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Incorporating Risk and Uncertainty into Undergraduate Environmental Engineering Curricula

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Incorporating Risk into undergraduate Environmental Engineering Curricula

Introduction

Analysis of risk and uncertainty are important components in undergraduate environmental engineering curricula. Including the topic of risk and uncertainty can be interpreted differently and covered in a variety of approaches across curricula. There are several external and internal mechanisms environmental programs use to develop program and course outcomes. In general, the ABET Environmental Engineering Program Criteria, American Academy of Environmental Engineers and Scientists (AAEES) Body of Knowledge (BOK), Fundamentals of Engineering Examination (FEE) specification, direct guidance from constituents and Board of Advisors (BOA), and the professional judgment of faculty are all valid approaches to determine the relevant topics covered and the required depth of coverage in a curriculum. This paper surveys risk and uncertainty across 18 different courses from ABET accredited programs. A description of how risk and uncertainty are taught within the United States Military Academy's Environmental Engineering program is included. A concept map and proposed lab activities, to expand modeling activities (deterministic and stochastic models), of risk and uncertainty, in an undergraduate hazardous waste management course, is presented.

Background

Environmental Engineering course and curricular design is often based upon the reported knowledge specific to the discipline. The ABET Environmental Engineering Program Criteria, which apply to all accredited engineering programs, states that "the curriculum must prepare graduates to … design environmental engineering systems that include considerations of risk, uncertainty, sustainability, life-cycle principles, and environmental impacts.[1]" Table 1 outlines the AAEES BOK for Outcome #5 (Risk, Reliability, and Uncertainty).[2] This outcome outlines the level of achievement to be attained at the completion of a baccalaureate degree in Environmental Engineering, but is not required for accreditation.

Table 1. BOK Risk Outcomes

BOK Outcome	Level Of Achievement
5.1	Identify potential hazards, exposure pathways and risks to the environment and the public health, welfare and safety associated with exposure to physical, chemical and biological hazards.
5.2	Identify the modes for failure of a system engineered to protect the environment and the public health, welfare and safety and the resulting consequences of such a failure.
5.3	Explain the significance of uncertainties in data and knowledge on the performance and safety of an engineering system.
5.4	Apply the principles of probability and statistics to the design of a simple engineered component using data or knowledge-based uncertainties.
5.5	Determine the potential exposure and risk to the environment and the public health, safety and welfare for well-defined chemical and biological exposure and hazards.

Last, the National Council of Examiners for Engineering and Surveyors (NCEES) Fundamentals of Engineering (FE) Environmental Computer-Based Test Exam Specification on Risk

Assessment (specification area 7) specifically tests knowledge related to dose-response toxicity (carcinogen, non-carcinogen) (7A) and exposure routes (7B).[3]

As curriculum and course design is completed, there are additional internal and external perspectives that offer a wide variety of interpretation as to what is included within this knowledge area. In the context of environmental engineering, risk can be defined as a measure of the probability and the associated adverse effects from exposure to physical, chemical, biological, or radiological hazards. Exposure can derive from the anthropogenic or natural release of these hazards as well as the failure of engineered systems designed to protect human health and the environment. Although risk analysis is a useful tool for decision making, there are associated unknown factors and uncertainties, which may obscure the true risk.

The inclusion of uncertainty analysis includes both known uncertainties (known-unknowns) and unknown uncertainties (unknown-unknowns). It is important to develop engineers that recognize an uncertainty as a critical component of a risk calculation or include this perspective in the analysis of their design. Additionally, uncertainties may propagate throughout the risk assessment process to influence the characterization and communication of risk. In order to account for this, an uncertainty factor or confidence interval incorporated into a risk calculation can produce a wider spectrum of possible outcomes. A clearer understanding of the potential risk and associated uncertainty can lead to a more flexible and reliable design of engineered components and mitigate exposure to potential hazards. Conversely, an inaccurate interpretation of risk or failure to account for the potential uncertainties can result in failure ranging from unnecessary (and costly) engineered modifications to catastrophic failure.

