps produced as well as information on how many were downloaded and sold. SGS and the USGS should be encouraged to maintain datasets on the costs while tracking map downloads, views, and sales to facilitate future analyses, tout their programmatic impact, and support state or federal funding requests. For evaluating the benefits of geological mapping, the development of questionnaires should incorporate statistical and economical proficiency, in addition to geological expertise, to ensure more robust results. The questionnaire should also undergo thorough beta testing prior to distribution to avoid any confusion in meaning or intent of specific questions. Significant resources should be dedicated for targeted outreach to ensure higher return rates. Although important to include at some level, narrative responses should be minimized. A national study for a country as large and complex as the U.S. will, however, incur challenges in adequately covering the diversity between regions and sectors in a single questionnaire. Future studies may therefore wish to consider options to narrow emphasis, including: (1) employing control groups for sampling various sectors; (2) focusing on particular economic sectors or geographic regions; (3) developing separate questionnaires for different user groups, economic sectors, or regions; and (4) focusing on specific types of geological maps and derivatives (e.g., 3D maps).

13.1: INTRODUCTION

This report is the first national study on the costs and benefits of geological mapping in the U.S. As described in Chapter 2, detailed cost sheets were distributed to State Geological Surveys (SGS) and the U.S. Geological Survey (USGS) to assess the costs of geological mapping (Appendix 1) while a comprehensive questionnaire was sent out to more than 81,000 stakeholders to capture the perceived value and benefits of geological maps (Appendix 2). Although significant effort went into developing and distributing the cost sheet and questionnaire, some modification to both the approach and content of these documents would probably have yielded more robust results. In this chapter, we describe the lessons learned in our analysis and provide suggestions for future studies. We address the cost sheets that provided expense data for producing geological maps, assess the stakeholder questionnaire and perceived benefits of the maps, review some of the major concepts and takeaways of the entire study, and conclude with specific suggestions for future analyses.

13.2: DATA FROM COST SHEETS

The cost sheet requested information from the SGS and USGS on funds expended annually for mapping from 1994–2019 from state, federal, and other sources, the percentage of each state mapped at various scales, and the availability of different types of derivative maps within individual states (Chapter 2 and Appendix 1). Federal funds allocated to the states through the STATEMAP component of the National Cooperative Geologic Mapping Program (NCGMP) were easy to obtain, but levels of funding from other sources were difficult for many states to document. While the NCGMP 1:1 match requirement for SGS also was relatively easy to obtain, many SGS “over-matched” the federal funds but maintained poor records of doing so. Fortunately, USGS records showed some of this SGS matching information, but not all. Cost reporting capabilities were not consistent among SGS nor consistent through time for individual SGS for the 26-year period covered by the cost sheet. Not every SGS was able to provide all of the required data because of a lack of resources, insufficient staffing, and/or lack of record keeping. Similarly, the USGS had challenges in assessing funds allocated to geological mapping outside of the FEDMAP and STATEMAP programs of the NCGMP. Thus, the reported costs by SGS and the USGS should be considered minimums but probably are not significantly lower than the actual costs. Also, parsing out mapping expenditures into particular years presented challenges, since most projects (even STATEMAP and FEDMAP projects) spanned more than one year, and fiscal years for most states differed from the federal government. Providing information on the percentage of a state mapped at various scales and availability of multiple types of derivative maps also were particularly challenging for many SGS, and thus many were unable to report such data. Even for those states that did have such data, questions arose as to what to report. For example, should all maps at 1:24,000 scale be included in the estimate or should only those maps still considered useful be included? Because of the various complications regarding the information requested of SGS and the USGS, we underestimated the time required by them to provide all types of data requested on the cost sheets, as this generally required careful analysis of past budgets and projects, much of which predated the digital age and commonly preceded the tenure of the current administrative staff.

Two major omissions in the cost sheet that would have provided valuable information included requests for the number of geological maps produced at various scales relative to funds allocated to mapping in a given year and the number of maps that were sold or downloaded. The lack of data on the quantity of maps produced by SGS in a specific year precluded estimates on the average cost of generating, for example, a 1:24,000-scale map, at least from the original questionnaire. However, the number of maps produced from STATEMAP by SGS was eventually provided by the USGS, and thus average costs per map were ultimately estimated for representative states in Chapter 8. As described in Chapter 7, information on the number of maps sold and downloaded was requested after the cost sheets were submitted. For most SGS and the USGS, digital copies of maps can be viewed and downloaded for free from their websites, while hard copies incur a minimal cost. For both digital copies downloaded and hard copies sold, such numbers are not tracked by many SGS, and it was discovered that web crawlers (i.e., robotic action or bots) further complicated estimates for downloaded copies. The USGS and about half of the SGS were able to report reliable estimates for the impact of web crawling bots. Estimates for both downloaded and sold copies of geological maps are clearly minimums. Requesting these data earlier in the process would have resulted in more robust estimates.

13.3: BENEFITS DATA AND STAKEHOLDER QUESTIONNAIRE

The questionnaire requested information on the general benefits and perceived value of geological maps from users as well as information on their profession (e.g., private vs. public sectors, type of industry, type of government organization, etc.). Both quantitative and narrative answers were sought for a series of 25 questions (Chapter 2 and Appendix 2). The questionnaire was sent to over 81,000 individuals, with nearly 4,800 responses returned.

Significant feedback was received regarding the content of the questionnaire. Although the questionnaire was generally considered comprehensive, many commented that there were too many questions and that some questions were too long. Notably, some respondents provided unreliable or no answers to some of the questions. The intent of this economic analysis was a nationwide study but also to evaluate differences between various economic sectors and geographic areas (regions of the U.S. and/or individual states). Once questionnaire responses were summarized, it was obvious that many respondents worked in numerous professional, commercial, and industrial sectors, which precluded attributing their responses to specific sectors. Also, some respondents worked in many parts of the U.S., which made it difficult to apply their answers to specific states or geographic regions. Therefore, as the study progressed, time did not permit a detailed evaluation of geographic regions or states beyond the discussion of general regional differences in Chapter 8 and identifying sectoral contributions to per capita GDP in Chapter 11. Future studies that further break down the data acquired in this study might reveal additional insight into regional, state, and sectoral differences or similarities.

In addition, the wording of some questions could have been more discrete in defining whether information on costs or benefits was being sought. For example, there may have been some confusion as to whether long-term value referred to in question 10 and an estimate of what one would expend on a map in question 17 implied benefits or estimates of costs. However, the median responses for these questions aligned much more closely with the willingness to pay (Chapter 6) as opposed to the estimated costs per map (Chapters 4 and 8), so confusion on the intent of these questions may have been minimal. Nonetheless, more discrete wording would have facilitated a more direct interpretation of the results and perceived intent of those filling out the survey, allowing the data analysis to be clearer and more reproducible.

