BHOPAL DISASTER AND RISK ANALYSIS: THE SIGNIFICANCE OF THE BHOPAL DISASTER TO RISK ANALYSIS AT ANY OTHER CHEMICAL PLANT (SAFETY EXPENDITURE WITH CAPITAL RATIONING)

Ernest V. Anderson

Probabilities, Utilities and Risks
Sun City West, Arizona 85375

ABSTRACT

Current frequency of chemical plant incidents involving the public my average one every ten years for a fifty man department (one every million man hours.) Prior to Bhopal these resulted in from 1 to 400 complaints per incident with visits to a first aid station the most common reaction. What guides should now be applied to such exposures?

Self regualtion of loss exposures has limitations due to ignorance, poverty and self deception. Effective safety measures require both minimum and maximum cost levels on money. Synergism between small exposures may require that each of us consider the implications of others following our safety guides and lowers the allowable level of imposed risk.

KEY WORDS: Bhopal, Negligible-risk, Safe-enough, Stopping-rules, Externalities, Synergism, Acceptable-risk-imposition.

OBJECTIVES OF THIS PAPER

The objectives of this paper are to increase public understanding of some principles that have been useful in the field of loss prevention with insured risks and with self-insured risks, and to suggest that self-regulation of the chemical industry while necessary is in three (3) particular cases not sufficient to prevent material and human loss.

PUBLIC UNDERSTANDING

PUBLIC UNDERSTANDING is pertinent to any discussion of risk analysis. Indeed, the words "public" and "understanding" each have implications for decision-making.

UNDERSTANDING is risk analysis is achieved when any concerned citizen would act with the same sense of urgency or caution as the person who gives a warning or conveys relevant information. Of course, there can be disagreements about safety decisions--and I will say more about that--but if there is UNDERSTANDING, both parties will appreciate <u>why</u>, <u>how</u>, or <u>what</u> they are evaluating differently.

The other part of PUBLIC UNDERSTANDING--the PUBLIC-- is too often

used in condescending manner. The public is the same person you see in the mirror or across the breakfast table. It includes legislators, State or Federal regulators, medical and academic opinion makers, consumers, producers, employees, retirees, and children. We all live on Spaceship Earth.

NEGLIGIBLE RISK

Perhaps the easiest point to make is that zero concentration, zero exposure, and zero risk do not exist. ZERO may be a shorthand term for 10-6, or even one part per million, but the only meaning to attach to a comment that there is "zero risk" is that the risk is negligible, too inconsequential to bother with, and simply not worth the cost of measuring.

Note that a negligible risk may still present a very small chance of a very large loss. Crossing the street or standing on the sidewalk both have such a risk from a car out of control. If the chance that the driver of the oncoming car has lost control is one in a thousand million, and my injury is valued at one million dollars, the resultant expected loss is one tenth of a cent. My worry about this problem with 1000 cars per hour passing my corner may save a dollar's worth of expected loss but will certainly drive me to an insane asylum or cost me more than that in wasted time. Erich Fromm's observations on neurotic worry are pertinent. (See highlighted box.)

RISK AND NEUROSIS

In the popular press, safety messages on risk-adverse and risk-purpose usually are slanted to praise the cautious individual. To even the balance, the following quotes by the eminent psychoanalyst Erich Fromm from an article in the New York Times of 11 December 1975 are instructive:

"If someone will not touch a doorknob because he might catch a dangerous bacillus, we call this person neurotic or his behaviour irrational.

"Normal thinking is based on the belief in a greater or lessor degree of probability. Paranoid-like thinking is based on the assumption of a logical possibility and wants to have absolute certainty that something could not happen even in the most remote circumstances.

"In individual life we know the irrationality of people who strive for absolute security--people such as hypochondriacs who spend most of their energy protecting their health, or overcautious people who avoid any risk because it could interfere with their craving for absolute security. "This craving is irrational (1) because there is no absolute security in life, (2) because once it is established as the dominant goal there is no limit to the means sought for to reach this goal, (3) because in the search for this goal the person cripples himself and loses all pleasure in living. In fact the chase after absolute security is a boomerang: it creates more insecurity than it avoids.

"A goal of absolute security is equally damaging when it dominates government policy. Economically it impoverishes us, politically it restricts freedom, psychologically it creates fear and apathy."

"Negligible risk should be tolerated, and severe risk should be reduced until the avoidable residual risk costs (loss-cost plus) risk-cost plus present value of ongoing control-costs imposed on others) are negligible." Note unavoidable costs or risks are compared with the benefits of an activity in determining if the activity should be undertaken at all but have no bearing on control costs if the word unavoidable is correct.