Engineering disciplines integrate risk assessment within the engineering decision making process. Environmental engineering programs may address the topic of risk across a variety of courses within their curricula. Although there might be some similarity in the teaching of risk concepts; the application of risk may differ. The United States Environmental Protection Agency (USEPA) uses the Human Health Risk Assessment[4] (HHRA) and the Quantitative Microbial Risk Assessment[5] (QMRA) to determine exposure pathways, potential hazards and risks to the public health. Both models typically follow the methodical framework of hazard identification, exposure assessment, and toxicity assessment to characterize risk. However, in order to identify modes of failure of a system engineered to protect the environment and public health, environmental engineers should use other forms for risk assessments (e.g. fault tree analysis).[6] Students who only study and apply one form of risk assessment may not sufficiently appreciate the degree of uncertainty or the proper application associated with risk.

The development and analysis of models to understand and communicate risk can be approached with deterministic models, stochastic models, or a combination of both. The USEPA HHRA's risk values are calculated using deterministic (e.g. mean values or 95th percentile) values while QMRA's risk values are calculated using at least some stochastic (e.g., probability distributions) values. These two approaches may yield different results due to the assumptions about uncertainties within different risk components. Stochastic modeling techniques such as the Monte Carlo simulation is a "well-established simulation procedure that replaces point estimate with random variables drawn from probability density functions."[7] Stochastic models can combine the requirements within the hazard identification, exposure assessment, and toxicity assessment to develop a risk assessment that is useful in decision making. One such application can be to enhance the Risk Assessment requirement common to the Remedial Investigation / Feasibility Study (RI/FS) process promulgated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) legislation.

Environmental Engineering ABET Accredited Program Survey

Selected ABET accredited Environmental Engineering Programs were surveyed to assess incorporation of risk and uncertainty in undergraduate curricula. This analysis was completed to map in-class hours to the AAEES BOK Outcome #5 (Risk, Reliability, and Uncertainty)[2] and the ABET Program Criteria (Design environmental engineering systems that include considerations of risk)[1]. The survey responses covered 18 different required or elective courses that were mapped to at least one of the BOK and/or the ABET criteria. Six of the required courses were not mapped to the ABET criterion, likely because these courses did not have a substantial design component. There were only 5 of 18 courses that mapped to all 5 components of the BOK and the ABET criterion. Four of these five courses were reported as an elective. This underscores the expectation that environmental engineering courses must balance the breadth and depth inherent in the broad spectrum of problems addressed within the discipline.

Table 2. Survey Data – All Courses (All Respondents)

BOK/ABET	Brief Description	# Courses Mapped	Low (hours)	High (hours)	Mean (hours)
BOK 5.1	Identify potential hazards	18	0.50	12	4.1
BOK 5.2	Identify the modes for failure	8	0.50	6	2.2
BOK 5.3	Explain the uncertainties	13	0.25	6	2.2
BOK 5.4	Apply probability and statistics	11	0.50	6	2.8
BOK 5.5	Determine exposure and risk	16	0.50	9	3.1
ABET	Design environmental eng systems	12	0.25	12	4.5

Notes:
[1]The total number of courses analyzed was 18; 11 were external to West Point.
[2]Low, High, and Mean hours was based upon only those courses mapped to the corresponding survey criteria.

Table 2 shows a summary of the range of hours reported in undergraduate engineering courses. There was no attempt to correlate this data amongst courses with similar titles as the curriculum design likely varies across institutions. Stated another way, course content may differ to meet demands from accreditation or program outcomes uniquely. The average hours demonstrates that the majority of course time is allocated to the ABET criteria to design systems with consideration of risk, BOK 5.1 (Identify potential hazards) and BOK 5.5 (Determine potential exposure and risk). This may indicate that most programs approach the topic of risk using the USEPA HHRA methodology. The FE Exam only focuses upon risk assessment with two knowledge areas 7A (Dose-response toxicity) and 7B (Exposure routes).

