Chapter 14
Designing Public Health Risk Management Programs

Risk management is a decision-making process that entails weighing policy alternatives, and then selecting the most appropriate regulatory action. This is accomplished by integrating the results of risk assessment with scientific data, as well as with social, economic, and political concerns—in order to arrive at an appropriate decision on a potential hazard situation (Cohrssen and Covello 1989; NRC 1994a, b; Seip and Heiberg 1989; van Leeuwen and Hermens 1995). Risk management may also include the design and implementation of policies and strategies that result from this decision-making process.

This chapter elaborates the key elements and steps necessary for the effectual design of typical public health risk assessment and risk management programs. Such risk management programs are typically directed at: risk reduction (i.e., taking measures to protect humans and/or the environment against previously identified risks); risk mitigation (i.e., implementing measures to remove risks); and/or risk prevention (i.e., instituting measures to completely prevent the occurrence of risks). Ultimately, the risk management (i.e., reduction, mitigation, and preventative) programs can generally help engender an increase in the level of protection to public health and enhance safety, as well as assist in the reduction of liability.

14.1 Risk Assessment as a Cost-Effective Tool in the Formulation of Public Health and Environmental Management Decisions

Risk assessment is a systematic technique that can be used to generate estimates of significant and likely risk factors associated with chemical exposure problems. Oftentimes, risk assessment is used as a management tool to facilitate effective decision-making on the control of chemical exposure problems. In fact, the chief

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purpose of risk assessment is to aid decision-making—and this focus should be maintained throughout any environmental or public health risk management program. On the whole, the application of risk assessment to chemical exposure problems can likely remove some of the ambiguities in the decision-making process. It can also aid in the selection of prudent, technically feasible, and scientifically justifiable risk control or corrective actions that will help protect public health and the environment in a cost-effective manner.

Risk assessments do indeed provide decision-makers with scientifically defensible information for determining whether a chemical exposure problem poses a significant threat to human health or the environment. Congruently, it would typically be conducted to assist in the development of cost-effective strategies for the management of chemical exposure problems. Among other things, the risk assessment process can be used to define the level of risk—and which will in turn assist in determining the level of analysis and the type of risk management actions to adopt for a given chemical exposure or environmental management problem. The level of risk considered in such applications can be depicted in a risk-decision matrix (Fig. 14.1)—in a manner that will help distinguish between imminent health hazards and risks. In general, this can be used as an aid for policy decisions, in order

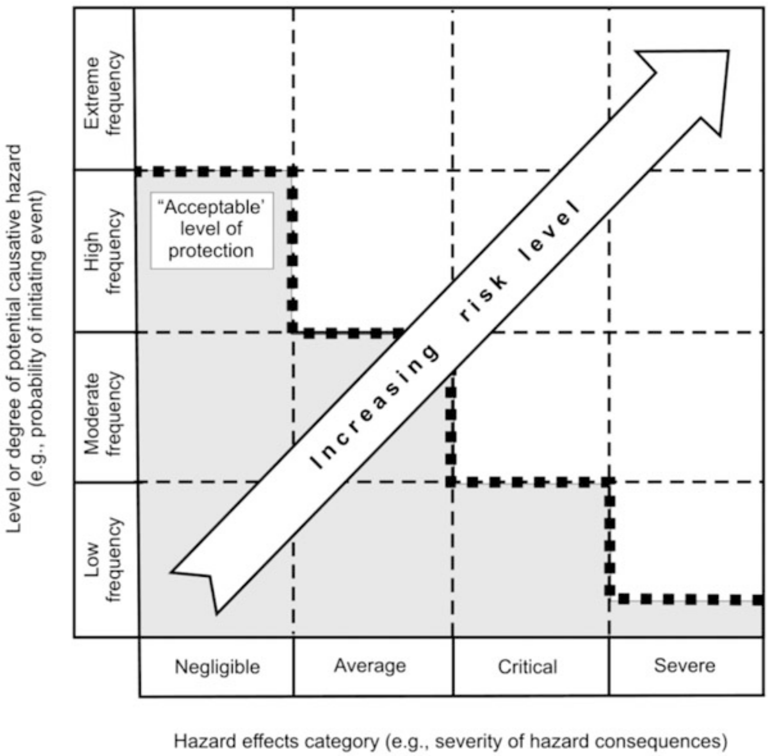

Fig. 14.1 A conceptual representation defining risk profiles in a risk-decision matrix

to develop variations in the scope of work necessary for case-specific public health risk management programs. At any rate, the procedures utilized in these efforts must reflect current/state-of-the-art methods for conducting risk assessments; for all intents and purposes, the following are noteworthy recommendations in the exercises typically involved:

- Performing risk assessment to incorporate all likely scenarios envisaged rather than for the 'worst-case' alone allows better comparison to be made between risk assessments performed by different scientists and analysts whose views on what represents a 'worst-case' may be very subjective, and therefore may vary significantly.
- Risk assessments performed for chemical exposure problems usually will, among other things, depend on an understanding of the fate and behavior of the chemical constituents of concern. Consequently, the fate and behavior issues in the various exposure settings should be carefully analyzed with the best available scientific tools.
- Exposure scenarios and chemical fate and behavior models may contribute significant uncertainty to the risk assessment. The uncertainties, heterogeneities, and similarities should be identified and well documented throughout the risk assessment.
- Whenever possible, the synergistic, antagonistic, and potentiation (i.e., the case of a non-hazardous situation becoming hazardous due to its combination with others) effects of chemicals and other hazardous situations should be carefully evaluated for inclusion in the risk decisions.
- It is prudent to appraise what the 'baseline' (no-action) risks are for a potentially hazardous situation or chemical exposure problem. This will provide a reflection on what the existing situation is, which can then be compared against future improved situations.
- An evaluation of the 'post-remedy' risks (i.e., residual risks remaining after the implementation of corrective actions) for a potentially hazardous situation or chemical exposure problem should generally be carried out for alternative mitigation measures. This will provide a reflection of what the anticipated improved situation is vis-à-vis the prior conditions associated with the problem situation.

Ultimately, the risk assessment efforts can help minimize or eliminate potential long-term problems or liabilities that could result from hazards associated with chemical exposure problems.

On the whole, the benefits of risk assessment designed to facilitate public health risk management decisions outweigh any possible disadvantages; still, it must be recognized that this process will not be without tribulations. Indeed, risk assessment is by no means a panacea. Its use, however, is an attempt to widen and extend the decision-maker's knowledge-base—and thus improve the decision-making capability. In conclusion, the method deserves the effort required for its continual refinement as a public health risk management tool.