It may be the case that the marginal reduction in the risk imposed has been reduced to the marginal cost of the last safety action and the totals are still above an accepted negligible level. Any continued expenditure by the firm is in effect valuing risk at a higher level than the public and requiring them to pay this higher rate if they wish the product. (Everyone must buy a station wagon to avoid the compact car risk.) It seems more beneficial to publicize the risk questions involved and make both products available so the public may choose.

The key question is not: Should the cost of correction limit the actions taken? Rather, the key question is: What values or trade offs are used to factor in such intangibles as. the importance of livelihood to an employee, of a life to each of us, or of the freedom of the jungle versus the security of the zoo!

Some will deny that a life can be valued; but every safety decision implies a hidden value, and it is better that it be in the open than hidden in a computer. In this century, the changes in society's valuation of a life can be illustrated by the Workers Compensation awards for a death. These awards have risen 10% per year from $1000 to a current maximum of about $1,000,000. This is about 50 times greater than the 20 fold increase in annual wages and 100 times the increase in cost of living. As Aaron Wildavsky says: "Richer is Safer."[1] or as I would say it: "Poverty Compels Risk Taking."

EFFECTIVE SAFETY EXPENDITURES

The willingness of any community to spend thousands of dollars to rescue a child who has fallen into a well is an another example of societal values. The limit in this case is the number of workers who can be effective in the rescue, not the dollar cost. In many industrial situations and government programs you will find that safety expenditure is limited by the lack of opportunities for effective expenditure as much, or as often, as by lack of financial resources or ignorance. The key work in this safety decision theory is "effective." A remedy is effective when the reduction in expected loss-cost is more than the expenditure.

Even if this is not the case, the remedy may still be supported by some in order to shift wealth or to reduce their burden by changing the price of this or that commodity or service. A remedy also may be a marketing or political ploy to appear to be taking "decisive" action, one, that might not be justifiable on the basis of risk alone.

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[1]Aaron Wildavsky, "Richer is Safer...," the Public Interest 60, 23-30 1980.

You will note that greed or lack of empathy is not included as a major cause of inadequate safety. The reasoning is that self-interest in these litigious times makes it more profitable to prevent than to pay for injury to others. The point you must not forget is that the trial lawyers association and the courts, not Congress or the regulating agencies are setting safety standards in today's society.

When a risk is appreciable but no effective remedy is known there is a need for further study. The hardest problems may require us to go back to the beginning. There may be equally efficacious but less hazardous alternative products or processes available. The question of when to replace existing facilities or product lines must be considered at least annually; and also upon any significant change in information. The latter, of course, includes loss history: both your own and that of your competitors. One of the few advantages of the growth of conglomerates is that it is easier for them to make a decision in favor of change.[2]

HOW SAFE IS SAFE ENOUGH?

Two paragraphs on risk in the field of product liability from the National Business Council for Consumer Affairs are also applicable to environmental risk and to employee risk:

> "Risks of bodily harm are not unreasonable when consumers understand that risks exist, can appraise their probability and severity, know how to cope with them, and voluntarily accept them to get benefits that could not be obtained in less risky ways. When there is a risk of this character, consumers have reasonable opportunity to protect themselves; and public authorities should hesitate to substitute their value judgments about the desirability of the risk for those of the consumers who choose to incur it.
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> But preventable risk is not reasonable (a) when consumers do not know that it exist; or (b) when though aware of it, consumers are unable to estimate its frequency and severity; or (c) when consumers do not know how to cope with it, and hence are likely to incur harm unnecessarily; or (d) when risk is unnecessary in that it could be reduced or eliminated at a cost in money or in the performance of the product that consumers would willingly incur if they knew the facts and were given the choice."[3]

And as Ralph Nader says: "The burden of proof rests on the party that

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[2]See George Terborgh, Dynamic Equipment Policy, McGraw Hill 1949 and Daniel Goldman, "Following the Leader," Science 85 (October): 18, 20.

[3]National Business Council for Consumer Affairs, Action Guide Lines, (date?) p. 218.

initiates the risk, that profits from the risk, and that has the greatest resources to do something about the risk."[4]

If the enternalities are going to be internalized by the courts, self-regulation will tend to become automatic. Another factor promoting self control is that internal plant loss may be much greater than loss outside the fence. The 1979 Three Mile Island nuclear loss, for example, affected the public only via mental uncertainty and travel costs. Yet the cost to shareholders of nuclear utilities has run into the tens of billions. For nuclear as for many other risks, the cost to the initiator is many times that to the public. I would argue that this market incentive for self-regulation is more efficient, effective, and reliable than governmental regulation.

Unfortunately it does not follow that one can do without the latter. There are at least three broad catagories of circumstances where self regulation is wanting. One, the more easily corrected of the three is ignorance. If I the chief executive do not know of the failings or shortcomings in safety practices at the plant they may continue until disaster strikes. Or if I do not appreciate the risk and lack knowledge of the long range effects of chemical (X) or of its synergistic combinations with the life style of the neighborhood; I may condone the storage of large quantities etc.