Mapping of required courses to the BOK is presented in Table 3. It is presumed that there may be less diverse or fewer curriculum requirements placed upon an elective course compared with a required course. This is supported by the seven different elective courses listed in the survey results. The low and high hours did not change between the required and elective courses. However, the average hours changed slightly between required and elective courses and did not change by more than 1 hour. It is interesting to note that more hours are mapped with BOK 5.4

and 5.5 than with the electives. Finally, BOK 5.2 (Identify the modes of failure) and 5.3 (Explain the significance of uncertainties) are the lowest mapped criteria.

Table 3. Survey Data – Required Courses (All Respondents)

BOK/ABET	Brief Description	# Courses Mapped	Low (hours)	High (hours)	Mean (hours)
BOK 5.1	Identify potential hazards	11	0.5	12	3.7 (0.2)
BOK 5.2	Identify the modes for failure	2	0.5	6	0.5 (0.4)
BOK 5.3	Explain the uncertainties	6	0.25	6	1.7 (0.3)
BOK 5.4	Apply probability and statistics	6	0.5	6	3.8 (-0.9)
BOK 5.5	Determine the exposure and risk	9	0.5	9	3.4 (-0.2)
ABET	Design environmental eng systems	5	0.25	12	4.3 (0.4)

Notes:
[1]The total number of courses analyzed was 11
[2]Low, High, and Mean hours were based upon only those courses identified as required and mapped to the corresponding survey criteria.
[3]The change observed from mean hours for all respondents (Table 2) minus the mean hours for only the required courses is given in (). A negative answer indicates that the required courses mapped more values than all responses.

Further comparison of West Point's required courses to the selected peer universities is shown in Table 4. This data identified a difference in the time allocated to achieving the BOK and ABET requirements compared to other univerisites. This was interpreted as an opportunity to expand current course content and student activities to enhance the coverage of risk and uncertainty across the curriculum. A stochastic modeling activity was added to the West Point Environmental Engineering curriculum in Academic Term 16-2 to address this concern.

Table 4. Survey Data – Required Courses (West Point versus Peer University Comparison)

		West Point		Peer University	
BOK/ABET	Brief Description	# Courses Mapped	Mean (hours)	# Courses Mapped	Mean (hours)
BOK 5.1	Identify potential hazards	7	1.4	6	6.0
BOK 5.2	Identify the modes for failure	1	0.5	1	3.0
BOK 5.3	Explain the uncertainties	4	1.4	4	1.8
BOK 5.4	Apply probability and statistics	2	2.0	4	4.5
BOK 5.5	Determine the exposure and risk	5	1.8	6	3.8
ABET	Design env eng systems	2	2.1	4	4.5

The Environmental Engineering Program at West Point

The environmental engineering program is housed within the department of Geography and Environmental Engineering. The program has retained ABET accreditation since 1994 and graduates serve in the United States Army within a variety of branches to include Engineers and the Medical Service Corps. The program teaches 12 required courses that provide the disciplinary depth component of the curriculum.

The number of in-class hours, allocated to each ABET Environmental Engineering Program Criterion was determined in 2013 and this data is presented in Table 5. A relatively small percentage of class time, 1.5%, was dedicated to ABET Criterion 14 (Risk) and 15 (Uncertainty). This data highlights the number of requirements associated with the ABET Environmental Engineering Program Criteria. It was determined that allocation of in-class hours should be adjusted to allow for Monte Carlo Modeling in EV488 (Solid & Hazardous Waste Treatment & Remediation), which would build a stronger foundation in risk and uncertainty. This resulted in a modest increase of three in-class hours spent on risk and uncertainty.

Table 5. In-Class Hours Dedicated to Each of the ABET Environmental Engineering Program Criteria Based on the 12 Courses Taught within the Program.