Another possible issue was the lack of knowledge by some respondents of the general costs of geological mapping while providing estimates of perceived value or willingness to pay for these maps. The nearly 4,800 respondents came from a wide range of backgrounds, sectors, and geographical regions, and thus their knowledge of the production process for geological maps probably varied extensively, which imparted potential bias in their responses.

In addition to potential impacts from the lack of understanding of producing geological maps, additional bias may have been imparted by different perspectives between the public and private sectors. Those in the private sector may have viewed geological maps from more of a market or for-profit perspective, whereas those from the public sector may have viewed them strictly as a public good, thus imparting differences in perceived value of such geological maps. In addition, perceived value and a long-standing “culture” of SGS and the USGS providing geological maps and related information at no or very low cost perhaps affected some private and public sector respondents from divulging their ability or willingness to pay. This was evidenced by many saying that they would pay nothing or a very small amount for a geological map. However, the opposite was also true, as several others (obviously for very large projects) were willing to pay millions. It is, for this reason, that we chose to report median rather than mean results to all of our questions (Table 6.5.1).

Another lesson learned regarding the stakeholder questionnaire was the lengthy process to evaluate the overwhelming response to eight text-based narrative questions (e.g., “Please describe an example of […]” or “Provide additional comments on […]”) and their associated ~700 pages of information, ~14,000 individual responses, and an average of 26 words per response. This required manually reading and categorizing 15% of the responses for each question, initiating lists of keywords, and then applying word-use frequency to generate additional predictive keywords. An automated procedure resulted in the categorization of up to 90% of the responses, with remaining outliers categorized manually. However, reflecting on the time and effort spent with these eight text-based questions, rephrasing the questions and providing “discrete selection categories" would have been considerably more efficient.

13.4: BROADER CONCEPTS AND TAKEAWAYS

Assessment of the costs and benefits of geological maps is complex and requires a broad approach to capture the diverse uses of such maps, but it should also provide sufficient detail to yield quantitative data on the costs incurred by SGS and the USGS and the resulting spectrum of benefits to the many user groups. The cost of producing geological maps is the sum of the equipment, travel, labor, and analyses needed to complete: (1) the fieldwork; (2) map compilation; (3) scientific analyses; (4) cartography; and (5) publication of the map. The benefits of a geological map are the integrated value of the scientific data, analyses, and interpretations, along with the consideration that the said analyses and interpretations are not possible without the map.

Geological maps produced by SGS and the USGS operate as an intermediate public good, which has an eternal diminishing unit cost with additive value with each use by public or private users. The effective value of a map is directly related to the sufficiency of an individual map, which hinges on its detail, potential applications associated with its location, and the scientific competence of the mapmakers. Geological maps produced by SGS and the USGS typically meet high levels of scientific criteria and are of sufficient detail to be recognized as the gold standard by map users. However, the actual value of an individual geological map may vary significantly depending on its location. For example, a detailed geological map of a wilderness area may have less overall value to society compared to a map within or adjacent to a major urban area or that containing appreciable mineral or energy resources that can be developed in an environmentally sound manner.

Private entities have a financial threshold for producing geological maps, constrained by expected returns on investment while also considering the sufficiency of the public maps to meet their economic decision-making needs. Interestingly, statistical analyses in this study showed consistent behavior among respondents across the U.S., with some regional variations, such as higher demand for detailed maps in the northeastern U.S. Application of geological maps clearly provides value in economic decision-making in a large number of economic sectors in the U.S. Public good maps provide access to less capitalized players who have a limited capacity to invest. Likewise, limits on the capacity to invest for users can lead to suboptimal decisions when access to sufficient geological maps for decision-making is unavailable and economic decisions are based on risk assumptions rather than factual data.

An important underlying thread to the above discussion and this report in general is that this study is an economic analysis of an intermediate public good that impacts many segments of society and realizes maximum value with expert use. Although the results of this analysis are meaningful and consistently demonstrate a high value of geological maps produced by SGS and the USGS to society, the analysis may not be as straightforward as compared to products fully produced within the private sector that are generally driven by market conditions. Although the wide variation in respondents to the questionnaire has the advantage of sampling a broad spectrum of society in terms of perceived benefits, the varying backgrounds and lack of control groups amongst the respondents also resulted in some challenges for interpreting the results, as mentioned above. This begs the question as to how the lessons learned in this study could be applied to enable future analyses that would yield more statistically robust results?

13.5: SUGGESTIONS FOR FUTURE STUDIES

In considering the lessons learned from this project in designing future studies, we are faced with some of the same questions recognized by the steering committee in the initial discussions of how best to approach this study. These include:

- How can the project design be broad enough to sample the many segments of society, including a wide array of both private and public sectors that utilize and benefit from geological maps?
- How can a questionnaire seeking information on perceived benefits be crafted for these many diverse sectors and yet be simple enough to be easily understood and completed in a timely fashion?
- How can the costs for geological mapping be easily obtained from SGS and the USGS?
- For a study as broad as this national assessment, what are the best means by which to assess geological map demand and use?

These questions remain for any subsequent studies, but with the knowledge gained from this study, how would we design a future analysis to avoid some of the challenges faced in this study while providing for and facilitating far-reaching results.

Changes to the cost sheet are the most easily addressed. In future studies, the cost sheets could be simplified to exclusively focus on funds expended for geological mapping from federal, state, and other sources. Data on the number of maps produced at certain scales should also be requested to facilitate estimates of the average cost per geological map. SGS and the USGS should be encouraged to compile such data in the coming years such that relevant data are readily available for future studies. However, information on the percentage of states mapped at various scales and availability of derivative maps can be the subject of other studies.

It is important to note that the economic analyses conducted in this report are based on traditional geological mapping techniques — that is, the representation of the subsurface is conveyed to the user in two dimensions (e.g., as a paper or digital map). With the emergence of digital technology, the science of geological mapping, like all Earth science research, has progressed into three dimensions or 3D data. The added dimension opens up many new opportunities for private and public sector applications that will benefit society in the future. It would therefore be useful if SGS and the USGS could parse out regions where 3D geological maps and models have been completed, and then evaluate their specific associated costs and benefits, both of which should be proportionately larger than that portrayed in the present economic analysis. Much higher data acquisition costs (e.g., drilling and geophysics) are required. However, even higher overall benefits are anticipated as society will be adjusting to uncertain climate change scenarios and transitioning to a "greener economy", both of which will rely on a more robust understanding and depiction of Earth's subsurface. This transition is already occurring as evidenced by recent increased interest by federal agencies and industry for energy storage, identification of buried critical minerals and geothermal resources, and delineation and modeling of groundwater resources. Thus, it is important to strongly advocate for increased funding for data acquisitions that will elucidate the subsurface (e.g., gravity and magnetic data), which will complement surficial data and allow for more widespread applications of 3D geological mapping.