The second class of circumstances where self regulation may fail are characterized by Poverty. I have bought less than adequate equipment, my wage scale keeps only the least capable workers or supervisors and profits are so questionable that continued operation for any length of time is doubtful. A false claim of inability to pay is always possible but refusal to pay is more often based on exaggerated cost estimates or remedies and minimization of benefit estimates than on claims of poverty. Note that the claim awards and punative damage awards make such tactics a very poor strategy.

The final case is - Self Deception. All parties involved, managers, supervisors and workers may know better but there is a tacit agreement not to rock the boat or raise embarrassing questions. (See the discussion pages 18 & 20 in the October issue of Science 85 by Daniel Goldman)

The answers to ignorance, proverty and self deception are not found at this conference but one can hope that a culture or climate which fosters open discussion of risks and requires a periodic assessment by the risk creator of the hazards and remedies available can reduce the shortcomings of self regulation to that level where outsiders be they government regulators, environmental groups or the insurers of the plant can cope with the risks that are left.

SAFETY EXPENDITURES WITH CAPITAL RATIONING

The general rule is that any improvement where the expenditure is less than the present value of the benefit by reduction in future losses ought to be made. However, where there are multiple candidates which pass

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[4]Ralph Nader, "Professional Responsibility Revisited," from the Proceedings of the Conference on Science, Technology, and the Public Interest held by the Brookings Institution in Washington, D.C., on 8 October 1973.

this screen or where there are insufficient funds to undertake the desired action further guides are needed. One such guide is a list of procedures to be followed in this less than perfect world for employment, environmental and product hazards.

When ever a known risk, or one which should be known, is imposed by A on B the first act must be disclosure of all the facts known by A. The second should be education of B so that an informed consent can be given, to any agreed upon continuation. When, as in the recent airline union negotiations, there is understanding by the second party that continued employment for enjoyment of some benefit) requires acceptance of a wage cut (or of some other hazard), he or she will elect that option with the minimum risk or maximum benefit. However; the understanding must result in a conviction strong enough to support the required action.

The major disagreements arise from the unwillingness of one side to permit the other to make any contribution in the decision process. In almost all cases both parties at a round table could agree on what is needed and what must be postponed to a more affluent year but neither is willing to abide by the others' unilateral decision. Thus even though the EPA may write the rules for Air Pollutant control, they will have difficulty in accepting a solution which is cost effective for plant A and its stakeholders in the community.

Similar problems arose with the "Pinto" gas tank. In the calculation of the cost of change, who is the customer who approves the trade off. The product safety design guide does not require each car to have the crash resistance of the M1 Tank but it is expected to meet or surpass the standards of a similar product now in use. Since this would never permit any reduction in safety an alternative test is that a buyer fully informed would rather bear the risk than spend the money to have the hazard reduced to a lower level.

But we are still left with the problem of the marginal producer or employer. Should a safety requirement drive him out of business or do the sunk costs and benefits of the ongoing operation offset some possible temporary externalities. Remember we are talking about continuation with full disclosure so there is willing acceptance by the stakeholders - the employees, the neighbors, the customers and the investors. Those who were unwilling have been (or could have been) compensated with the consent of the creditors and of the remaining stakeholders. It is an axiom of a free society that one can elect a course of action which does not interfere with the rights of others and when the continuation aids the lowest income group among the stakeholders not just the pockets of the owners it is presumptious of the crusader to say safety first. The argument that this or that hazard should not be permitted here or overseas is most often made by those yong idealists who would not accept their own parents' advice on risks involving only their own amusement but still have the arrogance to constrain others on the essential of a livelihood or food and shelter.

The Indian acceptance of the hazard at Bhopal was partly ignorance of the magnitude of the possible accident but also the result of their much larger risk of starvation à la Ethopia. Just as DDT is banned in the US and necessary elsewhere, the herbicides and pesticides can perform their needed work to feed the starving if we only learn to manage the inevitable risks of "Living."

To say that a plant should be isolated from a large city to reduce the exposure ignores the transportation problem for workers without cars while the partial remedy of buses operated by the plant does not prevent

the movement of squatters to the fence line as occurred in the El Paso lead pollution problem.

STOPPING RULES

The rule that a risk imposed on others must be negligible is not sufficient for reasons related to the Tragedy of the Commons. If you as one of the 5000 drivers in your town were to compute the cost of the added accident risk to a single one of your 10,000 neighbors for the first or should I say the last time you failed to stop at a traffic light or exceeded the posted speed to beat the light change, the amount is undoubtedly negligible. Let us suppose it is one ten thousandth of a penny to each of your neighbors or one cent added third party liability to you. This may also be an approximation of the direct injury risk to yourself. (You are definitely at the scene of your unsafe driving practices.)

