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BY GARRICK E. LOUIS

USING STRATEGIC RISK MANAGEMENT to maximize the benefit–cost ratio of community water projects

A RISK-BASED APPROACH TO COST–BENEFIT ANALYSIS HELPS MAKE SMALL-SCALE INFRASTRUCTURE PROJECTS MORE ATTRACTIVE.

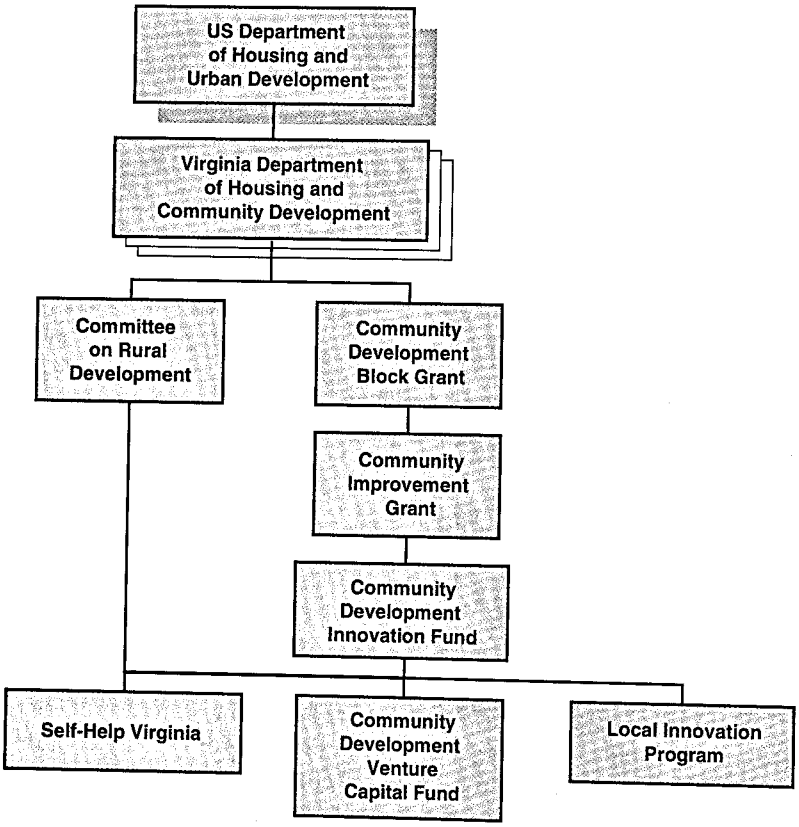
Private wells are the primary source of drinking water for many rural households, but these supplies can be compromised by contamination, drought, or overuse. Affected communities often cannot afford connections to public water systems or count on state funds to build their own systems. Because such infrastructure projects are dispersed over wide geographic areas and benefit small numbers of residents, state funding for these efforts may have trouble passing basic benefit–cost tests. The benefits are difficult to quantify, and the costs per capita are high relative to projects in more densely populated areas.

This article describes a risk-based approach to evaluating the costs and benefits of community sanitation infrastructure projects. The method calculates the life-cycle costs and benefits of the projects and uses this enhanced cost–benefit analysis to make small-scale infrastructure investments attractive by alleviating risk to the community from inadequate sanitation service. A program in Virginia is used as a case study of this approach.

RISK-BASED ANALYSIS INCLUDES BENEFITS AND COSTS OFTEN OVERLOOKED

The underlying goal of municipal sanitation service providers is the assurance of safe and reliable services, including drinking water supply, wastewater and sewage treatment, and municipal solid waste management. Safety is the measure of an acceptable level of risk (Derby & Keeney, 1981), e.g., in the quality of drinking water supplied to users, the quality of water discharged to surface waters from publicly owned treatment works, the containment and disposal of sludge from these treatment facilities, or the control and monitoring of all processes associated with the management of solid waste. Reliability is the likelihood that the system that provides the service will function as expected over a specified interval of time, given that the system is currently functioning as expected (Haimes, 1998). Risk is the product of the probability and value of the effect of an undesirable event (Fischhoff et al, 1984) such as a service

FIGURE 1 Self-Help Virginia administration and funding structure



interruption or the bypass of a sewage treatment system during a storm. Risk management is the evaluation, selection, and implementation of alternative actions to control risk (National Research Council, 1989). Because safety and reliability are both expressions of risk, municipal sanitation service providers must actively engage in risk management in order to achieve their underlying goal—assurance of safe and reliable services.

Simply put, strategic risk management (SRM) is getting the most from risk management investments. From expenditures for routine operation and maintenance to capital improvement and capacity expansion projects, SRM seeks to sequence the investments across the system and over a specified planning horizon (defined as the system life cycle) in order to assure the capacity for safe and reliable service while achieving the greatest realizable external benefits. These external benefits fall into three categories: (1) minimizing cost, (2) minimizing negative environmental consequences, and (3) maximizing the economic effect on the regional economy from the investment. Thus, SRM seeks to enhance current methods of decision-making for investments in sanitation infrastructure by including positive externalities in the decision-making process.

SRM specifies goals and objectives. SRM is an enhancement to cost–benefit analysis, the standard method for evaluating investments in infrastructure. Its aim is to include positive externalities such as cost reduction, environmental effect reduction, and regional economic development in the process of decision-making for short-term expenditures and long-term capital improvement projects.