Some of the most difficult information to obtain was online map download, view, and sales data from SGS and the USGS. It would be beneficial to all SGS and the USGS to consistently track these data, while at the same time account for bot activity that can significantly skew web statistics. Currently, very few SGS account for bot activity. Commonly, all of these statistics are most readily available at the end of calendar years. For any future assessment on the value of geological maps and related information, these data provide a metric of demand that SGS and the USGS can tout as showing significant programmatic impact.

How best to assess the value and benefits of geological maps is much more complex. At the root of this challenge is ensuring that appropriate statistical and economic expertise complement the geological proficiency in project design and development such that the questionnaires/surveys will yield more statistically robust results. We recognize that the steering committee for this project was weighted too heavily on geological expertise. In addition to a more scientifically diverse steering committee, more salient results may require: (1) thorough beta testing of the questionnaires; (2) separate questionnaires for different user groups; (3) implementation of control groups for sampling of different user sectors, including some groups that have a clear understanding of the process of producing geological maps; and (4) more targeted outreach to ensure a higher return rate on the questionnaires, which will be much easier to accomplish if not in the midst of a pandemic, as was the case for the present study. In addition, designing questions for stakeholders that better emphasize state-to-state and sectoral contributions is recommended to facilitate more detailed geographic and sectoral analyses.

Although care should be taken to keep future questionnaires as concise as possible, there are a number of research questions that could be posed to enhance understanding of the needs of various user groups and/or more broadly be analyzed by research teams. These include the following:

- How might the integration of scientific data, analysis, and interpretation in geological maps be optimized for various applications and users?
- To what extent does the value of a geological map diminish if any of its core components (data, analysis, interpretation) are compromised or missing?

- What are the specific economic and societal benefits of ensuring that geological maps are produced and maintained as a public responsibility?

- What is the value of updating a geological map? As technology, interpretation, and accuracy improve, the quality of a map, if updated, also increases, but how frequently and at what scale should maps be updated based on costs, value, and necessity?

- What factors determine the threshold for private entities to invest in the production of geological maps, and how might this threshold be increased? Is this a function of evolving applications of geological maps over time and as the economy changes?

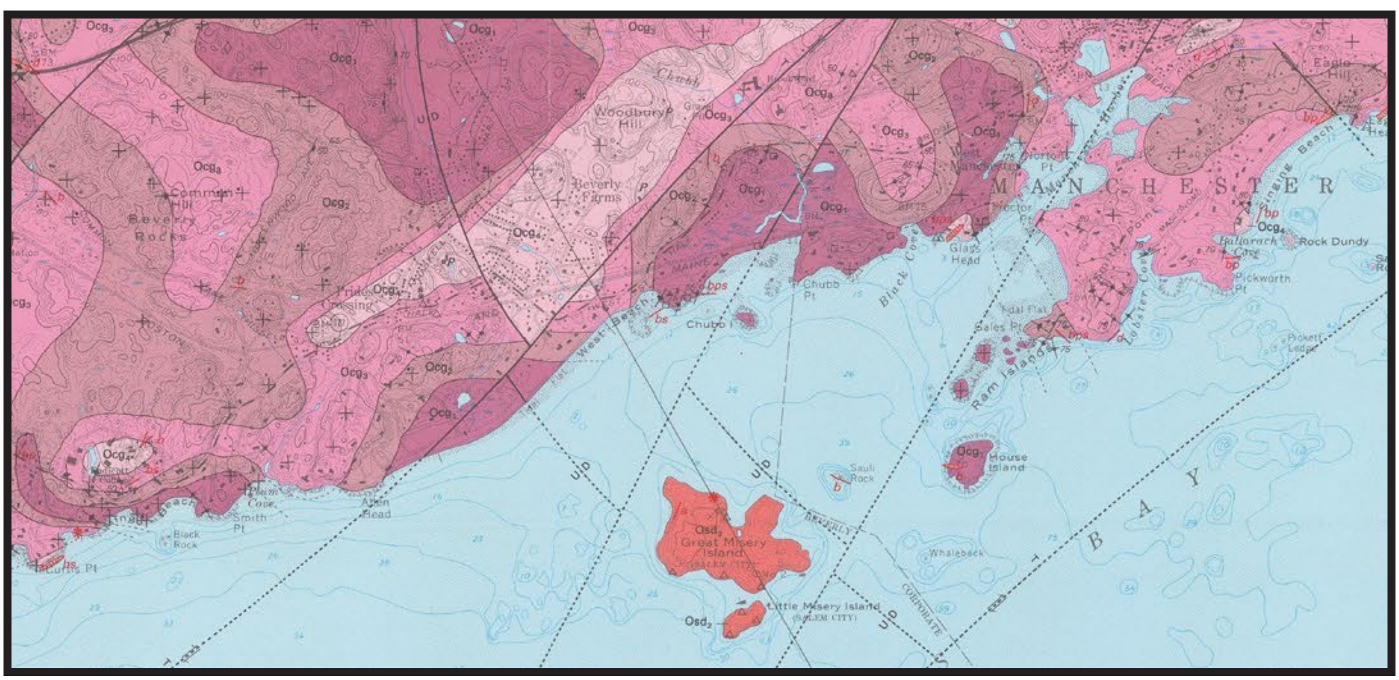
- Are there regional-specific needs for geological maps that have not been addressed by the current models, and how can these needs be incorporated into future production?

- How do variations in demand for geological maps, such as the heightened demand for detailed maps in the northeastern U.S., or the need for detailed 3D subsurface maps and models, affect the overall economic value of these maps?

- How might the accessibility and availability of geological information influence other sectors of the economy, beyond the ones currently studied, especially by increasing the number of entities that can utilize geological maps within their capacity to invest.

- What is the potential value of studying the impact and role of geological maps at finer granular spatial levels as they apply to varied intensity of sectoral activities.

This long list of relevant research questions for future studies demonstrates the complexity of any such economic analysis, as well as the challenges facing any group attempting to assess the costs and benefits of geological mapping in a single study. Although the results of this study reflect strongly on the high value of geological mapping to many public and private sectors throughout the U.S., it may be most prudent for subsequent studies to initially dissect the analysis into discrete user sectors and geographic regions prior to pursuing an all-inclusive national study.



Portion of: Dennen, W.H., 1991, Bedrock geologic map of the Marblehead North quadrangle, Essex County, Massachusetts: USGS Geologic Quadrangle Map GQ-1693, scale 1:24,000.

