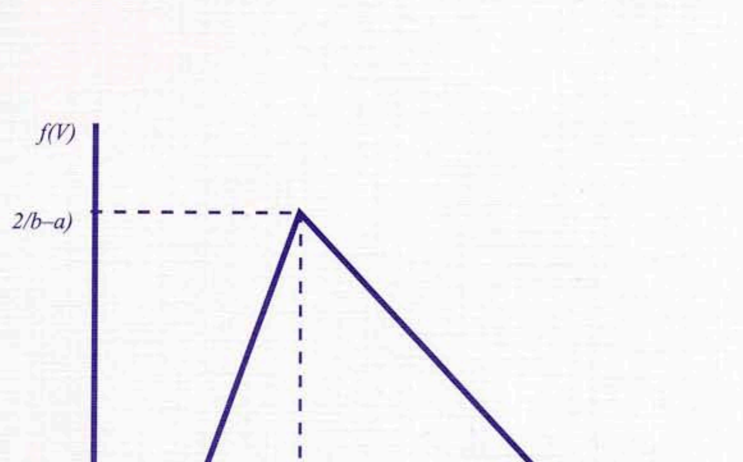
Economic benefits of detailed geologic mapping to Kentucky

Subhash B. Bhagwat
Senior Mineral Economist
Illinois State Geological Survey

Viju C. Ipe
Assistant Mineral Economist
Illinois State Geological Survey



Special Report 3

Department of Natural Resources
George H. Ryan, Governor
Illinois State Geological Survey

Economic benefits of detailed geologic mapping to Kentucky

Subhash B. Bhagwat
Senior Mineral Economist
Illinois State Geological Survey

Viju C. Ipe
Assistant Mineral Economist
Illinois State Geological Survey

Special Report 3

Department of Natural Resources
George H. Ryan, Governor
ILLINOIS STATE GEOLOGICAL SURVEY
William W. Shilts, Chief
Natural Resources Building
615 E. Peabody Drive
Champaign, IL 61820-6964
(217) 333-4747

Acknowledgments

This study would not have been possible without the gracious and complete cooperation of the Kentucky Geological Survey (KGS). Bart Davidson, Jim Cobb, John Kiefer, Carol Ruthven, and others of the KGS contributed a great deal to this endeavor by helping to design the questionnaire, mailing more than 2,200 copies, receiving and computerizing the user responses, and managing other logistics in a diligent and efficient manner. Special thanks are due to Carol Ruthven and Jim Cobb for reviewing the manuscript and making valuable suggestions for improvements. The assessment of map value by KGS employees was excluded from this survey, but this project could not have been completed in a timely manner without their active participation. The authors are greatly indebted to Professor James A. Gentry, Distinguished Professor of Finance, and Dr. Sarabjeet Seth, Lecturer in Finance at the University of Illinois at Urbana-Champaign, for reviewing this study and providing comments and suggestions that greatly improve the value of the study. The authors take full responsibility for any remaining errors.

Printed by the authority of the State of Illinois/2000/600

printed on recycled paper with soy ink

Table of Contents

Appendixes

Figures

Table

FOREWORD

In the 160-year history of the Kentucky Geological Survey, its most valuable accomplishment has been the geologic mapping of the state at a scale of 1:24,000. The 707 geologic quadrangle maps are the Survey's greatest assets and were the result of a 20-year cooperative program with the U.S. Geological Survey. The mission of the Kentucky Geological Survey has been and continues to be the investigation of the geology and minerals of the Commonwealth for the benefit of its citizens. The geologic mapping program that started in 1960 and finished in 1978 not only advanced this mission, but also contributed to all future work by the Survey and other agencies involved in mineral resources, water, geologic hazards, environment, construction, and land-use planning. The Kentucky Geological Survey owes a great debt of gratitude to the U.S. Geological Survey for the outstanding cooperation that occurred during the time this program was under way. The Kentucky Geological Survey provided 50% of the financial support and background knowledge of the geology of the state. The U.S. Geological Survey provided 50% of the financial support, geology and mapping expertise, cartography, and publishing. Of the more than 200 mappers who participated in the work, approximately 190 were from the U.S. Geological Survey's Geologic Division. Other mappers were from universities and the Kentucky Geological Survey. The successful completion of this program is a tremendous testimonial to the planning, foresight, geologic and administrative effort, and cooperation of these two groups. Demand for the maps has been strong. More than 5,000 geologic quadrangle maps are sold to the public each year, and the initial printing of a number of the geologic quadrangle maps has sold out completely. A number of remarkable benefits from these maps are not readily apparent.

1. The cost of the mapping program in Kentucky was justified for the economic development of oil, natural gas, coal, and minerals. The economic development of these natural resources was made possible by the valuable information these maps contain. Kentucky's mineral economy rose dramatically in the 1970s and 1980s, especially in the areas of coal, oil, and gas. What could not have been anticipated in 1960 when this mapping program began was that the use of these maps 30 years later for the management of land, water, and the environment would surpass their use for mineral development. In a society where landowners are responsible for their land and water, making information readily available for the prudent use of those resources is very important.

2. The geologic maps provide knowledge about the land and geology for a broad cross section of users in society (e.g., researchers, engineers, miners, urban planners, and hikers). In fact, there are so many diverse users that it is almost impossible to list them all.

3. If a picture is worth a thousand words, then certainly a geologic map is worth a million words. For the tens of thousands of requests that the Kentucky Geological Survey receives each year

from the public about land, water, minerals, and hazards, the geologic maps are sufficient to respond to a great number of them. In those instances in which more detailed information is needed, the geologic maps provide a context or base of understanding for more detailed data and analysis.

4. Following the completion of the geologic mapping program in 1979, a new state geologic map published at a scale of 1:250,000 became a popular map for statewide analysis and study. A geologic map published in 1988 at a scale of 1:500,000 also became popular for regional assessment. The publication of both of these maps was made possible by the existence of the original detailed geologic maps at a scale of 1:24,000.

5. Currently, the 707 geologic quadrangle maps are being converted into digital format for use in a wide variety of applications. Digital versions of the geologic quadrangle maps are available for the public to view and print from the Kentucky Geological Survey Web site. Vectorized and attributed geologic quadrangle maps will be available in the near future for use in geographic information systems. This will bring detailed geologic information into every office and home 24 hours a day, 7 days a week, for use whenever decisions requiring geologic information are being made.

What started 40 years ago as a program to spur the economic development of the mineral and fuel industries of Kentucky has proven to be enormously valuable in many other ways in both the public and private sector. The forethought of the Tenth Kentucky Geological Survey to commit itself to that challenge and to complete the geologic mapping program is a legacy whose value should never be underestimated. I cannot describe in stronger terms what a valuable resource the geologic maps have been and continue to be for the Kentucky Geological Survey and the State.

James C. Cobb
State Geologist and Director
Kentucky Geological Survey

FOREWORD

Most geological surveys were founded in the mid-1800s to early 1900s with a primary mission to develop mineral resources. However, as the world economy has changed and populations have increased, the missions of geological surveys gradually have been broadened to address not only mineral-assessment concerns, but also environmental and groundwater issues.

Geological surveys and the geological community in general must be responsive and proactive in preserving the environment, while at the same time assisting mineral-resource industries and promoting compatible and informed land use. At the end of the 20th century, the U. S. Geological Survey and state geological surveys have been emphasizing the need for large-scale geological mapping to address social concerns. Only through a vigorous and detailed geologic mapping program can the continuity, thickness, and properties of geologic materials be determined. Once determined, these characteristics provide the spatial context necessary to address the issues, whether strictly scientific or of societal relevance. Geologic mapping information provides a scientific basis for land-use planning and resource development because our society and infrastructure are built over and based in geologic materials.

This report is the first of its kind and the first attempt to evaluate the economic impact of long-standing geologic information on a broad-based, statewide user community. It documents the value of large-scale geologic mapping to society in a scientific manner, backed by sound economic theory.

Particularly important in this report is the conclusion that quadrangle maps at the 1:24,000 scale are considered the most desirable for modern-day applications, such as land-use planning and resource assessment. Although the study focuses on 1:24,000-scale maps, most of the conclusions could be extended to areas where geologic maps of smaller scales may be more appropriate, such as in the western United States or in Canada. Insights into the breadth and depth of the impact of geologic map use on the economy of Kentucky, provided by this report, and the substantial, documented dollar value of the maps offer a solid basis for public funding to conduct similar mapping elsewhere in the United States.

Finally, this huge geological mapping project, carried out over 18 years at a cost of more than $90 million in year 1999 dollars, though originally driven by resource interests in the energy industry, has been used to address a broad-based array of societal and environmental issues, from land-use planning to water production and protection. This finding illustrates the enduring value of basic geologic mapping in addressing problems and resource issues that could not have been predicted at the time the mapping was done.

William W. Shilts
Chief, Illinois State Geological Survey

INTRODUCTION

From 1961 to 1978, the geology of the entire state of Kentucky was mapped at a 1:24,000 scale (1" = 2,000'). Kentucky is the only state so mapped and for which there is a complete series of 7.5-minute quadrangle maps published.

A systematic determination of the long-term economic value of the Kentucky mapping program has never been conducted.[1] It has been more than 20 years since the completion of the project, and adequate data can now be compiled that can be used to estimate the value of these maps over time. The present study evaluates this Kentucky mapping program. The questions we ask are: who has been using these maps? how have they been used? and most importantly, what has been the economic value of these maps to their individual users and to Kentucky as a whole?

The unique challenge in this undertaking is to estimate the value of mapping as a knowledge-creating process. Creation of any kind of knowledge differs from creation of other public goods such as roads, dams, or other public services because knowledge remains intangible until it is applied for visible benefits.

Geologic knowledge involves interpretation of limited, objective information. Geologic quadrangle maps present subsurface geology that geologists interpret from data sampled from boreholes, mine openings, outcrops, and geophysical investigations. Geologic maps are one of the densest forms of depiction of interpretive human knowledge of the earth. In the form of spatial relationships in three dimensions, time sequences, and a multitude of geologic processes, they constitute a dense aggregation of knowledge and interpretations.

The Earth is the foundation of all human economic activity. We build our homes, stores, and factories on and with its materials; derive industrial raw materials, products, and fuel from its vast base of mineral resources; and extract from its pores water for drinking, agriculture, and industrial use. Weathered nutrient-rich earth materials form the fertile soils that provide our food. And geologic materials are the media within which we dispose our municipal and hazardous wastes.

Urbanization and major changes in land use have made it increasingly difficult to balance the need for earth resources with environmental

---

[1]In a series of papers and publications, McGrain (1966, 1967, 1979) reviewed the immediate positive economic effects resulting from the geologic mapping program in Kentucky. To our knowledge, only two other geologic mapping programs in the world have ever been evaluated economically. However, both evaluations were of small-scale maps of county areas. In 1991 the Illinois State Geological Survey (Bhagwat and Berg 1991) performed a benefit/cost study of a 1:24,000-scale geologic mapping program conducted in two counties in northern Illinois. The ISGS study was followed in 1993 by an economic analysis of the same scale of geologic mapping in Loudoun County, Virginia, by the USGS (Bernknopf et al. 1993).

protection. Earthquakes, erosion and deposition (along rivers and lakes), flooding, subsidence, landslides, and volcanic activity are all geologic processes that can greatly affect our lives.

Despite the impact of geology on their everyday lives, most citizens are unaware of the benefits derived from reliable and detailed geologic information. Only by knowing where materials and resources are and how geologic processes work, can we minimize the damages and maximize benefits. The only way to obtain geologic information and apply it to address the above concerns is through labor-intensive and expensive, large-scale geologic mapping.

This study on the value of geologic quadrangle maps of Kentucky will inform the taxpayers who financed this and future mapping programs of their costs and benefits. This report is divided into four sections:

1. A general discussion about public goods, their valuation, and aggregation of values over time.
2. The plan of the study.
3. A qualitative valuation of the mapping program.
4. A quantitative estimate of the value of the maps.

GEOLOGIC MAPS AS PUBLIC GOODS

In a perfectly functioning market, supply and demand determine price. Markets, however, often do not function perfectly and in certain cases fail completely. In these cases some costs and benefits are not accounted for in the exchange price. The unaccounted costs may be borne by society, or a few people may enjoy the benefits without adequately paying for them. The concept of public goods was developed to account for cases where the market fails to account for these "externalities" that are not reflected in the price.[2]

A "pure" public good is one that is consumed in equal quantities and simultaneously by all. A pure public good must be unexcludable. Because there is no mechanism to ration or control consumption, even those who do not pay for the good receive it. It also must be in joint supply. When it is supplied to one, it is available to all at no extra cost.

National defense is a good example of a "pure" public good. Every citizen benefits almost equally from it, and resources spent on it provide equal security to all at no extra cost to individuals. Pure public goods have both characteristics of being unexcludable and in joint supply, while pure private goods have neither. Most goods fall somewhere on the continuum between the two extremes.

Public goods "price" is not determined by the market because there is no easily defined market for public goods as there is for cars and washing machines. Since there is no easily defined market for these public goods, a market price that reflects their value does not exist.

Geologic quadrangle (GQ) maps present information created and made available as a public good, and are very nearly pure public goods: no one is excluded from receiving GQ maps.[3] Likewise, GQ maps are jointly supplied. As a result, the "free rider syndrome"—Why should I pay if I can get it almost for free?—exists in the case of GQ maps.[4] In other words, statewide geologic mapping programs would not be undertaken by the private sector in a market economy.

---

[2]The theory of public goods can be traced back to the groundbreaking work of Nobel laureate economist Paul Samuelson in 1954.