As applied to sanitation infrastructure, SRM has four main objectives:

- assure the capacity for safe, reliable service over the system life cycle;
- minimize the related cost;
- minimize the related negative environmental consequences; and
- maximize a measure of the regional economic gains derived from the given investments.

Mathematical formulas help quantify SRM goal and objectives. Risk is defined as the product of the probability and cost (consequence) of an undesirable event occurring in the sanitation system.

$$R = p \times C \qquad (1)$$

in which R is the risk of an undesirable event occurring, p is the probability of the undesirable event, and C is the value of the consequences of the event. Risk management consists of evaluating, selecting, and implementing alternative actions (a_i) from the vector of alternatives (A) to reduce either p or C.

Thus

$$a_i \in A, i = 1, n \qquad (2)$$

in which n is the number of elements in A.

When risk management is applied to capacity assurance for municipal sanitation service, the problem takes the form of

$$\text{Minimize } G = S - D \qquad (3)$$

subject to:

$$C \le C_B$$
$$E \le E^*$$
$$B \ge M^*$$

in which G is the gap in service capacity, S is the supply of service or maximum operating capacity, D is the demand for service, C is the net present value of cost in dollars, C_B is the project budget, E is the environmental consequence, E^* is the negotiated environmental end state, B is the external benefit, and M^* is the measure of regional economic effect.

This photo shows the *initial groundbreaking* for the Shipman (Va.) project, whose objective via Self-Help Virginia was *to eliminate the shortage* of water to households served by the project. The project also addressed Shipman residents' complaints of irregular flow, discoloration, odor, taste, and the suspected presence of volatile organic contamination in their well water.

Thus the objective function is to minimize any excess or deficit in service capacity over the planning horizon, with the benefits of minimum cost (as determined by the lower boundary of the budget), minimum environmental damage (as negotiated by the stakeholders/users, service providers, and regulators), and maximum measure(s) of regional economic gain. These measures include the value of new businesses attracted to the region and income from jobs created by these enterprises. Other measurable forms of development associated with the infrastructure project, such as increased property values, may be included.

For example, the presence of county-supplied drinking water infrastructure in a community may make it possible for restaurants to obtain health permits necessary to operate. This development might have been precluded in an area that previously relied on private wells or truck-borne water for drinking. These establishments, in turn, create jobs in the community that attract job seekers from outside the area. These ripple effects can increase the demand for local housing, resulting in higher property values. Currently, such external benefits are not explicitly included in the decision-making process for infrastructure investments. SRM aims to include benefits of this type in order to improve the standard method of cost–benefit analysis and yield more-informed decisions for long-term, sustainable system planning.

Terms and focus of SRM formulas explained. *Time is a primary influence.* Each of the terms in the capacity-planning problem is time-dependent, i.e., the terms G, S, D, C, E, and B are all functions of time, t. The planning horizon for infrastructure of this type is typically in the range of 20–50 years. SRM breaks this period into shorter intervals (e.g., five years) and then sequences the infrastructure investments over these five-year intervals.

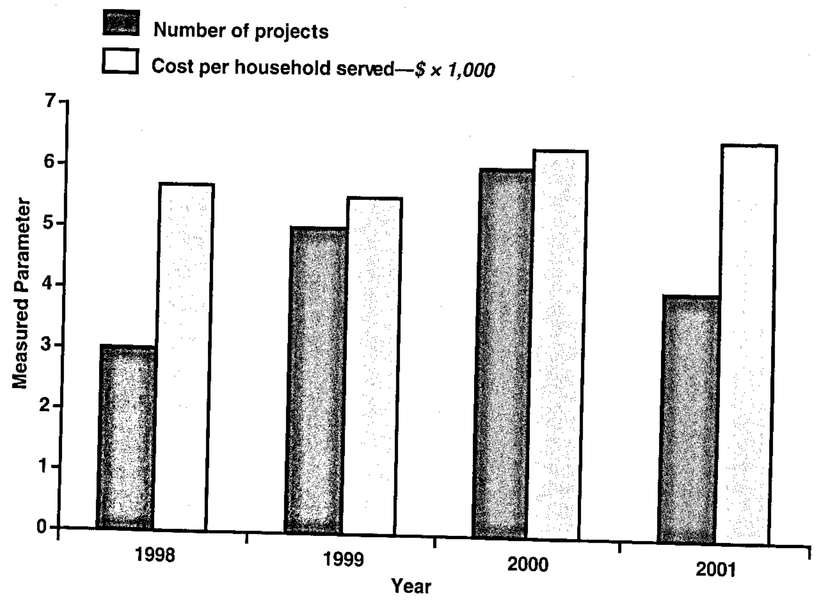
For example, investments in capital improvements to a 50-year community sewer project would be sequenced over 10, 5-year intervals. Thus, t_j acquires the index "j," in which j ranges from a value of 1 to the number of time intervals contained in the total project lifetime. In the community sewer example, j would range from 1 to 10. Partial intervals are rounded up to the next integer.

Services spotlighted by SRM analysis. SRM focuses on three sanitation services—drinking water supply, wastewater and sewage treatment, and municipal solid waste management. Thus, the terms G, S, D, C, E, and B are aggregates of the indexed terms G_k, S_k, D_k, C_k, E_k, and B_k. Here "k" is the index for the type of service and ranges from 1 for water supply to 3 for municipal solid waste management.