But his number is multiplied by the 100,000 intersections you pass in a year and by 5000 to compute an annual cost in just your town, IF YOU GRANT EACH OTHER DRIVER THE RIGHT TO DO AS YOU DO. Adding up the costs in each of 20,000 other neighborhoods makes the countrywide total ten billion dollars for even a one cent estimate on a single unsafe practice.

Moreover; the above calculating omits the synergistic effects found in multiple exposures, that is the compounding of risk that will result as more than one driver fails to stop at intersections (or more than one factory fails to limit stack emissions). It is thus an understatement of the costs of a negligible risk change. While such multiplication was most prominent with asbestos and smoking, it is the practice in almost all private risk calculus to consider current life styles as constant and project the effects of the proposed action with no other changes. The problems of synergism are incorrectly left to EPA and Congress. The moral obligation to act only as you would permit all others to act has particular significance when repetition of an act (N) times does much more than (N) times the societal injury (or yield more than N times the advantage to others).[5]

Since the (N) in the case of the U.S. population is of the order of 100,000,000 working adults or car drivers or families, the argument is that one should consider the repetition of your proposed action this number of times and weigh the consequences from the multiple interactions of that many repetitions.

As discussed above in the case of the speeding auto driver, whenever the interaction of two acts leads to greater loss (2 drivers fail to slow up at the same intersection) the total social cost will increase exponentially and all of us have a moral obligation to avoid this overloading of the commons and increasing of the risk load on the common man.

In the attached list of often overlooked costs involved in low probability-high consequence events a fair estimate of the cost from each

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[5] See pages 272-275 "Foundations of Inductive Logic" by Roy Harrod Harcourt, Brace and Company 1956-7. This book has also the best discussion of probability I have ever read.

item may be 2PL. (Where P is the probability of exceeding loss size L.) However; if there are interactions of this type, between the costs of my taking this action and everyone else following suit the cost of externalities will exceed the sum of all others.

All of the above should be combined with the following new postulate. (An axiom that can only be justified by the utility of the resultants):

THE ANNUAL EXPECTED PUBLIC COSTS FOR A FACTORY CREATED EXPOSURE SHALL NOT BE GREATER THAN 100 DOLLARS PER EMPLOYEE

If my exposure is reaching 1000 neighbors and I have 50 employees- the imposed risk is $5. per capita per year or 10 cents a week- definitely negligible and more than offset by the reduction in the property tax or other benefits of this operation.

The plant with 20 depts of 50 employees each may split its safety budget to secure the greatest returns by extra care on the hazardous operation. It must be remembered that the overall risk includes product liability as well and that this is a constraint on the maximum risk allowed from the entire operation. Where ever possible the plant will thru its safety, environment and quality depts reduce the outside impact. i.e., when ever an action will cut the expected loss by more than the cost of the action.

The figure of $100 per employee per year as the maximum acceptable expected accident cost for any effect outside the plant fence may also be applicable inside. Certainly many firms have a lower cost today both inside and out. Unfortunately not all and the best measure of the management we can think of is the ratio of their costs on such measures to that of their competitors. Many firms have improved but others over the years fail badly due to self deception, to proverty levels of spending on safety and due to ignorance of the interactions between their acts and those of the rest of society.

SOME MAJOR COSTS OMITTED IN JUDGEING LOW PROBABILITY RISKS

1. Expected Loss when (P) is the annual probability of exceeding loss size (L), is in the range 4PL to 8PL per year or 40 to 80PL per lifetime.
2. Disutility of large loss up to 95% of current wealth (W) has an equivalent utility value of approximately 3PL per year or 30 per lifetime.
3. Regret cost equals the value of perfect information, of always making the right decision. Might also be called reputation cost.
4. Sunk costs of other unusable investments if the event occurs.
5. Liquidity cost of reserves equal to the maximum possible loss.
6. Criminal liability for wrong or injury done to society.
7. Cost of frequency reduction measures.
8. Cost of severity reduction measures both by you and by others.
9. Cost of risk management: analysis, implementation, audit and insurance carriers overhead.
10. cost of information acquisition and of experimentation.
11. Externalities including those which will be transferred back by the courts.
12. Reversibility costs if we decide we don't want this risk.
13. Duration costs; how long do we bear this risk?
14. Costs of uncertainties in the values of the parameters and in our future risk portfolio.
15. UNKNOWN UNKNOWNS.

ENHANCING RISK MANAGEMENT BY FOCUSING ON THE LOCAL LEVEL: AN INTEGRATED APPROACH*

June Fessenden-Raden,** Carole A. Bisogni*** and Keith S. Porter****

Cornell University
Ithaca, New York

ABSTRACT

An integrated approach to risk management that focuses on the local level will lead to a more satisfactory and timely resolution of localized risk situations such as chemical contamination of groundwater that serves as a source of drinking water. More importantly this approach will result in additional positive long-range effects -- increased local capabilities to deal with future chemical risk problems and improved prevention of some types of chemical contamination of groundwater. Conceptualizing the management of risks as having inputs (the risk situation, laws and policies, technical context, and community context), process, and outcomes illustrates that neither outside intervenors nor the local community should approach a risk situation without regard for all of the inputs or without understanding the dynamics of the process of managing risks at the local level.