14.2 Comparative Risk Analysis: Application of Environmental Decision Analysis Methods to Public Health Risk Management Programs

Decision analysis is a management tool comprised of a conceptual and systematic procedure for rationally analyzing complex sets of alternative solutions to a problem—in order to improve the overall performance of the decision-making process. Decision theory provides a logical and systematic framework to structure the problem objectives, and to evaluate and rank alternative potential solutions to the problem. Environmental decision analyses typically involve the use of a series of techniques to comprehensively develop risk control or corrective action plans, and to evaluate appropriate mitigative alternatives in a technically defensible manner.

As part of a corrective action assessment program, it is almost inevitable that the policy analyst will often have to make choices between alternative remedial options. These are based on: an evaluation of risk tradeoffs and relative risks that exist among feasible decision alternatives; evaluation of the cost-effectiveness of corrective action plans; or a risk-cost-benefit comparison of several management options. In fact, comparing risks, benefits, and costs amongst various risk management strategies can become very important in the appraisal of most environmental and public health risk management programs—since this could ultimately facilitate better optimization of proposed solutions to the problem on hand. A number of analytical tools may generally be used to assist with the processes involved here (see, e.g., Ashford and Caldart 2008; Bentkover et al. 1986; Clemen 1991; Finkel 2003; Haimes 1981; Haimes et al. 1990; Hattis and Goble 2003; Keeney 1990; Lave et al. 1988; Lave and Omenn 1986; Lind et al. 1991; Nathwani et al. 1990; Raiffa 1968; Seip and Heiberg 1989; USEPA 1984a, b; Weinstein et al. 1996); examples of the relevant tools are annotated below.

14.2.1 Cost-Effectiveness Analysis

Cost-effectiveness analysis involves a comparison of the costs of alternative methods to achieve some set goal(s) of risk reduction, such as an established benchmark risk or environmental cleanup criteria. The process compares the costs associated with different methods of achieving a specific risk management goal. All in all, the analysis involved can be used to allocate limited resources among several risk abatement programs—aimed at achieving the maximum positive results per unit cost. The procedure may also be used to project and compare total costs of several risk management plans.

In the application of cost-effective analyses to risk management actions, a fixed goal is established, and then policy options are evaluated on the ability to achieve that goal in a most cost-effective manner. The goal generally consists of attaining a specified level of 'acceptable' risk—with the risk management options being compared on the basis of the monetary costs necessary to reach the benchmark risk. Cost constraints can also be imposed so that the options are assessed on their ability to control the risk most effectively for a fixed cost. The efficacy of the risk management action alternatives in the hazard reduction process can subsequently be assessed, and the most cost-effective course of action (i.e., one with minimum cost that meets the constraint of a benchmark risk/hazard level) can then be implemented. This would then guarantee the objective of meeting the overarching goal in concert with the constraints at the lowest feasible cost.

14.2.2 Risk-Cost-Benefit Optimization

Risk-cost-benefit analysis is a generic term for techniques encompassing risk assessment and the inclusive evaluation of risks, costs, and benefits of alternative projects or policies. In performing risk-cost-benefit analysis, one attempts to measure risks, costs and benefits; to identify uncertainties and potential tradeoffs; and then to present this set of information coherently to decision-makers. A general form of objective function for use in a risk-cost-benefit analysis that treats the stream of benefits, costs, and risks in a net present value calculation is given by (Crouch and Wilson 1982; Massmann and Freeze 1987):

$$\Phi = \sum_{t=0}^{T} \frac{1}{(1+r)^t} [B(t) - C(t) - R(t)] \tag{14.1}$$

where: Φ = objective function ($); t = time, spanning 0 to T (years); T = time horizon (years); r = discount rate; B(t) = benefits in year t ($); C(t) = costs in year t ($); R(t) = risks in year t ($). The risk term is defined as the expected cost associated with the probability of significant impacts or failure, and is a function of the costs due to the consequences of failure in year t. In general, tradeoff decisions made in the process will be directed at improving both short- and long-term benefits of the program.

In closing, it is noteworthy here that, subjective and controversial as it might appear to express certain hazards in terms of cost, especially where public health and/or safety is concerned, it nevertheless has been used to provide an objective way of evaluating risk management actions/problems. This is particularly true where risk factors are considered in the overall study.

14.2.3 Multi-attribute Decision Analysis and Utility Theory Applications

Multi-attribute decision analysis and utility theory have been suggested (e.g., Keeney and Raiffa 1976; Lifson 1972) for the evaluation of problems involving multiple conflicting objectives—such as is the case for a number of decisions on environmental and public health risk management programs. Indeed, environmental and public health risk management tend to be complicated and multidisciplinary in nature—such that the typical issues involved can be quite difficult to resolve analytically; multi-criteria/attribute decision analysis usually would provide a more effectual framework by which the appropriate types of critical decisions can be made. As typical in such situations, the decision-maker is usually faced with the problem of having to trade-off the performance of one objective for another. In addressing these types of problem, a mathematical structure may be developed around utility theory that presents a deductive philosophy for risk-based decisions (Keeney 1984; Keeney and Raiffa 1976; Lifson 1972; Starr and Whipple 1980).

For instance, risk tradeoffs between increased expenditure of a risk management action and the hazard reduction achieved upon implementation may be assessed by the use of multi-attribute decision analysis and utility theory methods. Multi-attribute decision analysis and utility theory can indeed be applied in the investigation and management of environmental contamination and chemical exposure problems, in order to determine whether one set of risk management action alternatives is more or less desirable than another set. With such a formulation, an explicitly logical and justifiable solution can be assessed for the complex decisions involved in environmental and public health risk management programs. In using expected utility maximization, the preferred alternative will be the one that maximizes the expected utility—or equivalently, the one that minimizes the loss of expected utility. In a way, this is a nonlinear generalization of cost-benefit or risk-benefit analysis.

On the whole, the use of structured decision support systems has proven to be efficient and cost-effective in making sound environmental and public health risk management decisions. Such tools can indeed play vital roles in improving the decision-making process. It should be acknowledged, however, that despite the fact that decision analysis presents a systematic and flexible technique that incorporates the decision-maker's judgment, it does not necessarily provide a complete analysis of the public's perception of risk. Also, it is worth mentioning here that, even though utility theory offers a rational procedure for evaluating environmental and public health risk management measures, it may transfer the burden of decision to the assessment of utility functions. Additionally, several subjective assumptions are used in the application of utility functions that are a subject of debate. Anyhow, the details of the paradoxes surrounding key conclusions derived from expected utility applications are beyond the scope of this elaboration, and are not discussed here.