Three user categories are included. Finally, SRM analysis considers three categories of users of sanitation services—residential users, commercial users, and industrial users. Each of these groups has its own time-variant demand function that must be matched by a planned supply of the service. Thus, for each time interval t_j, the planning variables are G_{kl}, S_{kl}, D_{kl}, C_{kl}, E_{kl}, and B_{kl} in which "l" is the index for the user group and varies from 1 for residential users to 3 for industrial users. Given these notes, for a given time interval j, the SRM planning approach may be formulated as

The underlying goal of municipal sanitation service providers is the assurance of safe and reliable services, including drinking water supply, wastewater and sewage treatment, and municipal solid waste management.

FIGURE 2 Average household cost and project summation for Self-Help Virginia



$$\text{Minimize } G(t) = S(t) - D(t) \qquad (4)$$

such that

$$C(t) \leq C_B(t)$$
$$E(t) \leq E^*(t)$$
$$B(t) \leq M^*(t)$$

in which t is t_j (in which $j = 1, n$), $G = \sum_{k,l} g_{k,l}$, $S = \sum_{k,l} s_{k,l}$, $D = \sum_{k,l} d_{k,l}$, $C = \sum_{k,l} c_{k,l}$, $C_B = \sum_{k,l} cb_{k,l}$, $E = \sum_{k,l} e_{k,l}$, $E^* = \sum_{k,l} e^*_{k,l}$, $B = \sum_{k,l} b_{k,l}$, $M^* = \sum_{k,l} m^*_{k,l}$, in which k is the service index (i.e., 1 indicates water, 2 indicates wastewater, and 3 indicates municipal solid waste management), l is the user index (i.e., 1 indicates residential, 2 indicates commercial, and 3 indicates industrial).

The benefit–cost ratio for evaluating these projects is defined as

$$BCR = \frac{B}{C} \qquad (5)$$

in which B is the present value of benefits over the life cycle of the project and C is the present value of costs over the life cycle of the project.

Items such as volunteer labor and contributed equipment that reduce the cost of the investment are subtracted from the life-cycle cost, thereby reducing the denominator of the ratio and increasing the overall benefit–cost ratio. Items that yield quantifiable benefits to users of the service are added to the life-cycle benefit of the project. This increases the numerator of the benefit–cost ratio and improves the attractiveness of the investment from the benefit–cost perspective.

The goal of Self-Help Virginia is "to tap neighborhood talent, manpower, and creativity to produce water and sewer services in areas where those services are difficult to provide through conventional means."

VIRGINIA PROGRAM MAKES THE MOST OF FUNDING DOLLARS

Standard cost–benefit analysis for infrastructure project evaluation can be biased against small-scale projects because these projects have relatively large capital costs but benefits that accrue to a small population. In contrast, infrastructure projects in densely populated areas have proportionally high capital costs but benefits that accrue to a much larger population. Thus, costs for small and large projects are proportional to the population served, whereas benefits for projects in small and rural communities are disproportionately smaller than benefits for projects in larger, urban communities with dense populations. By this evaluation criterion, larger projects have a greater benefit–cost ratio and appear more attractive, compared with their small counterparts. The result is a bias in the allocation of state funds to projects in larger metropolitan areas and city centers, leading to the potential neglect of needed projects in small and rural communities.

This bias against small-scale projects can be mitigated in two ways: (1) expand the definition of benefits and costs to cover the life cycle of projects and (2) include quantifiable external costs and benefits in the calculation of the benefit–cost ratio. Life-cycle cost–benefit analysis of infrastructure projects would include the benefits of economic development that occur in a community as a result of the project. In small communities, the marginal benefits can be large in proportion to the population because the new infrastructure may facilitate potential business investment, which may have been entirely absent before. By comparison, improvements to infrastructure in larger communities are made to an already large stock of infrastructure and thus may have marginal benefits that are small in proportion to the population. Furthermore, in small communities, the avoided costs of private wells, procurement of alternative infrastructure services, and ancillary costs from the absence of such services (such as higher fire insurance premiums) can significantly increase the life-cycle benefit of projects.

Finally, the use of volunteer labor and contributed professional services and equipment in self-help and community-based projects contributes to significant reductions of project cost in small communities. These reductions in cost, coupled with increases in the value of benefits, raise the benefit–cost ratio and increase the attractiveness of small-scale infrastructure projects when they compete with larger projects for state funding. The following section details how life-cycle or enhanced cost–benefit analysis and the cost reductions from community participation were applied in a Virginia program.

Self-Help Virginia (SHV) helps fund small-scale projects. Launched in 1998, SHV is administered by the Virginia Department of Housing and Community Development through its Committee on Rural Development (CORD). SHV funding is provided through Community Improvement Grants under the Community Development Block Grant program, which has been administered by the state Department of Housing and Community Development since 1982 and derives its funds from the US Department of Housing and Urban Development. SHV shares an annual allocation of approximately $2.5 million under the Community Development Innovation Fund with projects in the Local Innovation Program and the Community Development Venture Capital Fund. Figure 1 shows the administration and funding structure of the SHV program.

The Virginia Community Development Block Grant program provides funding to eligible units of local government to address critical community development needs, including housing, infrastructure, and economic development. Community Improvement Grants enable residents to implement solutions to identified local development problems. These solutions may include activities such as acquisition of real property, installation of infrastructure, improvement of housing, and construction of other physical improvements to the community.