KEY WORDS: Risk management, community response, groundwater chemical contamination, drinking water quality

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** Associate Professor of Biochemistry and Biology & Society, Program on Science, Technology, and Society, Division of Biological Sciences, Institute of Comparative and Environmental Toxicology.

*** Associate Professor of Nutritional Sciences, Division of Nutritional Sciences, Institute of Comparative and Environmental Toxicology.

**** Associate Director, Water Resources Institute, Center for Environmental Research.

INTRODUCTION

On the occasion of receiving the Society for Risk Analysis distinguished contribution award last year, Chauncey Starr (1985) suggested that the operations established for the management of risk were as important as the quantitative description derived from the risk. In our research on chemically contaminated groundwater, we have seen that risk management approaches designed far away from the risk locale have too often resulted in unsatisfactory outcomes from the perspectives of both the community and the risk managers. Our results suggest that the management of risk might be enhanced in terms of both the short-term and long-range effectiveness by taking an integrated, multidisciplinary approach and by focusing on the local level. We consider a successful outcome to be one that not only resolves the particular risk situation, but also provides for increased community competence to prevent and, as needed, to respond to any future chemical contamination problems. An example of prevention would be the establishment of groundwater protection programs, (e.g., establishing aquifer protection zones). We suggest that risk management planners and implementers need to utilize more multidisciplinary, integrated approaches and increase their sensitivity to the local community at risk.

When considering risk management operations that could be enhanced by focusing on the local level, groundwater chemical contamination problems serve as a highly illustrative paradigm. Groundwater contamination can result from a multiplicity of causes and human activities. To successfully deal with these problems, an involvement of many disciplines is necessary. Also, the adoption and implementation of any solution often requires the collective efforts of individuals, communities, industries and government agencies.

In this series of papers different members of our research group will illustrate the importance of considering several aspects of risk management: (1) integration of dimensions of risk management operations, (2) the community context of the risk, and (3) the risk management process itself. The papers reflect our belief that an integrated approach that focuses on the local level could enhance protection of the public health and the environment.

As the introductory paper in the series we first will present brief background information on the chemical contamination of groundwater and associated public health risks. We then will describe a conceptual framework for risk management at the local level, that we have found helpful in our efforts to understand risk management at the local level.

GROUNDWATER, CHEMICAL CONTAMINATION, PUBLIC HEALTH

The water supply for over half of the U.S. population comes from groundwater. In many rural areas, over 95% of residents are dependent on groundwater as an economically irreplaceable source of drinking water. Unfortunately, the purity of groundwater can no longer be assumed. Chemicals contaminate groundwater across the U.S. New risk situations are reported to the public almost daily. More than twenty pesticide residues and hundreds of synthetic organic chemicals have been found in public and private drinking water supplies from groundwater. The length of time and full extent of such contamination is unknown.

Chemical contamination of groundwater is often a localized problem, and contaminants may come from multiple sources -- underground storage

Table 1

Attitudes Toward Additional Pollution Controls

	Support additional controls (no mention of closure)			Support additional control (if closure might result)		
	Yes	No	Don't Know	Yes	No	Don't Know
Hearing	58%	34%	8%	51%	42%	7%
Phone	40%	29%	30%	32%	47%	21%

Table 2

Correlation With Risk Tolerance

Item	Pearson r*
Harmful effects vs benefits of smelter	.863
Do you think the smelter is a health hazard	.818
"Real risks" (in S's judgement) are higher or lower than EPA estimates	.807
Personal immunity to cancer caused by ASARCO emissions	525
Voluntarines of exposure to ASARCO emissions	.470
Should standards be based on affordability	.454
Personal immunity to general environmentally caused cancer	.387
Agencies should not wait for certainty before acting to reduce risks	.386
Costs versus benefits of pollution controls in general	.374

*All correlations presented are significant at less than the .001 level.

Table 3

Results of Factual Knowledge Questions
for Hearing Respondents

	Risk Estimate Question		Regulation Question	
	Correct	Incorrect[1]	Correct	Incorrect
Less Risk Tolerant	62%	38%	47%	53%
More Risk Tolerant	41%	59%	26%	74%
Overall Percentage	52%	48%	37%	63%

1. Percentages cited as incorrect include those who gave incorrect answers as well as those who did not answer or selected the Don't Know response option.

2. Chi square analyses reveal the differences between MT and LT groups to be significant at less than the .001 level for both questions.