[3]A small price has to be paid by each consumer. The price charged is actually a minuscule fraction of the cost of preparing the map. Yet, because a price, however small, has to be paid, they are not available "at no extra cost," nor are their benefits distributed equally among the taxpayers. A similar example would be a park with a small entry fee, where taxpayers pay for the development and maintenance of the park. People who go to the park, as in the case of GQ map users, get more benefit than the non-users, although everybody pays equally for the creation of these public goods. The price charged is so small that GQ maps very nearly satisfy the definition of a pure public good.

[4]When the cost of a facility is paid by the government or any private or corporate entity, individual users of the facility are inclined not to share the cost willingly. In their view, it makes no difference whether they pay a part of the cost or not, because someone has already paid. This is described as the "free rider syndrome."

The nature of public goods such as geologic maps may prompt an individual consumer to be unwilling to pay a price commensurate with the value of the map to him/her. An individual's willingness to pay (WTP) may thus underestimate the true value of the map to a user. Even if we are able to estimate a dollar value for WTP, the real value of public goods is often expressed through qualitative statements, descriptions, and reactions of users if these goods are not made available.[5]

Many empirical ways have been designed and described in the literature on the valuation of public goods. All are intended to assess consumer WTP. The specific approaches always need to be tailored to the case at hand. There are no "one-size-fits-all" recipes.

Methodologies for the valuation of public goods and economics of information (Arrow 1971, Gould 1974, Hess 1980, Laffont 1989) generally take an approach that involves asking the public good user for his or her value assessment, while taking care to avoid or neutralize biases in the responses.[6] The present study follows these methodologies.

We have made an effort to reduce the bias by eliciting a range of possible values on three different questions. According to Bohm (1991), this approach reassures the respondents that the investigators' intentions are not to raise the price, which reduces the respondents' bias. The respondents in this study were asked three basic questions on the value of the Kentucky geologic quadrangle maps: 1) the amount of money they would spend to gather the information contained in the map had the maps not been available, 2) their realized cost savings from the maps, and 3) their willingness to pay for the map. They were also asked to reveal their subjective estimates of maximum, minimum, and the best estimated values for the above three questions. Basing the results on nine possible elicited values reduces the bias that could arise from the *strategic behavior* of respondents in revealing their subjective estimates.

Aggregate costs and benefits

An aspect of valuation of public goods that often causes concern is how to account for the aggregate benefits or costs of public projects. Consumer responses to WTP queries tend to focus on current value, whereas public goods generally are long lasting and provide long-lasting benefits. Kentucky geologic maps, for example, have been in use more than three decades. The costs for the mapping program were incurred from 1961 to 1978, whereas

[5]Another way to assess their value is to try to find the consumers' willingness to accept (WTA) compensation for not producing the public good. Because the government is not obligated to produce GQ maps, however, it is also not obligated nor likely to offer payments to individual map users in lieu of GQ maps. The WTA approach is, therefore, not applicable in this case.

[6]Respondents may understate the value of a public good or public service provided by the government because of the fear that prices may be raised in the future if they assess the value too high, or they may overstate the value to persuade the government to continue to provide the goods or services. The two opposite biases may not affect the outcome if they occur with roughly equal frequency and magnitude.

this study determined the value of maps to users in 1999. In order to compare the costs with the value of the maps, it is necessary to convert either the costs to 1999 dollars or the benefits (map value) back to an agreed upon past point in time. We have chosen to convert the costs to 1999 dollars and compare them with the 1999 value of the maps.

The map users were not asked to estimate the future value of maps to them. The assessment of the present worth of maps involves subjectivity, and even greater uncertainties would be involved if users were to assess the dollar value of maps in future years.[7]

Although efforts have been made in our sampling to reach the widest variety of users of geologic maps, it may not be possible to identify all the users nor all the possible secondary benefits. New users may put geologic maps to new uses in the future, as has happened in the past. When this happens, geologic maps generate hitherto unknown or unsuspected secondary benefits to society and the economy.

In general, public goods and services are provided by the government because governments are interested in maximization of social welfare without diminishing any single person's welfare in the process. Because private investments, geared toward profit maximization, are not intended to improve social welfare, private enterprise does not produce public goods such as the GQ maps, or, if it does, the product is not easily accessible to the public. These two opposing motives are fundamental to determining the discount rates, commonly called social discount rates, to compute the present worth of future public benefits.

Economists' recommendations for social discount rates vary from negative to slightly lower than the rate for risk-free investments, such as treasury notes. Even if the future values of GQ maps were to be available, their conversion into 1999 dollars by using the projected future development of the Consumer Price Index (CPI) would be justifiable. The use of CPI to adjust for the time value of money implies that the real discount rate is zero and the nominal rate is equal to the rate of inflation. The zero real discount rate is within the range of social discount rates recommended for public investments (Hanley and Spash 1993, Brent 1996). It implies that society values the current and the future consumption of benefits from GQ maps equally. Some practitioners of benefit/cost estimation studies recommend a small positive discount rate of 1 to 2% above inflation. We have chosen zero real discount rate because GQ maps represent the fundamental step of knowledge creation, the value of which does not diminish with time. Therefore, we believe that the use of CPI (zero real discount rate or nominal rate equal to rate of inflation) to determine the present value of the past cost of production of GQ maps is well justified.

[7]In the hypothetical case, when users might be able and willing to make such an assessment of future value, a discount rate would have to be determined to convert future benefits of map use to the 1999 level. In industrial projects, a discount rate is determined by considering the market rates for risk-free investments and adding an appropriate risk factor to them. However, geologic maps are public goods and need to be handled differently, because benefits of public goods to society are not quantifiable through market price determination.

STUDY PLAN

The Kentucky Geological Survey (KGS) compiled a list of more than 2,200 individuals and companies most likely to have used GQ maps of Kentucky. The list included members of the Kentucky Geological Society, geologic and environmental consultants, government regulators, mining companies, researchers, planning officials, and teachers. Input from this group was sought through an appropriately designed questionnaire. A questionnaire (see appendix 1) was designed with these objectives:

1. Determine activities that require the use of GQ maps:
2. Discover which map features (lithology, formation contacts, structures etc.), scales, and media (digital or paper) are valued by users.
3. Assess the importance of using GQ maps in projects undertaken by users.
4. Determine how maps make a contribution to quality, credibility, cost, etc. of the user's work.
5. Estimate the dollar value of GQ maps to users.

Meeting the first two objectives will help plan for future mapping products. The other three objectives were used to assess the value of GQ maps in qualitative as well as monetary terms.

The questionnaire contained 14 questions, which required over 60 numeric or yes/no responses and 5 descriptive responses from each respondent. The response rate to the questionnaire was very encouraging and exceeded commonly accepted response rates in marketing strategies. About 440 responses were received as of mid-December 1999. This is a 20% response rate and is about four times the rate considered acceptable in the marketing business. KGS staff mailed the questionnaire and prepared computerized tables of all the responses for further analysis. This involved entry of nearly 27,000 data items and more than 2,200 elaborate descriptive responses.

QUALITATIVE VALUE OF GEOLOGIC QUADRANGLE MAPS

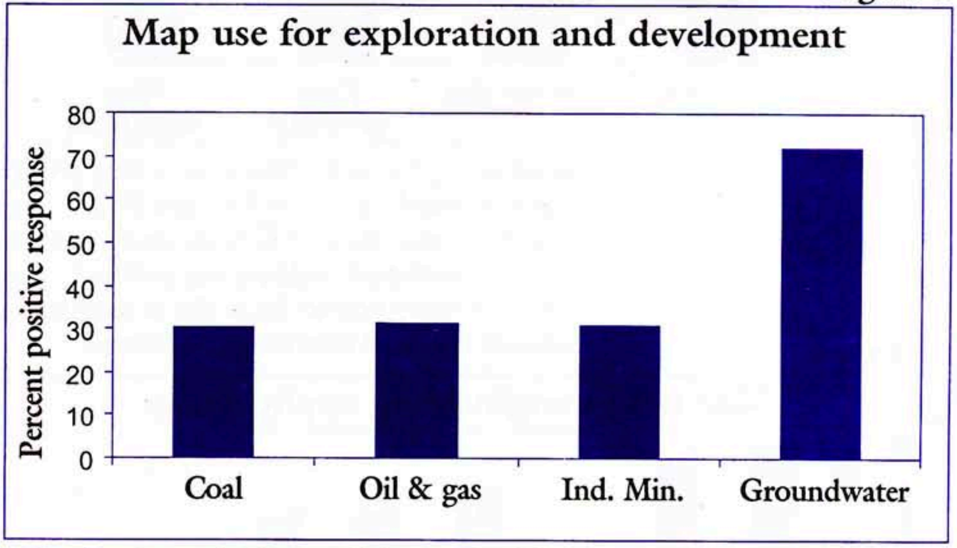
Current map uses and future needs

GQ maps are required for activities that cover nearly the entire spectrum of societal enterprises. The figures below illustrate the first comprehensive assessment that on a statewide basis evaluates user groups and reasons for using GQ maps. Within the seven identified areas of economic and environmental activity that require GQ maps, the bars indicate the percent of respondents who acknowledged a particular map application in each of the 25 sectors represented.[8]

[8]The total in each area is greater than 100% because most respondents indicated more than one use.

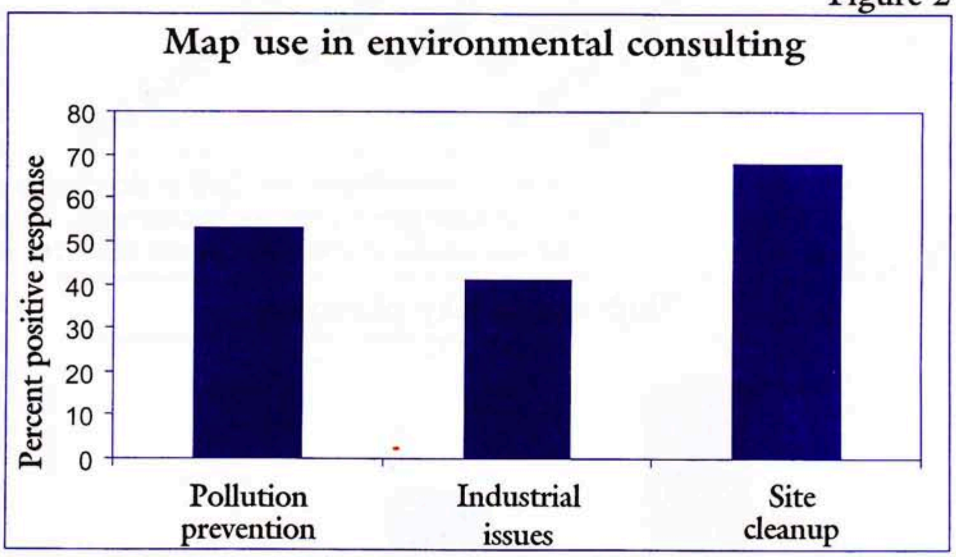
The appearance of groundwater exploration and development as the most frequent use for GQ maps (fig. 1) indicates both the importance of groundwater as a commodity and the value of GQ maps in the development, sustainable use, and protection of this resource. According to KGS, about 21,000 groundwater wells have been installed since 1985 alone, more than 90% of Kentucky's rural population depends exclusively on groundwater, and about 18% of the population using public water supply systems is supplied with groundwater. Roughly a quarter of Kentucky's population relies on groundwater (Alley et al. 1999), and significant land areas of the state have high levels of nitrate and pesticide applications that potentially can enter aquifers (USGS 1999b).

Figure 1



The second most important use of GQ maps is in the exploration and development of minerals and fuels, a vital component of Kentucky's economy. There are about 475 coal mines, more than 100 pits and quarries, more than 23,000 producing oil wells, and some 13,000 gas wells in Kentucky. About 45,000 workers are employed in these mineral industries, and the market value of the minerals and fuels they produced in 1997 was about $4.1 billion. This employment in the mineral industries plays a significant role in a state of fewer than 4 million people, and the minerals themselves make an important contribution to the state GSP of about $100 billion.

Figure 2



The response of environmental consulting professionals (fig. 2) reflects the high priority given in Kentucky to mitigating polluted sites, but it also indicates that the future tasks of preventing pollution and applying geologic maps to industrial issues are considered equally important. Today in year 2000, the U.S. Environmental Protection Agency reports 16 Superfund toxic waste sites in Kentucky on the National Priority List, 132 hazardous waste sites, and 423 toxic release sites in the state.[9]

[9]Toxic release sites are where toxic chemicals are used, manufactured, treated, transported, and released to the environment.