ENHANCED BENEFIT–COST RATIO FOR SHIPMAN PROJECT

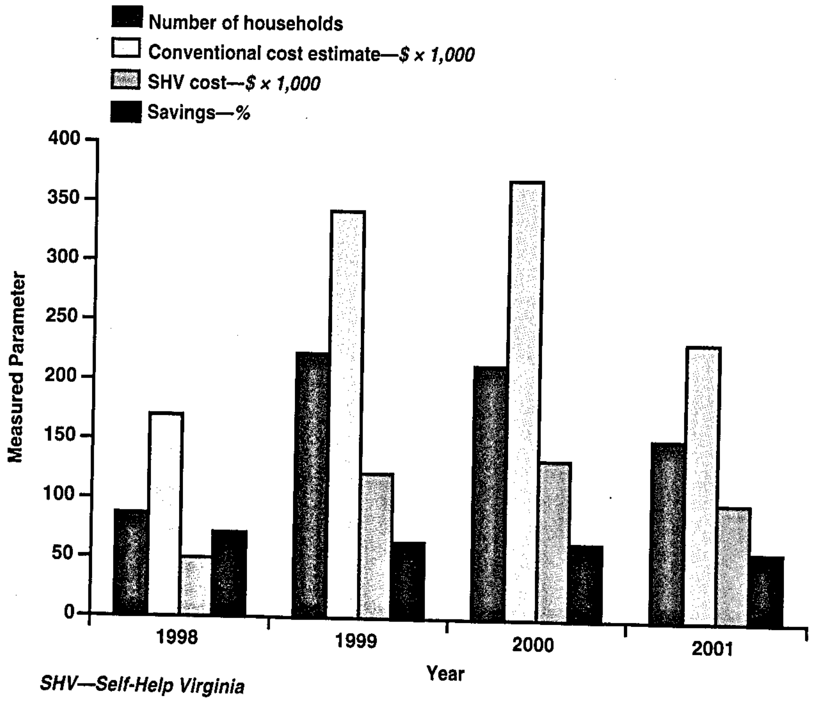
Conventional cost estimate	$649,000
Self-Help Virginia (SHV) cost estimate (for hardware)	$300,000
Savings	$349,000
Percent savings provided by SHV	54%
Risk premium = enhanced project benefit	$49,403
Original benefit–cost ratio	$300,000:$649,000
Value of original benefit–cost ratio	0.46
Benefit–cost ratio with SHV reduced cost	$300,000:$300,000
Value of benefit–cost ratio with SHV reduced cost	1.00
Benefit–cost ratio using SRM with risk premium	$349,895:$300,000
Value of benefit–cost ratio using SRM with risk premium	1.16

The goal of SHV is "to tap neighborhood talent, manpower, and creativity to produce water and sewer services in areas where those services are difficult to provide through conventional means" (Castillo, 2000). CORD undertakes the task of organizing the community to apply and qualify for SHV funds. The community then provides the volunteer labor and other resources required to complete the project with the funds provided by SHV. The water projects completed in Virginia since the inception of the program have realized an average of 64% in savings compared with the estimated cost of using private contractors for the projects.

Figure 2 shows the number of projects and cost per household served since the SHV program began. Figure 3 shows the number of households served and the savings achieved by SHV compared with conventional cost estimates for the four years the program has been in existence. These figures demonstrate that SHV has grown modestly over its three-year life. The number of households served has expanded from 87 in 1998 to 217 in 2000. Unit cost per household served has increased by 9% over the three years (when adjusted for inflation). Percent savings from the conventional cost estimate has decreased from 71% in 1998 to 64% in 1999 and 2000 to 58% in 2001.

Self-Help programs are under way nationwide. Currently 11 states have established Self-Help programs. SHV is patterned after similar programs in New York and Texas. The Texas program has a much larger budget and has been in operation since 1983. The Small Towns Environment Program (STEP) provides drinking water and wastewater infrastructure

FIGURE 3 Comparison of SHV costs and conventional costs, 1998–2001



SHV—Self-Help Virginia

to small communities using the Self-Help approach. A project of the Rensselaerville Institute of Rensselaerville, N.Y., STEP is operated in partnership with the US Environmental Protection Agency (USEPA), the Ford Foundation, and the states with active STEP functions. The state-based program enables small communities to define and solve water and wastewater problems using local resources. STEP has been active in Arkansas, Idaho, Maryland, New York, North Carolina, Oregon, South Dakota, Tennessee, Texas, and Washington. Table 1 summarizes those Self-Help programs for which data were available.

SHV'S HIDDEN BENEFITS MAKE IT PRIME CANDIDATE FOR SRM ANALYSIS

Virginia program's goal and objectives can be evaluated by SRM format. As stated previously, the goal of SHV is "to tap neighborhood talent, manpower, and creativity to produce water and sewer services in areas where those services are difficult to provide through conventional means." In pursuit of this goal, the program has three main objectives:

- help build a community's capacity and readiness for a Self-Help project,
- promote community development through funding for sanitation infrastructure, and
- increase economic opportunities in the community.

SHV's goal and related objectives are directly compatible with those of SRM. The primary objective of SRM is to assure capacity for sanitation services (i.e., drinking water supply, wastewater and sewage treatment, and municipal solid waste management) over the long term. Thus, with the exception of the provision for municipal solid waste management, the assurance of capacity under SRM coincides with "producing water and sewer services in areas where those services are difficult to provide through conventional means."