Table 4

Risk Decision Aspects Used in Item Generation

- Risk
  - Mortality
    - Self
    - Others
      - General Public
      - Workers
      - Future generations
  - Morbidity
    - Self
    - Others
      - General Public
      - Workers
      - Future generations
  - Knowledge of hazard
    - Self
    - Science and government
  - Dread of hazard
    - Self
    - Others
- Benefits
  - Economic
    - Self
    - Others
  - Non-economic
    - Self
    - Others
- Costs
  - Property damage
  - Income loss
- Environmental effects
  - Plants and animals
  - Non-living environment

tanks, hazardous wastes, sanitary landfills, fertilizers and pesticides, mining wastes, household cleaning agents, leaking public sewage systems and private septic systems, chemical spills, even highway deicing salt. Just one aspect of the potential problem, leaking underground storage tanks, is illustrated by some figures in upstate New York. Of the more than 120,000 underground fuel storage tanks, 20% or 24,000 currently are believed to be leaking. Nationwide there may be as many as 200,000 leaking underground storage tanks.

Because of its complexity, once groundwater is contaminated, it is both technologically difficult and very expensive to decontaminate. Chemical contaminants in groundwater move anywhere from inches to feet per year. They move in plumes with only limited dilution from the point of application to discharge. The amount and concentration of the contaminant in the groundwater, as well as the time it takes for the contaminant to get to the saturated water zone or aquifer, depends on the intrinsic properties of the chemical, the subsurface soil, and the amount and distribution of precipitation in the aquifer recharge area. For example, in Minnesota, arsenic used as a pesticide in the 1930's is only now showing up in the groundwater (Steenhuis, 1985). On the other hand, aldicarb pesticide residue was found in Long Island groundwater within four years of the pesticide's first use (Pacenka and Porter, 1987).

The health effects from drinking, cooking with, and bathing in chemically contaminated water generally are unknown. At the concentrations commonly found in groundwater many chemicals may pose little or no health threat. Others such as toluene, trichloroethylene and tetrachloroethane may cause immediate or acute health effects such as skin rashes, dizziness, headaches, even heart arrhythmias. In addition, chemicals may pose risks of chronic health problems such as cancer, or neurological, immunological and reproductive dysfunctions. Any health risk is dependent not only on the properties of the chemicals and the conditions of the exposure, but also on the exposure to other chemicals, individual susceptibility and lifestyle. The risk to the health of any single individual is just not known. Toxicologists can, at best, with much uncertainty, estimate the risk to some statistically healthy population.

AN INTEGRATED APPROACH TO RISK MANAGEMENT

Over the past five years our interdisciplinary project at Cornell has been considering the problems of management of risks at the local level associated with chemically contaminated groundwater used as a source of drinking water. We have as our overall goal the expansion of risk management capabilities of communities and individuals with respect to groundwater and chemical contamination. Our multidisciplinary research team is utilizing its diverse expertise to study non-metropolitan communities, primarily in New York State (Lemley, et al., 1985; Hughes, et al., 1982; Fitchen, et al., forthcoming). In these communities we are looking into such factors as: the environmental fate of the chemical, the hydrogeological features of the area, evaluation of potential health risks, the community's level of knowledge about the contaminated water situation, and the decisions and responses of individuals and institutional factors.

The conceptual framework we have used to study the management of risks from chemically contaminated groundwater was adapted from the nutrition communication model of Gillespie and Yarbrough (1984). Shown in Figure 1, this conceptual framework has been useful in identifying various

Table 5

Risk Decision Variables Included in Analysis

Endogenous variables

- Risk
  - ASARCO
    - Mortality/morbidity: Self
    - Mortality/morbidity: Other
  - Earthquake
    - Mortality/morbidity: All
- Benefits
  - ASARCO
    - Benefits: All
  - Earthquake
    - Benefits: Economic
    - Benefits: Non-economic
- Information seeking
  - (Same for both hazards)
- Risk mitigation/reduction
  - (Same for both hazards)

Exogenous variables

- Scientific background
- Attitude toward science/technology
- Attitude toward government
- Concern in hazard information

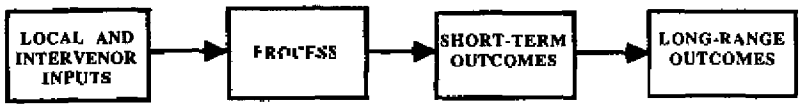

Figure 1

Risk Management

aspects of risk management that are critical to optimal resolution of a situation and in need of more attention from both researchers and the public policy makers.