14.2.3.1 Utility-Attribute Analysis

In its application to environmental contamination and chemical exposure management problems, both hazards and costs can be converted to utility values, as measured by the relative importance that the decision-maker attaches to either attribute. Attributes measure how well a set of objectives is being achieved. Through the use of multiple attributes scaled in the form of utilities, and weighted according to their relative importance, a decision analyst can describe an expanded set of consequences associated with an environmental or public health risk management program. Adopting utility as the criterion of choice among alternatives allows a multifaceted representation of each possible consequence.

Although it may conceptually be viewed as a more-or-less linear-type relationship, in practice, the utility function need not be linear since the utility is not necessarily proportional to the attribute. Thus, curves of the forms shown in Fig. 14.2 can be generated for the utility function. An arbitrary value [e.g., *0* or *1*] of *1* can be assigned to the 'ideal' situation (i.e., a 'no hazard/no cost scenario')—and the 'dooms-day' scenario (i.e., 'high hazard/high cost') is then assigned a corresponding relative value [e.g., -1 or *0*] of *0*. The shape of the curves is determined by the relative value given each attribute. The range in utilities is the same for each attribute, and attributes should, strictly speaking, be expressed as specific functions of system characteristics.

In assigning utility value to hazard, it is a commonplace to rely on various social and environmental or public health goals that can help determine the threats posed by the hazard, rather than use the direct concept of hazard. These utility values can then be used as the basis for selection among the environmental and public health risk management action alternatives.

14.2.3.2 Preferences and Evaluation of Utility Functions

Preferences are directly incorporated in the utility functions by assigning an appropriate weighting factor to each utility term. The weighting factors are changed to reflect varying tradeoff values associated with alternative decisions. For instance, if minimizing hazards is k times as important as minimizing costs, then weighting factors of $[k/(k + 1)]$ and $[1/(k + 1)]$ would be assigned to the hazard utility and the cost utility, respectively. These weighting factors would reflect, or give a measure of, the preferences for a given utility function. Past decisions can help provide empirical data that can be used for quantifying the tradeoffs, and therefore the k values. In the end, the given utilities are weighted by their preferences, and are summed over all the objectives. For n alternatives, the value of the i-th alternative would be determined as follows:

$$V_i = \frac{\mathrm{k}}{(\mathrm{k}+1)} U(H_i) + \frac{1}{(\mathrm{k}+1)} U(\$i) \tag{14.2}$$

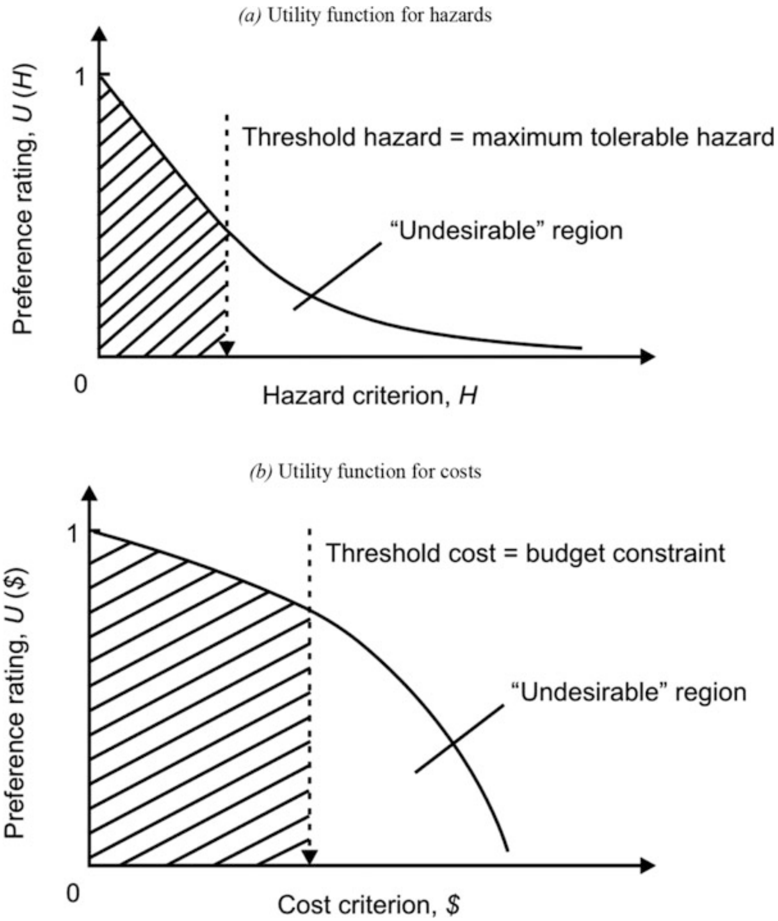

Fig. 14.2 Utility functions giving the relative values of hazards and costs in similar (dimensionless) terms. (**a**) Utility function for hazards. (**b**) Utility function for costs

where:

V_i = the total relative value for the i-th alternative
$U(H_i)$ = the hazard utility, H, for the i-th alternative
$U(\$_i)$ = the cost utility, $\$$, associated with alternative i.

In general, the largest total relative value would ultimately be selected as the best alternative.

On the whole, evaluation of utility functions requires skill, and when the utility function represents the preferences of a particular interest group, additional difficulties arise. Nonetheless, risk tradeoffs may be determined by reasonably applying weighting factors of preferences in a utility-attribute analysis.

14.2.3.3 Utility Optimization

To facilitate the development of an optimal risk management program, the total relative value can be plotted against the cost (Fig. 14.3). From this plot, the optimum cost is that cost value which corresponds to the maximum total relative value. The optimum cost is equivalently obtained, mathematically, as follows:

$$\frac{\mathrm{dV}}{(\mathrm{d}\$)} = \frac{\mathrm{d}}{(\mathrm{d}\$)}\left[\frac{\mathrm{k}}{(\mathrm{k}+1)}\mathrm{U(H)} + \frac{1}{(k+1)}\mathrm{U}(\$)\right] = 0$$
$$\text{or,}$$
$$k\frac{\mathrm{dU(H)}}{(\mathrm{d}\$)} = -\frac{\mathrm{dU}(\$)}{(\mathrm{d}\$)} \tag{14.3}$$

where: $\frac{\mathrm{dU(H)}}{(\mathrm{d}\$)}$ is the derivative of hazard utility relative to cost, and $\frac{\mathrm{dU}(\$)}{(\mathrm{d}\$)}$ is the derivative of cost utility relative to cost. The optimum cost is obtained by solving this equation for $\$$; this would represent the most cost-effective option for project execution.