No.	Program Criteria	In-class Hours	%
1	Apply knowledge of math through differential equations	7.7	1.5
2	Probability and statistics	3.1	0.6
3	Calculus based physics	3.5	0.7
4	Chemistry (including stoichiometry, equilibrium and kinetics)	43.3	8.2
5	Earth science (geology)	41.7	7.9
6	Biological science	39.2	7.4
7	Fluid mechanics	28.5	5.4
8	Material and energy balances	46.9	8.9
9	Analyze fate and transport between air, water and soil	35.0	6.6
10	Conduct experiments and critically analyze data in air systems	8.3	1.6
11	Conduct experiments and critically analyze data in land systems	7.7	1.5
12	Conduct experiments and critically analyze data in water systems	43.9	8.3
13	Conduct experiments and critically analyze data in environmental health	17.5	3.3
14	Design environmental engineering systems considering risk	7.6	1.4
15	Design environmental engineering systems considering uncertainty	7.7	1.5
16	Design environmental engineering systems considering sustainability	20.3	3.8
17	Design environmental engineering systems considering life cycle principles	8.5	1.6
18	Design environmental engineering systems considering environmental impacts	53.1	10.1
19	Advanced principles and practices relevant to program objectives	44.6	8.5
20	Professional practice issues	21.5	4.1
21	Project management	5.5	1.0
22	Roles and responsibilities of public and private organizations pertaining to policy and regulations	24.0	4.5
	Science fundamentals	7.7	1.5
	General humanities	0.8	0.2
	TOTAL	527.0	100.0

Of the twelve required courses taught within the curriculum, seven courses address risk and uncertainty as summarized in Table 6. The three courses that contributed the most in-class hours to achieving Criterions 14 and 15 are highlighted in Table 6.

Table 6. The West Point Environmental Engineering Courses addressing Risk and Uncertainty

Course	Title	Thematic Focus Area
EV301	Environmental Science for Scientist and Engineers	• USEPA HHRA process

EV396	Environmental Biology	• Describe and communicate risk in a pre-deployment briefing scenario
EV488	Solid & Hazardous Waste Treatment & Remediation	• USEPA HHRA applied to RI/FS

EV301: Environmental Science for Scientist and Engineers

In this introductory course, the course outcome determine the risk posed by exposure to carcinogenic and non-carcinogenic toxins applies. Three lessons are used to introduce the USEPA HHRA model and apply it to both carcinogenic and non-carcinogenic toxins. Students must incorporate information from several sources such as public health data, community data, physical and chemical data, and regulatory guidance to determine the single-point risk estimates.

EV396: Environmental Biology

A unique opportunity for development of oral presentations skills and risk communication is offered in EV396. The course outcome evaluate environmental engineering aspects of public health microbiology and preventive medicine, to include establishment of regulatory standards applies. Students evaluate and present the occupational and environmental health and endemic disease (OEH/ED) threats associated with an Army unit's deployment scenario. Acting as the preventive medicine officer, students identify, assess, and communicate OEH/ED hazards in their assigned area using the operational risk management process[8]. The students provide a commander with the information needed to make appropriate decisions based on the medical threat and provide recommended mitigation strategies.

EV488: Solid and Hazardous Waste Treatment and Remediation

This course is taken during the last semester of a student's academic program. The course is designed to allow students to explain the fundamental requirements associated with the RI/FS process as outlined by CERCLA including Risk Assessment applies. This course uniquely blends reinforcement of the knowledge and skills previously introduced with the application to relevant to hazardous waste treatment and remediation case studies. The course design is a block of four lessons with a dedicated laboratory period. The objectives from this block are:

- Apply the concepts of Risk and stochastic modeling to analyze a public health scenario and inform environmental engineering decision making.
- Reinforce the knowledge of calculating chronic daily intake (CDI) values.
- Develop a Monte Carlo simulation to model the statistical and associated uncertainty to a relevant environmental engineering scenario.