According to our conceptual framework, the management of risks at the local level has three major components: inputs, process, and outcomes. The inputs include (1) the characteristics of the actual risk situation such as the nature of the chemical and the number of people or wells affected; (2) the laws and policies invoked by that risk situation, and (3) the technical context such as the technological options and limitations for treating the contaminants. To resolve groundwater contamination problems, expertise from a variety of disciplines is needed. However, few technical experts have the full complement of knowledge, skills, and experience in all of the technical areas needed to address groundwater contamination problems. Thus, a variety of technical experts are often involved. Our studies have shown that integration is needed among the technical experts including engineers, toxicologists and hydrogeologists.

Our studies indicate that a second type of integration also is needed in risk management -- integration between the technical and human dimensions of the problem. This series of papers will focus on the need to recognize the human dimension of risk management and actively incorporate this dimension into risk management. Risk managers must be sensitive to the local community context of the risk situation such as economics, demographics, community attitudes, beliefs and values and socio-political institutions.[1] We have seen that intervenors have often ignored this input entirely.

Janet Fitchen, a cultural anthropologist, in the next paper will present research that supports our contention that local response to the risk and the risk management process is shaped by the local context. Fitchen's paper examines the dynamics of the interactions between risk management and the community. She identifies ten local context factors that appear most important in shaping community response. Since local response will affect both short-term and long-range effectiveness of risk management, it is argued that risk management planners and implementers need to pay more attention to the local community context (Fitchen, 1986).

Inputs are brought to the risk management process by outside

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[1]For the purpose of our research we have defined community as the local population and its local institutions involved or affected by the risk and its management.

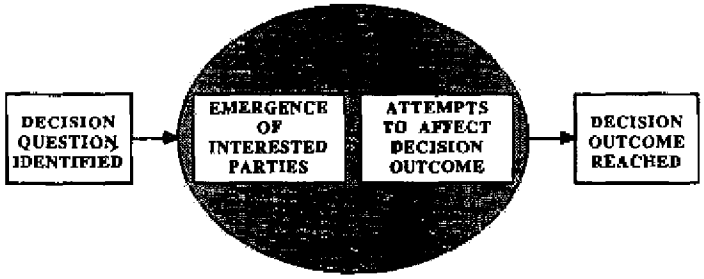

Figure 2

The Process

intervenors and local people. Outside intervenors are defined as technical experts or representatives of institutions that are involved with the community because of their technical expertise or statutory authority. These intervenors include, but are not limited to, engineers, regulators, lawyers, educators, toxicologists, and public health specialists. They provide technical input into the risk management process in terms of their specialized knowledge, skills and experiences. Intervenors also bring beliefs, attitudes and values about groundwater, its protection, chemical risks, regulations, other technical experts and the community at risk. Intervenor inputs affect how intervenors (1) relate to the community and other intervenors, (2) are perceived by the community and other intervenors, and (3) participate in the risk management process. Often we have found intervenors enter a risk management operation with preset options and predetermined strategies that may or may not be applicable to the specific community at risk. The dominant risk management approach seems to be the one-sided intervention of technical experts (e.g., government personnel or consultants) with technological solutions to be implemented in the local community under the direction of the outside intervenor.

The many individuals who live and work in the locality bring another set of critical inputs to the risk management process, regardless of whether or not these inputs are acknowledged by intervenors. Local participants bring a variety of credentialed and non-credentialed expertise to the risk management process such as knowledge about past use of an area, successful local management experience, and local folk wisdom. Unfortunately, intervenors too often ignore such local experience as irrelevant to the management of the risk. Also, local participants bring beliefs, attitudes, and values related to themselves, their community and their risks. How they participate in the risk management process, whether they accept or reject intervenor technical information and advice, and how they will react to the outcome(s) are all affected by these beliefs, attitudes, and values.

Many intervenors seem to believe the locals "can't really understand the situation." Bonney Hughes, a graduate student in environmental toxicology, discusses citizens' knowledge, beliefs, and actions related to chemical contamination of groundwater (Hughes and Bisogni, 1986). One approach to enhanced risk management at the local level is through

increasing the knowledge of local citizens related to groundwater and chemical contamination. However, for educational programs to be effective or meaningful to citizens, educators must consider citizens' existing beliefs, attitudes, and practices.

Our research shows that regardless of the beliefs of intervenors, local citizens do provide critical inputs and do contribute to the effectiveness of risk management. Management of risks from chemically contaminated groundwater is not conducted exclusively by federal or state governments, but involves inputs from all governmental levels and the private sector. While the risk management processes at the local level vary across the more than a dozen communities that we have studied, we suggest that some features are common. The risk management process is dynamic. It is interactive involving many decisions spread out over time. The process also is iterative. The results in a number of intermediate or short-term outcomes can feedback to influence both concurrent and future decision-making as well as the inputs of the intervenors and the local participants.

Jenifer Heath, a graduate student in environmental toxicology, has focused specifically on the interactive nature of the risk management process. Some details of the process identified as important in influencing short-term and long-range risk management effectiveness are presented in the third paper in this series (Heath and Fessenden-Raden, 1986).