In an evaluation similar to the one presented above, a plot of total relative value against hazard provides a representation of the 'optimum hazard' (Fig. 14.4). Again, this result can be evaluated in an analytical manner similar to that presented above for cost; the 'optimum hazard' is given, mathematically, by:

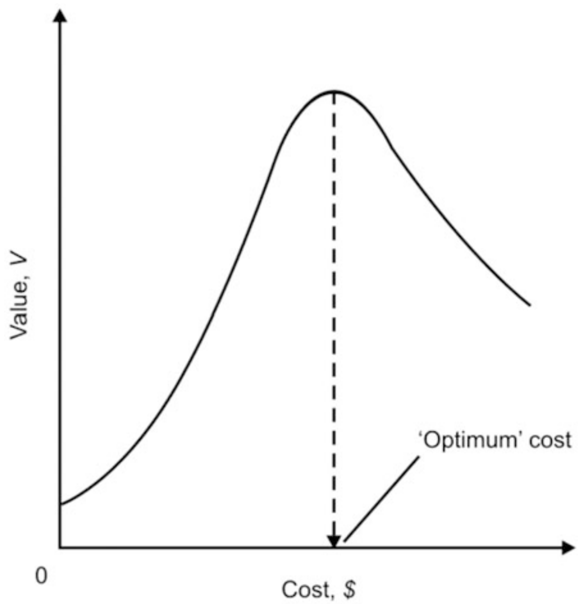

Fig. 14.3 Value function for costs

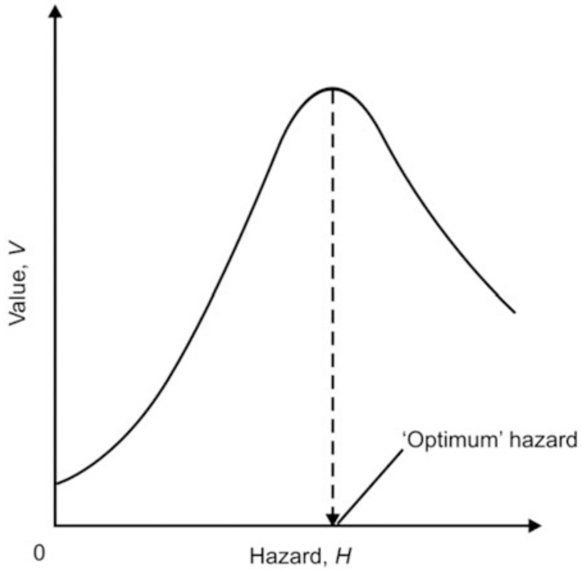

Fig. 14.4 Value function for hazards

$$\frac{dV}{(dH)} = \frac{d}{(dH)}\left[\frac{k}{(k+1)}U(H) + \frac{1}{(k+1)}U(\$)\right] = 0$$
or
$$k\frac{dU(H)}{dH} = -\frac{dU(\$)}{(dH)} \tag{14.4}$$

where: $\frac{dU(H)}{(dH)}$ is the derivative of hazard utility relative to hazard, and $\frac{dU(\$)}{(dH)}$ is the derivative of cost utility relative to hazard. Solving for *H* yields the 'optimum' value for the hazard.

14.3 A Framework for Risk Management Programs

Risk management decisions generally consist of complex processes that involve a variety of technical, political, and socioeconomic considerations. Notwithstanding the complexity and the fuzziness of the issues involved, the ultimate goal of public health risk management programs is to protect public health—and this can be effectively accomplished in a reasonable manner. The application of risk assessment can indeed remove some of the ambiguity in the decision-making process—albeit the relationship between risk assessment and risk management can itself be quite ambiguous and disagreeable; it can also aid in the selection of prudent, technically feasible, and scientifically justifiable risk management actions that will help protect public health in a cost-effective manner. To successfully apply the risk assessment process to a potential chemical exposure problem, however, the process must be tailored to the case-specific conditions and relevant regulatory constraints. In the end, based on the results of a risk assessment, decisions can then be made relating to the types of risk management actions needed for a given chemical exposure problem. If unacceptable risk levels are identified, the risk assessment process can further be employed in the evaluation of remedial or risk control action alternatives. This will ensure that net risks to human health are truly reduced to acceptable levels via the remedial or risk management action of choice.

Figure 14.5 provides a framework that may be used or adapted to facilitate the environmental and public health risk management decision-making process involved in chemical exposure programs. The process will generally incorporate a consideration of the complex interactions existing between the exposure setting, regulatory policies, and technical feasibility of risk management options. Ultimately, the tasks involved should help public health risk analysts to: identify, rank/categorize, and monitor the status of potential chemical exposure problems; identify field data needs and decide on the best investigation or sampling strategy; establish appropriate public health goals; and choose the risk management action that is most cost-effective in controlling or abating the risks associated with the chemical exposure problem.

In the arena of chemical exposure problems, it is noteworthy that, public health risk management decisions should typically be based on a wide range of issues relevant to a holistically-designed risk analysis—including medical opinion, epidemiology, and professional judgment, along with socioeconomic factors and technical feasibility. It is also imperative to: systematically identify hazards throughout an entire public health risk management system; assess the potential consequences due to any associated hazards; and examine corrective measures for dealing with the case-specific type of problem. Risk management—used in tandem with risk assessment—offers the necessary mechanism for achieving such goals.

14.3.1 Hazard Characterization as a Foundational Basis for Environmental and Public Health Risk Management

Hazard accounting and characterization usually represents a very fundamental activity that needs to be undertaken before any credible risk management decisions and/or actions can take place. The general purpose of a hazard characterization is to make a qualitative judgment of the effect(s) caused by an agent or stressor under consideration and its relevance to a target population of interest. In translating hazard characterization into corresponding risk value or indicator, the processes involved need to consider, among other things, the severity of critical effects and the specific affected population groups, etc.; for instance, in determining 'safe exposure limits' associated with human exposure to nitrate, it is important to

