JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT **32**, 204–218 (1997)
ARTICLE NO. EE960963

Estimating the Social Value of Geologic Map Information: A Regulatory Application*

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Received January 22, 1996; revised May 23, 1996

People frequently regard the landscape as part of a static system. The mountains and rivers that cross the landscape, and the bedrock that supports the surface, change little during the course of a lifetime. Society can alter the geologic history of an area and, in so doing, affect the occurrence and impact of environmental hazards. For example, changes in land use can induce changes in erosion, sedimentation, and ground-water supply. As the environmental system is changed by both natural processes and human activities, the system's capacity to respond to additional stresses also changes. Information such as geologic maps describes the physical world and is critical for identifying solutions to land use and environmental issues. In this paper, a method is developed for estimating the economic value of applying geologic map information to siting a waste disposal facility. An improvement in geologic map information is shown to have a net positive value to society. Such maps enable planners to make superior land management decisions.

I. THE ISSUE

The physical environment represents a resource whose productivity is affected by land use decisions that may be subject to regulatory rule making. In this paper a model of regulatory land use decision making is developed which incorporates the individual objectives of the regulator and makes explicit use of geologic map information. This model is applied to a particular land use decision.[1] In conducting this analysis the following question is addressed: is investment in additional geologic map information socially justified? The benefits of additional geologic information are computed by comparing the economic impacts of decisions that

* We received several helpful comments from Janie Chermak, Ron Cummings, and two anonymous referees.

[1] This paper is based on a study that evaluates the social value and describes the use of digital geologic map information in land management decisions. For further details see Bernknopf *et al.* [2].

0095-0696/97 $25.00

would be made using the new map information relative to decisions based on existing map data. Additions to geologic map information are shown to have a net positive social value when used in a regulatory setting.

Project uncertainties exist when the physical attributes of a site are not adequately considered in the implementation of generalized design and engineering regulations [9, 14].[2] Geologic information should be considered an element in the regulation of exposure to environmental risk. In this paper a geographic information system (GIS) that includes earth science and economic information is used to introduce geologic map information, at two scales, into a regulatory decision making model. The losses avoided from decisions based on the improved geologic map information represent the benefits derived from this information.

A pilot study in Loudoun County, Virginia, is presented to demonstrate the use of the improved geologic map information in a decision to site a county landfill. The results suggest that refinements in geologic map information provide for improved siting decisions and the value of the losses avoided are computed as changes in property values in the region.

II. ECONOMIC DECISION FRAMEWORK

Land use regulatory decisions commonly are made with some level of uncertainty regarding actual near-surface geologic conditions.[3] The regulator is charged with enforcing land-management regulations by allowing or disallowing certain uses of parcels of land. A regulatory standard can be defined, for example, in terms of a particular geologic characteristic to be applied as a threshold in permitting a particular land use. The issue addressed here is to evaluate the effect of new geologic map information for permitting a *particular* land use when permits are based on the application of thresholds of adverse environmental conditions. The measurement of the risk associated with the policy action is uncertain. The decision maker's problem is to set a regulatory safety standard that will be violated not more than some given fraction of the time. That is,

$$\mathrm{Prob}\{R > R_0\} \leq (1 - P), \tag{1}$$

where R_0 is the regulatory standard, R is the actual level of risk exposure, and $1 - P$ is the frequency with which the standard is violated. The level of safety can be increased by raising R_0 or by lowering $1 - P$. The analysis presented in this paper focuses on the role of additional and more accurate (hereafter improved) geologic map information in enabling the regulatory decision maker to lower $1 - P$. The value of the improved information is determined by its impact on the regulatory outcome.[4]

In the "public choice" model of regulatory behavior [16, 18], regulators are modeled as conventional economic agents maximizing individual utility subject to constraints. A key result of modeling regulators' behavior in this way is that the

[2] In this paper risk is used to refer to the expected losses associated with the environmental hazard while uncertainty is used in the usual economist's way to mean risk *or* uncertainty [7].

[3] Lichtenberg and Zilberman [8] and Lichtenberg *et al.* [10] explicitly incorporate the impact of information uncertainty when policy is being set.

[4] The value of risk reduction is lower for risks that are less well understood (have a higher variance). Reducing the variance will also increase the return to raising R_0.

regulator is shown to be risk averse with respect to adverse consequences of regulated activities.[5] That is, the regulatory process will result in a standard that reduces the probability of a bad outcome to lower levels than are socially optimal as the individual preferences of the regulator replace the social (risk neutral) preferences.

If the decision maker behaves *as if* risk neutral, they permit land uses on the basis of the expected value of the potential losses, and any information that merely reduces uncertainty (reduces the mean-preserving spread) has no value. If the decision maker behaves *as if* risk averse, then such information does have social value [13, 17] as it reduces the extent of over- or under-response to the risk posed by the environmental hazard. In this paper the public choice model will be adopted and the regulator will be assumed to be a risk averse agent maximizing selfish preferences. Uncertainty regarding the true state of the geology may be exploited to defend an allocation that the decision maker prefers.