CHAPTER 14: SUMMARY AND CONCLUSIONS

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14.1: INTRODUCTION

An act of the U.S. Congress in 1879 created the U.S. Geological Survey (USGS) and tasked it to study various aspects of Earth sciences and make its findings available to the public freely or at minimal cost. Water, minerals, and other natural resources, as well as Earth hazards, were specifically mentioned in the act. Much of the knowledge acquired from the studies has been presented in the form of maps and reports. Thus, the act was a social choice to put geological maps in the domain of public goods to be generated and disseminated at public expense, because it was deemed in the national interest, and cost determination was not to be influenced by the market. The differences between "public" and "private" goods have been analyzed extensively in economic literature. As time progressed, new domains of the economy recognized the importance of geological information, and larger amounts of public funding were made available for the study of geology. With the rising allocation of public funds, it became necessary to ascertain that the investments into the study of geology yielded enough societal benefits to account for the production of geological maps. Most states in the U.S. followed suit and established State Geological Surveys (SGS) to conduct geological studies in their own jurisdictions. In 1992, the National Geologic Mapping Act established the National Cooperative Geological Mapping Program (NCGMP) as a cooperative effort between the USGS and SGS to conduct geological studies and generate maps, while mandating that SGS were required to 100% match USGS funds. The present economic study was commissioned by the USGS to assess the expenditures for geological mapping during the 1994–2019 period and evaluate benefits of this program to society.

This economic analysis of geological mapping is the first such analysis for the entire U.S. and it is the largest and most comprehensive jurisdictional economic assessment for geological mapping ever conducted. The study has adhered to presenting the value of benefits based on responses from just under 4,800 stakeholders nationally. However, quantitative evaluations of geological map values, particularly as presented in Chapters 6 and 7, focus on highlighting the most conservative approach and associated conclusions.

The expenditures on geological mapping were relatively easy to document. The USGS provided most of the funding, with SGS commonly more than matching the USGS grants depending on priorities and availability of funds. Funding from other federal, as well as state, local, and private sources was also acquired. A questionnaire was sent to SGS and the USGS to solicit data on geological mapping expenditures, mapping accomplished to date, and the types of derivative maps (maps created for specific purposes) available and desired in their jurisdictions. The more difficult task was the assessment on the "returns" on the mapping investments, because as a "public good", geological maps, data, and reports are not sold at prices determined by market demand and supply, as is the case for "private goods".

Geological maps prepared by public institutions are produced at various scales, contain information on select strata and structures of the Earth, can focus on specific commodities, and/or address specific Earth hazard or land-use issues. Some users may be able to use these maps as published, whereas others may need to enhance them with their own efforts. In all cases, the existence of geological maps provides a public good that is cost effective by saving time and/or money to map users. Every map user may have their own estimate of what those savings may involve. These estimates are "stated savings" as opposed to "reported savings" gleaned from executing a project with and without an existing map. Reported savings are possible in some specific case studies as opposed to a national scale study. Once a project is executed based on available geological information, there is rarely a chance to go back and use a new or revised map. In this study, map users or stakeholders were asked to estimate their potential savings that are derived from a public good. These potential savings are estimates of benefits received by geological map users and, hence, a plausible proxy of map value to them. In addition, potential savings are savings to taxpayers. SGS and the USGS obviously spend taxpayer money to produce geological maps. Stakeholders from the private sector are taxpayers and commonly utilize geological maps funded by government spending, so their benefits are clear. Public sector stakeholders from other federal, state, and local governmental entities are involved in undertakings that are also paid from taxpayer money. Therefore, public sector savings are taxpayer savings as well.

In collaboration with SGS and other professional organizations and administrative/governing entities, a questionnaire containing 25 queries was sent to over 81,000 stakeholders, who were deemed to be map users or who could reasonably be expected to benefit from geological information contained in the maps. Some questions were intended to obtain stakeholder background, while the objective of other questions was to make quantitative estimates of geological map value in monetary terms and in terms of time saved. A third category of questions sought to collect qualitative/descriptive input about the benefits of geological maps from stakeholder experiences. A total of 4,779 individuals responded, of which 202 were eliminated because they were either solely international respondents or employed by SGS involved in the mapping program themselves. A study of preferences of geological map users and their assessment of economic value of maps had never been conducted for the entirety of the U.S. prior to this study.

14.2: SUMMARY OF SGS AND USGS GEOLOGICAL MAPMAKING

The publicly funded geological mapping effort in the U.S. is a major undertaking. In 2020, about 10,200 individuals were employed by SGS and the USGS, with nearly half of them geoscientists and the rest supporting the effort (e.g., GIS analysts and cartographers).

Total spending for geological mapping by SGS and the USGS during the 1994–2019 period was $1.99 billion in constant 2020 dollars. In 2020 dollars, the trend of annual expenditure on geological mapping had declined from about $80 million in 1994 to about $70 million in 2019. However, recognizing the need to accelerate the search for critical minerals in the U.S. and the overall value of geological mapping for addressing many natural resource and environmental issues, Congress has appropriated additional funds for the NCGMP since 2019.

Geological maps can be large scale (at scales 1:62,500 or more detailed), medium scale (e.g., 1:100,000), or small scale (at 1:500,000 or less detailed). As reported by SGS and the USGS, and as expected, greater area mapping coverage has been accomplished at small scales than at other scales. This is expected because detailed mapping builds upon the initial small-scale or more regional mapping. This report shows that many more SGS reported complete coverage in their jurisdictions at small scales than those reporting complete coverage at large scales. The coverages vary greatly between states depending on population, size, availability of funds, and economic activity. Although complete coverage in all states is desirable, mapping activity in the future will be guided by demand for geological maps at various scales and available funds. SGS also reported that 73 different kinds of derivative maps (maps prioritizing a specific natural resource, land use, or Earth hazard) have been generated by them.

14.3: PROFILE OF STAKEHOLDERS

Stakeholder responses were received from all 50 states and the District of Columbia, and many stakeholders worked in multiple states. Internationally active stakeholders also provided feedback. However, responses from stakeholders who only worked internationally, and stakeholders who worked at SGS were not included in the determination of map value, the latter to avoid any conflict of interest. About 63% of respondents worked in the private sector, while 37% were employed in the public sector.

Private sector responders broadly represented the mineral and energy industries, water resource industry, construction, transportation, geotechnical industry, independent geologists, public utilities, environmental industry, education and research, tourism, real estate, and not-for-profit organizations. Stakeholders from the public sector included those from all levels of governments (federal, state, county, community) and educational institutions.

The responses received from the broad spectrum of the economy indicate the comprehensiveness of coverage and provide confidence in the representative nature of this cost and benefit economic analysis of geological mapping. Stakeholders represented all sizes of organizations, from those employing less than five to greater than 5,000 individuals. Small organizations and individuals working alone represented the largest group of stakeholders, about 25%, with the remaining coming from larger organizations.