Assessment

Both indirect assessment (an indicator of perception of outcome attainment) and direct assessment (an embedded indicator of performance in outcome attainment) are used to assess course outcomes in our program. Because both types of data are important, all outcomes are evaluated using an overall assessment score, which is based on indirect data from surveys (Likert scale) and performance based (embedded) indicators. The indirect score is based on a scaled assessment (1-5 Likert scale) from student surveys using the web-based end of course feedback system and the instructor's assessment. The students and instructor(s) review each course outcome and determine to what degree cadets can perform each outcome: strongly agree (score of 5) to strongly disagree (score of 1). The grade based assessment for each course outcome is typically based on embedded indicators that sum to at least 5% of the total course grade. For example, a course with 10 outcomes should use embedded indicators that sum to at least 50 points to assess each course outcome (assuming 1000 total course points). Final embedded indicator scores are based on a weighted (using point value) average and converted to a scale of 1-5. The overall course indirect score is the mean of the student response, weighted 60%, and the Course Director/instructor response, weighted at 40%. An overall assessment is made by combining the indirect and performance-based assessments. The performance-based assessment is weighted 80% and the indirect-based assessment is weighted 20%. A final score of greater than four is considered acceptable. Examples of assessment of course outcomes that include risk, uncertainty, and risk communication in three of our courses, in 2015, is presented in Table 7. Although these outcomes are broader than risk and uncertainty, the data indicates that we are generally developing students in these areas. Individual homework assignments and project grades (in these courses and others) are also used to monitor performance in risk and uncertainty (data not shown).

Table 7. Assessment of Course Outcomes that are related to risk and uncertainty.

Course	Outcome	% Course Points	Student Score	Instructor Score	Direct Score	Overall Score	Overall Score Previous Year
EV301	Determine the risk posed by exposure to carcinogenic and non-carcinogenic toxins.	12.8	4.45	4.00	4.12	4.13	4.14
EV396	Evaluate environmental engineering aspects of public health microbiology and preventive medicine, to include establishment of regulatory standards.	13.3	4.24	4.20	4.13	4.15	4.36
EV488	Explain the fundamental requirements associated with the RI/FS process as outlined by CERCLA including Risk Assessment	13.8	4.58	4.50	4.01	4.12	4.05

Incorporating Monte Carlo Simulations

The results of this study and internal analysis of our curriculum identified an opportunity to further incorporate risk and uncertainty into the curriculum. Further discussion amongst the course Instructors and the Environmental Engineering Curriculum Coordinator identified additional concerns to be addressed by conducting computer modeling exercise as a part of a laboratory period. As stated above, the USEPA's deterministic risk mythology provides limited information about uncertainty. Thus, the use of stochastic modeling was developed to include several factors such as individual exposure, gender, and body weight in the model. In addition to calculating risk, we leveraged the opportunity to enhance each student's knowledge and use of statistical analyses, modeling to evaluate uncertainty, and risk communication.

A laboratory assignment that re-visits a familiar scenario from a previous course is used to analyze risk using both deterministic and stochastic models. A concept map and associated illumination statements, for the assignment, is presented in Figure 1. Within the concept map, the applicable BOK component (green arrow) was integrated with the illumination statement. There is no design applicable in this example and thus no claim to enhance the ABET criteria as that was determined to be well met through other courses within the required curriculum.