The decision maker begins with a prior on the geologic (physical and environmental) characteristics of a parcel of land. As the quantity of information increases or the quality improves, the uncertainty regarding this prior is reduced.[6] In the public choice model, the regulators will base their decision on both the expected value of the loss *and* the uncertainty surrounding this value. The regulatory standard (an acceptable level of risk exposure) is defined as some specific value of a geologic criterion, but the true state of the geologic information is known only with uncertainty (geologic map attributes can be represented as a probability distribution). On the basis of credible scientific information, the regulator would be able to justify accepting or rejecting parcels of land for a given use if the standard lies within some interval around the mean. Typically, an acceptable interval is defined as being within the 95% confidence level. While there is a socially optimal level of safety based on the expected value of the losses avoided, the actual regulatory process may lead to a level of regulation that departs from this optimal level when the uncertainty is incorporated into the decision process. The regulatory agency cannot, however, set a standard arbitrarily low (or high), because the oversight committee responsible for the agency's authorization will demand justification for standards that are too lax or too stringent.[7]

Improvement in the information will alter the assignment of land uses to optimize the aggregate level of risk exposure. With the narrower distribution, the regulator is less able to justify overly stringent or lax regulatory decisions. As a result, land management decisions become more socially optimal because parcels are rejected as inappropriate on the basis of probability distributions that are less

[5] One view of the behavior of regulators is that they attempt to maximize social welfare by imposing an optimal level of safety [15]. The optimal level of safety is achieved by permitting a land use to occupy a site only when the expected value of the regulatory criterion is below (in the case of minimum standards) or above (in the case of maximum standards) the mandated standard. In this view, regulatory agencies choose to ignore the uncertainty inherent in the information and focus solely on the risk (expected value) when evaluating a parcel of land. Such behavior is consistent with Arrow and Lind's [1] proposition that public sector decision makers should behave *as if* risk neutral since the risk is spread over a very large cohort (the entire population).

[6] Rothschild and Stiglitz [13] develop a definition of increasing risk as a mean-preserving spreads in the variable being observed.

[7] See Weingast and Moran [18] for a discussion of the behavior of regulatory agencies under oversight.

diffuse. Thus, the focus is on the regulator's use of improved information in the application of an existing set of standards rather than in the setting of new standards.

This concept is illustrated in Fig. 1, in which the probability distribution of a geologic attribute is plotted for two different levels of information, d_1 and d_2, corresponding to distributions generated from both existing and improved geologic information.[8] R_0 in Fig. 1 denotes a regulatory standard (threshold) and $\bar{g}_k$ denotes the expected value of the geologic attribute for a given parcel of land. The 95% confidence interval about the expected value is indicated for the distribution d_1 and $2\sigma_{v1}$. With this information, the hypothesis that the allowed standard, R_0, is met for this parcel of land is not rejected, because it is within two standard deviations of the expected value. With improved geologic map information, based on larger scale maps and/or newer field data, distribution d_2 results.[9] The improved information allows a more precise estimate of the actual conditions. As such, distribution d_2 has less uncertainty (shown as a smaller standard deviation, $2\sigma_{v2}$) than d_1.[10] Using distribution d_2, the null hypothesis is rejected because the expected value of the geologic attribute minus two standard deviations is greater than the standard, R_0. The rejection of a particular land parcel with the new information occurs because the information in d_2 is more precise, not because there is a bias in the original, d_1, data.

The social gains from the improved information may be demonstrated by the analysis presented in Fig. 2. Safety (horizontal axis) is denoted as the fraction of land (parcels or cells) in the region that is rejected (require mitigation) for a particular land use. Losses avoided through implementation of regulations are measured in terms of a money metric on the vertical axis. As the vulnerable, or "at risk," cells are eliminated, society's exposure to that risk is reduced. As the level of safety increases there is an increase in expected losses avoided. The change in expected losses avoided is shown in the figure as the marginal expected loss avoided, $E(L_a)$, for restricting an additional cell. The *net* marginal expected loss avoided (the cost of avoiding losses is constant) is normalized on the figure by representing the $E(L_a)$ as deviations from zero. Therefore, an optimal level of safety is shown as the intersection of the $E(L_a)$ curve and the horizontal axis (net marginal expected loss avoided is zero) at the point labeled K^* in the figure.

There is uncertainty regarding the actual losses to be avoided by restricting cells because there is uncertainty about the geology underlying a cell. This uncertainty is indicated in Fig. 2 by the dashed lines above and below $E(L_a)$. Two levels of uncertainty are shown, each of which is consistent with a different level of geologic map information (d_1 and d_2 in terms of Fig. 1). In each case, the dashed lines enclose the 95% confidence interval for the respective geologic characteristic.

[8] A geologic attribute for a location can be described by a probability distribution. The central point of the probability distribution is the expected value of the geologic attribute in a specific location. The variance of the attribute corresponds to the variability of the geologic attribute over an entire map.

[9] At any map scale, there is a lower limit to the resolution of geologic attributes and hence a minimum cell size in a rectangular grid. In the case of a 1:500,000 scale geologic map, the geologic attribute has one measurement per 1 km × 1 km cell, while at a 1:100,000 scale, the attribute has 16 measurements covering the same area.

[10] For expositional convenience all changes will be represented as a change in variance although the principle is more general [13, 18].