The final paper in this series is by Hank Hughes, a water resource specialist. He will provide evidence that intervenors can work with communities in productive ways in which each learn (Hughes, 1986). In each project, members of the community have worked with the Water Resources staff from Cornell in identifying valid options, in evaluating the technical merits of the options and in selecting the preferred options for community implementation.

CONCLUSION

We conceptualize management of risks from chemically contaminated groundwater as involving inputs, process and outcomes. Neither the outside intervenors nor the local community should approach a risk situation without regard for all the inputs or without understanding for the dynamics of the risk management process.

We take the position that the local community is not merely a passive setting within which outside technical experts briefly perform their specialties in the management of a given risk. The community is an interactive setting in which both the risk and the management of the risk are embedded. We contend that to enhance risk management, an integrated, multidisciplinary approach focusing on the local level where the risk is being experienced, is needed. Improved communication and use of scientific and technical information related to chemical contamination of groundwater, public health, and risk assessment is also essential. Technical responses from engineering to health must be better integrated with each other. The technical response as a whole needs to be integrated with the local inputs. For an optimal outcome of any risk management operation, there should be learning by both the intervenors and the local community. The local community should acquire some competence to (1) more readily deal with any future chemical risk problems, and (2) act to prevent such problems as much as is possible. The community should better know where to go for information and help when it is needed. Ideally

Table 6

ASARCO: LISREL Maximum Likelihood Parameter Estimates
(all t-values greater than 2.0)

Dependent Variable	Predictors	R^2	R^2 (Without Hazard Information)	Total Effects of Concern
MMO1	SCI (-0.21), STA (0.20), GOVA (0.33), CON (0.26)	0.25	0.25	0.26
MMS1	MMSI (0.43), STA (0.22	0.28	0.28	0.11
BEN1		0.00	0.00	0.00
MIT1	CON1 (0.43)	0.19	0.00	0.43
INFO1	MIT1 (0.17), CON1 (0.40)	0.25	-	0.48
MMO2	MMO1 (0.46), STA (0.21), CON (0.35)	0.45	0.36	0.46
MMS2	MMS1 (0.16), MMO2 (0.37), INFO2 (0.20)	0.28	0.27	0.29
BEN2	BEN1 (0.63)	0.39	0.39	0.00
MIT2	MIT1 (0.40), CON2 (0.42)	0.36	0.27	0.60
INFO2	MMS1 (0.26), CON2 (0.45)	0.27	-	0.48
MMO3	MMO1 (0.25), MMO2 (0.59), INFO3 (0.24)	0.64	0.58	0.47
MMS3	MMS2 (0.53), MMO3 (0.24), CON3 (0.14)	0.46	0.49	0.40
BEN3	BEN1 (0.24), BEN2 (0.46), CON3 (0.25)	0.40	0.40	0.00
MIT3	MIT1 (0.33), MIT2 (0.20), MMO3 (0.24), CON3 (0.25)	0.40	0.36	0.63
INFO3	INFO2 (0.38), CON2 (-.28), CON3 (0.63)	0.48	-	0.53

Table 7

Earthquake: LISREL Maximum Likelihood Parameter Estimates
(All t-values greater than 2.0)

Dependent Variable	Predictors	R^2	R^2 (Without Hazard Information)	Total Effects of Concern
MMA1		0.00	0.00	0.00
EBEN1	MMA1 (0.33), GOVA (-0.27)	0.18	0.18	0.00
NBEN1	EBEN1 (0.40)	0.16	0.16	0.00
MIT1	EBEN1 (0.27)	0.08	0.08	0.00
INFO1	COM1 (0.35)	0.12	-	0.35
MMA2	MMA1 (0.59), INFO2 (0.17), CON2 (0.21)	0.50	0.44	0.28
EBEN2	EBEN1 (0.43)	0.18	0.18	0.00
NBEN2	NBEN1 (0.40), MMA2 (0.14), EBEN2 (0.28), INFO2 (0.16)	0.36	0.35	0.11
MIT2	MIT1 (0.45), NBEN2 (0.27)	0.30	0.29	0.03
INFO2	CON2 (0.42)	0.17	-	0.43
MMA3	MMA2 (0.78), CON3 (0.10)	0.62	0.64	0.32
EBEN3	EBEN1 (0.20), EBEN2 (0.28), MMA3 (.12), NBEN3 (0.48)	0.60	0.61	0.10
NBEN3	NBEN2 (0.58), MMA3 (0.20)	0.42	0.46	0.13
MIT3	MIT2 (0.58), NBEN3 (0.20)	0.44	0.44	0.04
INFO3	INFO2 (0.32), CON3 (0.49)	0.40	-	0.52

the long-range impact of a successful risk management operation also would provide for improved intervenor response elsewhere, and perhaps even improved public policy.

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