Further breakdown of stakeholder responses shows that nearly every industry category, as well as environmental entities, multiple levels of government, research and educational institutions, and other activities of private citizens are represented in this study. Their stated uses of derivative maps indicate that ground and surface water related issues are dominant (included in 40% of the responses), followed by hazards (e.g., earthquakes, tsunamis, floods, and landslides) (15%), and minerals and energy (13%). About 81% of respondents indicated a preference for large-scale maps, with 37% preferring maps of 1:24,000-scale and 35% favoring more detailed maps.

Geological maps have been traditionally printed and distributed free or at minimal cost. Widespread computerization has changed user preferences because of the availability of online digital maps. Digital access allows for quicker dissemination of the maps and related geological data and analyses. Users can choose to review and download online geological maps or print them as needed.

14.4: MAP VALUE ASSESSMENT

The monetary value of geological maps is assessed in two different ways: The first assessment is based on stakeholder responses to queries about money and time that they perceived to have saved, because maps were available to them. Questions about the value of geological maps were worded to address different ways to assess value. Some questions inquired about the time and money saved, because maps were available from SGS and the USGS at little or no cost. Other questions asked what one would willingly pay for a map. Stakeholders were also asked to estimate the long-term value of geological maps, because they can be used repeatedly by different people for different projects over many years. Table 14.4.1 (summarizing results from Chapter 6) summarizes the stakeholder assessment of the monetary value of geological maps.

Table 14.4.1. Summary of Quantitative Evaluations by Respondents.

Question 3: Time/Cost saved over 5 years	► Median project time saved — 20%. ► Median project cost saved — 15%.
Question 7: Project cost increase if maps unavailable; Responses included maximum and minimum budget statements.	► Median project cost increase — 30%, Median budget size of 776 projects - min. $250,000, max. $300,000. ► Median number of maps used — 4. ► Median value per map — $11,062 - $18,375.
Question 8: WTP for a map if not available (Choices of $ bins)	► Median WTP — $3,000.
Question 10: Long-term value of a map	► Median long-term value of a map — $10,000.
Question 17: Expected payment for a map	► Median expected to pay — $2,883. ► (Best data, least uncertainty, and note consistency with question 8).

Results from stakeholder responses to the various queries differed significantly. The variance is expected, because the responses are estimates, not specific to any type or scale of map, and not necessarily the result of the actual experience of the respondents. Due to the wide range of data, particularly with some very high values representative of very large expenditures on major projects, the median values are considered more representative than the mean values, and they are also more conservative. The median values obtained from various questions are tabulated above in Table 14.4.1.

As a public good, geological maps are non-excludable and non-rivalrous. Therefore, no user can be prevented from using them, and use by one person does not reduce their availability to others. It entails that benefits of geological maps are cumulative over time. To compare the total benefits of geological maps to society with the cost of mapping, it is necessary to estimate how many people use them.

The 1994 to 2019 project period for this study experienced a rapid decline of sales of paper geological maps (primarily distributed at the cost of printing or copying), as these transactions were replaced by the increasing availability of digital versions that could be accessed, downloaded, or consulted online according to need and typically they are free. For this economic analysis, this transition warranted that geological map demand was best represented by numbers of map downloads and online views. Therefore, SGS and the USGS provided data on direct downloads and online views of geological maps, and a few SGS also provided some data on geological maps sold primarily as paper maps.

A complicating factor affecting the reporting of web statistics, including geological map online view and download data, is the interaction of robots, or "bots", with web sites. Designed to perform specific and repetitive tasks automatically, faster, and often more effectively than if humans performed them, their downside is that they can skew web statistics and make websites appear more popular than reality.

Nine SGS and the USGS were able to account for bot activity in their geological map web view and/or download numbers, saying that their data were either "bot free" or very minimally impacted by bot activity. All other SGS either did not have the capacity to evaluate bot activity or did not report on their degree. Therefore, their raw website view and download data were reduced to account for bots according to annually reported 2012–2019 industry data on bots versus human traffic (from a high of 59% in 2014 to a low of 37% in 2019). Bot data from industry sources are not available prior to 2012. Therefore, between 2004 and 2011 (years for which SGS and USGS data were provided), web view and download data by SGS and the USGS were reduced by an average of 44.3% based on the 2012–2019 average of industry data on bot versus human traffic.

In addition to accounting for bot activity, marketing companies have developed algorithms that estimate what percentage of online web page views result in transactions (i.e., the percentage of website visitors that turn into customers). It is called a conversion rate. A transaction is said to occur if an actual purchase or a comparison of products with the intention to purchase takes place. Download actions from websites also are considered transactions.

To determine a conversion rate for online views of SGS and USGS geological maps, nine SGS were able to provide online view and download data for 33 cumulative years covering the latter portion (2012 to 2019) of the study period, and this yielded a conservative conversion rate of 3.32%. This conversion rate was applied to online visits reported by SGS and the USGS to arrive at a download number of 378,546, in addition to actual reported downloads of 3,558,150 and views equal to downloads of 802,586. The total number of downloads was therefore estimated to be 4,739,282. In addition to downloaded maps, 86,673 paper maps were reported sold, bringing the total of maps downloaded and sold to 4,825,955.

Additionally, 24 SGS provided geological map view and/or download data accounting for 65.14% of the total SGS costs, and the 24 SGS that did not/could not provide these data accounted for 34.86% of the total costs. It was assumed that the 24 SGS that did not/could not provide any online view and/or download data had a high likelihood of contributing to the overall download data, because they received federal funds for geological mapping and were required to 100% match those funds. Applying the most conservative 3.32% conversion rate of map views to downloads from 1994–2019 and extrapolating map sales data results in an additional 2,275,768 downloads and 46,383 maps sold for a total of 7,148,106 downloads/maps sold.

Using the most conservative median amount that respondents expected to pay per map in response to question 17 of the stakeholder questionnaire as the basis ($2,883), the cumulative range of values between the actual maps downloaded and sold (4,825,955) with the extrapolated amounts (7,148,106) would be between $13.91 and $20.61 billion. In comparison, the cost of producing the geological maps during the 1994–2019 period was $1.99 billion. Therefore, the minimum value estimates range between 6.99 and 10.35 times the expenditure.

The above provides the most conservative estimate of geological map demand. However, mere "viewing" of geological maps may provide adequate information to the user without downloading it. Again, using the median amount that respondents expected to pay per map ($2,883), the cumulative range of values between the actual maps viewed, downloaded, and sold (15,849,376 following adjustments to account for bots and without conversion rate adjustments) with the extrapolated amount as discussed above (24,331,250) would be between $45.69 and $70.15 billion. Therefore, maximum value estimates range between 22.95 and 35.23 times the expenditure. Although these maximum values are not realistic, it is safe to assume, considering the conservative nature of this entire economic assessment, that value estimates would lie somewhere between the 6.99 and 10.35 values and the higher extrapolated values of 22.95 and 35.23.