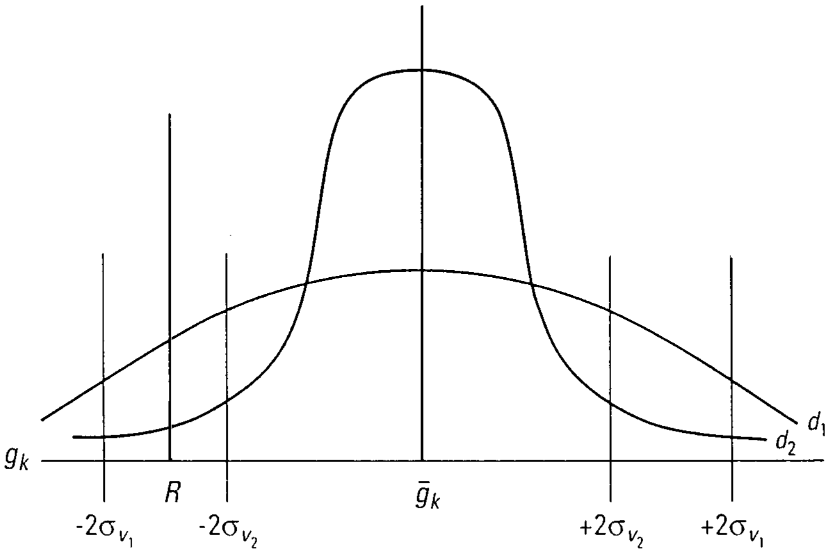

FIG. 1. The probability distributions, d_1 and d_2, of a geologic characteristic, g_k, for two geologic maps of different vintages and different scales, v_1 and v_2, for the same area. R_0 represents a regulatory standard. $\bar{g}_k$ denotes the expected value of the geologic attribute for a given locality or parcel of land. 2σ is the 95% confidence level about the expected value for the distributions.

The impact of improved information on regulatory decisions is demonstrated by the comparative statics exercise shown in Fig. 3. The regulatory agent is assumed to maximize a utility function that is defined over monetary payoffs, π, and risk, $(1 - P)$,

$$U = U(\pi, 1 - P) \tag{2}$$

where π is a good and $1 - P$ is a bad. The regulatory agent faces a constraint in the form of a transformation function that relates the regulatory standard, R_0, to the level of risk and the quantity of information, I:

$$1 - P = f(R_0; I). \tag{3}$$

When the regulator sets the regulatory standard at a high level, the regulated activity earns smaller profits and this translates ultimately into a smaller payoff to the regulator [16, 12]. Thus, the regulator faces an inverse relation between the level of the regulatory standard and *monetary* payoffs:

$$R_0 \propto 1/\pi. \tag{4}$$

These three relations yield the constraint facing the regulator,

$$T = T(\pi, 1 - P), \tag{5}$$

which implies a tradeoff between monetary payoffs and risk reduction. The regulator maximizes utility (Eq. (2)) subject to the constraint (Eq. (5)) and this yields a regulatory standard, R_0, and a risk exposure of $1 - P$.

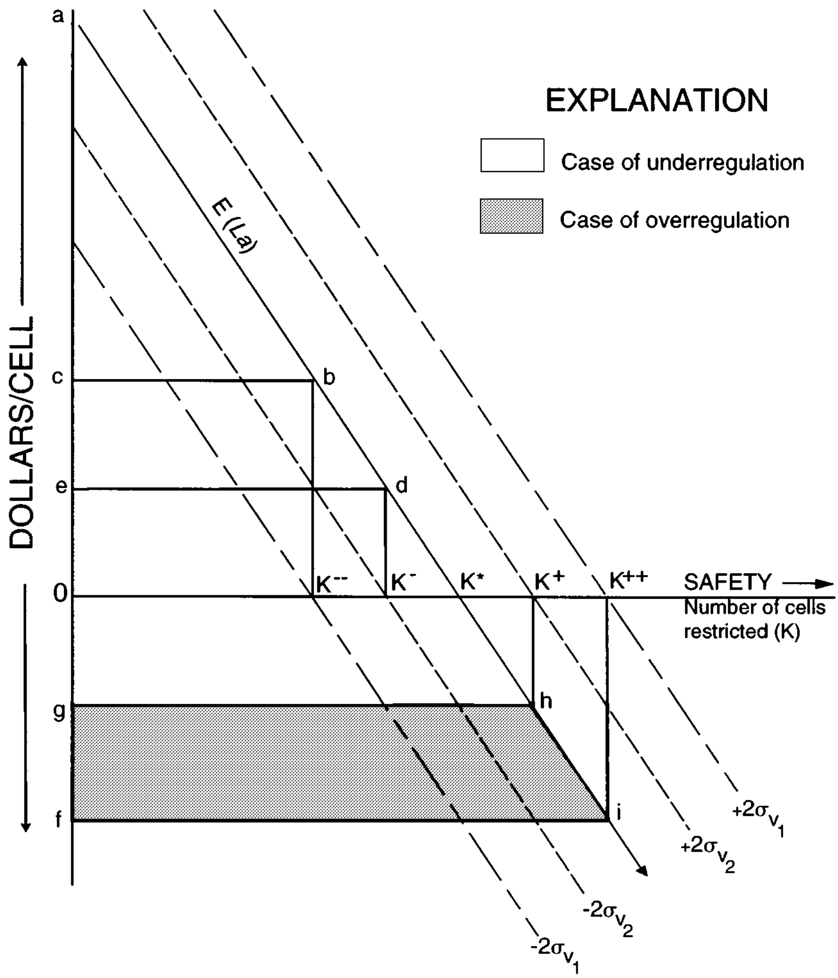

FIG. 2. Economic impact of a regulation based on geologic map information. $E(L_a)$ is the marginal expected loss avoided; K* is the optimal level of safety. See text of in-depth discussion.