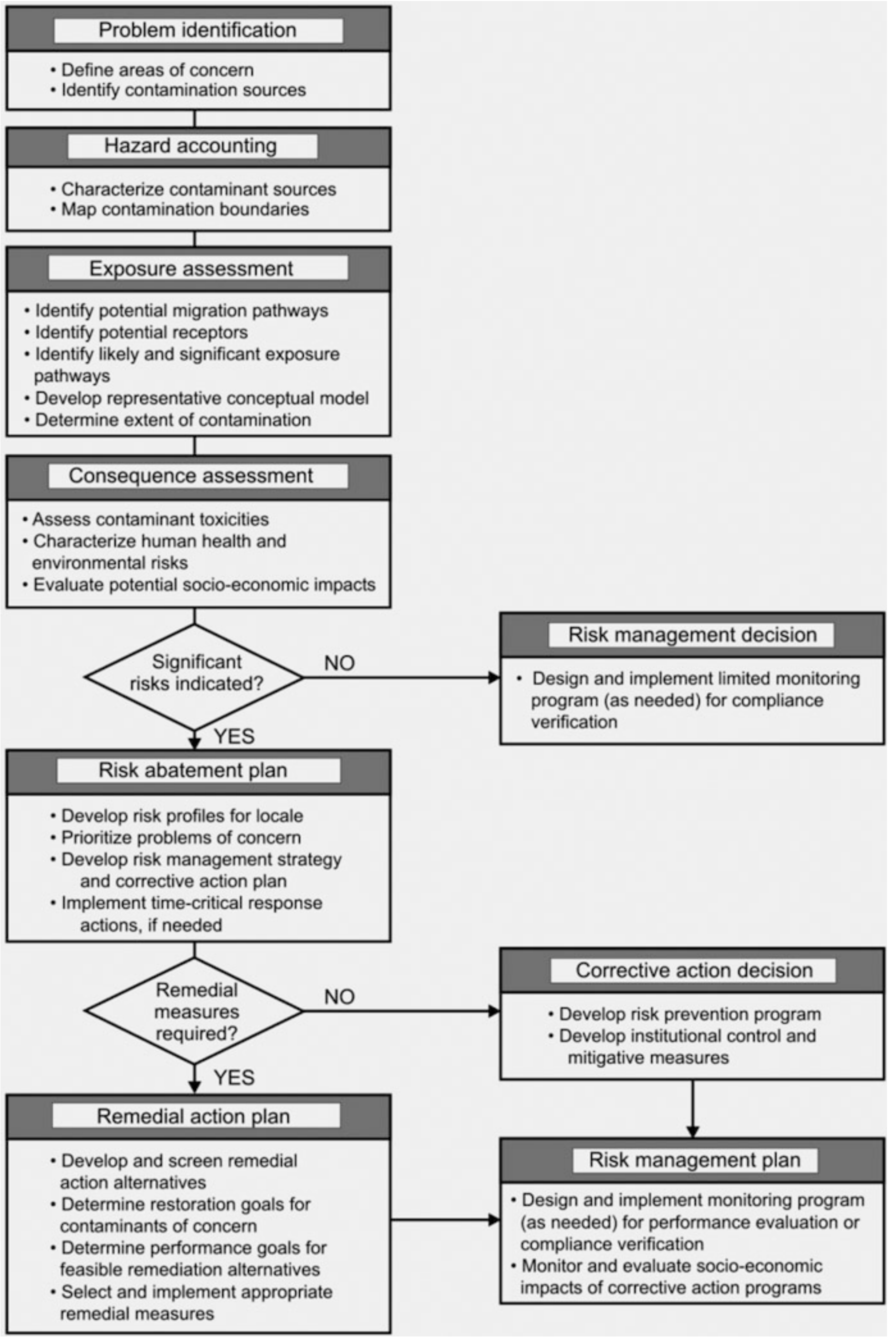

Fig. 14.5 A risk management decision framework for the management of chemical exposure problems

recognize the fact that infants are very sensitive to nitrate exposures (related to methemoglobinemia)—whereas, in general, this critical effect would not be relevant to the development of an occupational exposure limit. Overall, it is important to carefully consider the scenarios of interest (with respect to population, duration, exposure routes, etc.) in such characterization efforts—in order to arrive at realistic and pragmatic risk conclusions.

Meanwhile, it is worth the mention here that, to ensure that risk assessments are maximally useful for risk management decisions, the questions that risk assessments need to address must be raised before the process begins—also recognizing that the more complex and multifaceted the problem to be dealt with, the more important the need to operate in this manner; indeed, by focusing on early and careful problem formulation, and on the options for managing the problem, implementation of this type of paradigm or structural framework can do much to improve the utility of risk assessment (NRC 1996; NRC 2009).

In the final analysis, the levels and complexity of hazard and risk assessments (especially with regards to planning efforts and design elements) should generally be consistent with the goals of the overarching and/or anticipated decisions to be made in the long run. Indeed, one could argue that risk assessments should not be conducted unless it is clear that they are designed to answer very specific questions, and that the level of technical detail along with uncertainty and variability analysis is appropriate to the decision context; such attention to planning should probably assure the most efficient use of resources, as well as affirm the relevance of the risk assessment to decision-makers (NRC 2009).

14.4 Risk Communication as a Facilitator of Risk Management

Risk management combines socioeconomic, political, legal, and scientific approaches to manage risks. Risk assessment information is used in the risk management process to help in deciding how to best protect public health. Thus, essentially, risk assessment provides *information* on the risks—and risk management develops and implements an *action* based on that information. This means that, risk assessment can in principle be carried out objectively, whereas risk management usually involves preferences and attitudes, and should therefore be considered a subjective activity (Seip and Heiberg 1989; NRC 1983; USEPA 1984a, b). The subjectivity of the risk management task calls for the use of very effective facilitator tools/techniques—with good risk communication being the logical choice; risk communication is an interactive process or exchange of information and opinions among interested parties or stakeholders concerning risk, potential risk, or perceived risk.

Risk communication has formally been defined as the process of conveying or transmitting information among interested parties about the following types of issues: levels of health and environmental risks; the significance or meaning of health or environmental risks; and decisions, actions, or policies aimed at managing or controlling health or environmental risks (Cohrssen and Covello 1989). It offers a forum at which various stakeholders discuss the nature, magnitude, significance, or control of risks and related consequences with one another. Effective risk communication is indeed important for the implementation of an effectual risk management program. It is therefore quite important to give adequate consideration to risk communication issues when developing a risk management agenda. As a matter of fact, in many a situation, even credible risk assessment and risk management decisions may never get implemented unless they are effectively communicated to all interested stakeholders. Thus, risk communication should be viewed as rather vital to the risk assessment and risk management processes—and, ultimately, to the success of most risk management actions.

In practice, to be able to design an effectual risk management program, a variety of qualitative issues—such as relates to sound risk communication—become equally important in addition to any prior risk quantification. Risk communication may indeed dictate public perception, and therefore public acceptance of risk management strategies and overall environmental and public health risk management decisions. One paramount goal of risk communication is to improve the agreement between the magnitude of a risk and the public's political and behavioral response to this risk—necessitating researchers to investigate a number of message characteristics and risk communication strategies (Weinstein et al. 1996; Weinstein and Sandman 1993). The process involved provides information to a concerned public about potential health risks from exposure to toxic chemicals or similar environmental hazards. In fact, because the perception of risks often differs widely, risk communication typically requires a somehow perceptive approach, and should involve genuine dialogue (van Leeuwen and Hermens 1995). Among several other factors, trust and credibility are believed to be key determinants in the realization of any risk communication goals. Apparently, defying a negative stereotype is crucial to improving perceptions of trust and credibility (Peters et al. 1997). Anyway, the literature available on the subject addresses several other important elements/issues—including checklists for improving both the process and content of risk communication efforts. Meanwhile, only limited presentation on the risk communication topic is given in this book—with more detailed elaboration/discussions to be found elsewhere in the literature (e.g., Cohrssen and Covello 1989; Covello 1992, 1993; Covello and Allen 1988; Fisher and Johnson 1989; Freudenburg and Pastor 1992; Hance et al. 1990; Kasperson and Stallen 1991; Laird 1989; Leiss 1989; Leiss and Chociolko 1994; Lundgren 1994; Morgan and Lave 1990; NRC 1989a, b; Pedersen 1989; Peters et al. 1997; Renn 1992; Silk and Kent 1995; Slovic 1993; van Leeuwen and Hermens 1995; Vaughan 1995; Weinstein et al. 1996; Weinstein and Sandman 1993).