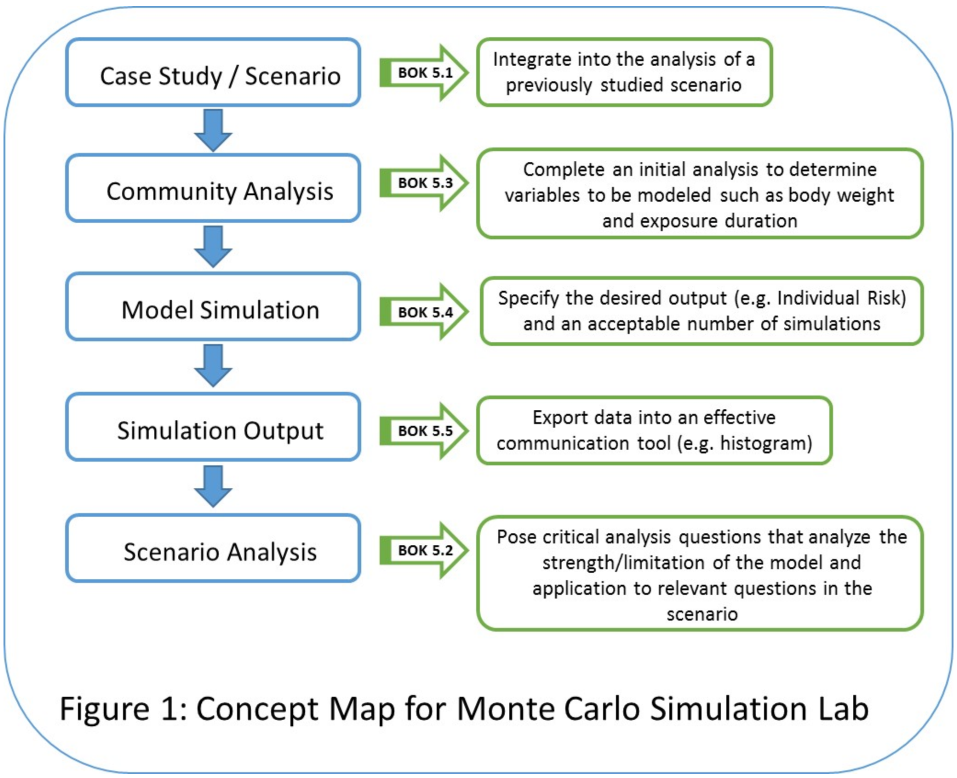

Figure 1: Concept Map for Monte Carlo Simulation Lab

In the lab scenario, students are presented with the fictitious scenario of arsenic contaminated drinking water wells in the town of Woburn, MA. The scenario states that a group of concerned citizens in Woburn, MA has funded a study to determine if the proposed Applicable or Relevant and Appropriate Requirements (ARARs) used to clean up arsenic contamination near two contaminated wells will result in health problems. Students must also use data from the USEPA to complete the lab. This lab activity is completed as an individual assignment.

The laboratory period and assignment are designed to achieve the objectives by further analysis of the Woburn, MA case study introduced in an earlier course Term Project (EV394 – Hydrogeology). The lab period consists of a short lecture to further introduce stochastic modeling and the use of Monte Carlo simulation. Students are given time to work through the modeling requirements with the Instructor available for consultation. Students must analyze the representative community's data (students are provided the number of years each person has declared residence and their body weight provided). Students analyze this community data to calculate the mean and standard deviation for each, and then create a simulation to model the population in the study. The final requirements are to analyze the data and prepare a written submission. The laboratory material presented to the students is included as Appendix A. Assessment of student work and analysis of the Monte Carlo modeling lab will be completed in 2016.

Conclusion

A preliminary survey of undergraduate environmental engineering courses was conducted to assess interpretation of risk and uncertainty criteria at different ABET programs. The majority of hours within typical courses was dedicated to teaching topics of risk using the USEPA HHRA (BOK 5.1 and BOK 5.5). It was not surprising that courses allocate the least amount of time to identify the modes for failure (BOK 5.2) and to explain the significance of uncertainties (BOK 5.3). We applied this analysis to internal assessment data and identified an opportunity to add more depth within the curriculum to enhance the requisite understanding of risk and uncertainty. Specifically, the internal analysis identified an opportunity to further incorporate BOK 5.2 and BOK 5.3 into the curriculum. Prior to the change, we allocated under 16 hours to design environmental engineering systems considering both risk and uncertainty. With the transition and development of EV488 into a laboratory course, three in-class hours were allocated to analyzing risk and uncertainty using both deterministic and stochastic models. The Monte Carlo Simulation lab provided by the West Point Environmental Engineering Program can be used as a template to further incorporate risk and uncertainty to achieve more depth within an individual course design.