Land-use regulation utilizes key geologic attributes to determine whether a particular use will be permitted for a given parcel of land. The standard would involve the application of the rule in Eq. (6) to each land parcel and a test to evaluate whether the average value of the relevant geologic attribute ($\bar{g}_k$), minus two standard deviations, is greater than or less than the regulatory standard.

$$\bar{g}_k - 2\sigma_v (> \text{or} <) R_0 \tag{6}$$

Improved geologic information shifts the production function (Eq. (3)) inward. This shifts the constraint facing the regulator upward as shown in Fig. 3. The regulator's utility maximizing decision now yields a lower exposure to risk, $1 - P$.

The associated welfare gains from the improved map information can be shown by further reference to Fig. 2. With the original information the regulator sets the standard to restrict K^{--} cells from use for the proposed land use. With only K^{--}

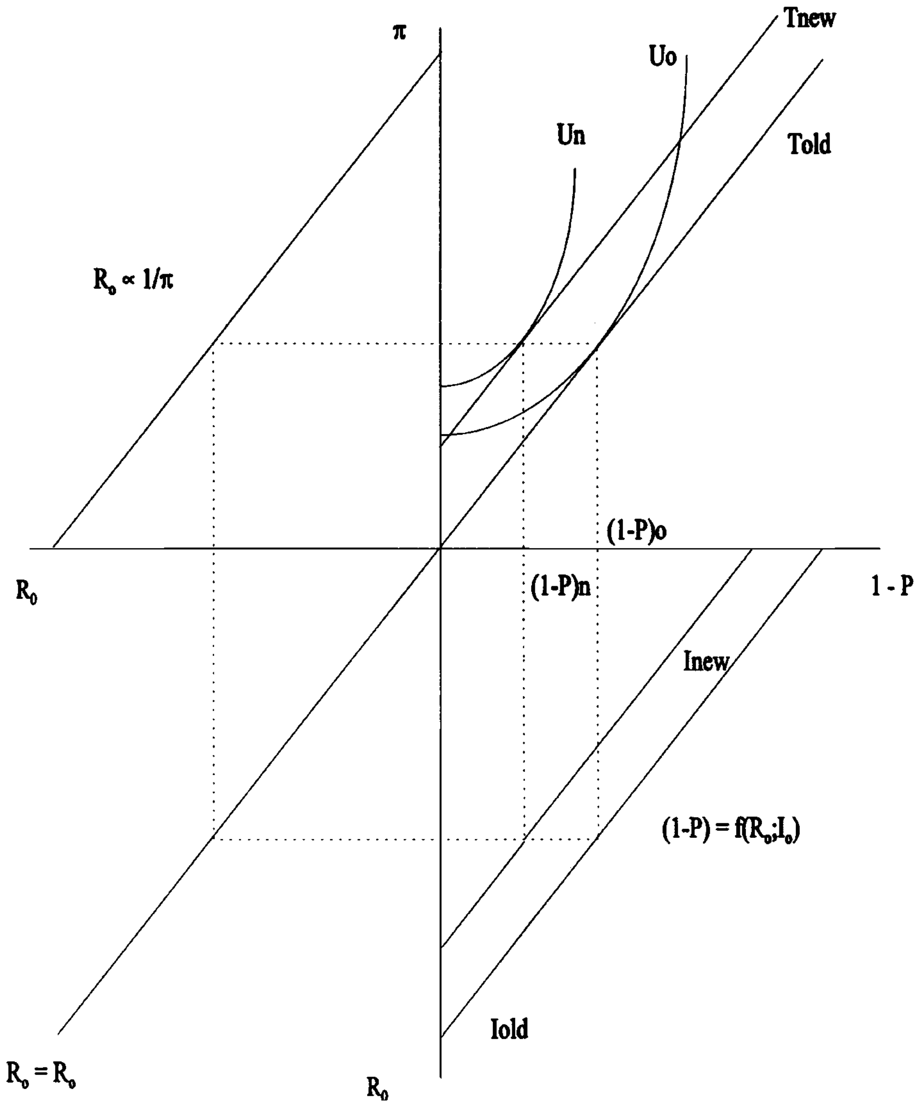

FIG. 3. Model of regulatory decision making.

cells restricted, the social loss is given by the area bc0K* (surplus that is foregone when the regulatory standard is set below the optimal level of K*). Improved geologic map information results in the level of regulation being increased so that K^- cells are now restricted (improved information, d_2). The welfare loss is now given by the area de0K*. The value of the improved geologic map information is the gain in consumer surplus (reduction in the welfare loss) shown as the area cbde in Fig. 2.[11]

[11] In the case of overregulation the regulator sets the standards at K^{++}. The welfare loss associated with this amount of overregulation is the area if0K*. With the improved information, the regulator reduces the number of cells restricted to K^+. The gain from this information is the area fihg.

In the case of waste facility siting, the relevant geologic characteristic is rock permeability which measures the potential for on- and off-site contamination. Because contamination is an adverse environmental impact, the regulation dictates that waste disposal facilities avoid environments in which the rocks near the surface are highly permeable. As improved geologic map information becomes available and the variance of the geologic attribute decreases, the number of locations classified as acceptable is better constrained.[12] Hence, as the geologic map information becomes more reliable, the regulatory response would tend to be more stringent and to restrict more locations from this land use. This standard is applied as a threshold condition for permitting the landfill. The regulatory decision for parcels with existing geologic map information and with improved geologic map information are compared. Thus, the value of information is measured by the change in expected avoided losses due to changes in the land use restrictions.