The remaining two objectives of SHV may be subsumed under the third objective of SRM. Thus, where SRM seeks to realize the maximum economic benefit from investments in infrastructure, measures of this benefit may include such positive externalities as new businesses attracted to the area and increased development attributable to the availability of sanitation infrastructure. These indirect benefits are part of an economic multiplier effect from the infrastructure investment.

It is difficult, however, to ascribe the full economic multiplier effect in a community exclusively to SHV investments (Heikkila, 2000), and SRM does not attempt to do so. Instead, in computing the benefit–cost ratio for SHV projects, SRM includes the reduction in cost and the increase in benefits associated with the SHV approach. Both of these changes increase the benefit–cost ratio, making the projects more attractive.

In addition to these accounting improvements, SRM seeks to minimize the explicit negative environmental effects from any infrastructure investments to an end condition (E^*) negotiated by the stakeholders in the project. These stakeholders are likely to be the community residents, the local or county service authority, and the state environmental agency. In the case of SHV water projects, E^* generally takes the form of erosion control and landscaping requirements set by the state. In summary, imposing the SRM framework on the SHV program highlights the following advantages of the Self-Help approach:

- Projects not affordable by conventional means become more attractive to funding sources.
- SHV yields direct savings, which may qualify the project for Community Development Block Grant funds.
- Risk reduction enhances these savings through external benefits.
- SRM is a win–win proposition for all parties.

TABLE 1 Self-Help Virginia in the national context*

State	Year Begun	Annual Budget	Number of Projects Completed	Number of Households Served
Kansas	1999	$500,000	1	80
Louisiana	1997	$600,000	10	450
New York	1986	No set budget	100	2,100
Oregon	1995	$75,000	3	85
Texas	1983	$3,700,000	425	NA†
Virginia	1988	$1,300,00	NA	NA
Washington	1993	NA	10	500

*No information was available for current Self-Help programs in the states of Arkansas, Arizona, Florida, Idaho, Maryland, Mississippi, North Carolina, Pennsylvania, South Dakota, and Tennessee.
†NA—not available

Approach uncovers risks associated with Virginia projects. There are three sources of risk in the SHV water projects: (1) water quantity risks attributable to interrupted or inadequate supply to meet household demand, (2) water quality risks arising from chemical or biological contaminants, and (3) water confidence risks arising from unacceptable odor, taste, and/or color. The risk from these sources is the product of the likelihood that these events will occur and a measure of the consequence or effect of these events, should they occur.

Risks can be measured for each source. Eq 6 can be used to compute the risk associated with each of the three sources:

$$r_i = p_i \times C_i,\ i = 1, 3 \qquad (6)$$

In which r is the risk from an individual source. The total risk for the project is given by

$$R = \sum_i r_i \qquad (7)$$

Assigning a cash value to the consequence of any of these events is difficult. What is the formula for calculating the cost of no drinking water supply or an interrupted water supply when a well temporarily runs dry? Similarly, what dollar value should be assigned to the presence of a biological or chemical contaminant or unacceptable odor, taste, or color in a private water supply? Even if a dollar value could be assessed, it would likely be different for each resident. Because the direct dollar value of the consequences cannot be assessed, this study uses the dollar value of the expenditures that residents make to avoid these events as a measure of their revealed preference (Nicholson, 1989) for the cost of these consequences.

This study uses a three-year planning horizon, which represents the life of the SHV program. A discount rate of 3%, the minimum charged by the Department of Environmental Quality under the Virginia Water Facilities Revolving Loan Fund, is used. Under this approach, the cost to the community of interrupted or inadequate water supply is assumed to be the present value of the total cost of new wells drilled by residents and all water trucked into the community over the past three years. Ideally, the premium paid for homeowner's insurance because of the absence of fire hydrants close to their houses should be included in the total cost of the consequence of inadequate water quantity. However, data on this differential were not available.

The cost of poor water quality is assumed to be the total cost to the community of bottled water and water treatment systems used by residents. The cost of low confidence in the water supply attributable to color, taste, or odor is assumed to be part of the total expenditure on bottled water and water treatment systems, as well as the expenditure on pay-laundry use to avoid discoloration or noxious odors on clothing laundered at home. The present value of these costs is calculated over a three-year period. (In the illustration for this article, only one full year of cost is used, and these costs are assumed to accrue at the start of the project.) Thus

$$C_1 = \Sigma \text{ (well costs + trucked water costs in 2000\$) for water quantity} \qquad (8)$$

$$C_2 = \Sigma \text{ (bottled water costs + water treatment costs in 2000\$) for quality} \qquad (9)$$

$$C_3 = \Sigma \text{ (commercial laundry costs in 2000\$) for water confidence} \qquad (10)$$

The associated probabilities for these cost events are computed as the percentage of residents in the community who undertake these risk-avoidance expenditures. Standard practice would have been to determine the relative frequency of adverse water quantity, water quality, and water confidence events in communities similar to the one under study or to use historical data for the events in the community under study. From these frequencies, event probabilities for the study community could be extrapolated. In this application, however, SRM uses the subjective probabilities assessed from the preference actions of residents in the community. The hypothesis is that residents do not have access to the relative frequency information and act on their perception of the risk associated with these adverse events. Under this