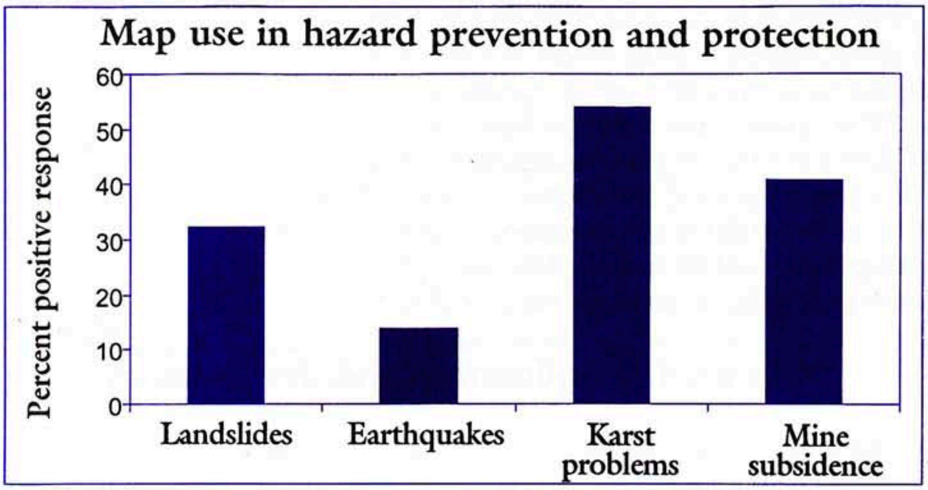


Figure 3

Figure 3 reflects the utility of maps for understanding the causes of geologic hazards, preventing their occurrence, and keeping Kentucky's citizens out of harm's way. The number one use of geologic maps for hazard prevention and protection in Kentucky is delineating areas susceptible to karst problems. About 55% of the state is underlain by karst. Here, dissolution of limestone and dolomite has caused sinkholes, caves, and underground streams. The west-central portion of the state, around Mammoth Cave National Park, is well known for this phenomenon. The three next most significant map uses for hazards are for mine subsidence, landslides, and earthquakes. Earthquake-related uses will likely increase in western Kentucky as more becomes known about the potential for a major earthquake in the New Madrid region of southeastern Missouri.

Figure 4

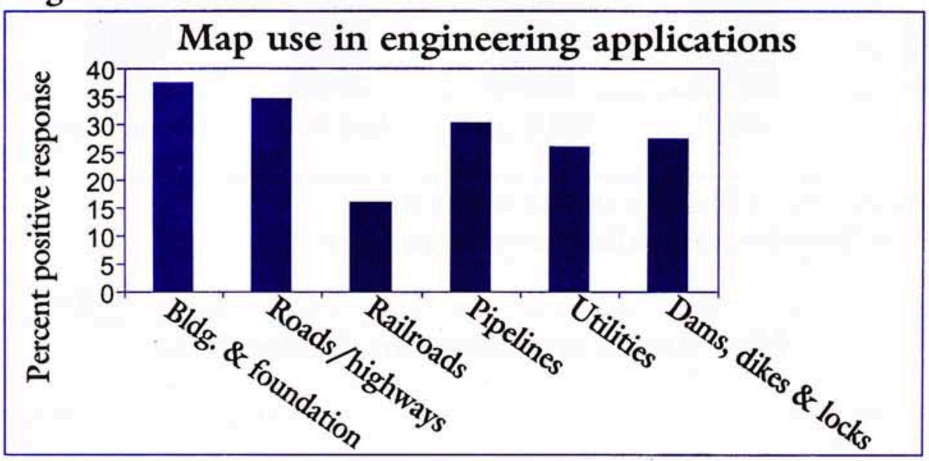
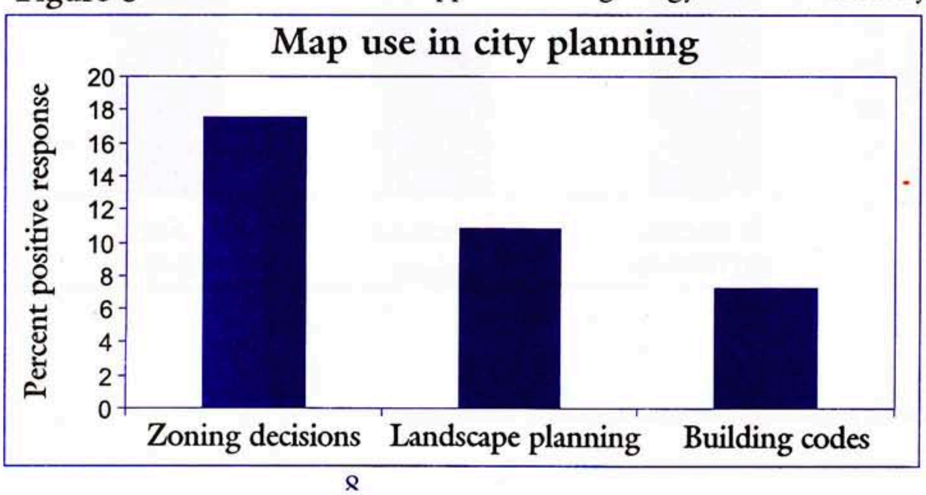


Figure 4 shows the use of geologic maps in maintaining the state's infrastructure and for building, road, pipeline, dam, dike, lock, utility, and railroad construction. Most construction requires high-quality aggregate materials for concrete, and geologic maps help to locate nearby sources of aggregate, which reduces high transportation costs. Maps also help predict construction and excavation conditions, and help in developing mitigation plans for construction in karst-prone geologic hazard areas. Figure 4 indicates how broad based the application of geology is in the Kentucky economy.

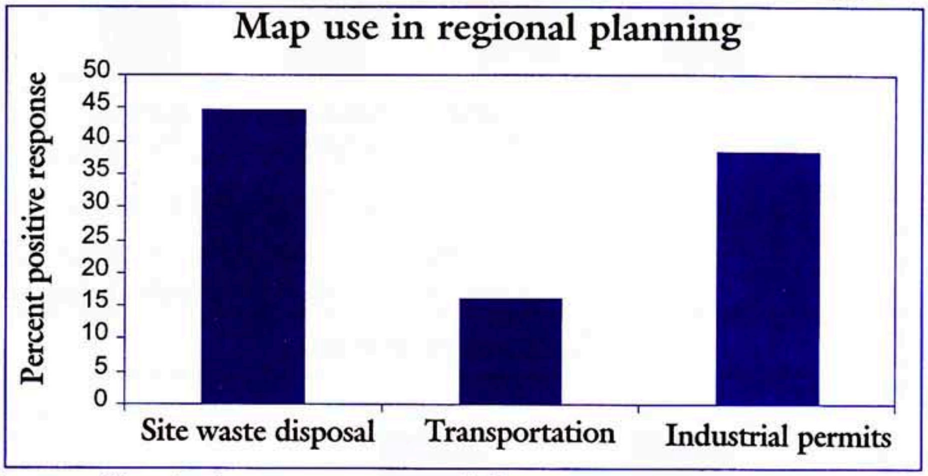
Figure 5



Figures 5, 6, and 7 show responses from users of Kentucky's 1:24,000-scale geologic maps for planning and property valuation.

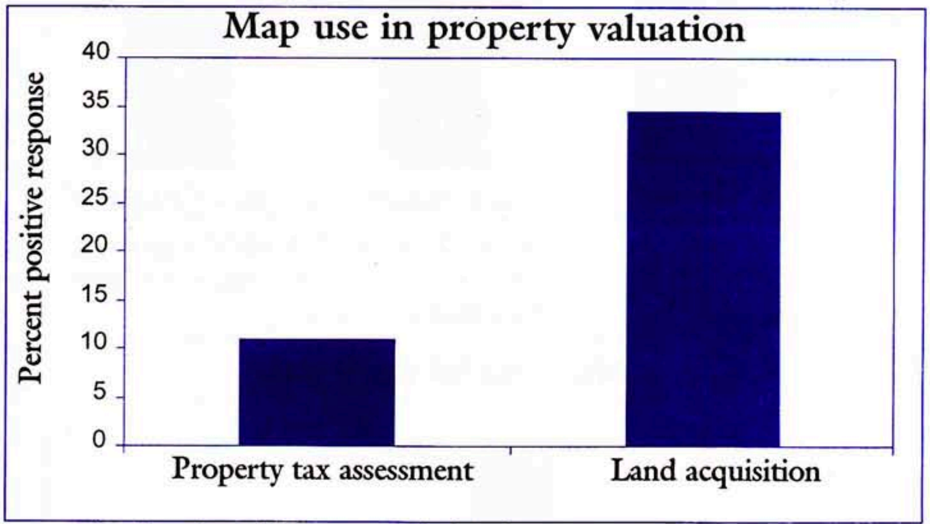
GQ map use for city planning has mainly focused on zoning and landscaping (fig. 5). Population growth and shifting patterns of growth can place considerable stress on an environment if the geologic conditions are not compatible with a particular land-use change. Kentucky, like most states, has experienced growth in metropolitan areas. The Natural Resources Inventory for Kentucky shows that urban land grew from 1,238,400 acres in 1982 to 1,955,300 acres in 1997, a 58% increase totaling 1120.2 square miles. The 1:24,000-scale geologic quadrangle maps provided planners with answers to critical questions about wise land use. Planners also used geologic maps to help develop building codes. Geologic factors such as earthquakes, subsidence, and karst landscapes have a direct effect on the requirements needed for safe construction.

Figure 6



Regional planners used geologic maps for selecting waste disposal sites, for issuing industrial permits, and, to a lesser extent, for locating transportation corridors (fig. 6). Safe waste-disposal siting cannot be accomplished without evaluation of geologic conditions, both regionally and locally. Geologic information is essential in the permit review process for industrial or other land-use activities that have a potential environmental impact. If geologic maps are not available, information must be obtained from alternative sources, if available, often at a high monetary and time cost.

Figure 7



Land acquisition decisions frequently involve use of GQ maps (fig. 7). Prospective buyers want to know of geologic conditions that could result in future problems and liabilities, and geologic maps have essential information on these conditions. For example, an old industrial complex underlain by thick shales or fine-grained lake sediments would be more appealing to potential purchasers because there is less potential future liability for groundwater contamination than if it were underlain by more porous sand and gravel or fractured rock, which are more likely to allow contaminated fluids to pass through. In addition to land acquisition issues, local governments have shown increasing interest in maps for tax value assessment. The value of land that contains mineral resources, for example, could be higher than land without the resources. Similarly, land that is less susceptible to groundwater pollution may be more valuable than other lands to industrial users.

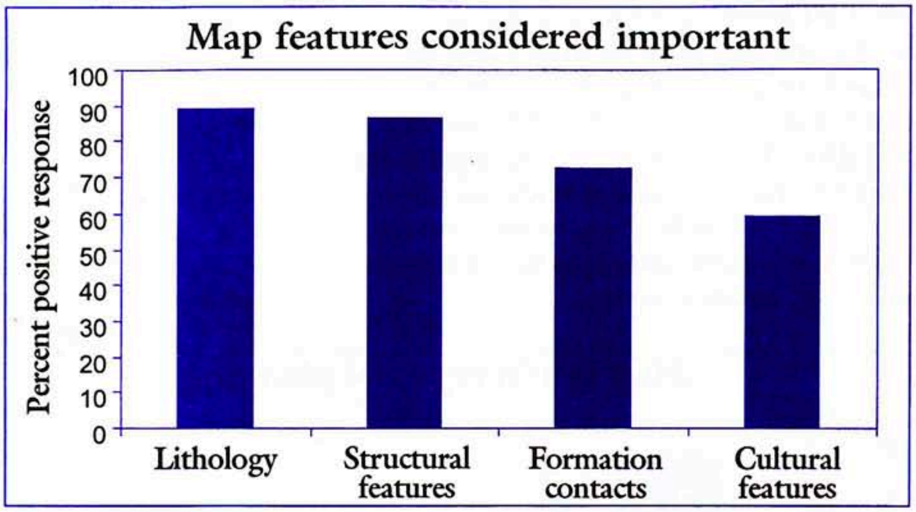


Figure 8

For future mapping programs, it is important to know what features and map scales users consider desirable and how they use the maps. Figures 8, 9, and 10 summarize responses to these questions. Figure 8 shows that respondents mentioned lithology (rock type), structural features (e.g., folds and faults), and formation contacts (where geologic units touch one another) roughly as often as they did cultural surface features (schools, churches, cemeteries, etc). Map users considered all to be very important.

Figure 9 indicates that the respondents currently use the maps more frequently as overlays, copies, and enlargements than in the AutoCAD and Geographic Information Systems (GIS). Figure 10 indicates that the overwhelming scale preference is for 1:24,000 maps. This conforms to the scale chosen for three-dimensional mapping in Illinois, Indiana, Ohio, and Michigan for the Central Great Lakes Geologic Mapping Coalition project (Berg et al. 1999). Speakers and attendees at public forums for geologic map users held in Indianapolis in 1997 and Columbus in 1999 repeatedly stated the need for geologic information at the 1:24,000 scale, a scale these users believe better facilitates planning and resource decisions than do other scales.