III. THE EMPIRICAL ANALYSIS

The regulatory model is implemented in a demonstration study in Loudoun County, Virginia, to locate a waste disposal facility.[13] The Loudoun County population, commercial base, and road network are distributed in a manner that reflects the underlying geologic framework. The western portion of the county is mostly rural and oriented to agriculture while east of the U.S. 15 corridor, the county plan has delineated large tracts of land for intensive regional growth.[14]

The existing geologic map information is from the 1963 geologic map of Virginia compiled and published at 1 : 500,000 scale [11]. The map describes the *general* distribution of *three* geologic units in eastern Loudoun County with boundaries (contacts) between them located in many instances only to the nearest 1.5 to 2 km. Because there are no onsite observations contained in this map, a uniform distribution is assumed for describing the geologic attributes of a cell (site) when regulatory standards are applied. The improved geologic map information is a USGS geologic map of Loudoun County, Virginia, which was compiled at 1 : 100,000 scale [3]. This map describes the *specific* distribution of *16* geologic units in the eastern part of the county with the contacts between them located on an average spatial resolution of about 60 m. Given the existence of on-site observations and systematic sampling, a normal distribution is assumed for describing the geologic attributes in a cell when regulatory standards are applied.[15]

[12] The quality of the geologic map information generally increases with larger scale maps (more detailed) and with newer vintage maps. More detailed (larger scale) maps provide more accurate statistics (yield a reduction in the dispersion of the distribution).

[13] The 1963 geologic map has been used in a number of ways in Loudoun County and elsewhere in Virginia. Geologic map information contained in the 1963 geologic map of Virginia has limited application in a decision making environment. Two documented applications of this geologic map have been used as a teaching tool for the geologic framework of Virginia and for the general distribution of rock units that are potential sources for building stone, aggregate, or road metal.

[14] These cells are underlain by part of a Mesozoic basin filled with a sequence of sedimentary rocks that are faulted and interlayered with basalt or intruded by dikes and sills. This geologic setting provides opportunities for the development of ground-water well fields, construction of public and private waste facilities, and extraction of construction materials. Given the location of the current landfill and intensity of economic development in the eastern part of the county, the part of the county underlain by rocks of Mesozoic basin was selected as the study area.

[15] For purposes of demonstration and analysis the eastern Loudoun County portion of each geologic map was converted to digital format in a geographic information system (GIS). GIS relational database techniques were required for handling and formatting data for statistical and spatial analyses.

The information on the two geologic maps is used to derive a statistical geologic attribute that affects the siting of a waste disposal facility: the ground-water yield (in gallons per minute), i.e., a measure based, in part, on rock permeability.[16] Figure 4 shows the uniform and normal distributions for average ground-water yield. In addition, for faulted and intensely fractured areas, the value of the ground-water yield is doubled because these physiographic features serve to markedly increase the rate of water flow.[17]

III.a. The Regulatory Application

The payoff to the improved map information is demonstrated by developing landfill siting rules that are based on a geologic protocol. Integration of geologic map information into a decision framework for evaluation of the marginal benefits of the improved map information requires several steps. The variables used in the analysis are defined in Table I.

An analysis prepared by HDR Engineering [6] provided the recommendations concerning landfill sites for the projected quantity of waste in the county through the year 2015. Depending on the actual parcel attributes, the total size of a landfill to accommodate the disposal needs for a 20 year period starting around 1995 is at least 600 acres (about 2.5 km^2) to adequately buffer the site and to mitigate community impacts.

For each cell on each map, the value of $\bar{g}_k$, plus or minus two standard deviations, is compared to the regulatory standard. From Fig. 1 it is clear that a more precise distribution leads to fewer meeting the condition stated in Eq. (1). The results of applying the standards for siting a waste disposal facility for the two geologic maps including the possible outcomes of the process are listed in Table II. For instance, outcome 2 represents the case where no cells were restricted when the earlier geologic map information is used but 321 cells were restricted when the improved information is used (this is the under regulation case).[18] Figure 4 compares the spatial distribution of the restricted cells between the existing and the improved geologic map information.

For each cell in the study area, a probability of loss, $P(L_k)$, is estimated as a function of the geologic attribute of the cell. For the cells identified in step 1, these probability values become the basis for estimating expected losses avoided. The

[16] A. Froelich and R. Parker, USGS, personal communication, 1991, and was supplemented by information in Laczniak and Zenone [8]. On the basis of a squared ranks test [4] the average yield variable as reported by the old map has a statistically higher variance than for the new map. The t value is 2.63 which is significant at the 99% confidence level for a one-tailed test. Thus, the improved geological information is quantitatively different than the existing information and has the potential to yield better regulatory decisions.

[17] These two geologic-map-based attributes are only a subset of the information that would be necessary to actually conduct this type of land use analyses.

[18] According to the HDR study, three areas were identified for further review by the county for potential use as a landfill. One of these is the proposed southward extension of the existing waste site and is within our limited study area. Thus, the question is "are there any cells restricted on the earlier geologic map or the improved geologic map for a 1 km $\times$ 1 km area for the landfill extension south of the existing site?" Our investigation indicates that there are no restrictions when the earlier geologic map is used. Of interest, however, is that there are seven 250 m $\times$ 250 m cells restricted when the improved geologic map is used. All are based on the implementation protocol of average yield of ground water and the associated screening value. This result supports the conclusion that in the waste site demonstration the use of the earlier geologic map leads to underregulation (which is consistent with the public choice model in which the regulator is "captured" by the development interests).

