CHE 3XX – Uncertainty in Environmental Engineering Course Syllabus

Instructor Information

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Teaching Assistants

TA1

TA2

Course Hours

Lectures (MY 360) will run from 10:10 – 11:30 on Tuesdays and Thursdays. Tutorials (MY 370) will be from 16:10 – 17:00 on Thursdays.

Office hours for Tim Rodgers (ES 3142) will be from 11:30 – 12:30 on Tuesdays and Thursdays, directly after the lectures. If you would like to schedule an appointment outside of these hours please email directly.

Requirements & Prerequisites

This course requires knowledge of linear algebra, statistics and basic programming. Programming for course deliverables will be conducted in Python, using Jupyter Notebooks – prior experience with Python is not necessary but would be helpful. Communicating your results will be an important part of the course – students should be well versed in presentation and technical writing skills.

Description

This course will dive into uncertainty in environmental engineering, looking at how that uncertainty can influence design, decision-making and the ability to plan for the future. This course is meant to help those that will go on to use computational models for decision making in an environmental engineering context – examples could include models for predicting climate change, chemical transport and fate, air pollution, ozone layer depletion and many others.

Deliverables

One goal of this course is to illustrate the strategies and techniques necessary for analyzing and solving real-world environmental problems. Students will work in teams throughout the semester to analyze an environmental problem and propose a solution. Students will need to develop a computational model to analyze their problem, and to help make a final recommendation. Interim deliverables throughout the semester will be part of the same project, allowing students to work iteratively towards a final report that should contain a solution. Improvements to later pieces, based on feedback from the instructional team, can help students improve their grades throughout the semester. There are 6 deliverables as follows:

1. Interim proposal (0-5%), due on the third week of class. This deliverable will outline the project students wish to pursue. Proposals will be returned at tutorial on this week, and feasible proposals will be able to continue with the project proposal (Deliverable 2). Groups with **infeasible proposals will be given 0%** on this assignment (re-assigned to project proposal) and assigned a project of the instructors choosing.

2. Project proposal (10-15%), due on the fourth week of class. This proposal should outline the motivation for the project, methods that will be used to solve the problem, and possible outcomes. This outline should also outline the important variables for the project, and show the uncertainty associated with those variables
3. Report Introduction (10%), due on the sixth week of class. This should be a fully fleshed introduction incorporating research on the environmental project that is being analyzed, the techniques that are used to evaluate the problem, and potential sources of uncertainty or error. This introduction should build on the project proposal, but be distinct and written in the past tense.
4. Midterm Presentations: Stakeholder Engagement Meeting/Townhall (25%), presented in the ninth week of class. This presentation should outline the work completed to date, the motivation for the project, and ask for feedback from stakeholders (roleplayed by your instructional staff and peers). Results from your stakeholder engagement meeting should be incorporated into your final report.
5. Draft Report (0-10%), due the eleventh week of class. This draft should be written as a technical report, although some pieces may still be in outline form. The draft should fully describe the introduction and methods for the report and give examples of key figures and results. This report will be edited by the instructional team for indications of how to achieve an excellent final report and handed back in tutorial on the final week of classes. Significant improvements on the final report, incorporating comments from the draft, will lead to the 10% from this deliverable being shifted to the final report
6. Final Report (40-50%), due 2 weeks after classes finish. The final report for this project should be written as a technical report, with a clear introduction, methods, results & discussion and recommendations as to how the environmental problem could be ameliorated. Full discussion of the impacts of uncertainty on the decision-making process should be considered, and the final recommendation should reflect this uncertainty.

Learning Objectives

Foundational Knowledge

- Define the problem-solving domains in the Cynefin framework
- Explain the features of different probability distribution functions (PDFs)
- Explain the difference between “Known knowns” and “unknown unknowns”
- Define global & local sensitivity analyses

Application

- Use a problem-solving domain to determine a strategy to solve a given problem
- Apply appropriate PDFs to input parameters for environmental & decision-making models (ie precipitation data is often lognormal)
- Analyze links between the types of uncertainty and different problem domains.
- Differentiate between uncertainty and sensitivity in a problem-solving model
- Apply global and local sensitivity analysis in order to compare and contrast the different approaches.
- Develop a decision-making model to analyze an environmental issue.
- Analyze the sensitivity of their problem-solving model to variations in input parameters

Integration

- Relate a problem-solving domain to the skills required to solve a problem. For instance, if the problem is to design a beam, use the appropriate code to determine the thickness
- Compare approaches that explicitly integrate uncertainty with those that do not. How could showing uncertainty lead to a false confidence in results?
- Evaluate problem-solving models, to see if all types of uncertainty have been captureds
- reflect on the conditions where uncertainty can be definitive vs conditions where uncertainty is impossible to fully quantify.