14.4.1 Designing an Effectual Risk Communication Program

Several rules and guidelines have been suggested/proposed to facilitate effective risk communication (e.g., Cohrssen and Covello 1989; Covello and Allen 1988)—albeit there are no easy prescriptions *per se*. In fact, it is very important that risk communication should consider and embrace several important elements (Box 14.1)—in order to minimize or even prevent suspicion/outrage from a usually cynical public. Thoughtful consideration of the relevant elements should generally help move a potentially charged atmosphere to a responsible one, and one of cooperation and dialog. Ultimately, a proactive, planned program of risk communication will—at the very least—usually place the intended message in the public eye in advance of negative publicity and sensational media headlines. Under all circumstances, a reliable tool and channel of communication should be identified to ensure effective and timely transmittal of all relevant information. Overall, a systematic evaluation using structured decision methods—such as the use of the event tree approach (see, e.g., Asante-Duah 1998)—can greatly help in this direction. The event tree illustrates the cause and effect ordering of event scenarios, with each event being shown by a branch of the event tree in the context of the decision problem. The event tree model structure can indeed aid risk communicators in improving the quality and effectiveness of their performance and presentations.

Box 14.1 Important Strategic Considerations in Developing an Effective Risk Communication Program

- Accept and involve the public as a legitimate partner—especially all parties that have an interest or direct stake in the particular risk situation.
- Involve all stakeholders as early as possible—via taking a proactive stance, based on a coherent strategy, sound tactics, and careful planning of community relations and actions.
- Listen to your audience—recognizing communication is a two-way activity, and take note of the public's specific concerns.
- Ensure an effective two-way discourse/dialogue, to ensure adequate flow of information in both directions between the risk communication team and the interested public/parties. That is, flow of information should be from, and to all stakeholders.
- Be honest, frank, and open—since lost trust and credibility are almost impossible to regain.
- Focus should be on what the risks are, and what is already being done to keep these risks as low as reasonably possible.

(continued)

Box 14.1 (continued)

- Have an even greater focus on long-term implication of risk management decisions/strategies, without necessarily discounting potential short-term consequences.
- Have an elaborate evaluation of alternative choice of proposed risk management strategies.
- Anticipate or investigate the affected party's likely perception to the prevailing or expected risks, since this could be central to any response to proposed actions or risk management strategies.
- Speak clearly and with compassion—especially minimizing excessive use of technical language and jargon.
- Avoid use of unnecessary jargon and excessive technical details, in order to allow the community to focus on the real/practical issues of interest to the PARs.
- Anticipate controversy, request for changes to proposed risk management plans, and then offer positive response that may form a basis for consensus between all stakeholders.
- Keep the needs and perceptions of the 'outsider' stakeholders in perspective, to ensure a balanced and equitable program needs.
- Focus more on psychological needs of community, rather than economic realities/interests of project.
- Plan carefully and evaluate performance—to help re-focus, if necessary.
- Coordinate and collaborate with other credible sources—such as by issuing communication jointly with other trustworthy sources like credible university scientists, area physicians, trusted local officials, and opinion leaders.
- Meet the needs of the media—recognizing that they tend to play a critical role in setting agendas and determining outcomes.
- Clarify who the risk assessment protects—i.e., the community and/or stakeholders.
- Identify potentially overlooked stakeholder project knowledge—and incorporate such useful information in the overall strategic plan.
- Give credit for stakeholder roles and contributions in a decision—also explaining how and why stakeholder input has or has not been used in the process.

Ultimately, scientific information about health and environmental risks is generally communicated to the public through a variety of channels—ranging from warning labels on consumer products to public meetings/forums involving representatives from government, industry, the media, the populations potentially at risk, and other sectors of the general public (Cohrssen and Covello 1989). Important traditional techniques of risk communication usually consist of community public health education programs, 'fact sheets', newsletters, public notices, workshops, focus groups, public meetings, and similar forum types—all of which seem to work very well if rightly implemented or utilized. Anyhow, irrespective of the approach or technique adopted, however, it must be acknowledged that hazard perception and risk thresholds tend to be quite different in different parts of the world—and maybe, at times, even between different communities within the same region, etc. In fact, there could also be variations within different sectors of a community or society within the same locale or region. Even so, such variances should not affect the general design principles when one is developing a risk communication program.

14.5 The Use of Contemporary Risk Mapping Tools: GIS in Public Health Risk Management Applications

A Geographic Information System (GIS) is a computer-based tool used to capture, manipulate, process, and display spatial or geo-referenced data (Bernhardsen 1992; Gattrell and Loytonen 1998; Goodchild et al. 1993, 1996). It is a tool that can serve a wide range of research and surveillance purposes; it allows the layering of health, demographic, environmental and other traditional data sources to be analyzed by their location on the earth's surface. Indeed, the GIS technology has become an important tool for public health professionals—as this generally allows for the efficacious mapping and analysis of public health and environmental management data.

It is apparent that, recent advances in the application of GIS technology have significantly improved, and will continue to revolutionize the spatial analysis of diseases, environmental contamination, and social/demographic information. In a way, the unlimited future of GIS in public health risk management is derived from comparable situations from centuries ago, whereby public health surveillance activities by health professionals have relied on maps to locate and identify changes in patterns of human disease. The GIS of today provides a relatively easy tool for overlaying and analyzing disparate data sets that relate to each other by location on the earth's surface. The growing availability of health, demographic, and environmental databases containing local, regional, national, and international information are further propelling major advances in the use of GIS and computer mapping with spatial statistical analyses.

Broadly speaking, understanding and communicating the association between environmental hazards and disease incidence are essential requirements of an effective environmental health policy. For instance, in the United States, routine public health surveillance programs generate massive amounts of information. Environmental monitoring and simulation modeling projects also provide an equally large volume of data. But, due to the lack of a coordinated framework to organize, manage, analyze, and display the data, majority of this information had been poorly utilized in the past. This is one reason why the advances in the geospatial information technologies, such as GIS, have become so very useful in a whole wide range of public health risk management functions.