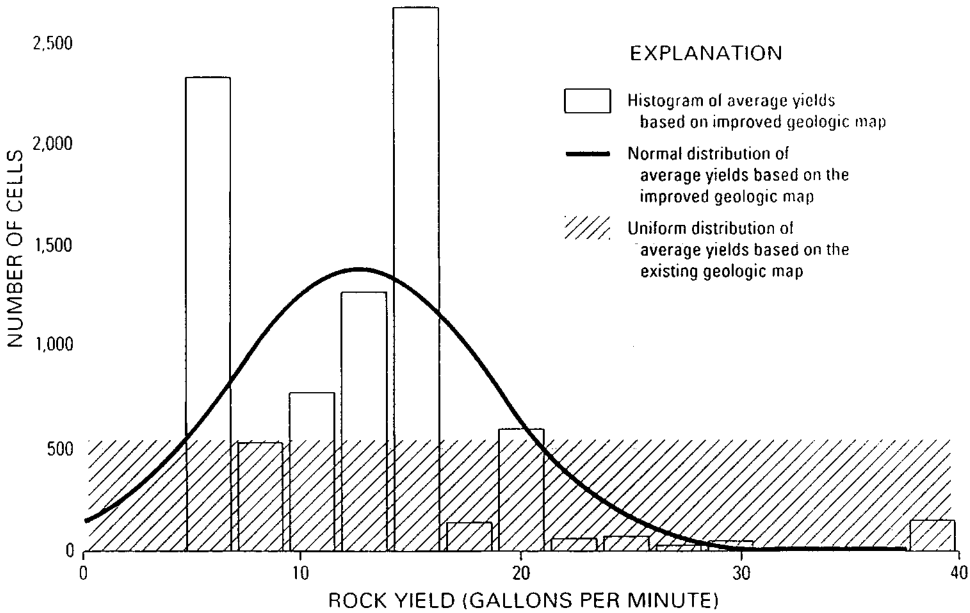

FIG. 4. Frequency distributions for average ground-water yields based on the two different geologic maps.

probability of loss is

$$P(L_k) = P(H_k \mid g_k) = f(g_k, V_k) \tag{7}$$

estimated in Eq. (7) for each land use.

For each (250 m × 250 m) cell a conditional probability (log odds) of contamination $P(L_k)$ is estimated by applying Eq. (7) as a function of the rock types. The conditional probability of contamination, in Eq. (8), is a binary choice logit regression based on the average yield of rock materials in locations surrounding

TABLE I

Variables Used in Empirical Demonstration of Value of Geological Map Information

Variable	Definition
$\bar{g}_k$	Geologic attribute of rock materials in cell k such as faulting and permeability of rock materials; $k = 1, \dots, K$.
L_k	Monetary loss in cell k.
$P(L_k)$	Probability of a loss L_k in cell k.
R_j	Safety standard for land use j, defined as restrictions on allowed land uses or requirements for a given land use, for example, building codes.
$E(L_a)_k$	Expected loss avoided for cell k.
$E(L_a)_j$	Expected loss avoided for land use j.
H_k	Hazard in cell k.
V_k	Additional physical attributes in cell k.

TABLE II
Number of Cells Restricted for Waste Facility Siting

	1 : 500,000 scale map (Old map)	1 : 1,000,000 scale map (New map)	Number of 1 km × 1 km cells
Outcome 1	Restriction	Restriction	61
Outcome 2	No restriction	Restriction	321
Outcome 3	Restriction	No restriction	0
Outcome 4	No restriction	No restriction	223

solid waste landfills located in the Mesozoic basic of the northeastern U.S.[19]

$$\ln\left[(P(L_k))/(1 - P(L_k))\right] = -1.23 + 0.37(\mathrm{AVGYLD}_k) \tag{8}$$
$$t \text{ statistic} \qquad (-1.41) \quad (1.95) \qquad n = 83,$$

where $P(L_k) = 1$ if ground water at the waste disposal site exceeds the state primary drinking water standard for any constituent, and $P(L_k) = 0$ otherwise, and H_k comprises a contamination incidence ("yes" or "no") given an average yield $(\bar{g}_k)$. AVGYLD is equal to the natural log of the area-weighted average yield of rock units. The conditional probability of contamination ranges from 0.37 to 0.53, has a mean of 0.42, and a standard deviation of 0.03 for the 8,671 250 m × 250 m cells.

Now, the appropriate monetary value in each cell is estimated. This value, L_k, represents the property at risk. In this study, only property value losses (L_k) are estimated. There is no attempt to quantify the expected value of health effects or economic disruption that would ensue from a contamination incident. This results in a downward bias in the measurement of the benefits from improved map information.

Monetary measures for property values are developed from 1990 census data. The number of residences by census block are taken from the 1990 U.S. Census to estimate the property-value affects in each cell. A census block commonly includes all or part of several grid cells. To estimate the number of dwellings in a cell, the area 1 proportion of a census block in that cell is multiplied by the total number of dwelling units in the census block. On the basis of recent real estate transactions, an average residence is assigned a value of $150,000.

For *each cell* identified as outcome 2 in Table II, the expected loss avoided (the savings), $E(L_a)_k$, is estimated in Eq. (9) as the product of the probability of a loss and the monetary value of the loss in cell k:

$$E(L_a)_k = P(L_k)L_k. \tag{9}$$

The benefit of the improved geologic map information is calculated as the difference in expected loss avoided between the two geologic maps as defined by the regulatory standards. On the basis of the assumption that the county needs to

[19] Because Loudoun County has only one existing landfill, the probability of contamination is estimated for an analogous geologic terrain, the Mesozoic basin in central New Jersey, where water monitoring data and waste sites are more plentiful. The coefficients from the New Jersey equation are extrapolated to the study area in eastern Loudoun County.