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Appendix A: EV488 Lab (Risk Assessment and Monte Carlo Simulation)

1. **Objectives**

   After completing this lab, you should be able to
   - Apply the concepts of risk and stochastic modeling to analyze a public health scenario and inform environmental engineering decision making.
   - Reinforce your knowledge of calculating chronic daily intake (CDI) values.
   - Develop a Monte Carlo simulation to model the statistical and associated uncertainty to a relevant environmental engineering scenario.

2. **Administration**
   - This is an INDIVIDUAL ASSIGNMENT.
   - Document your work IAW the Institution standards.
   - Assignment is due as identified on the course syllabus.
   - You will submit your Monte Carlo model electronically to your Instructor.

3. **Reference**
   - See the reading assignments.
   - The FERM has applicable CDI equations and USEPA typical values.

4. **Safety**
   - Not applicable as this is a computer modeling lab.

5. **Background**

Environmental Engineers must incorporate information from several sources such as public health data (e.g. lab samples), community data (e.g. demographic information), physical and chemical data (e.g. groundwater well reports), and regulatory guidance to solve the complex problems that might be impacting a community. We must remember that many public health related problems are made more challenging as the typical environmental burdens are mobile in the environment, can bioaccumulate and transform, and may have different impacts upon different subsets within a defined population or community. Another way to say this is that there is a temporal and spatial perspective that makes it difficult to have a precise or definitive answer. As such, we often rely upon statistical analysis and modeling to better communicate the impact upon a population. We use techniques such as Monte Carlo simulation (a stochastic modeling technique) combine the requirements of the hazard identification, exposure assessment, and toxicity assessment to develop a risk characterization that is associated with the Remedial Investigation / Feasibility Study (RI/FS) process as promulgated under CERCLA legislation. In practice, this process requires the integration of several subject matter experts within the disciplines of chemistry, biostatistics, molecular biology, toxicology, statistics, medicine, and engineering.

6. **Lab Procedures**

This laboratory period and assignment is designed to achieve the objectives by further analysis of the Woburn, MA case study.

The lab period will consist of a short lecture to further introduce stochastic modeling and the use of a Monte Carlo simulation. Students will then be given time to work through the modeling requirements of the lab. The final requirements to analyze the data and prepare the written submission will be completed outside the scheduled lab period.

PRIOR TO CLASS: Please make sure that you have the Excel data analysis tool for histogram available. This is found under the Data Tab → far right Analysis and titled "Data Analysis." If this is not found there, go to your File Tab → Options → Add-Ins → Analysis ToolPak.

Modeling Steps:
Worksheet: "Citizen Information"

(1) Based upon the information given, analyze the number of years each person has declared residence and their body weight provided. Calculate the mean and standard deviation for each.

Concept Note: you will now create a simulation to model your population to meet the mean and standard deviation that your data set has identified.

Worksheet: "MC Simulations"

(2) Create a new worksheet to develop your simulation (one has been started for you). Research the current population of Woburn, MA. You will model this population using the Mean and Standard Deviation for exposure duration (time lived in Woburn) [Column B] and body weight [Column C] found in Step (1). Use the Excel Function: NORMINV(RAND(), Mean, Standard Deviation).

Hint: this should generate X random entries which is equal to the number for population. You may have manually copy the equation into the X number of cells.

(3) Calculate the CDI for each resident [Column D] that you are modeling. In this scenario, you are modeling the ingestion of water that might have been contaminated with arsenic.

Modeling Tip: Insert a column to give a modeling ID # [Column A]. You can then sort your data and have a reference number to compare values.

(4) Calculate the Individual Risk for each resident modeled [Column E]. Then report the Risk as "1 in #" in a separate column [Column F]. This is equivalent to the reciprocal of the Individual Risk.

(5) Analyze the data from your simulation. Create a summary table as shown.