Human Dimension

- Relate the problem-solving domains to a personal problem you have faced in the past. How would knowing what type of problem it is help to solve it?
- Determine how to display uncertainty so that decision and policy -makers can understand and use it.
- Students will reflect on the conditions where uncertainty can be definitive vs conditions where uncertainty is impossible to fully quantify.

Caring

- Students will get excited about problem solving by applying the different domains to current political issues
- What aspects of stating uncertainty are valuable for making a decision?
- When would different approaches to stating uncertainty lead to better outcomes?
- How can the acknowledgement of uncertainty be applied to decisions you make every day?

Learning how to learn:

- Identify sources of information which will find new approaches to problem solving, and how those might differ from the frameworks presented in class.

Course Schedule

Week	Lecture	Tutorial	Deliverable
1	1. Introduction & Course Outline. Uncertainty in engineering problem solving activity	Team selection exercise	Teams – List due to TA by Sunday at 11:59 PM
	2. Problem solving frameworks. Course summative project outline		
2	3. An introduction to Bayesian statistics. Bayesian statistics activity	Writing a project proposal	
	4. More Bayesian statistics		
3	5. Variable identification & types of uncertainty. Identifying stakeholders	Feedback & peer-editing of interim proposals	Interim Proposal
	6. Developing a conceptual model. Problem identification & conceptual model development activity		
4	7. Problem solving models – decision matrices, weighting functions, etc	Monte Carlo Simulation exercise	Project Proposal

	8. Problem solving models – decision making under uncertainty		
5	9. Introduction to Monte Carlo Simulation 10. Defining input probability distribution functions	Writing an introduction	
6	11. Uncertainty vs sensitivity & associated activity 12. Sensitivity analysis methods – local vs global	Peer-review of report introductions	Final Report Introduction
7	13. Now what? Interpreting sensitivity analysis results 14. So what? Interpreting uncertainty analysis results	Report introduction feedback reflection	
8	15. Stakeholder Analysis: Interests, ideals & power. Stakeholder exercise 16. Types of model – mechanistic, heuristic, predictive, etc.	Midterm presentation work period	
9	17. Midterm presentations 18. Midterm presentations	Midterm Presentations	Midterm Presentations
10	19. Modelling best practices 20. Modelling pitfalls – over-parameterization	Midterm presentation feedback reflection	
11	15. Model calibration & parameter fitting 16. Model evaluation	Final report work period	Draft Final Report
12	17. Using uncertainty to make good decisions 18. Course reflection, final report Q&A	Final report work period	Final Report (2 weeks after classes finish)

Situational Factors for "Understanding Uncertainty in Engineering Problem-Solving"

	Situational Factor	Implication
Organizational/Contextual	300-level elective undergraduate course, ~ 60 students, 2 x 1.5 hrs/wk lectures	Students will need to have taken a statistics course but might not have much background apart from this.
	Brand new course, some similarity to other courses	This course will be built from the ground up. May be similar to some other courses (eg ENV 1001, environmental decision making) but with an engineering focus. Will be more math & numbers driven.
External Groups	Society expects environmental decisions to be thorough and evidence-based	Environmental decisions are often highly politicized and can be subject to significant litigation. Thus, being able to accurately assess uncertainty is critical to maintaining credibility
	Data heavy approaches are increasingly the norm	The ability to work with real data and make decisions based on uncertainty from "big-data" approaches through numerical methods is useful.
Nature of the Subject	Environmental decisions are complex	Environmental decisions are often complex & involve significant uncertainty, allowing for examples with a high relevance to the "real world"
	Broad subject	Can bring in different aspects of students' interest from more technical issues, like analyzing a tailings dam failing point, to societal issues, such as looking at how climate stress can impact conflict.
The Learner	Students are preparing for capstone projects the next year	Course will be useful in the capstone design process, where proper understanding of uncertainty will help differentiate their project from peers'

	Students from other disciplines welcome	Since environmental decisions are often interdisciplinary, having multiple perspectives is key. Need to ensure that students have appropriate statistical background – other engineering disciplines would be easy whereas sciences or arts may not be possible
	Deadlines in other courses	Need to ensure that my deadlines are appropriate given the workload of the students. If they are coming from a variety of departments, could be difficult to ensure that there isn’t too much overlap.
The Teacher	Environmental engineering background	I am passionate about environmental issues and will bring that perspective to the class.
	Enjoys active learning	I try to use active learning in my lessons, and feel that I teach better and students learn better from me when I can do this effectively. I know that this means I need to be very careful about time – it is easy to get behind with every activity!
	Programming and modelling based research	I might have trouble remembering what it is like not to have programming experience, so will need to be careful around instruction for this.