Figure 9

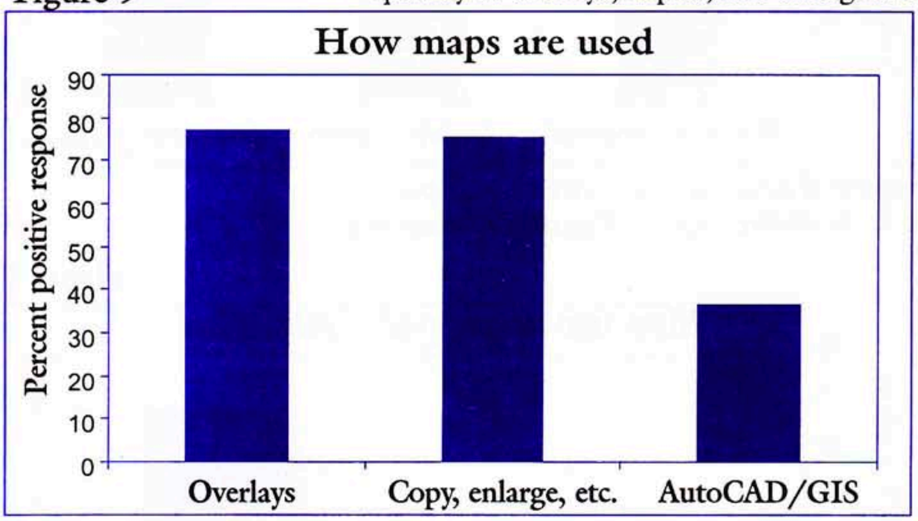
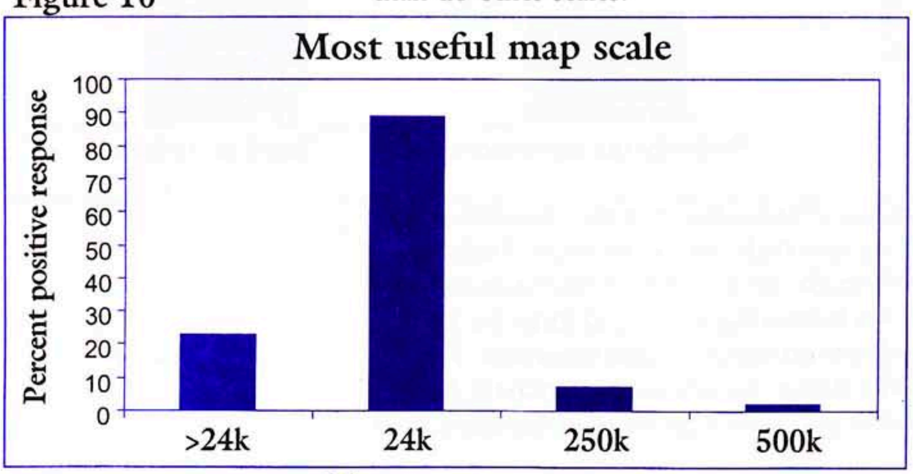


Figure 10



The use of computerized and/or digitized products appears to be increasing, as the product-use data in figure 11 indicates. Digitized surface photos and scans of conventional topographic maps are being used as frequently as digital elevation data files that the user converts to maps. An overwhelming majority (82%) of respondents agreed that digital geologic maps would be valuable to them. Currently, only digitized surface photos, scans of conventional topographic maps, and digital elevation data files are available in digital format at 1:24,000 scale.

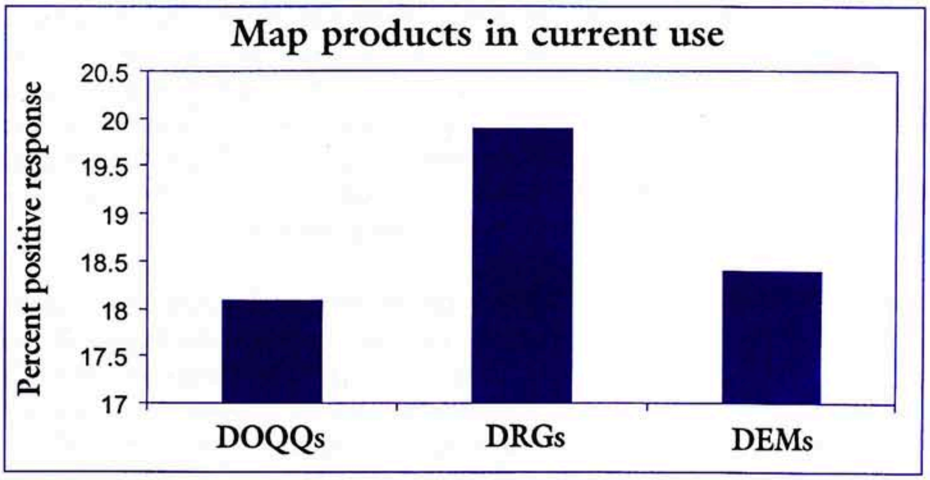


Figure 11

Conclusions from survey results

1. Geologic information is fundamental for a large number of economic and environmental applications.

2. Detailed 1:24,000-scale GQ maps that include major features—lithology, structural features, and formation contacts—are the need of the future, a need that was correctly anticipated in Kentucky three decades ago.

3. Users consider digital geologic maps to be valuable.

Descriptive value judgment

As in any study of benefits and costs of a public good, descriptive value judgments are at least as important as quantitative ones to the decision-making process. Often they are more important because they capture intangibles and psychological aspects. Users were asked three questions to ascertain how GQ maps influence the qualitative aspects of their work. The questions below were aimed at a direct and indirect estimation of user judgement:

- Give as many examples as possible of how geologic quadrangle maps improved the *quality* of your work.
- Give as many examples as possible of how geologic quadrangle maps add *credibility* to your work.
- Describe projects in which the *lack of* geologic quadrangle maps contributed to *poor planning or extra cost.*

We listed the more than 1,300 descriptive answers and separated them into like categories. The following three lists summarize how users see quality and credibility enhanced when maps were used and how they suffered when maps were not available.

How geologic quadrangle maps improve quality of work

- Users feel more confident in own work
- Improved communication among experts (geologists, engineers, planners)
- Excellent educational tool for citizens
- Provide regional geologic context

- Better identification of mineral and groundwater resources
- Better mining and quality control decisions
- Increased precision in well-drilling (location, depth, success rates)
- Improved assessment of groundwater contamination potential
- Superior remediation designs in environmental applications
- Satisfying regulatory requirements
- Aid in court litigation

How geologic quadrangle maps add credibility to work

- Maps created by pool of scientists without profit motives
- They bring standardization of nomenclature
- Geological Survey enjoys reputation in business
- Aid in verification of own field work
- Provide regional context to site-specific geology
- Make visualization easy for non-scientists
- Regulatory agencies require them for credibility

Effects of non-availability of geologic quadrangle maps

- Project costs increase by up to 40%
- Substantial drop in well-drilling success
- Most environmental projects unfeasible without expensive site-by-site mapping by contractor
- Costly errors in engineering decisions
- Delays in project completions
- Teaching Kentucky geology difficult

The broad economic applications of GQ maps, combined with the improvements they enable in quality and credibility of work, make an immeasurable contribution to the state's economy—immeasurable because they are qualitative and pervasive throughout the spectrum of economic and environmental activities routinely carried out in Kentucky.

Another way to assess the intangible value of GQ maps is to study the negative consequences for projects had the maps been not available. Delays in project completions, diminished success rates, costly mistakes, higher overall expenses, and occasional inability to undertake projects entirely are the consequences.

The social and political benefits of being able to use GQ maps or the consequences of not being able to do so can far exceed the direct monetary consequences. An example of both the social and political consequences would be the current discussion about locating waste disposal sites or environmentally sensitive businesses near poorer neighborhoods or neighborhoods with predominantly minority populations. Therefore, the qualitative value of GQ maps discussed above may be far greater than the monetary value discussed in the next section.

QUANTITATIVE VALUATION OF GEOLOGICAL QUADRANGLE MAPS

Because GQ maps have many different users, emerging and unknown new uses, and repeated uses over time, placing a quantitative valuation on them is an extremely complex problem. Our approach has been to first estimate the value to an individual map user and then to extend that value to all the possible map users over time to get an estimate of the aggregate benefits from the Kentucky geologic mapping program.

Theoretical framework

Consider a map user who in preparing a project report uses the GQ map to gather technical information about geology and thus makes better decisions. A typical map user could be a consultant using the maps to prepare a report on a project, or other users such as mining companies, county and city planners, construction engineers. The project could be a planned mining and exploration activity, setting up a landfill, or an environmental clean-up operation. Assume that the map user and his or her clients are risk neutral.[10]

The map user's objective is to minimize the expected total cost of preparing a given quality project report. Given the information available to the user, he or she chooses the level of effort necessary to prepare the report so that total costs are minimized. Increasing the level of effort will increase the total costs. Let T be the level of the consultant's effort, R the credibility of the consultant's report, and α the geologic information available. Then the expected cost function may be represented as

$$EC(T, \alpha, R) \text{ where } \frac{dC}{dT} > 0, \frac{dC}{d\alpha} < 0, \frac{dC}{dR} > 0 \qquad (1)$$

where EC represents the expected value of the total cost. The specification $dC/dT > 0$ indicates that each extra unit of effort put in by the consultant increases total costs over the relevant range of the cost function. Similarly, as more geologic information becomes available, the consultant's total costs tend to fall; hence, $dC/d\alpha < 0$. As in the case of effort, the costs increase as the credibility of the report increases, indicated by $dC/dR > 0$. The consultant minimizes his or her expected total cost, choosing the level of effort T, while adhering to a certain minimum level of credibility, i.e., $R \geq \bar{R}$ where $\bar{R}$ is the minimum level of credibility required for the project report.

[10]To understand risk neutrality, consider the following numerical example: A choice is given between a) accept $10 for sure or b) roll a dice in a gamble which pays off $100 with a 10% probability and $0 with a 90% probability. The person who prefers a) is risk averse, the person who prefers b) is a risk lover, and a person who is indifferent between a) and b) is risk neutral.

Mathematically, this problem of the consultant can be represented as

$$\underset{T}{Min}\ EC(T, \alpha, R) \text{ subject to } R \geq \bar{R}\,. \tag{2}$$

The Lagrangian equation for the above minimization problem is

$$L(T, \lambda) = EC(T, \alpha, R) + \lambda(R - \bar{R})$$

where λ is the Lagrangian multiplier. The Lagrangian multiplier can be interpreted as the value of increasing the credibility of the consultant's report at the margin, say by one unit. In other words, from an economist's perspective, it is the marginal (shadow) value of the credibility of the consultant's report. The first-order conditions for the minimization problem defined in equation 2 are

$$\frac{dL}{dT} = \frac{dC(T, \alpha, R)}{dT} + \lambda \frac{dR(T)}{dT} = 0. \tag{3}$$

$$\frac{dL}{d\lambda} = R(T) - \bar{R} = 0. \tag{4}$$

These first-order conditions define the optimal effort that will minimize the user's cost of preparing the project report.

Now consider a scenario when geologic quadrangle maps are not available. In this case, the consultant has only limited prior information about the geologic conditions, attributable to his or her own experience or smaller scale maps. Let α_p depict the prior information. Note that the subscript p refers to the limited prior information because large-scale geologic maps are not available. In most cases such prior information may not be sufficient to complete the task. The consultant will have to put in some extra effort to get additional information so that the credibility constraint $R \geq \bar{R}$ is satisfied. The consultant in this situation will have to choose the optimal effort that will minimize the total costs while meeting the credibility standards. Mathematically, the consultant's problem under this situation can be depicted as

$$\underset{T}{Min}\ EC(T_p, \alpha_p, R) \text{ subject to } R \geq \bar{R}\,. \tag{5}$$

where T is the level of effort put in by the consultant to prepare his or her report when the geologic quadrangle maps are not available. Let T_p^* be the solution to the above minimization problem. Then the expected cost (EC) under optimal effort is $EC(T_p^*, \alpha_p, \bar{R})$.

Note that the consultant will have to put in some extra effort (in the absence of large-scale geologic maps) to collect the required geologic information, which will increase the total costs. Intuitively, since the consultant minimizes the costs, he or she will put in only the minimum extra effort required to satisfy the credibility constraint. In other words, the credibility of the report under this scenario will be $\bar{R}$.

Now consider an alternative scenario when large-scale geologic quadrangle maps are available and the consultant is working on the same problem, but with the maps. Assume that all the relevant geologic information required for the project is available in the maps and that these maps increase the credibility of the report.[11] Let α_m represent the geologic information contained in the maps. The subscript m represents the second scenario when geologic maps are available. Note that geologic maps provide much of the relevant information and hence a user prefers α_m to α_p. When maps are available, the user would not have to put in the extra effort to collect geologic information required to complete his or her project. The consultant, as in the first scenario, minimizes the expected total costs subject to the standards of credibility. The consultant's problem can then be represented as

$$\underset{T}{Min}\ EC(T_m, \alpha_m, R) \text{ subject to } R \geq \bar{R}. \quad (6)$$

Note that the problem defined in equation 6 differs from the one in equation 5. In the latter case the consultant works with the map, while in the former case it is assumed that the consultant works without the map. Let T^*_m be the solution to the problem defined in equation 6. Then the consultant's expected cost is $EC(T^*_m, \alpha_m, R)$. Since $T^*_p > T^*_m$, it follows (by definition, $dC/dT > 0$) that $EC(T^*_m, \alpha_m, R) < EC(T^*_p, \alpha_p, \bar{R})$. Intuitively, it is rational to assume that when the geologic maps are not available, the consultant has to expend additional effort to collect such information. Hence his or her costs under such a scenario will be higher than those when the maps are readily available. Then the value of the maps to the user is the expected savings in costs when maps are available. Thus, it follows that the expected value of the map to an individual user is

$$EV = EC(T^*_p, \alpha_p, \bar{R}) - EC(T^*_m, \alpha_m, R). \quad (7)$$

Although equation 7 presents an economic model to estimate the value of the map, the relevant data required to estimate it may not be available in the real world. The section below develops an empirical approach to estimate the model presented in equation 7.