TABLE 2 Laboratory results for Shipman water quality samples

Sample Number	Iron *mg/L*	Manganese *mg/L*	Ratio Iron Tested/ Iron USEPA*	Ratio Manganese Tested/ Manganese USEPA	Coliforms
1	4.65	0.13	16	310	Not present
2	8.38	0.37	20	559	Not present
3	0.06	0.13	0.2	4	Not present
4	0.85	0.25	3	57	Not present
5	4.58	0.13	15	305	Not present
6	0.14	0.13	0.5	9	Not present
7	8.25	0.06	28	550	Not present
8	17.1	1.14	57	1140	Not present
9	BQL†	BQL	NA‡	NA	Present
10	4.2	0.16	14	280	Not present
11	0.08	BQL	0.3	5	Not present
12	2.51	0.22	8	167	Not present

*USEPA—US Environmental Protection Agency
†BQL—below quantification limit
‡NA—not available

TABLE 3 Budget estimate for the Shipman water project*

Item†	Quantity	Material Cost	Estimated Installed Cost
Mobilization	1	$100	$1,500
VDOT† permit	1	$50	$500
8 in. (200 mm) PVC‡ main pipe	18,050 ft (5,502 m)	$126,350	$357,390
3 in. (75 mm) PVC house pipe	1,275 ft (389 m)	$6,375	$14,025
Water boring	70 ft (21 m)	$4,480	$8,400
Open cut	100 ft (30 m)	$1,800	$5,000
Fire hydrants	13	$17,771	$26,455
Gate valves	4	$2,012	$2,752
8 in. (200 mm) tee	1	$127	$220
2 in. (50 mm) air-release valve	1	$899	$1,496
Erosion control	12,200 cu ft (346 m^3)	$11,224	$23,424
Temporary seeding and mulch	8,500 units	$8,245	$20,825
Permanent seeding	8,500 units	$4,505	$11,730
Rock excavation	100	$1,100	$2,750
Material removal/replacement	1,625	$17,875	$11,875
4 in. (100 mm) blowoff valve	1	$700	$1,140
Altitude and pressure valve	1	$2,000	$4,000
Connection fee	0	$0	$0
Installation to house (LMI§ household)	24	$6,000	$24,000
Installation to house (non-LMI household)	19	$4,750	$19,000
Equipment rental and fuel	1	$50,000	$50,000
Inspection personnel	1	$7,500	$7,500
Miscellaneous	1	$23,947	$47,756
Total estimated		$297,810	$647,738

*Source: Castillo, 2000
†VDOT—Virginia Department of Transportation
‡PVC—polyvinyl chloride
§LMI—low or moderate income

hypothesis, the revealed preference approach for both *p* and C provides a more accurate measure of the community's risk as it is perceived by residents than would an attempt to assess and extrapolate from relative frequencies or direct valuation of consequences.

In the case of low- and moderate-income communities, the percentage of residents able to afford risk mitigation measures may not reflect the true percentage of residents who would like to adopt such measures based on their perception of risk. Some residents simply may not have the financial resources to act on the perceptions of risk from their private water supply. This shortcoming is acknowledged in the revealed preference values used to calculate risk in the SHV case.

Risk-based analysis eliminates some costs and includes others. SHV projects enable communities to avoid the costs incurred by residents to mitigate risk. Thus, the value of these avoided costs becomes an additional project benefit, and the term $b_{k,l}$ is added to the benefit term in the benefit–cost ratio for the project.

The cost of the infrastructure is included as a project cost, but the value of that stock of assets represents a benefit to the community. It is included in the calculation as the present value of the annualized depreciation charges on the hardware over the three-year planning horizon, using the straight-line method of depreciation. For this article, only the first year of costs and benefits was calculated. Thus, the asset value of the infrastructure investment is equal to the cost of the hardware because no depreciation has occurred at the start of the project.

SHV KEEPS WATER FLOWING IN SHIPMAN

Shipman is a town of approximately 600 residents located in Nelson County (Va.) 35 mi (56 km) southwest of Charlottesville. Some 46 households in the town complained about the quality of their well

TABLE 4 Savings from SHV* projects through 2000

Project Name	County	Number of Households Served	Conventional Estimate	SHV Estimate	CDBG† Contribution	Total Local Contribution	Project Cost	Savings Over Conventional Estimate %
Pocahontas	Sussex	25	$242,000	$98,000	$94,000	$11,000	$105,000	56
Thomaston Road	Southampton	28	$405,000	$210,000	$206,000	$9,000	$215,000	47
St. Clair's Creek	Smyth	49	$503,000	$213,000	$210,000	$4,000	$214,000	57
Pea Patch	Buchanan	42	$1,255,000	$359,000	$350,000‡	$10,000	$360,000	71
Bearwallow	Tazewell	24	$623,000	$220,000	$226,000	$7,000	$233,000	63
Shipman	Nelson	44	$649,000	$300,000	$295,000	$5,000	$300,000	54
Total		212	3,677,000	1,400,000	1,381,000	46,000	$1,427,000	61

*SHV—Self-Help Virginia
†CDBG—Community Development Block Grant
‡An additional $125,000 was contributed by an interested party.

water and petitioned CORD for help in improving the quality of their drinking water. The residents' complaints included irregular flow, discoloration, odor, taste, and suspected volatile organic chemical contamination in their well water.

Tests underscored water quality issues. Water samples were drawn from outdoor faucets of 12 households before connection of county water service. Table 2 summarizes these test results. The percentages reported for water quality in Shipman are linear extrapolations from these 12 samples to the 46 households originally considered for the project. (Three households were added to the project after construction began and are not included in the water quality results.)