14.5.1 Utilization of GIS in Public Health Risk Assessment and Environmental Management Programs

Invariably, use of a GIS can allow for the processing of geo-referenced data and provide answers to such questions as relate to the particulars of a given location, the distribution of selected phenomena and their temporal changes, the impact of a specific event, or the relationships and systematic patterns of a region (Bernhardsen 1992). In fact, it has been suggested that, as a planning and policy tool, the GIS technology could be used to 'regionalize' (or perhaps even 'globalize') the risk analysis process—moving it from its traditional focus on a micro-scale (i.e., site-specific problems) to a true macro-scale (e.g., urban or regional risk analysis, comparative risk analysis, risk equity analysis) (D. Rejeski, in Goodchild et al. 1993).

GIS is indeed a rapidly developing technology for handling, analyzing, and modeling geographic information. It is not a source of information *per se*, but only a way to manipulate information. Overall, when the manipulation and presentation of data relates to geographic locations of interest, then our understanding of the real world is enhanced. Example application types for the utilization of GIS in environmental and public health risk management decisions are briefly discussed below.

- *Exposure Assessment of Population Groups*. The exposure assessment of population groups is usually made through the linkage of environmental and health data. However, environmental and exposure data are generally referred to scattered and instantaneous samples, while epidemiological data integrate periods of time within administrative territories. GIS can be used as an organizing tool of health and environmental data sets. For example, in a case for a water supply system, potential health risk in a locality or supply area can be examined via the overlay of information layers containing data on the presence and quality of water supply service vs. the primary georeferenced data such as: the census tract which contains information on the manner of how the household is supplied; the water distribution system; and the water quality data derived from a monitoring program. The population groups potentially at risk can then be identified, and then appropriate corrective actions can subsequently be undertaken.
- *Development of Thematic Map Layers for Risk Management*. By combining population density information with ambient concentrations for a specific chemical ($\mu g/m^3$), and the unit risk factor for that chemical ($risk/\mu g/m^3$), a map showing the risk per unit of population may be produced—that could be used to facilitate risk management decisions.

- *Data Improvement for Source/Pathway Characterization.* It is recognized that, in general, an adequate characterization of the exposure pathways that affect the fate and behavior of risk-inducing agents can help improve risk estimates significantly. Thus, more spatial data could be added to a GIS model to empirically describe the environmental medium and its effects on the distribution or dispersion of risk agents.
- *Community Health and Environmental Assessments.* GIS is an effective tool that can be used by local environmental community health departments to perform health and environmental assessments, improve public access to environmental health information, and increase organizational effectiveness and efficiency. In fact, in the daily work activities required to protect public health and welfare, environmental health departments usually collect large amounts of useful data. Much of this data has a geographic component. These data, while integral to daily environmental health tasks, can have many additional applications—especially as the field of environmental health grows more assessment-oriented. Indeed, a trend for regulatory and public health agencies to track their activities with GIS offers environmental health departments a unique opportunity to join in sharing information while serving the public's interest in health and environmental needs.
- *Potential Risk Cataloging System.* A potential risk cataloging system may be designed to serve as a screening methodology that ranks key areas of concern (e.g., hazardous facilities, industrial sectors, etc.) vis-à-vis multimedia chemical releases, chemical toxicities, and selected demographics of surrounding populations. The system can utilize GIS technologies to display vast quantities of data to assist users in cumulative risk analysis and other decision-making processes. A 'vulnerability index' is used to characterize potentially exposed populations—highlighting those that may be more vulnerable. In this manner, the screening can include population characteristics without using broad assumptions about exposure conditions. The 'chemical release index' and the 'vulnerability index' can then be overlaid to identify potential incidence of highly toxic and large release combinations within areas with relatively high percentage of vulnerable populations, or the like.
- *Characterization and Mapping of Public Health Concerns and Problems Associated with Various Industrial Sectors in a Region.* An important aspect of public health risk management with growing interest relates to the coupling of environmental health data and environmental models with information systems—such as GIS—in order to allow for effectual risk mapping of a study area. GIS can indeed be used to map the location and proximity of risk to identified or selected populations. The GIS can process geo-referenced data and provide answers to such questions as the distribution of selected phenomena and their temporal changes, the impact of a specific event, or the relationships and systematic patterns of a region. In fact, it has been suggested that, as a planning and policy tool, the GIS technology could be used to 'regionalize' a risk analysis process. For the characterization and mapping of public health concerns and problems associated with various industrial sectors, a typical study could consist

of a survey of workers and communities within major industrial bases, and an investigation of the pattern of likely environmental health problems borne by such communities. GIS can then be used to examine the spatial distribution of risks around toxic sources (such as hazardous waste sites or incinerators and smelters). This would incorporate the development of thematic map layers for public health risk management.

- *Design of Risk Reduction Strategies*. Once risks have been mapped using GIS, it may be possible to match estimated risks to risk reduction strategies, and also to delineate spatially, the regions where resources should be invested, as well as the appropriate strategies to adopt for various geographical dichotomies.
- *Utilization in Remediation Planning and Design*. GIS may be used to examine the spatial distribution of risks around toxic sources, such as hazardous waste sites or incinerators and smelters. The ability of GIS to aid in the calculation of volumes, for instance, would allow soil removal and transport costs to be estimated, and for an optimal remedial action decision to be made.
- *Investigation of Risk Equity Assurance Issues*. Considering the fact that the notion of environmental justice, based on an equitable distribution of risks, is emerging as a critical theme in environmental and public health risk decision-making, GIS could become a powerful tool of choice for exploring such risk equity issues. This type of application moves beyond simply calculating risks based on somehow abstract and subjective probabilities, and actually presents comparative analyses for all stakeholders and 'contesting' regions or neighborhoods.

In general, the evaluation of possible exposures to environmental chemicals requires the integration of information from several and various sources.Oftentimes, environmental sampling and chemical exposure data is analyzed to determine the magnitude and extent of contamination and/or human exposures; GIS provides a means of viewing spatial characteristics of such contamination or exposures. As an illustrative example, the sampling data may be overlayed with geographical features such as roads, streams, schools, and census data. During the assessment of possible exposures, a user may define locations of concern (such as areas within a groundwater plume, or areas with contaminated soil) by drawing a polygon. Environmental sampling data contained within the polygon is then summarized, and population characteristics for residents within the polygon are estimated from census data. The user may also define an exposure pathway by tying together the sampling data and population characteristics, along with other information such as the exposure route (e.g., oral ingestion), the period of time over which the exposure occurred, and characteristics of different groups within the exposed population (e.g., the body weight of children). All this information may then be used to estimate exposure doses—and subsequently, the potential for adverse health effects to occur. GIS has indeed proven to be a valuable tool during these types of evaluation. It provides the means to visually assess large quantities of environmental and public health information, and to relate that information to locations where exposures might occur. Overall, the GIS technology provides a way to manage and analyze information—and perhaps even more importantly allows users to visualize information using combinations of different map layers.