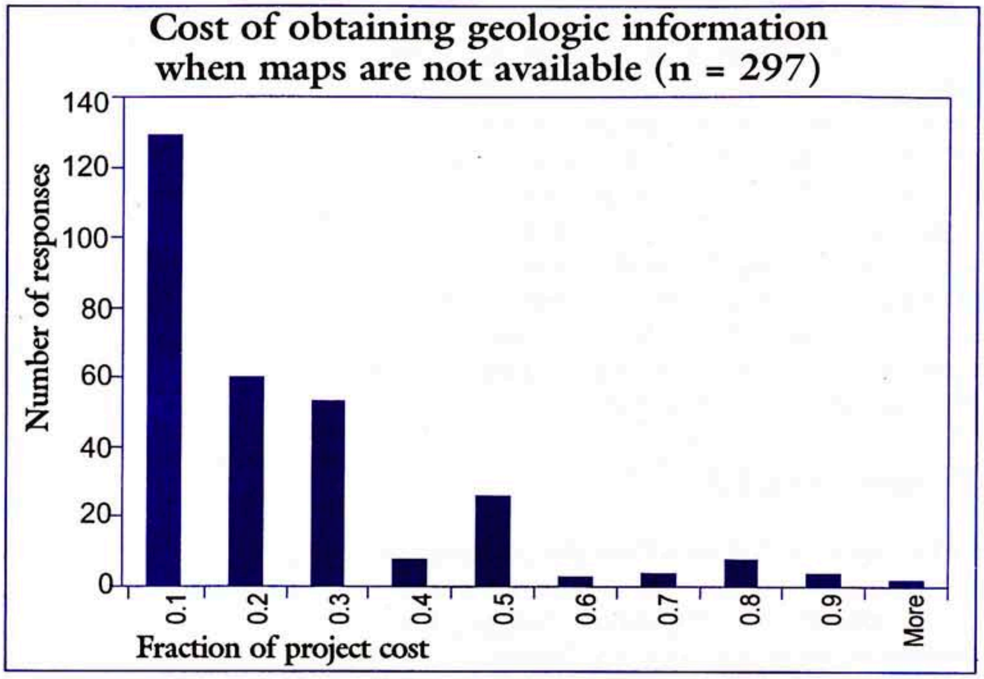
Empirical model

An approximation of the monetary value of GQ maps was first derived from user response to question 9, which asked: "On a typical project for which there is no geologic map, what percentage of total project cost would be spent on obtaining geologic information?" This question was based on the premise that in the absence of GQ maps the users have to spend money to collect geologic information themselves.

Many respondents indicated that they worked in other states in addition to Kentucky and had experienced difficulties when GQ maps were not available.

---

[11]Fifty-nine percent of the respondents indicated that the GQ maps increased the credibility of their report.



Among the 297 respondents who answered this question, 130 indicated that up to 10% of the total project costs would be spent for collecting relevant geologic information if the maps were not available, 60 respondents stated that they would spend 10% to 20%, and 50 gave a range of 20% to 30% (fig. 12). The remaining estimates were higher than 30%. The weighted average estimate of all 297 respondents was about 17% of the total project costs.

Figure 12

Equation 7 outlines a theoretical model to estimate the value of maps when the user is risk neutral. In the real world one does not observe either T^*_p or T^*_m and hence may not be able to estimate $EC(T^*_p, \alpha_p, \bar{R})$ and $EC(T^*_m, \alpha_m, R)$. However, one may observe, or the users may be asked to reveal, the costs saved by the users when maps are available. Such data on cost savings will provide a measure of the expected value postulated in equation 7. The empirical estimation of the value is based on the savings in costs because of the availability of maps. Such methods fall under the general class of bidding games (Randall et al. 1974, Brookshire et al. 1976).

The users were asked to reveal their subjective estimates of cost saved in the context of a single project. Implicit in this context is the assumption that most projects need the area equivalent of one quadrangle map. In actual applications, at least some projects straddle quadrangle boundaries. The subjective estimates of cost savings elicited from the users are then used to estimate expected values. The respondents were first asked to reveal the amount of money they would have been willing to spend to collect the information contained in the map, had the maps not been available (question 14B, appendix 1). This is the cost of additional effort, $T^*_p(\bar{R}) - T^*_m$, the consultant will have to expend when maps are not available. In other words, it is the savings in costs from not having to put in the additional effort, $T_p^*(\bar{R}) - T^*_m$, and is represented as $EV = EC(T^*_p, \alpha_p, \bar{R}) - EC(T^*_m, \alpha_m, R)$. When maps are not available, a rational user, in order to minimize the total cost, will put in only the minimum effort required to meet the minimum credibility requirements. In economic terms, this implies that the credibility constraint will hold with equality under such a situation. The answer to this question provides an estimate of the amount of money a user will spend to collect the relevant information while maintaining the minimum level of credibility. Hence its expected value will provide the minimum value of the map to the user and is defined as $V_{min}(T^*_p, \bar{R})$. The respondents were also asked to reveal the amount of money saved because of the availability of maps (question 14c, appendix 1). This is also a measure of the value of the maps as presented in equation 7 but differs from question 14b. When maps are not available, the consultant collects just enough information to meet $\bar{R}$, the minimum required credibility aspect of the report. But when maps are available, he or she can use all the information contained in the map and prepare a report that has a credibility higher than $\bar{R}$. Hence, the savings in costs when maps are available are the maximum value of the map and are represented as V_{MAX}. The respondents were also asked to reveal the amount of money they would be willing to pay (WTP) for the map (question 14d, appendix 1).

The next step is to estimate the expected values of V_{MIN} and V_{MAX}. The expected values were estimated by using elicited subjective probability distributions of the variables (Bessler 1981, Young 1983). The elicited distributions are then used to estimate the expected values. The first step in this process is the selection of a suitable form of probability distribution. The criteria for selection of the distribution and the elicitation procedure are the ease in data collection and the minimization of time spent by respondents. The triangular density function (Law and Kelton 1990), which meets these criteria, is selected for the purpose. The advantage of this distribution is that it can be approximated with three data points. The data requested are the maximum, the minimum, and the most likely value (mode) of the cost savings from the use of the maps.

It is first assumed that the savings in costs and the implied value of the map, V, is a continuous random variable. Then the first step in using this approach is to identify an interval $[a, b]$ where a and b are real numbers such that $a < b$. The interval $[a, b]$ is identified such that V will lie in this interval with probability 1; that is, $P(V < a) = 0$ and $P(V > b) = 0$, where P is the probability. Thus, a is the respondent's subjective estimate of the lowest possible cost savings from using the map and b is the subjective estimate of the highest possible cost savings. In order to obtain subjective estimates of a and b, the respondents were asked to reveal their most pessimistic and most optimistic estimates, respectively, of the cost savings. They were then asked for their subjective estimate of the most likely cost savings. The most likely value c is the mode of the distribution of V. Once an interval $[a, b]$ and the mode c are identified, the next step is to place a probability density function on $[a, b]$ that is thought to be representative of V.

Given the values of a, b, and c, the random variable V is represented by a triangular distribution on the interval $[a, b]$ with mode c (fig. 13). Then the subjective probability density function of V is (Law and Kelton 1990)

$$f_s(V) = \begin{cases} \dfrac{2(V-a)}{(b-a)(c-a)} & \text{if} \quad a \le V \le c \\ \dfrac{2(b-v)}{(b-a)(b-c)} & \text{if} \quad c < V \le b \\ 0 & \text{otherwise.} \end{cases} \tag{8}$$

The parameters a, b, and c are real numbers with $a < c < b$, where a is a location parameter, $b - a$ is a scale parameter, and c is a shape parameter. The cumulative distribution function then is

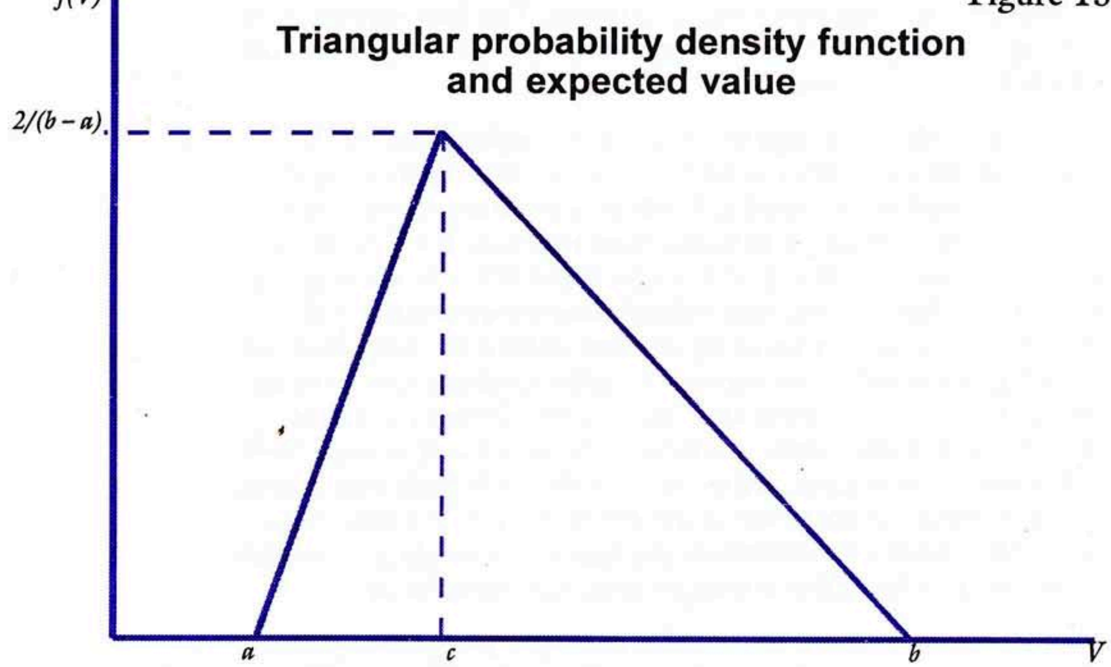
$$F_S(V) = \begin{cases} 0 & \text{if } V < a \\ \dfrac{(V-a)^2}{(b-a)(c-a)} & \text{if } a \le V \le c \\ 1 - \dfrac{(b-v)^2}{(b-a)(b-c)} & \text{if } c < V \le b \\ 1 & \text{if } b < V. \end{cases} \tag{9}$$

Equations 8 and 9 represent the map users' subjective estimates of the distribution of cost savings from the map. Then the expected value of the map to the individual map user is

$$EV = \int V f_S(V)\,dV \tag{10}$$

where EV represents the expected value of the map to an individual map user. The above analysis assumes that the map user is risk neutral and minimizes her/his costs.

Figure 13



Parameters: *a, b* and *c; a < c < b* and range [*a, b*].
a is the subjective estimate of the minimum value of *V*.
b is the subjective estimate of the maximum value of *V*.
c is the most likely value of *V*.
f(V) is the probability density function.
2/(b – a) is the probability that *V* takes the value *c*.

Expected value of *V* is computed by summing up all values multiplied by their respected probabilities as follows:

$$\int V f(V)\,dV.$$

Expected value of the geologic quadrangle maps of Kentucky

The expected values of V_{MIN} and V_{MAX} and the willingness to pay (*WTP*) were estimated from the data collected from the sample of map users. Among the 440 respondents who returned the questionnaire, 69 (15.8%) respondents provided their subjective estimates of V_{MIN} for all the three parameters (*a*, *b*, and *c*) of the triangular density function. In the case of V_{MAX}, 52 (11.9%) respondents provided data on all the three parameters of the density function. Parameter estimates of *WTP* were provided by 49 (11.2%) respondents. The expected values of V_{MIN}, V_{MAX}, and *WTP* on the average are presented in table 1.[12]

The expected ***minimum*** value of one quadrangle map to a single user, EV_{MIN}, on the average is $27,776. The expected ***maximum*** value of a quadrangle map, EV_{MAX}, is $43,527, and the *WTP* for the map on the average is $342. It may be noted that these are expected values of one quadrangle map to a single user. A user, however, may use the map for more than one project. Such multiple uses are not accounted for in this study. Hence the estimated values are very conservative.

Expected value of the geologic quadrangle maps ($/map/user)

EV_{MIN}	27,776
EV_{MAX}	43,527
WTP	342

Table 1

The expected minimum value of the map, EV_{MIN}, ranged from $43 to $396,800 (appendix 2). The expected maximum value, EV_{MAX}, ranged from $13 to 396,800 (appendix 3). The expected values of *WTP* ranged from about $4 to $3,340 (appendix 4).

Aggregation of benefits, mapping costs, and determination of socially optimal level of investment in mapping programs

Theoretical basis for benefit aggregation

As for most public goods, markets do not exist for GQ maps in the sense that they exist for private goods such as cars or computers. Each individual user probably derives different marginal benefit from the maps.[13] Consider figure 14, in which the horizontal axis L represents the scale of GQ maps and the vertical axis represents their marginal value to the user. The cost of mapping increases with scale, while the marginal increase in benefits of larger

[12]The parameters of the probability distribution of V_{MIN}, V_{MAX}, and *WTP* and the expected values for the individual respondents are presented in appendixes 2, 3, and 4. The incomplete answers to questions 14b, 14c, and 14d are summarized in appendixes 5–11.

[13]Our results show that valuations are different for different users, see appendixes 2, 3, and 4.