The median map value ($3,000) determined in response to question 8 yields a similar benefit ratio, whereas value estimates from questions 7 and 10 yield benefit ratios of about 25 times the expenditure.

14.5: BENEFIT ASSESSMENT USING USEPA SUPERFUND DATA

Independent of the stakeholder survey responses used above, benefits of geological maps were assessed using data provided by the USEPA as part of their SuperFund program, which was established to clean up polluted industrial sites with funds from Congressional appropriations and the parties responsible for the sites. It was based on the rationale that future contamination mitigation costs, resulting primarily from waste disposal and industrial sites, could be minimized significantly or even avoided had geological information been available and used prior to the locating of these potentially detrimental sites.

USEPA data show their total expenditures for the years 1994 to 2019 in nominal dollars (not inflation adjusted) of $29,943,391,516 and private party commitments of $34,686,400,000 resulted in a total of $64,811,791,516 dedicated to SuperFund cleanup and associated activities. This $64.8 billion, once inflation-adjusted to 2020 dollars, is $86,227,531,539. Obviously, it is not known if and to what extent geology was considered, when waste disposal and/or industrial sites were located (often many years prior to being designated as SuperFund sites), or at the time pollution occurred, nor is it possible to retrospectively estimate how much of this expenditure would have been saved with the availability and proper use of geological maps. However, it is reasonable to assume that at least some of the pollution could have been avoided and some of the cost of clean-up saved. From the present study we know that $1.99 billion was spent on geological mapping nationwide from 1994 to 2019. This means that a 2.3% savings from the SuperFund expenditure of $86.23 billion would have paid for the entire 26 years of geological mapping in the U.S.

14.6: QUALITATIVE ASSESSMENT OF MAP VALUE

Because not all the benefits of geological maps can be expressed in monetary terms, stakeholders were asked in various ways to describe in text format the benefits and uses of geological maps and analyses provided by SGS and the USGS. These questions concerned the quality and confidence of SGS/USGS work and their credibility as experts. Examples of repeated comments include time and cost savings, assistance in resource exploration and development, general education, geological research, filling information gaps, enhancing decision making including planning, providing credibility, furnishing accurate and unbiased information, and affording context to site-specific work.

Lastly, respondents representing 20 public and private entities rated the value of geological maps on a scale of 1 (low) to 5 (high). The groundwater industry rated geological maps the highest at 4.5, while 10 other sectors including the geotechnical industries, most extractive industries, and government agencies rated them at 4.0 or above. The remaining nine, including agriculture, forestry, public safety and utilities, metals, uranium, critical minerals, geothermal, state parks and recreation, and non-for profits all provided ratings ranging from 3.3 to 3.9.

14.7: REGIONAL VARIATIONS IN COSTS AND BENEFITS OF GEOLOGICAL MAPPING

An additional approach to evaluating the costs and benefits of geological mapping is a review of responses to the questionnaire from the private and public sectors as well as geological mapping expenditure datasets from SGS/USGS for six regions of the U.S. (Chapter 8 and Appendix 6). The regions are identified as Northeast, Southeast, Great Lakes/Great Plains, South-Central, Intermountain West, and Pacific Rim. In this analysis, the estimates from respondents on how much they would spend on a map were viewed as costs, while appraisals of long-term value were viewed as benefits. All calculations show a high percentage of positive long-term values (benefits), ranging from 71% to 87% for both public and private sectors.

The lower/upper quartiles, lower/upper extremes, and mean of the distributions of costs incurred by both the private and public sectors were determined for each region. The mean cost-benefit was also determined for each region, and this ranged from ~$11,000 to $30,000 for both the private and public sectors, with the Intermountain West yielding the highest values and the South-Central region exhibiting the lowest values. In addition, expenditures on geological mapping reported by SGS and the USGS were compared to the number of maps produced annually for representative states from the six regions to determine the average cost of producing a relatively detailed geological map (1:24,000 to 1:100,000 scale), and this ranged from ~$42,000 to ~$123,000, with the lowest costs from the Southeast region (Tennessee) and highest costs from the Pacific Rim region (Washington State). Using 2019 as an example year, these values were verified by actual costs reported by the USGS and the Illinois State Geological Survey.

14.8: ECONOMIC MODEL OF GENERAL GEOLOGICAL MAP APPLICATIONS

Econometric analysis was another major approach in evaluating the costs and benefits of geological mapping. At the root of this analysis is the observation that geological maps as a public good are not an endpoint but rather an intermediate good of production that supports multiple economic sectors. The market for maps indicates that geological maps produced by SGS and the USGS provide sufficient detail, reliability, and consistency to make actionable and supportable decisions. While scientific sufficiency of geological maps is critical, the private capacity to invest to produce a map comparable to the public good map has a limiting threshold based on the required return on investment for a particular firm. A range of logistic multinomial regressions were estimated and tested to establish the capacity to pay for a geological map. With the driving mechanism of the economic activity related to the application sectors, the analysis was extended to evaluate how the economic value of each sector was expressed by the various levels of investment of that sector in geological mapping. Using the Gross Domestic Product (GDP) component of each sector, the sectoral contribution to per capita GDP was identified. Analyzing the actual survey response rates by economic sector and whether the project used off-the-shelf, transitional, or custom mapping, the allocation of each mapping type was calculated for nine major sectors of the GDP, including mining, energy, real estate, construction, professional, transportation, education, state/local government, and federal government. Real estate had the highest sector per-capita allocated by rate for geological maps in the public good or off-the-shelf category. Aggregate behaviors of respondents were generally very consistent across all regions of the U.S., with some regional differences such as a demand for finer scale mapping in the Northeast.

14.9: CONCLUSIONS

This economic cost and benefit analysis of geological mapping is the first such assessment for the entire U.S., and it is the largest and most comprehensive jurisdictional cost and benefit assessment for geological mapping ever conducted. Quantitative evaluations of geological map values focus on highlighting the most conservative approach and associated conclusions.

- Four questions evaluated geological map values, and they yielded a wide range of answers from zero to hundreds of millions of dollars. For those who valued maps at zero, it is uncertain if respondents did not understand the question or assumed that regardless of project size or size of an organization conducting geologically related work that public goods should be free of charge. There were also high budget outliers that may have been overestimates of very large long-term projects. This group particularly skewed average values, created a statistical approximation that was too spread out, and consequently forced the use of median values as being most representative of the value of geological maps. The median long-term value of a map ($10,000) was a viable option to represent the overall value of geological maps. When cost was factored with demand numbers, the cost and benefit ratio is 24:1. However, the median expected payment for one geological map ($2,883) was chosen as not only the most conservative value, but also the best data with the least uncertainty. This yielded the lowest cost and benefit ratio of 1:6.99.