Cancer Population		**Risk (1 In ___)**	
High:		High:	
Low:		Low:	
Sample size =			

As part of your discussion, comment on the values generated in this table and what their significance. Did you get negative numbers? Why were they generated in the model and what do they mean? How does this impact your analysis? It might help to analyze the data if you sort the results from lowest to highest.

(6) Generate a Histogram. Use the Data Analysis Add-In and follow the prompts. You should have your x-axis be the "Risk (1 in __). Plot this from 0 to 1300 in increments of 50 (this is your bin size). Note that anything outside the range you specific will be labeled as "More". It will be helpful to put the specific values of your bin range in the worksheet [Column G].

Excel Note: This will create a new worksheet with the histogram and the frequency analysis completed.

(7) Analyze your model. Report the Mean and Standard Deviation of the Cancer Risk from your simulation. What is the 95% Interval of Cancer Risk? Determine the probability of having a risk greater than 1 in 1,000. What would change if you cleaned the site to a different standard? Use your model to propose and support a scenario that would meet the USEPA's accepted risk criteria.

7. Lab Assignment (50 Points)

A. Scenario

A group of concerned citizens in Woburn, MA has formed the Concerned Citizens of Woburn (CCW) to voice their concerns. The CCW has hired your firm to determine if the proposed ARARs used to clean up arsenic near the infamous wells G and H will result in health problems, if the wells are used once again for drinking water. They have asked you to use the *most conservative data (from their perspective)* that the EPA has available.

B. Requirement #1: Executive Summary

[Grade on A-F scale] Write a well-constructed Executive Summary (1-2 paragraphs) for the Concerned Citizens of Woburn (CCW) that addresses the following items.

- Provide your findings to answer each of the concerns proposed by the CCW. Summarize (4-6 sentences each) what you recommend in each case.
  - Support your answer with any data to support your case.
  - Address any uncertainty or level of confidence you have with your recommendation.
  - Propose specific actions you would think prudent for the CCW to take.
  - Should the citizens be concerned with Arsenic contamination in the GW wells?

C. Requirement #2: Woburn Data Evaluation and Research

a. Use the file on Blackboard (under Lab #2) entitled, "EPA Risk Assessment Wells G&H Tables" page 577 (menu bar page number) to identify the monitoring well with the highest arsenic concentration. Report this value *with correct units along with the name and depth of the monitoring well.*

b. Use the EPA Integrated Risk Information System (IRIS) web portal to identify the oral slope factor for arsenic (***<u>per</u>*** mg/(kg day))

c. Research the current population of Woburn, MA to the nearest thousand people. Provide a reference for your source.

D. Requirement #3: Stochastic Modeling – Arsenic Concern

In an environmental scenario, your results will rarely be deterministic due to uncertainties in your input. Following the instructions in the excel file (see Blackboard "Lab #3 – Cadet" Excel File), complete a Monte Carlo simulation for the CCW.

NOTE: EACH STUDENT WILL DEVELOP THEIR OWN MODEL INDIVIDUALLY AND SUBMIT THEIR EXCEL FILE TO THE INSTRUCTOR VIA E-MAIL.

a. Your written submission for this section will include:
- a short discussion of your results and the questions outlined below (section 3c)
- any summary tables or graphs you deem appropriate such as your model inputs and outputs.

b. Your model will be graded based upon your electronic submission. Your electronic work will be assessed for completeness and ease to read/follow. See the Lab Procedure for the required model output that should be included in the report. These include:
   - Citizen Analysis – exposure duration and body weight. [see 6(1) above]
   - Population size of your simulation.
   - Summary Table of the simulation [see 6(5) above].
   - Histogram [see 6(6) above].
   - Analysis of the histogram [see 6(7) above].

c. Specific question to address:
   (1) Estimate the lifetime average chronic daily intake (CDI) and exposure risk from arsenic in the city water supply at the concentration based upon the mean values.
   (2) Does your answer fall outside of EPA's acceptable risk of 10^{-4} to 10^{-6}? Show all work.