Aggregation of map values over *n* users

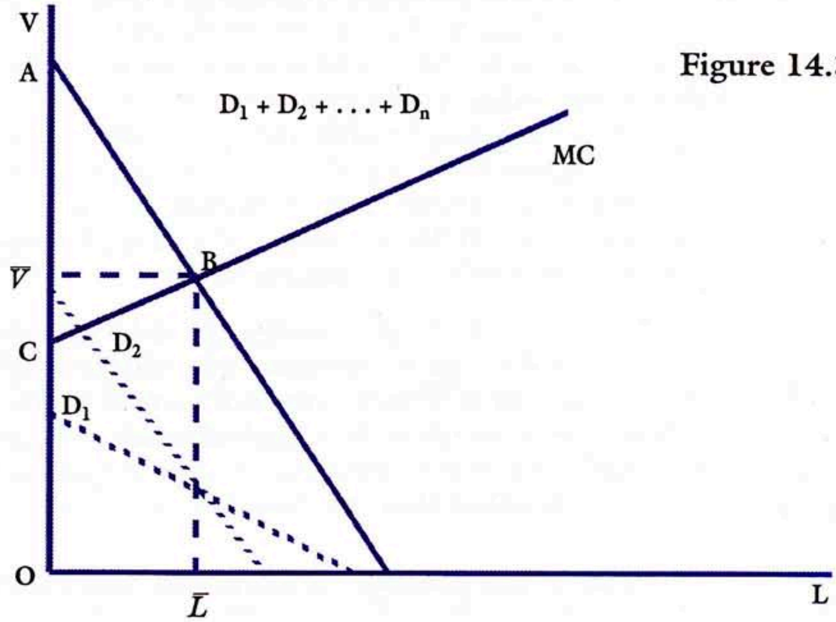


Figure 14.3

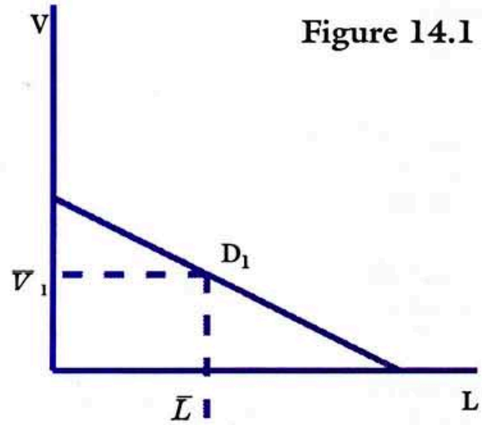


Figure 14.1

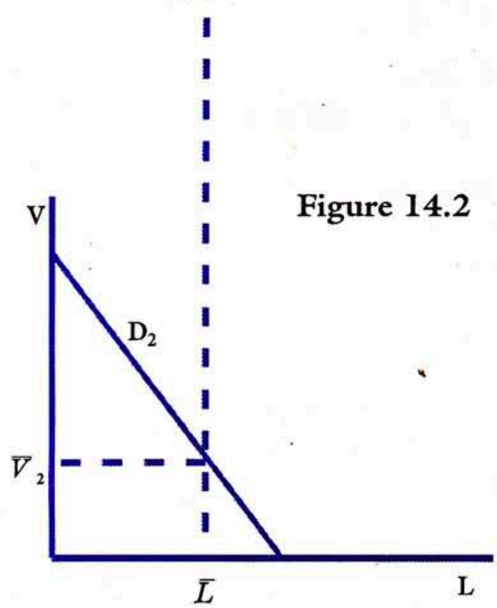


Figure 14.2

scale maps declines.[14] The curve D_1 in figure 14.1 represents the marginal benefits derived by individual 1. Similarly the curve D_2 in figure 14.2 represents the marginal benefits derived by individual 2. The curve MC in figure 14.3 is the marginal cost of producing the maps of increasing scales. If we suppose that there are *n* map users $i = (1, \ldots, n)$, the aggregate marginal benefit is obtained from a vertical aggregation of the individual benefit curves, as in figure 14.3. The socially optimal scale of maps, then, is obtained by equating the marginal cost of producing the maps to the marginal social benefits derived from their use. In figure 14.3, the aggregate marginal social benefit $\bar{V}$ is equal to the marginal costs when the map scale is $\bar{L}$. Thus, if the scale $\bar{L}$ is chosen (along with the cost that it implies), the marginal benefit derived by individual 1 is $\bar{V}_1$ as in figure 14.1 and by individual 2 is $\bar{V}_2$ as in figure 14.2. Because the cost of mapping increases with scale, $\bar{L}$ can serve as proxy for the investment in mapping programs. To generalize, when the generation of maps is at the socially optimal level $\bar{L}$, the marginal benefits derived by each individual user is $\bar{V}_i$. The total social benefits are represented then by the area $AB\bar{L}O$, and the area *ABC* represents the net social benefits. The marginal benefits and costs associated with different scale maps were not solicited from map users in this study, and, thus, the estimation of the areas $AB\bar{L}O$ and *ABC* was not targeted. The benefits also accrue over a

[14] The assumption of declining marginal benefits with increasing map scale is based on the rationale that the highest benefits are derived from even the smallest scale geologic maps when no geologic maps exist at all. From this point on, as geologic maps of larger scale become available their additional value is successively smaller than that of the very first (smallest scale) geologic map ever made available. There will be exceptions to this rule, for example, when a larger scale map may be absolutely essential for a specific application or where a smaller scale map will not do. However, the general rule of diminishing marginal value remains valid as map scale increases.

period of time into the future as new uses may arise in the future. Such future benefits were also not included in this study.

A discrete estimate of the aggregate value of GQ maps at 1:24,000 scale is obtained as

$$\sum_{i=1}^{n} \overline{V}_i$$

where n is the number of map users. These estimates of the average expected values of GQ maps to the individual map users are listed in table 1. The aggregate yearly benefits are estimated by multiplying the number of users by the average value of map to an individual user. The number of map sales is used as a proxy for the number of map users. We assume that each individual buyer will use the map for at least one project and may use the map for more than one project. The results based on the above assumption thus provide a conservative estimate of the aggregate benefits.

A second dimension in the estimation of aggregate benefits is aggregation over time. We have estimated the value of the maps on the basis of data collected in 1999. We recognize that estimates of value expressed in 1999 may or may not reflect the values in the past years because of evolving markets and legal and technological environments. However, the scope and costs of projects for which maps were used also evolved over time. The relative value of GQ maps to the user in the contexts of past projects can, therefore, be assumed to be similar to their current assessment. Thus, the 1999 estimates of value were multiplied by the numbers of GQ maps sold in the past years to arrive at their aggregate value over time.

Empirical estimate of aggregate benefits

Kentucky geologic maps were produced by the U.S. Geological Survey but were sold by USGS, KGS, and the Kentucky Department of Commerce (KDC). Sales records available are primarily limited to those of KGS. Even these are limited to the 1972–1977 (Cressman and Noger 1981) and 1995–1999[15] periods. Accordingly, the number of maps sold by KGS in these 11 years alone totaled about 65,000. At least 16,000 more maps were sold by KDC in the three-year period of 1974–1976 (Cressman and Noger 1981). No records for the remaining years of sales by KGS and KDC are available, nor are the sales records by USGS for any of the years since the start of the program. The documented sales of Kentucky geologic maps total about 81,000. It is conceivable that at least three times as many more maps were sold in other years for which no data are available. Without speculating about the actual map sales, we base the following calculations on a (conservatively low) total sales volume of 81,000 GQ maps.

- The expected minimum aggregate value of GQ maps then would be 81,000 × \$27,776 = \$2.25 billion in 1999 dollars.
- The expected maximum aggregate value of GQ maps would be 81,000 × \$43,527 = \$3.53 billion in 1999 dollars.

[15]Personal communication from Bart Davidson, Kentucky Geological Survey.

- The aggregate willingness to pay (WTP) for the GQ maps would be 81,000 × \$342 = \$27.7 million in 1999 dollars.

The total mapping expenses for the State of Kentucky mapping program completed in the 1961 to 1978 period were estimated to be \$16.035 million in 1960 dollars (Cressman and Noger 1981) or \$90 million in 1999 dollars, based on the Consumer Price Index. The above results aggregated over time indicate that, in monetary terms, the estimated total value of the mapping program at the minimum is at least 25 times the cost of the program. The estimated maximum aggregate value of the Kentucky mapping program is 39 times the cost of the program. In other words, the minimum net social surplus from the mapping program is \$2.16 billion in 1999 dollars. Although the aggregate WTP is estimated to be about 31% of the cost of the program, it must be remembered that the value estimates are based on only 11 years of map sales data from KGS and 3 years of sales data from KDC and ignore all sales by USGS.

Another way to compare these estimated values to the cost of GQ mapping is to consider the average payback period in terms of the number of projects in which a quadrangle map is used. The cost of mapping the 707 quadrangles in Kentucky totaled about \$90 million in 1999 dollars, or \$127,300 per quadrangle. With an average EV_{MIN} value of \$27,776 per quadrangle map per project, the mapping project for an individual quadrangle breaks even when a quadrangle map is used in about 5 projects. If we consider the EV_{MAX} value of \$43,527, the cost of mapping one quadrangle is paid back when the map is used in about 3 projects. The most conservative estimate of the total number of maps sold is around 81,000 or an average of about 114 maps of each quadrangle. It may also be noted that a buyer may use the same map for multiple projects over a period of time. Whether the break-even point is reached after 3 or 5 project uses, it is evident that the average sales per quadrangle of 114 maps are indicative of benefits exceeding costs by ratios of about 23:1 and 38:1, which are close to those calculated previously.

A third way of looking at the results is to compare the average estimated dollar values with the estimates of the proportions of project costs the geologic information accounts for as represented in figure 13. The average expected minimum value of \$27,776 per quadrangle map is plausible when we consider that, on the average, about 17% of project cost is attributable to obtaining geologic information when maps are not available.[16] This percentage would put the average total project cost (size) at about \$164,000. Considering the same share of 17% and the average expected maximum value of a GQ map of \$43,527, the total project cost (size) would be about \$256,000. Based on our experience with GQ map users, geologists, and project managers, we think that these numbers are plausible. This context lends credibility to the expected minimum and maximum values determined from the responses.

---

[16]The share of total project cost that would be spent on obtaining geologic information when maps are not available (question 9, appendix 1) on the average was 17%.

Even using these very conservative sales figures, this is a surprisingly robust value for a public good. Since GQ maps are a non-excludable public good, the full benefits of the maps accrue to any individual user even if that individual willingly pays only a negligible price (the "free rider syndrome"). User response to question 14B in the questionnaire confirms that users are not willing to pay the full cost of producing the map. Yet, based on only a fraction of the map sales data, users have shown the willingness to pay at least 31% of the cost of the mapping program in Kentucky. The actual number of maps sold until now is estimated to be at least two to three times higher, indicating that users are probably willing to pay fully for the cost of the mapping program in Kentucky. Considering the additional intangible benefits of geologic maps described in the first part of the report, we conclude that the geologic mapping program in Kentucky has been an excellent public sector investment for society.

The above results are based on the assumption of zero real discount rates. An alternative scenario could be to assume a real discount rate of 1 or 2% above inflation. In our basic calculations, we have adjusted the cost of the mapping program for inflation by using the Consumer Price Index (CPI) instead of discounting the benefits to a past date; i.e., we have assumed a zero real discount rate above inflation. Assuming that the mapping costs increased by 1% above inflation annually (1% real discount rate), the cost of the mapping program in 1999 dollars would be $130 million. In this case, the minimum expected value of the GQ maps would be 17 times the cost, the maximum expected value would be 27 times the cost, and the WTP would be 0.21 times the cost. Alternatively, if the cost of the mapping program were increased by 2% above inflation annually (2% real discount rate), it would be $188 million in 1999 dollars, and the ratios would be about 12:1 for the minimum expected value, 18.5:1 for the maximum expected value, and 0.15 for the WTP. Note that these very conservative scenarios, also based on only a fraction of the map sales data, indicate that investment in geologic mapping has been highly productive and that the returns to mapping investment far exceeded the costs.

SUMMARY AND CONCLUSIONS

This study was conducted in Kentucky because it is the only state that has completed 1:24,000-scale geologic mapping, published maps for all quadrangles, and seen at least two decades of map use. Sufficient time has elapsed to evaluate which sectors of Kentucky's economy have been using GQ maps, the reasons for using the maps, and how much the maps have been worth to the users.

Studies of the value of public investments are difficult because of their intangible and future benefits. This empirical study is anchored in solid foundations of economic theory of public goods and uses the most conservative assumptions possible.

A total of 2,200 actual and potential users of geologic maps was polled. The response rate of 20% (440 responses) provides a representative sample of the user population. It includes geologists working independently or for mining or utility companies, geology teachers, county and city planners, and government employees involved in environmental and other regulations concerning health and safety. While it is impossible to identify the whole user population, we believe that a very large fraction of the user population has been polled and given an opportunity to participate.

Users were asked to answer a questionnaire designed to solicit data on map uses, desirable map features, and subjective dollar value of maps to the users.

Map use

The user responses indicate that GQ maps are used in nearly all sectors of the economy to ensure environmental safety, to prevent hazards to man-made structures, and to explore and develop natural resources such as groundwater, minerals, and fuels. The use of GQ maps improves the quality and credibility of work and saves money. Most importantly, geologic mapping generates knowledge, a public good vital to the economy, public safety, and public health. This knowledge would not be produced if left to private enterprise, and has not been produced by private enterprise elsewhere, except on a site-specific basis or under contract to a public agency. Map users indicated the desirability of lithology, structural features, formation contacts, and cultural features in maps. The most desirable map scale was 1:24,000. Although most users currently use maps as overlays, copies, enlargements, and in AutoCAD and GIS, they indicated an overwhelming desire for digital maps for the future.

Map value

The aggregate value of GQ maps in this study was based on only a fraction of actual sales data. On the basis of the user response, the study computed the average minimum and maximum expected values of a quadrangle map to be $27,776 and $43,527. We calculated the aggregated value of GQ maps sold over a fraction of the study years to be at least $2.25 billion at the minimum and $3.53 billion at the maximum in 1999 dollars. The cost of the geologic mapping program in Kentucky was about $90 million in 1999 dollars. The value of the geologic maps to the users was at least 25 to 38 times higher than the cost of the mapping program. When cost estimates for the mapping program were inflated by 1% per year above inflation, the value of the maps outweighed costs by a minimum margin of 17:1 and a maximum of 28:1. Even when mapping costs were inflated by 2% per year above the rate of inflation, the value remained comfortably higher than costs, at a minimum ratio of 12:1 and a maximum of 18.5:1.