- Twenty-four SGS provided data for online geological map views and downloads, and the USGS provided their data on online views. The USGS had the longest record of available data that began in 1999, while the average earliest year of reporting from SGS was 2011. SGS were not able to report their earlier years of online web activity. Therefore, SGS geological demand numbers for online views and downloads of geological maps are considerably underreported.

- Only 13 SGS provided demand numbers for geological maps sold over the project period. Some lacked the ability to separate out geological map sales from overall publications. Therefore, these numbers are also very underreported.

- The discovery of the impact of robotic action (bots) with websites resulted in a significant lowering of geological map online views and downloads and therefore map demand numbers. This was based on annual industry reporting of bot activity since 2012, ranging from a high of 59% in 2014 to a low of 37% in 2019. As a corollary to SGS sites offering web access to maps, several university map libraries were contacted, and they also could not offer any perspectives on their bot activity and its effect on reporting of their web statistics. Despite the national cyber security issue of website protection, it is obvious that SGS and at least some other public institutions have not been keeping track of bot activity. This resulted in our use of the high percentages of industry-reported bot activity, resulting in a likely underreporting of the actual number of geological maps viewed and downloaded and that, in turn, significantly lowered cost and benefit ratios.

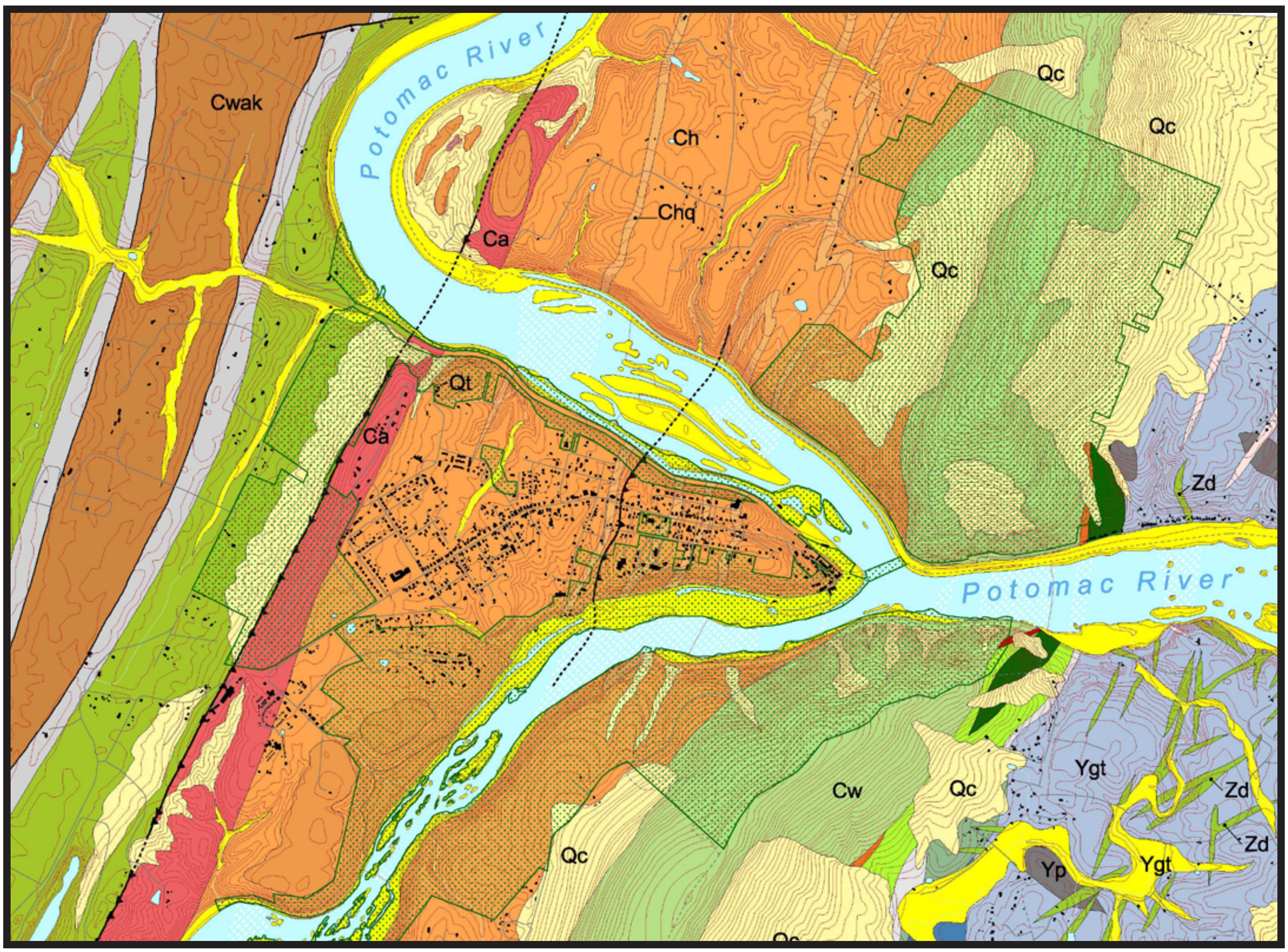
- Lastly, the marketing community uses a conversion rate of online views resulting in transactions, and downloading of geological maps are considered transactions. The 4.7% conversion rate covering both the 1994–2019 project period plus the 2020–2022 data could have been justified considering the rapid increase in geological map views and downloads as reflected in the higher conversion rate starting in 2020, which would reflect current trends. However, the most conservative 3.32% conversion rate was used for the 1994–2019 period.

14.10: BROAD IMPLICATIONS

Despite using (1) the lowest geological map value number ($2,883); (2) underreported numbers of geological map views, downloads, and sales — all significantly lowering map demand numbers; and (3) the highest industry reported bot statistics that further lowered demand numbers by an average of 44.3%, all of these actions still resulted in a minimum cost and benefit ratio of 1:6.99, our most conservative estimate. When factoring in extrapolated view and download numbers from those SGS that did not provide any online web data, this increased the cost and benefit ratio to 1:10.35. This above approach, plus three other approaches that (1) evaluated regional costs and benefits; (2) utilized an econometric model of geological map applications; and (3) assessed the SuperFund cost avoidance scenario, all derived significantly positive values for using geological maps. Results of these approaches are within the range of economic values of geological mapping as reported in previous studies, and all underscore the vital significance of geological information as a foundational component of understanding Earth's complex infrastructure that supports society's most basic needs for clean drinking water, environmental protection, human health and safety, and sustainable development of all natural resources. Projected climate change will likely impact land- and water-use, and it will have a cascading effect on environmental degradation and potential redistribution of human populations. This basic issue necessitates the need to address anticipated climate change through energy storage and other green technologies, the latter of which heavily relies on critical minerals, and both require a detailed understanding of geology and the Earth's subsurface through characterization of geological materials and geological mapping.