Laboratory tests of the 12 water samples indicated that 75% of the wells had iron concentrations significantly above the secondary standard set forth by USEPA. In addition, 83% of the wells had manganese levels higher than the standard. Although both iron and manganese are considered to be secondary contaminants and do not pose a threat to health, their aesthetic effects of discoloration and odor could undermine residents' confidence in the quality of their drinking water. This lack of confidence could lead residents to incur additional costs for water treatment, bottled water, and purchased laundry services.

In addition, one (8.3%) of the samples tested positive for coliforms. This violates the USEPA's primary standard for drinking water in community water services established by the Safe Drinking Water Act (SDWA). Turbidity was the final aspect of water quality tested. Tests indicated that 16.7% of the samples exceeded the standards set forth for public water systems. Higher turbidity levels are often associated with higher concentrations of disease-causing microorganisms, which can lead to such symptoms as nausea, cramps, diarrhea, and headaches.

Federal standards for community water systems do not apply to private wells in Virginia. However, the federal standards can be used as a benchmark to assure that the residents in SHV communities like Shipman receive the same level of protection for their drinking water afforded to the rest of the US population covered by SDWA standards.

Residents work together to improve water supplies. The community of Shipman did not rely on trucked water. After a consultation with the Nelson County Service Authority, it was decided that residents could be connected to the public water supply, which ended in the adjacent town of Lovingston. This service line was connected to the fire hydrants along the main county road through Shipman.

Table 3 shows the project budget. Additions to the preliminary design led to an estimated installed cost of $649,000 for the project. SHV agreed to meet the cost for materials. CORD worked with town residents to ensure that they could supply the labor and other resources required for installation of the new

For Virginia communities facing a gap in their capacity for drinking water or wastewater treatment services, Self-Help Virginia provides a means to acquire this infrastructure with state support.

TABLE 5 Cost of risk avoidance in Shipman

Annual Risk Avoidance Item	Value
Wells: 40 at $3,000/household	$120,000
Water treatment: 10 at $2,000/household	$20,000
Annual filter maintenance: 10 at $100/household	$1,000
Bottled water: 2 gpd (7.6 L/d) per household at $0.50/gal ($0.13/L) × 40 households × 365 days a year	$14,600
Laundry (wash only): $5/week/household × 30 households × 52 weeks a year	$7,800
Insurance premium	NA*
Total	$163,400
Cost per household	$3,335

*NA—not available

TABLE 6 Calculating the risk premium for Shipman

i*	Adverse Event	p_i†	C_i‡	R_i§
1	Unreliable water quantity	0.326	$74,293	$24,220
2	Suspected biological/chemical contaminant	0.065	$14,813	$963
3	Unacceptable color, odor, and/or taste	0.326	$74,293	$24,220
	Total risk premium for Shipman			$49,403

*Index for source of risk
†Probability of undesirable event
‡Value of consequence of the event
§Risk of undesirable event

water supply system. CORD required residents to complete a community labor survey and a preliminary community assessment. In addition, CORD held four town meetings to organize the community for the volunteer effort required to complete the project. Given the available labor supply, a start date of Sept. 30, 2000, was established. The estimated end date was Dec. 16, 2000, but the supply of labor became irregular after the Thanksgiving holidays and the start of the hunting season. The project was completed in May 2001.

Shipman project can be written in SRM format. The objective function of the Shipman Self-Help effort was to eliminate the shortage of water to households served by the project. When these households are connected to the Nelson County Service Authority supply, the water deficit is zero. Thus, the objective function becomes

$$\text{Minimize } G = S - D \qquad (11)$$

such that $G \geq 0$ in which G is the gap between the demand for drinking water and its supply. The constraints are $C \leq C_B$, $E \leq E^*$, and $B \leq M^*$. Here C_B = $300,000, the state's contribution to SHV, E^* is the erosion control and landscaping required by the state Department of Environmental Quality, and M^* is the asset value of businesses permitted to operate in town because of piped water plus the income from new jobs created as a result of the presence of a public water supply.

Tax revenues from business establishments and Shipman residents are not included in the calculation o benefits. Taxes are merely transfe payments and should not be counte toward the benefits of this projec (Gramlich, 1990). Additionally, a a result of the project, residents fro the community gained experience i operating equipment such as tractors, backhoes, loaders, and borin machines as well as in the installation of pipe and fittings. Althoug the cost of providing this trainin through traditional schooling coul be calculated and added to the benefit assessment from the project, thi analysis does not include this cost. Similarly, the benefit of having an organized community group that could serve as a permanent advocate for development in Shipman is another project benefit that was not quantified for the analysis.

Project benefits add up. Table 4 summarizes the project savings for Shipman along with data for all SHV projects in 2000. As the table shows, the program yielded significant savings compared with the use of outside contractors to install community-level infrastructure projects. Savings ranged from 47 to 72% for the six projects completed in 2000. To assess the full benefit from these projects, however, the benefit total should include the payments that the community made before startup of a project to avoid risks to water quantity, water quality, and water confidence. Once a project is completed, the community will no longer incur these costs. In effect, the community no longer pays the risk premium associated with the use of its private water supply.

Simply put, strategic risk management is getting the most from risk management investments.