The average willingness to pay (WTP) was reported to be $342 per map. The very limited map sales data available indicate a WTP/mapping cost ratio of 0.31. Complete map sales data would raise the ratio to cover the entire cost of the mapping program and probably much more. Case studies of public policy decisions and projects involving public goods indicate that WTP/cost ratios less than one are not uncommon. Since public goods are non-excludable, individual users may not be willing to pay the full cost of providing the public good as he or she will not get exclusive rights to the good. He or she pays only a user fee that is much less than the cost of producing and facilitating the public good. Hence a WTP/cost ratio less than one is not an unexpected result.

Finally, a whole section of this study is devoted to intangible benefits derived by map users. These include such vital aspects as increased credibility of reports and studies prepared by map users, time saved in project completions, and the unbiased information in maps prepared by scientists without a vested interest. These kinds of intangible benefits often outweigh the monetary value of public goods. Such benefits are especially important in the case of public goods that create and deliver scientific knowledge, such as the geologic maps, as against public goods that provide physical facilities of economic or recreational value, such as parks, roads, or bridges.

References

Alley, W. M., T. E. Reilly, and O. L. Franke, 1999, Sustainability of Ground-water Resources: U.S. Geological Survey Circular 1186, 79 p.

Anderson, L. G., and R. F. Settle, 1977, Benefit Cost Analysis—A Practical Guide: Lexington Books, D. C. Heath and Company, Lexington MA, 140 p.

Arrow, J. K., 1971, The value and demand for information, *in* Essays in the Theory of Risk Bearing: Markham, Chicago.

Berg, R. C., N. K. Bleuer, B. E. Jones, K. A. Kincare, R. R. Pavey, and B. D. Stone, 1999, Mapping the Glacial Geology of the Central Great Lakes Region in Three Dimensions—A Model for State-federal Cooperation: U. S. Geological Survey Open-File Report 99-349, 64 p.

Bernknopf, R. A., D. S. Brookshire, D. R. Soller, M. J. McKee, J. F. Sutter, J. C. Matti, and R. H. Campbell, 1993, Societal Value of Geologic Maps: U. S. Geological Survey Circular 1111, 53 p.

Bessler, D. A., 1981, Some Theoretical Considerations on the Elicitation of Subjective Probability: Department of Agricultural Economics, Purdue University, West Lafayette, Indiana, Bulletin No. 332.

Bhagwat, S. B., and R. C. Berg, 1991, Benefits and Costs of Geologic Mapping Programs in Illinois—Case Study of Boone and Winnebago Counties and Its Statewide Applicability: Illinois State Geological Survey Circular 549, 40 p.

Bohm, P., 1991, An approach to the problem of estimating demand for public goods: Swedish Journal of Economics, v. 73, p. 94–105.

Brent, R. J., 1996, Applied Cost-Benefit Analysis: Edward Elgar Publishing Company, Northampton, Massachusetts, v. 74. p. 336.

Brookshire, D. S., B. C. Ives, and W. D. Schultze, 1976, The valuation of aesthetic preferences: Journal of Environmental Economics and Management, v. 3: p. 325–346.

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.

Gould, J. P., 1974, Risk, stochastic preference, and the value of information: Journal of Economic Theory, v. 8, p. 64–84.

Hanley, N., and O. L. Spash, 1993, Cost-Benefit Analysis and the Environment: Edward Elgar Publishing Company, Northampton, Massachusetts, 278 p.

Hess, J., 1980, Risk and gain from information: Journal of Economic Theory, v. 27, 231–238.

Laffont, J. J., 1989, The Economics of Uncertainty and Information: The MIT Press, Cambridge, Massachusetts, 289 p.

Law, A. M., and W. D. Kelton, 1990, Simulation Modeling and Analysis. McGraw-Hill Book Company, New York.

McGrain, P., 1966, Some Economic Aspects of Kentucky's Geologic Mapping Program: Society of Mining Engineers, preprint 66H301, 10 p.

McGrain, P., 1967, The Application of New Geologic Maps to the Economic Growth of Kentucky: Kentucky Geological Survey, Series 10, Special Publication 14.

McGrain, P., 1979, An Economic Evaluation of the Kentucky Geologic Mapping Program: Kentucky Geological Survey, Series XI, 12 p.

Randall, A., B. C. Ives, and C. Eastman, 1974, Bidding games for evaluation of aesthetic environmental improvement: Journal of Environmental Economics and Management, v. 3, p. 325–346.

Samuelson, P. A., 1954, The pure theory of public expenditure: The Review of Economics and Statistics, v. 36, p. 387–389.

U. S. Geological Survey, 1999a, Sustainable Growth in America's Heartland—3-D Geological Maps as the Foundation: U.S. Geological Survey Circular 1190, 17 p.

U. S. Geological Survey, 1999b, The Quality of Our Nation's Waters, Nutrients and Pesticides: U.S. Geological Survey Circular 1225, 82 p.

Young, D. L., 1983, A Practical Procedure for Eliciting Subjective Distributions, Paper presented at the American Economics Association meeting, West Lafayette, Indiana.

Related readings

Illinois State Geological Survey, 1996, Break from Tradition, Annual Report, 26 p.

Illinois State Geological Survey, 1997, New Directions, Annual Report, 30 p.

Illinois State Geological Survey, 1998, Geology for a New Generation, Annual Report, 58 p.

Just, R. E., D. L. Hueth, and A. Schmitz, 1982, Applied Welfare Economics and Public Policy: Prentice Hall, Inc., New Jersey.

Marchak, J. and K. Miysawa, 1968, Economic comparability of information systems: International Economic Review, v. 9, p. 137–141.

Preckel, P. V., E. T. Loehman, and M. S. Kaylen, 1987, The value of public information for microeconomic production decisions: Western Journal of Agricultural Economics, v. 12, p. 193–197.

Roe, T., and F. Antonovitz, 1985, A producer's willingness to pay for information under price uncertainty: Theory and application: Southern Journal of Economics, v. 52, p. 382–391.

Sugden, R., and A. Williams, 1978, The Principles of Practical Cost-Benefit Analysis: Oxford University Press, New York, NY. 275 p.

U.S. Environmental Protection Agency, 2000, Envirofacts Warehouse, [www.epa.gov/superfund/sites/index.htm] and [www.epa.gov/opptintr/tri/tri97/pdf/97state/ky97.pdf].

Appendix 1
Questionnaire: Assessment of benefits of geologic quadrangle maps of Kentucky

1. Activities in your organization that may require the use of geologic quadrangle maps: (Check all that apply)

   Exploration and development
   - ☐ Coal
   - ☐ Groundwater
   - ☐ Oil and natural gas
   - ☐ Other (specify)
   - ☐ Industrial minerals (limestone, sand/gravel, clay, ore deposits)

   Environmental consulting
   - ☐ Pollution prevention
   - ☐ Site cleanups
   - ☐ Industrial

   Hazard prevention/protection
   - ☐ Land slides
   - ☐ Karst problems
   - ☐ Earthquakes
   - ☐ Subsidence

   Engineering applications
   - ☐ Buildings and foundation problems
   - ☐ Pipelines,
   - ☐ Roads/highways
   - ☐ Utilities,
   - ☐ Railroads
   - ☐ Dams, dikes, river locks

   City planning
   - ☐ Zoning decisions
   - ☐ Building codes
   - ☐ Landscape design and planning

   Regional planning
   - ☐ Siting waste disposal facilities
   - ☐ Permitting industrial facilities
   - ☐ Transportation

   Property valuation
   - ☐ For tax purposes
   - ☐ Land acquisitions

2. What percentage of your work in the last five years depended on using geologic quadrangle maps?
   - ☐ By number of projects ____(%)
   - ☐ By hours ____(%),
   - ☐ By dollar value ____(%)

3. What features shown on the geologic quadrangle maps are important for your work?
   - ☐ Lithology
   - ☐ Formation contact
   - ☐ Structural features
   - ☐ Relationship of the above to cultural features

   What features would you want on geologic quadrangle maps that are currently not on such map? Please list:

4. How do you use geologic quadrangle maps:
   - ☐ Overlay with other data
   - ☐ Put into Auto CAD or GIS, then manipulate
   - ☐ Photocopy, reduce or enlarge for technical reports

5. What scale of geologic maps is most useful to you?
   - ☐ Larger than 1:24,000
   - ☐ 1:250,000
   - ☐ 1:24,000
   - ☐ 1:500,000

6. Which, if any, of the following digital map products are you using now? (Check all that apply.)
   ☐ Digital Orthophoto Quarter Quads (DOQQs)   ☐ Digital Elevation Model (DEMs)
   ☐ Digital Roster Graphic (DRGs) Other (specify)

7. Would digital geologic maps be of value to you?
   ☐ Yes   ☐ No
   Comments:

8. How do you obtain the needed information if there is no geologic quadrangle map?
   ☐ Own field work   ☐ Hire a consultant
   ☐ Contract Geological Survey

9. On a typical project for which there is no geologic map, what percentage of total project cost would be spent on obtaining geologic information?____________%.

10. Give as many examples as possible of how geologic quadrangle maps improved the quality of your work. (Use separate sheet if necessary.)

11. Give examples of how geologic quadrangle maps add credibility to your work. (Use separate sheet if necessary.)

12. Describe projects in which the lack of geologic quadrangle maps contributed to poor planning or extra cost? Explain how. (Use separate sheet if necessary.)

13. Estimate the dollar value of geologic quadrangle maps in Kentucky for you or your company. $____ ______________. Please explain.

14. Case example:
   A. Name a particular project for which you used geologic quadrangle maps.

   B. Had the maps not been available, how much money would you have willingly spent to get the information contained in the maps for the above use? (We know that this and the following questions are difficult but give us the best estimate.)

   ☐ Maximum spent $______________   ☐ Minimum spent $______________

   ☐ Best estimate of money spent $______________

   C. Estimate the money you saved because of the availability of maps.

   ☐ Maximum savings $______________   ☐ Minimum savings $______________

   ☐ Best estimate of savings $____________

   D. Given the value of the map to you, how much money would you have paid for the map?

   ☐ Maximum $_________________   ☐ Minimum $_________________

   ☐ Actual payment $_________________

If you wish to identify yourself and your company by name, please do so here.

SBB/isgs/June23,1999

Parameters of the distribution of the minimum value of the map (V_{MIN}) and expected values (EV_{MIN}; \$)

ID #	a	b	c	EV_{MIN}
2	40,000	75,000	50,000	54,560
5	5,000	10,000	250,000	87,627
9	2,000	5,000	5,000	3,968
10	3,000	100,000	50,000	50,592
12	3,000	15,000	12,000	9,920
17	100	1,000	50	380
30	4,000	10,000	7,000	6,944
51	2,000	10,000	4,000	5,291
52	800	1,400	900	1,025
54	2,000	4,000	2,000	2,645
59	2,000	10,000	3,000	4,960
63	40,000	75,000	50,000	54,560
83	5,000	30,000	5,000	13,227
88	500	1,000	100	529
91	100	550	1,000	546
93	10,000	50,000	20,000	26,453
96	100	250	125	157
119	25	250	75	116
136	100,000	250,000	150,000	165,333
146	15,000	25,000	525,000	186,827
149	5,000	100,000	25,000	42,987
152	500	2,000	1,000	1,157
160	100	500	500	364
162	2,000	150,000	80,000	76,715
163	10,000	25,000	18,000	17,525
164	1,000	10,000	100	3,670
169	4	500	100	200
176	50	150	100	99
186	10,000	20,000	10	9,923
190	5,000	20,000	15,000	13,227
199	1,000	2,000	1,980	1,647
201	500	2,000	1,000	1,157
205	500	1,000	500	661
216	1,000	1,500	500	992
224	1,000	5,000	2,500	2,811
227	50	250	100	132
239	10,000	20,000	12,000	13,888
244	30,000	60,000	50,000	46,293
245	1,000	5,000	2,000	2,645
251	1,000	10,000	3,000	4,629
264	2,000	10,000	50	3,985
267	150	300	75	174
268	250,000	500,000	65,000	269,493
276	6,500	12,500	8,000	8,928
278	1,000	5,000	2,000	2,645
293	10,000	25,000	30	11,583
324	5	500	100	200
330	1,000	10,000	1,000	3,968
336	15,000	50,000	3,000	22,485
339	10	200	10	73
340	500	2,500	2,000	1,653
343	200	500	300	331
346	500	5,000	1,500	2,315
347	5,000	10,000	8,000	7,605
348	500	7,000	2,000	3,141
351	1,000	5,000	2,500	2,811
354	300	2,000	500	926
375	1,000	50,000	25,000	25,131
378	20,000	50,000	40,000	36,373
386	500	1,500	1,500	1,157
392	1,500	5,000	500	2,315
393	500	1,000	50	513
394	250,000	500,000	450,000	396,800
398	10,000	50,000	25,000	28,107
399	10	100	20	43
411	10,000	25,000	15,000	16,533
422	200	5,000	350	1,835
434	100,000	200,000	150,000	148,800
436	100	500	150	248

Mean V_{MIN}	27,776
Max V_{MIN}	43
Min V_{MIN}	396,800

Appendix 3

Parameters of the distribution of the maximum value of the map (V_{MAX}) and expected values (EV_{MAX}; $)