Moreover, this study assesses more than the value of geological maps. Geological maps reflect an "end product" of geological comprehension that is rooted in a deep understanding of the age, order, and distribution of geological materials, as well as the Earth processes responsible for their formation.

Geological mapping may be one specific activity within the broad discipline of geology. However, because it has been possible to obtain specific mapping costs from all SGS and the USGS, as well as measurable benefits from a wide range of geoscientists and other direct users of geological maps, the economic value of geological mapping epitomizes the importance of the geoscience discipline to modern society. As this national study shows, the value of geological mapping reflects a wide range of economic sectors that directly benefit from geological information. As we move forward, it is paramount that we truly understand the value of geological information, as it directly touches all the above issues and serves as a cornerstone to modern society.



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APPENDICES LIST

APPENDIX 1: COST SHEET TEMPLATE

https://profession.americangeosciences.org/reports/geological-mapping-economics/appendix-1-cost-sheet-template/

APPENDIX 2: QUESTIONNAIRE TO STAKEHOLDERS

https://profession.americangeosciences.org/reports/geological-mapping-economics/appendix-2-questionnaire-to-stakeholders/

APPENDIX 3: EXAMPLE SOLICITATION LETTER REQUESTING STAKEHOLDERS TO PARTICIPATE IN NATIONAL COST-BENEFIT ASSESSMENT

https://profession.americangeosciences.org/reports/geological-mapping-economics/appendix-3-example-solicitation-letter/

APPENDIX 4: SUMMARY STATISTICS, OUTLIERS, AND CONFIDENCE INTERVALS

Elijah T. Mlawsky (Nevada Bureau of Mines and Geology, University of Nevada, Reno)

https://profession.americangeosciences.org/reports/geological-mapping-economics/appendix-4-summary-statistics/

APPENDIX 5: ANNUAL STATE GEOLOGICAL SURVEY ONLINE MAP VIEWS, DOWNLOADS, AND MAPS SOLD, AND USGS ONLINE MAP VIEWS: 1994–2022 (WITH IMPERVA 2013, 2023 BOT REDUCTIONS)

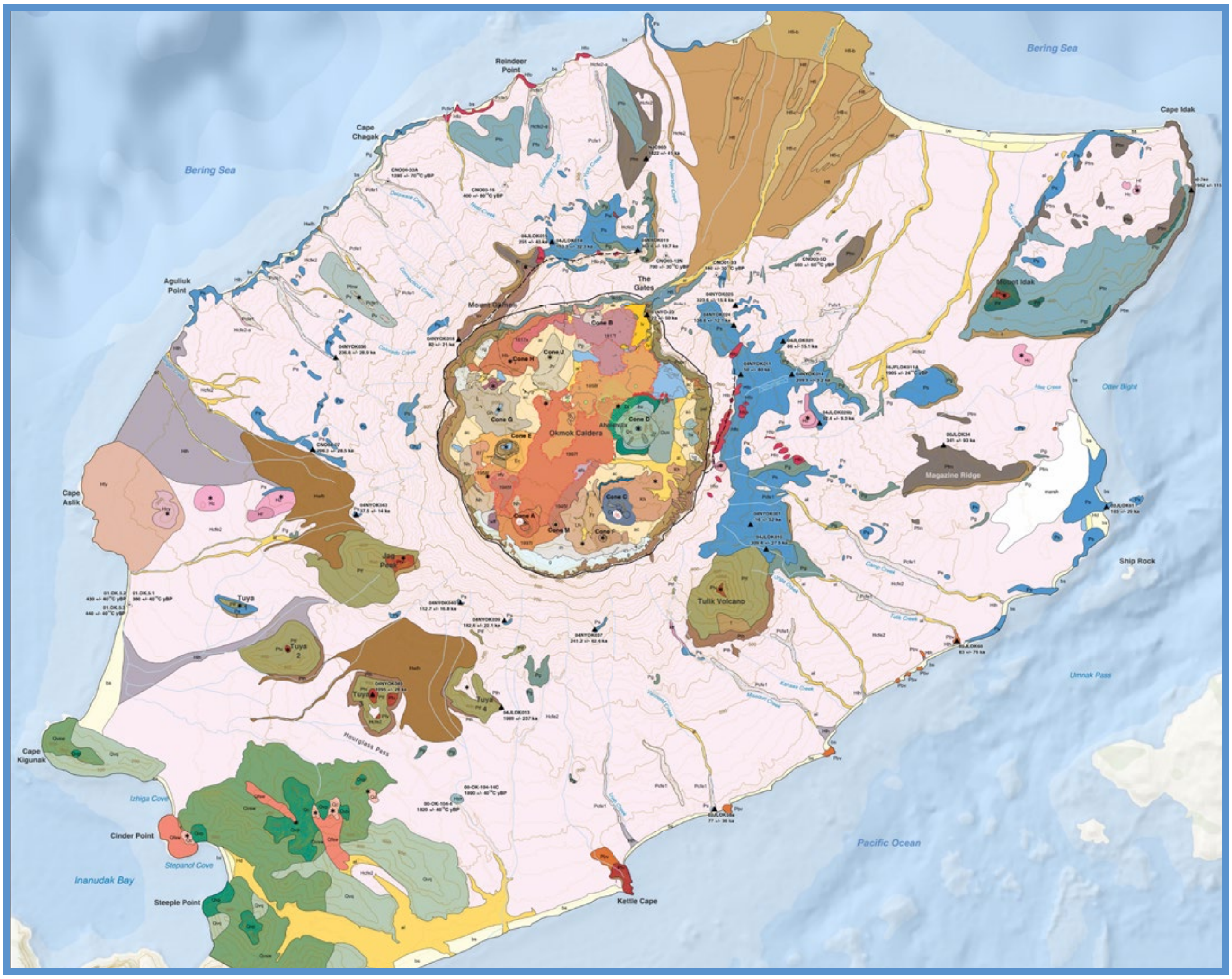
https://profession.americangeosciences.org/reports/geological-mapping-economics/appendix-5-annual-state-geological-survey-map-views/

APPENDIX 6: REGIONAL COST-BENEFIT ANALYSIS DATASETS

https://profession.americangeosciences.org/reports/geological-mapping-economics/appendix-6-regional-cost-benefit-analysis-datasets/

APPENDIX 7: SUPPLEMENTAL CHAPTER 8 (REGIONAL VARIATIONS IN COSTS AND BENEFITS OF GEOLOGICAL MAPPING) FIGURES AND TABLES

https://profession.americangeosciences.org/reports/geological-mapping-economics/appendix-7-chapter-8-supplemental-figures-and-tables/



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Economic Analysis of the Costs and Benefits of Geological Mapping in the United States of America from 1994 to 2019

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James E. Faulds, Editors

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