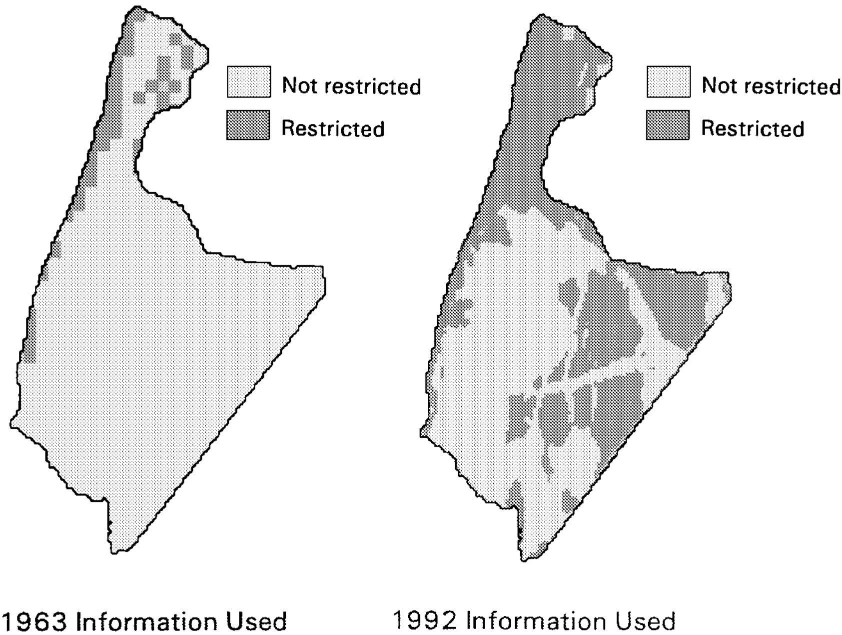

FIG. 5. Spatial distribution of cells in eastern Loudoun County, Virginia, restricted from further consideration as a possible landfill site based on existing (1963) and improved (1992) geologic map information.

proceed with the construction of at least one new waste disposal facility, this case study is an estimate of the benefits for selecting a site in the study area. The site is assumed to occupy a 1 km^2 area to conform with the proposed sites described in an environmental impact analysis (sites selected for future landfills ranged from 302 to 978 acres, [6]).

Depending on the location of the proposed waste disposal facility, the difference in expected loss avoided, $E(L_a)$, between the two geologic maps ranges from $39,241 per cell to $124,791 per cell. The difference in average expected loss avoided, $E(L_a)_k$, for any cell in the study area is $94,027 per cell.

For a landfill site, the average $E(L_a)_k$ is multiplied by 16 to estimate the societal value of the improved geologic map in this land use.[20] The areas that would be restricted by use of the improved geologic map while not being restricted using the existing map (outcome 2 in Table II) are shown in Fig. 5. The total benefit of the improved geologic map in locating a waste disposal site in Loudoun County is approximately $1,500,000.

The marginal cost of the improved geologic map information is determined as the total cost (capital and labor) of producing a new geologic map, including the opportunity cost of capital, C.[21] Total cost for the improved geologic map information, the 1 : 100,000 scale USGS map, is about $1,160,000 distributed over 6 years.

[20] There are 16 250 m × 250 m cells in a 1 km × 1 km area.

[21] Because the current interest is in the value of the new geologic information, the cost of the old map is not needed.

The capital and operating costs for the mapping project are \$913,000 and \$55,000, respectively. An opportunity cost of capital of \$189,000 compounded semiannually at 10% during the production period is included.

The net benefits from the use of the improved geologic map information (the USGS 1 : 100,000 scale map) are the benefits for the new geologic map information (\$1.50 million) minus the cost of producing that map (\$1.16 million). Therefore, the expected net benefit from use of the 1 : 100,000 scale Loudoun County, VA geologic map in one application is approximately \$0.34 million.

IV. IMPLICATIONS AND AN EPILOG

This study has demonstrated the use of geologic information in a regulatory decision setting. A method for evaluating geologic risk, including both the probability of a change in physical state (water contamination) and the expected loss