ID #	*a*	*b*	*c*	EV_{MAX}	ID #	*a*	*b*	*c*	EV_{MAX}
2	300,000	500,000	400,000	396,800	224	1,000	15,000	1,200	5,687
5	5,000	10,000	250,000	87,627	244	10,000	25,000	10,000	14,880
9	5,000	10,000	10,000	8,267	245	500	1,000	700	727
10	10,000	90,000	90,000	62,827	264	5,000	9,000	7,000	6,944
50	5,000	15,000	10,000	9,920	267	50	200	100	116
51	2,000	10,000	4,000	5,291	268	185,000	435,000	245,000	286,027
52	700	1,300	800	926	276	1,250	2,500	1,500	1,736
54	40,000	50,000	40,000	42,987	278	500	2,000	1,000	1,157
59	2,000	10,000	3,000	4,960	293	10,000	25,000	24,000	19,509
63	300,000	500,000	400,000	396,800	330	1,000	10,000	10,000	6,944
83	10	20	10	13	336	10,000	20,000	15,000	14,880
88	100	900	900	628	346	500	5,000	1,500	2,315
93	8,000	45,000	18,000	23,477	348	300	5,000	1,500	2,249
96	250	1,000	500	579	351	500	4,000	2,500	2,315
119	25	$250	75	116	354	300	1,700	200	727
136	100,000	250,000	150,000	165,333	355	100	15,000	3,000	5,985
146	10,000	20,000	50,000	26,453	375	1,000	50,000	25,000	25,131
152	500	2,000	1,000	1,157	378	20,000	50,000	40,000	36,373
164	10,000	100,000	1,000	36,704	379	25,000	50,000	40,000	38,027
170	3,000	10,000	5,000	5,952	386	500	1,500	1,500	1,157
176	50	150	100	99	392	1,000	4,500	2,500	2,645
190	20,000	60,000	40,000	39,680	393	450	850	700	661
199	30,000	40,000	40,000	36,373	394	250,000	500,000	450,000	396,800
201	500	1,000	1,000	827	398	10,000	50,000	25,000	28,107
205	1,000	10,000	5,000	5,291	422	25	4,500	500	1,662
216	1,000	1,500	1,500	1,323	436	100	500	150	248

Mean V_{MAX}	43,527
Min V_{MAX}	13
Max V_{MAX}	396,800

Parameters of the distribution of the willingness to pay for the map (*WTP*) and expected values (EV_{WTP}; $)

ID #	*a*	*b*	*c*	EV_{WTP}	ID #	*a*	*b*	*c*	EV_{WTP}
9	500	1,000	10	499	197	18	200	18	78
10	5,000	5,000	100	3,340	199	250	500	20	255
12	5	100	4	36	201	8	20	8	12
17	4	10	4	6	216	50	250	150	149
30	10	100	15	41	224	2	1,000	5	333
50	5	30	10	15	227	4	4	4	4
52	5	75	15	31	244	200	2,000	500	893
59	5	20	5	10	245	50	200	100	116
77	7	25	7	13	251	6	100	6	37
91	15	100	15	43	268	8	12	8	9
96	5	10	7	7	276	125	250	150	174
117	10	25	12	16	278	15	30	15	20
118	2	25	5	11	293	10	15	8	11
119	5	10	8	8	320	5	10	3	6
146	100	1,000	500	529	341	5	10	5	7
149	75	5,000	125	1,719	348	100	500	100	231
152	5	25	5	12	351	10	15	2	9
160	25	50	50	41	354	300	750	350	463
164	50	100	10	53	361	5	10	5	7
170	3	12	4	6	386	15	50	20	28
176	5	20	10	12	392	50	5,000	50	1,686
186	50	100	10	53	398	1,000	5,000	4	1,985
188	500	1,000	50	513	399	5	50	10	21
190	500	2,000	1,200	1,223	422	5	20	12	12
Mean *WTP*		342.19							
Min *WTP*		3.97							
Max *WTP*		3,339.73							

Appendix 5

Parameters of the distribution of the minimum value of the map V_{MIN} ($) in cases where information provided is incomplete

Respondents who provided *a* and *b* only

ID #	*a*	*b*
77	500	2,500
89	5,000	10,000
124	10	75
143	10,000	100,000
153	50	1,000
154	3,000	6,000
156	500	5,000
178	100	500
179	25	75
188	2,000	10,000
219	7	100
225	10,000	50,000
237	25	1,000
241	5	10
254	500	2,000
275	15,0000	600,000
289	2,000	10,000
313	25	75
341	500	2,000
342	300	1,500
349	100	200
355	30	3,000
366	500?	25?
372	1,000	200,000
374	300	500
397	1,000	5,000
400	500	1,800
402	500	5,000
424	1,000	4,000
Mean V_{MIN}	6,749	36,476
Min V_{MIN}	5	10
Max V_{MIN}	15,000	600,000

Respondents who provided *b* and *c* only

ID #	*b*	*c*
11	3,000	3,500
15	2,500	350
117	1,000	300
122	200	10
126	100,000	5,000
197	200	100
247	100,000	50,000
260	5,000	50
284	5,000	500
286	1,000	100
350	10,000	2,500
365	35	35
367	10,000	500
417	100	25
Mean V_{MIN}	17,003	4,498
Min V_{MIN}	35	10
Max V_{MIN}	100,000	50,000

Respondents who provided *a* only

ID #	*a*
214	100,000
261	1,000
383	20,000
387	25,000
Mean V_{MIN}	36,500
Min V_{MIN}	1,000
Max V_{MIN}	100,000

Parameters of the distribution of the minimum value of the map (V_{MIN}; \$) in cases where information provided is incomplete

Respondents who provided *b* only		Respondents who provided *c* only	
ID #	*b*	ID #	*c*
4	500	26	300
14	500	42	200
18	1,000	48	10,000
19	2,000	76	800
43	500	84	80,000
46	200	95	2,000
50	10,000	118	500
53	500	138	250,000
72	25,000	140	5,000
81	60,000	145	5,000
82	1,000	151	1,000
94	50,000	157	80,000
142	10,000	159	10,000
155	200	183	100,000
161	500	184	2,000
171	1,800	192	5,000
182	50,000	193	500
206	1,000	210	10,000
223	200	211	10,000
230	10,000	236	50,000
248	100	249	250
273	1,000	257	400
281	10,000	266	500
298	500	280	200
306	10,000	288	15,000
307	8,000	344	4,000
314	1,000	359	5,000
317	1,000	362	20,000
320	1,000	369	10,000
325	10,000	395	5,000
356	30,000	406	25,000
361	10,000	410	1,000
376	50	415	200
404	1,000	416	4,000
408	200	421	3,000
426	1,000	423	5,000
437	10,000	429	10,000
		430	500
		435	4,000
Mean *b*	8,642	Mean *c*	18,855
Min *b*	50	Min *c*	200
Max *b*	60,000	Max *c*	250,000

Appendix 7

Parameters of the distribution of the maximum value of the map $(V_{MAX}; \$)$ in cases where information provided is incomplete

Respondents who provided *b* only

ID #	*b*
14	500
43	1,000
46	200
53	2,000
82	1,000
94	1000,000
142	10,000
147	2,000
154	6,000
178	5,000
182	100,000
186	1,000
219	100
227	150
241	1,000
243	50,000
248	90
254	20,000
281	9,800
284	4,500
286	10,000
301	250
306	20,000
307	5,000
314	1,000
320	100,000
322	300
325	5,000
342	5,000
356	30,000
362	200
366	15,000
367	9,000
376	35
395	2,000
404	500
426	1,000
Mean *b*	3,8341
Min *b*	35
Max *b*	1,000,000

Respondents who provided *c* only

ID #	*c*
18	500,000
26	500
42	100
72	100,000
76	800
84	80,000
95	15,000
118	1000
124	50
126	10,000,000
129	500
138	250,000
140	4,000
145	5,000
151	600
159	10,000
161	350
169	1,000
171	24,000
179	25
183	100,000
184	1,000
192	5,000
193	500
206	500
210	8,000
211	50,000
218	10,000
236	24,000
249	400
257	350
260	4,950
266	500
273	100,000
280	200
288	10,000
344	40,000
359	5,000
361	100,000
370	2,000
372	100,000
374	100
387	18,000
397	3,000
408	500
410	1,000
416	20,000
421	10,000
423	5,000
429	10,000
430	400
Mean *c*	227,908
Min *c*	25
Max *c*	10,000,000

Appendix 8

Parameters of the distribution of the minimum value of the map (V_{MIN}; $)

Respondents who provided *b* and *c* only

ID #	*b*	*c*
11	250,000	250,000
12	2,000	5,000
91	1,000	1,000
117	1,000	300
122	190	190
149	95	10,000
162	100,000	10,000
163	20,000	15,000
197	40	40
247	100,000	50,000
289	25,000	20,000
340	10,000	50,000
347	1,000	800
350	10,000	2,500
365	30	30
399	100	100
Mean V_{Min}	32,528	25,935
Min V_{Min}	30	30
Max V_{Min}	250,000	250,000

Respondents who provided *a* only

ID #	*a*
48	100,000
214	100,000
324	500
383	15,000
405	50,000
424	100,000
435	1,000
437	10,000
Mean V_{Min}	47,063
Min V_{Min}	500
Max V_{Min}	100,000

Respondents who provided *a* and *b* only

ID #	*a*	*b*
4	100	2,500
77	500	2,500
89	5,000	8,000
143	25,000	175,000
188	2,000	10,000
225	10,000	50,000
237	100	5,000
251	10,000	1,000,000
261	1,000	1,000
313	25	60
349	500	5,000
406	20,000	40,000
411	5,000	10,000
Mean V_{Min}	6,094	100,697
Min V_{Min}	25	60
Max V_{Min}	25,000	1,000,000

Appendix 9

Parameters of the distribution of the maximum value of the map (V_{MAX}; $) in cases where information provided is incomplete

Respondents who provided *b* only

ID #	*b*
14	500
43	1,000
46	200
53	2,000
82	1,000
94	1,000,000
142	10,000
147	2,000
154	6,000
178	5,000
182	100,000
186	1,000
219	100
227	150
241	1,000
243	50,000
248	90
254	20,000
281	9,800
284	4,500
286	10,000
301	250
306	20,000
307	5,000
314	1,000
320	100,000
322	300
325	5,000
342	5,000
356	30,000
362	200
366	15,000
367	9,000
376	35
395	2,000
404	500
426	1,000
Mean *b*	38,341
Min *b*	35
Max *b*	1,000,000

Respondents who provided *c* only

ID #	*c*
18	500,000
26	500
42	100
72	100,000
76	800
84	80,000
95	15,000
118	1,000
124	50
126	10,000,000
129	500
138	250,000
140	4,000
145	5,000
151	600
159	10,000
161	350
169	1,000
171	24,000
179	25
183	100,000
184	1,000
192	5,000
193	500
206	500
210	8,000
211	50,000
218	10,000
236	24,000
249	400
257	350
260	4,950
266	500
273	100,000
280	200
288	10,000
344	40,000
359	5,000
361	100,000
370	2,000
372	100,000
374	100
387	18,000
397	3,000
408	500
410	1,000
416	20,000
421	10,000
423	5,000
429	10,000
430	400
Mean *c*	227,908
Min *c*	25
Max *c*	10,000,000

Appendix 10

Parameters of the distribution of willingness to pay (*WTP*) for the pay in cases where information provided is incomplete

Respondents who gave *c* only

ID #	*c*	
11	2	
76	800	
126	5	
140	2,000	
151	8	
159	10,000	72
183	100,000	83
266	5	
280	15	
324	5	
387	2	
393	5	
397	50	
406	25,000	218
435	4,000	
Mean *WTP*	9,460	
Min *WTP*	2	
Max *WTP*	100,000	330

Respondents who provided *a* and *b*

ID #	*a*	*b*
45	100	300
92	2	5
171	250	533
205	5	20
225	50	100
237	10	100
241	5	10
261	1,500	1,000
313	2	20
346	5	25
350	500	10,000
355	3	500
366	25	150
372	25	1,000
394	15	30
411	2,000	8,000
436	5	25
Mean *WTP*	265	1,283
Min *WTP*	2	5

Respondents who gave *b* and *c*

ID #	*b*	*c*
15	25	4
21	50	4
48	1,000	25
51	200	25
54	10	5
25	4	
100	4	
122	200	10
136	15,000	15
147	20	4
161	15	6
162	30	10
179	25	6
15	4	
257	400	4
260	20	3
264	200	10
297	100	4
500	10	
340	25	25
347	25	10
362	100	7
365	30	4
375	10	5
400	25	6
408	10	5
417	50	10
Mean *WTP*	674	8
Min *WTP*	10	3
Max *WTP*	15,000	25

Respondents who provided *a* only

ID #	a
145	100
169	4
236	20
416	10
Mean *WTP*	34
Min *WTP*	4
Max *WTP*	100

Appendix 11

Parameters of the distribution of willingness to pay (WTP) for the map in cases where information provided is incomplete

Respondents who provided *b* only

ID #	*b*
4	500
14	100
18	1,000
28	8
42	8
43	25
46	200
53	500
82	10
85	5
93	15
124	75
142	500
154	100
178	1,000
182	10
210	100
212	10
230	10,000
243	20
249	20
273	1,000
281	500
284	100
286	5
288	100
289	25,000
301	100
302	2,000
306	100
314	4
322	50
344	50
346	25
356	25
359	1,000
367	100
374	500
376	25
395	2,000
404	200
405	500
409	10
415	20
421	25
426	2,000
430	500
437	50
Mean *b*	1,046
Min *b*	4
Max *b*	25,000