Table 5 summarizes this risk-voidance calculation for Shipman. n order to differentiate the portion of this risk-avoidance cost from the expenses the community would bear outinely for its drinking water, the community's revealed preference about risk from their private water supply must be used (Raucher et al, 2002). The risk premium can then be determined (such a calculation was performed for the Shipman project and is shown in Table 6).

Strategic risk management seeks to leverage infrastructure investments to assure the safety and reliability of basic services and at the same time achieve positive external benefits.

A survey was administered to the Shipman households served by the water project. Respondents were asked why they wanted to connect to the county water supply and whether they currently had wells and water treatment systems. Residents were also polled about their use of bottled water, trucked water (none), commercial laundry use (wash only, excluding dry cleaning), and homeowner's insurance premiums for the absence of fire hydrants in most of the community (insufficient data were received to compute the fire insurance premium).

A total of 46 households originally signed up for the project; another three were added after Dec. 31, 2000, but these were not included in the survey results. Of the original 46 households, 15 (32.6%) responded that they sought relief from an unreliable water supply, and the same number (though not all the same households) responded that they were very dissatisfied with the color, odor, and/or taste of their drinking water. Three households (6.5%) suspected coliform bacteria or some petroleum-based contaminant in their water supply. (Actual water quality results from a sample set taken in Shipman are summarized in Table 2.)

Because it was not possible to allocate the cost of risk avoidance to any single category, the total annual cost of risk avoidance in Shipman was partitioned among the three risk categories on the basis of their probabilities. The total risk was then calculated as the sum of the cash value of the risk in each category. This value represents the enhanced project benefit.

According to this calculation, the benefit–cost ratio for the Shipman project increases from 1.00 to 1.16. Thus, without the labor provided by the community under the SHV approach, the benefit–cost ratio for the Shipman project was 0.46 ($300,000: $649,000). When the volunteer labor cost is subtracted from the installed equipment cost, the ratio increases to 1.00 ($300,000:$300,000) for one year's costs and benefits assumed to accrue at the start of the project.

With the addition of the risk premium no longer paid by residents to avoid perceived hazards from their private water supply, the benefit–cost ratio for the Shipman project increases to 1.16 ($349,403:$300,000). Enhanced cost–benefit analysis using the SRM method increases the benefit–cost ratio for the project by a factor of 2.5, from an unimpressive value of 0.46 to a competitive value of 1.16. Thus, a small-scale infrastructure project becomes an attractive investment, according to the benefit–cost evaluation criterion described in this article. (The enhanced benefit–cost ratio for the Shipman project is summarized in the sidebar on page 71.)

In practice, the benefit of public works projects is carefully calculated, particularly when those projects involve transportation, water, and wastewater (Heikkila, 2000; Mishan, 1976). Indeed, many authors argue that the net present value is a more reliable criterion than the benefit–cost ratio for evaluating competing projects and urge caution in the use of the latter measure (Boardman et al, 2001; Heikkila, 2000; Layard & Glaister, 1994; Gramlich, 1990; Wohl & Hendrickson, 1984; Collier & Ledbetter, 1982; Swartzman et al, 1982; Dasgupta & Pearce, 1980; Mishan, 1976). To the extent that the benefit–cost ratio remains an important criterion for infrastructure investment decisions, the enhanced ratio provides a means of increasing the attractiveness of small-scale projects under this test.

CONCLUSIONS

SRM seeks to leverage infrastructure investments to assure the safety and reliability of basic services and at the same time achieve positive external benefits. In the case of municipal sanitation, i.e., drinking water supply, wastewater and sewage treatment, and solid waste management, the goal of SRM is to ensure the capacity to meet demands on the system over long-term planning horizons of 30 years or more. In pursuit of this goal, SRM seeks four objectives: (1) minimize the gap between service supply and demand over the planning period, (2) minimize cost, (3) minimize environmental damage, and (4) maximize economic effects on the region where the infrastructure investment is made.

In the United States, community water systems receive their supply from either public or private providers, who are subject to the standards of the SDWA. However, communities in periurban and rural areas, which are not served by these providers, must rely on supplies from private wells, springs, or other sources that are not subject to SDWA regulation. Though many states have standards for private water supply, inspection and monitoring are far from adequate, compared with the controls that exist for community water systems.

For Virginia communities facing a gap in their capacity for drinking water or wastewater treatment services, SHV provides a means to acquire this infrastructure with state support. The program enables communities to use sweat equity to acquire the services in which they are deficient. Program funds pay for the hardware required for the project, and community residents provide the labor and other resources needed to complete the project. Since the program was launched in 1998, SHV has completed a total of 15 projects, delivering water to 518 households in 9 counties. Over its three-year life, the program has spent \$3.1 million on projects conventionally estimated to cost \$8.8 million. Thus, SHV has provided direct savings to the state of \$5.7 million or 65%.

Enhanced cost–benefit analysis subtracts the sweat equity provided by the community from the total project cost. It also includes the risk premium that residents no longer pay to avoid perceived hazards from their private water supply as a benefit of acquiring the public infrastructure. These changes can increase the benefit–cost ratio of a small-scale infrastructure project from unimpressive values (<1.00) to attractive values (>1.00). In the case of the Shipman water supply project, enhanced cost–benefit analysis increased the project's benefit–cost ratio from 0.46 to 1.16, a factor of 2.5. By including all benefits accruing to a project, SRM cost–benefit analysis helps underscore that over their life cycles, these projects produce significantly greater benefits than costs to their communities.

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