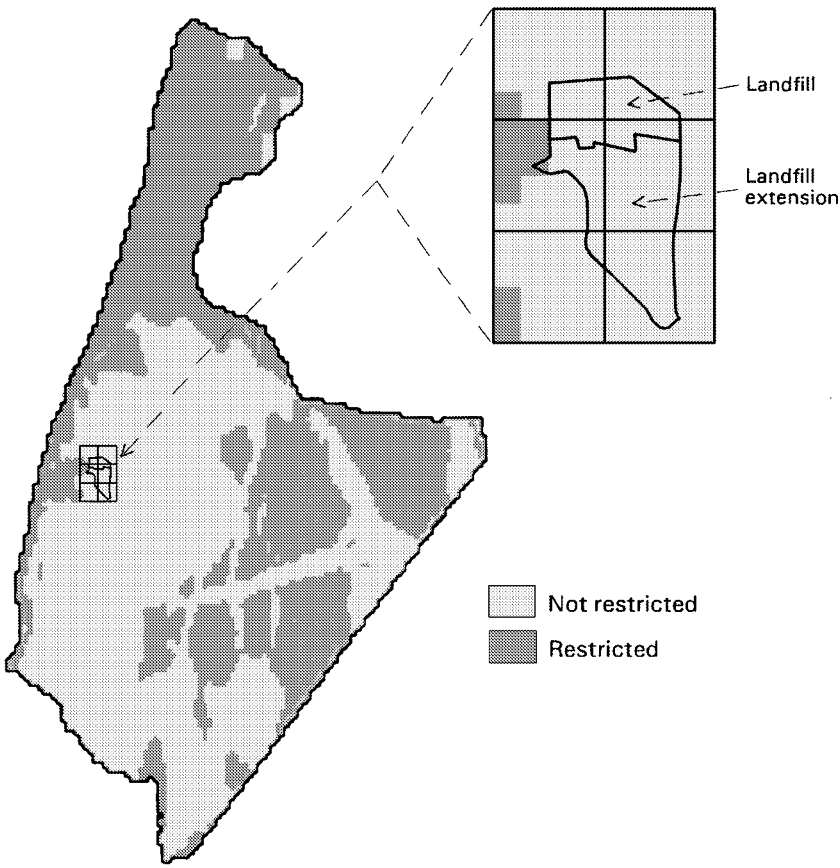

FIG. 6. Comparison of present landfill and its extension to areas in eastern Loudoun County, Virginia, that would be restricted when the improved geologic map is used. For deriving the value of information, a 1 km^2 landfill is assumed and this is represented by 1-km cells in the enlarged part of the map. Referring to Fig. 4, note that using the previous geologic map information, the landfill site would not be restricted.

avoided from an adverse environmental impact, was developed and applied. The application of the improved geologic information would have resulted in additional losses avoided and this is a measure of the value of this scientific information. These results should be considered a lower-bound estimate of benefits since they represent the benefits of only one application of the information. Once the information has been produced, it may be applied in a variety of land-use regulatory and planning applications such as airport expansion and siting, and in land use management.

The current conditions at the existing Loudoun County landfill suggest the above calculated net benefits may be conservative. The landfill does encroach on areas that would be rejected with the improved geologic map information. The new geologic map recommends restricting the 1 km cells that include both the existing landfill and a new landfill extension (see Fig. 6). The previous map information supported landfill development. In 1993 ground-water contamination was detected at landfill monitoring wells causing nearby residents to become concerned about the safety of their well-water supplies. To minimize future pollution problems the County arranged for public water delivery to homes surrounding the landfill at an estimated cost to the County of $5.4 million.

REFERENCES

1. K. J. Arrow and R. C. Lind, Uncertainty and the evaluation of public investment decisions, *Amer. Econom. Rev.* **60**, 364–378 (1970).
2. R. L. Bernknopf, D. S. Brookshire, D. R. Soller, M. J. McKee, J. F. Sutter, J. C. Matti, and R. H. Campbell, "Societal Value of Geologic Maps," U.S. Geological Survey Circular 1111 (1993).
3. W. C. Burton, A. J. Froelich, J. S. Schindler, and C. S. Southworth, "Geologic Map of Loudoun County, Virginia," U.S. Geological Survey Open-File Report 92-716, scale 1 : 100,000, 3 sheets (1992). [A preliminary version of this map was used for this report.]
4. W. J. Conover, "Practical Non-parametric Statistics," 2nd ed., Wiley, New York (1980).
5. A. J. Froelich, Map and geotechnical properties of surface materials of the Culpeper basin and vicinity, Virginia, and Maryland, U.S. Geological Survey Miscellaneous Investigations Series Map I-1313-E, scale 1 : 125,000 (1985).
6. HDR Engineering, Inc., "Summary Report: Solid Waste Landfill Site Selection Study Identification of Candidate Landfill Sites for Loudoun County, Virginia, Alexandria VA," HDR Engineering, Inc. (1989).
7. J. Hirshleifer and J. G. Riley, "The Analytics of Uncertainty and Information," Cambridge Univ. Press, Cambridge, UK (1992).
8. R. J. Laczniak and C. Zenone, Groundwater resources of the Culpeper basin, Virginia and Maryland, U.S. Geological Survey Miscellaneous Investigations Series Map I-1313-F, scale 1 : 125,000 (1985).
9. E. Lichtenberg and D. Zilberman, Efficient regulation of environmental health risks, *Quart. J. of Econom.* **103**, 167–178 (1988).
10. E. Lichtenberg, D. Zilberman, and K. Bogen, Regulating environmental health risks under uncertainty: Groundwater contamination in California, *J. Environ. Econom. Management* **17**, 22–34 (1989).
11. R. C. Milici, C. T. Spiker, and J. M. Wilson (compilers), Geologic map of Virginia, Virginia Division of Mineral Resources, scale 1 : 500,000, 1 sheet (1963).
12. S. Peltzman, Toward a more general theory of regulation, *J. Law Econom.* **19**, 211–240 (1976).
13. M. Rothschild and J. Stiglitz, Increasing risk I: A definition, *J. Econom. Theory* **2**, 225–243 (1970).

14. S. Shavell, A model of the optimal use of liability and safety regulation, *RAND J. Econom.* **15**, 271–280 (1984).
15. F. M. Scherer and D. Ross, "Industrial Market Structure and Economic Performance," Houghton Mifflin Co., Boston, MA (1992).
16. G. J. Stigler, The theory of economic regulation, *Bell. J. Econom. Management Sci.* **2**, 3–21 (1971).
17. H. Theil, An economic theory of the second moments of disturbances of behavioral equations, *Amer. Econom. Rev.* **61**(1), 190–194 (1971).
18. B. Weingast and M. Moran, Bureaucratic discretion or congressional control? Regulatory policy making by the Federal Trade Commission, *J. Polit. Econom.* **91**, 765–800 (1983).