14.5.2 The General Role of GIS Applications in Public Health Risk Assessment and Environmental Management Decisions

Every field of environmental and exposure modeling is increasingly using spatially distributed approaches, and the use of GIS methods will likely become even more widespread. Notwithstanding, it is noteworthy that models lacking a spatial component clearly have no significant use for GIS. That said, it is apparent that the specific role of environmental and exposure models integrated with GIS would largely be in their ability to communicate effectively—i.e., via the use of maps as a well-understood and accepted form of information display, as well as by generating a widely accepted and familiar format for the sharing of information (Goodchild et al. 1993). In general, the GIS would describe the spatial environment, and the environmental and risk modeling simulates the functioning of exposure processes (Goodchild et al. 1996). Thus, GIS can serve as a common data and analysis framework for environmental and exposure models. Even so, however, it must be acknowledged that, although linkage of environmental and exposure models with GIS has frequently been encountered in the past, in the majority of the cases, the GIS and environmental/risk models had not been truly integrated—but simply used together (Goodchild et al. 1993). The GIS has often been used as pre-processors to prepare spatially distributed input data, and as post-processors to display and possibly analyze model results further. Compared to maps, however, GIS has the inherent advantage that the data storage and data presentation aspects are separate. Consequently, data may be presented and viewed in a variety of ways.

Finally, it is notable that in typical application scenarios, the GIS will generally form a central framework and integrating component that provides a variety of map types for use in an overall environmental and public health risk management system. Maps or overlays include simple line features (such as residential boundaries) or complex topical maps serving as background for the spatially distributed environmental models. A simple example of such a representation is concentration fields of pollutants from air, groundwater or surface water models stored as grid cell files. Ultimately, the integration of GIS into risk assessment and environmental management programs can generally result in the following particularly important uses for GIS:

- Serves as a tool in environmental and exposure modeling;
- Serves as a tool for hazard, exposure and risk mapping; and
- Serves as a tool for risk communication.

Indeed, exposure analysis as an overlay of sources and receptor represents an almost classical GIS application. After all, GIS have the ability to integrate spatial variables into risk assessment models—yielding maps that are powerful visual tools to communicate risk information (Goodchild et al. 1993). In principle, the conceptual mapping of risk makes it much easier to communicate hazard and risk levels to potentially affected society and other stakeholders.

14.6 The General Nature of Risk Management Programs

The management of chemical exposure problems usually involves competing and contradictory objectives—with the prime objective being to minimize both hazards and risk management action costs under multiple constraints. Typically, once a minimum acceptable and achievable level of protection has been established via hazard assessment, alternative courses of action can be developed that weigh the magnitude of adverse consequences against the cost of risk management actions. Anyhow, in general, reducing hazards would tend to require increasing costs—and cost minimization during hazard abatement will likely leave higher degrees of unmitigated hazards (Fig. 14.6). At the end of the day, a decision is usually made based on the alternative that accomplishes the desired objectives at the least total cost—total cost here being the sum of hazard cost and risk management cost.

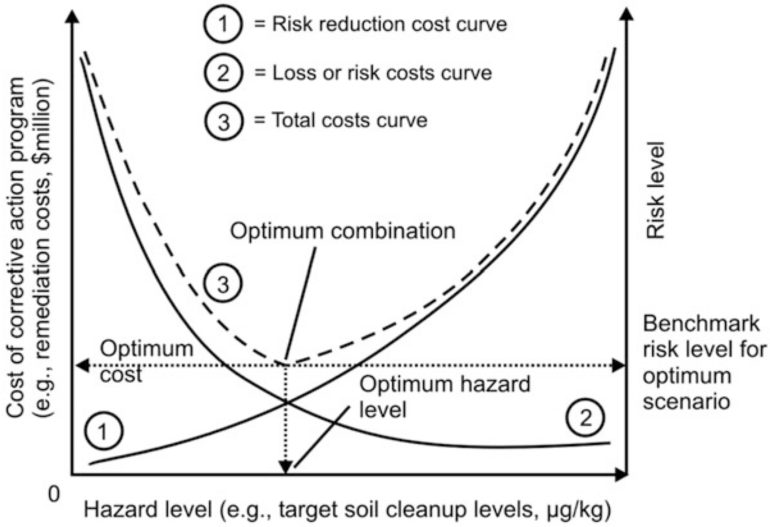

Fig. 14.6 Risk reduction vs. costs: a schematic of corrective action costs (e.g., cleanup or remediation costs) for varying hazard levels (e.g., chemical concentrations in environmental media or residual risk)

Invariably, risk management uses information from hazard analyses and/or risk assessment—along with information about: technical resources; social, economic, and political values; and regulatory control or response options—to determine what actions need to be taken in order to reduce or eliminate a risk. It is comprised of actions evaluated and implemented to help in risk reduction policies, and may indeed include concepts for prioritizing the risks, as well as an evaluation of the costs and benefits of proposed risk reduction programs. Examples of risk management actions that are commonly encountered in environmental and public health risk management programs include:

- Deciding on how much of a chemical a manufacturing company may discharge into a river;
- Deciding on which substances may be handled at a hazardous waste treatment, storage, and disposal facilities (TSDF);
- Deciding on the extent of cleanup warranted at a hazardous waste site;
- Setting general permit levels for discharge, storage, or transport of hazardous materials;
- Establishing levels for air contaminant emissions for air pollution control purposes;
- Determining allowable levels of contamination in drinking water or food;
- Deciding on the use of specific chemicals in manufacturing processes and related industrial activities;
- Determining hazardous waste facility design and operation requirements;
- Consideration of the harmful effect of chemical pollutants that need to be controlled; and
- Determining the relinquished benefits of using a pesticide or other toxic chemical.

In fact, risk management decisions associated with these types of issues are made based on inputs from a prior risk assessment conducted for the applicable case-specific problem. Ultimately, risk assessment results, serving as input to risk management, generally help in the setting of priorities for a variety of chemical exposure problems—further to producing more efficient and consistent risk reduction policies. Risk management does indeed provide a context for balanced analysis and decision-making—with public health risk management programs generally designed with the goal to minimize potential negative impacts associated with chemical exposure problems.