Uncertainty in Environmental Engineering – Problem-Based Learning Project Description

Introduction:

Uncertainty is everywhere and informs everything that we do. Decisions are often made with incorrect ideas about uncertainty, resulting in sub-optimal outcomes for everyone involved. Since the environment is such a complex system uncertainty abounds; it can be difficult to adequately define a problem such that the uncertainty is manageable and an informed decision can be made. In environmental decision making, unexpected consequences are the norm rather than the exception, Environmental decisions are often "wicked" problems with no right answer, and many stakeholders with conflicting interests. Navigating this tricky world is the work of environmental engineers such as ourselves, and so we need to not only understand the underlying environmental problems, their solutions & the associated uncertainty but must also understand how to communicate these concepts to stakeholders with different levels of scientific awareness.

As such, your task is to identify an environmental problem that you wish to solve and provide a recommendation as to how it could be resolved. This project will span the entire course, and each of the deliverables will build on the others, allowing for an iterative assessment process that will more closely mimic the "real-world", where collaboration and iteration are keys to success. For this project your course instructor will act as your client while your teaching assistants (TAs) will act as your managers/senior engineers, able to offer advice and feedback as well as assessment on your performance.

Deliverables

There are 6 deliverables for this course. Some grades will be re-assigned depending on performance, see the syllabus for full details. The syllabus also contains a short description of each deliverable. This document contains detailed instructions for the final report, please see each of the assignment outlines on the course website for their detailed instructions.

Table 1: List of deliverables, along with their corresponding due dates and their weighting for your overall course grade.

Deliverable	Due Date	Weighting
Interim proposal	3rd week of class	0 – 5 %
Project Proposal	4th week of class	10 – 15 %
Report Introduction	6th week of class	10 %
Midterm Presentation	9th week of class	25 %
Draft Final Report	11th week of class	0 – 10 %
Final Report	12th week of class	40 – 50 %

Final Report

Your final report should be written in the style of an academic journal article for submission to a peer-reviewed journal of your choice. Different journals have different submission guidelines, these should be followed for your submission. In choosing a journal, you should think about the audience you want to reach (i.e. academics, practitioners, policymakers) and the type of article that these journals publish. Some potential journals include:

- Environmental Science and Technology (ES&T) is a popular and well-respected journal in the field of environmental sciences. This is a good choice if your topic is of relevance to academics.
- Ambio is a journal dedicated to human-environment interactions. Articles in Ambio are often more policy-focussed, with explicit management or policy recommendations based on their results. This is a good choice if your topic is policy- or management- focussed and you want to reach policymakers.
- The Journal of Environmental Engineering is an engineering-focussed journal and is therefore more focussed on technical & engineering solutions to environmental problems. This journal is a good choice if your topic is technical or design oriented and if you want to reach practitioners and engineers.

Remember, these are just suggestions and there are many journals you could prepare your submission for. We ask that you submit a copy of the author guidelines along with your draft & final reports to assist with grading. Before preparing your report, make sure to read through articles from the journal you plan to prepare the manuscript for so that you understand their tone & practices.

Regardless of which journal you choose, your manuscript will be marked on the following rubric . Remember that your course instruction team is a key audience that you want to reach! Some key points to remember:

- Journal articles require an introduction that allows scientifically literate non-specialists to understand the motivation and relevance of the paper. The introduction should firmly situate your work in the literature and show the research gap that it will fill. All acronyms should be explained on first use. All claims must be backed up with evidence, this is either a reference to peer-reviewed literature or your own results.
- Methods should be described so that your process can be reproduced. If you are using an established method, make sure you provide a reference and a description of how you applied the method – we will be marking you on this description! Some of this information can go in the supplementary information (SI), which acts like an appendix.
- Figures should be high-quality and well rendered. Figure captions go below the figure and should be detailed enough that someone does not need to read the accompanying text to understand the figure. Figure titles are usually included in the figure caption, rather than being written on the figure. Some journals count figures of different sizes towards the word count in different ways, while others specify a word count and a number of figures allowable for publication.
- Tables should be clear and concise. Table captions go above the table and should be detailed enough that someone does not need to read the accompanying text to understand the table. Table 1 in this document is an example of a “publication-quality” table. Some journals count tables of different sizes towards the word count in different ways, while others specify a word count and a number of tables allowable for publication.
- Finally, remember that your report needs to demonstrate and apply your learning throughout this course. As such, you must have a robust sensitivity & uncertainty analysis for your model, demonstrating how the uncertainty impacts your final results.

Table 2: Rubric for the "Final Report" assessment

CATEGORY	BELOW EXPECTATIONS (< 7)	MEETS EXPECTATIONS (7-8)	VERY GOOD (8-9)	EXCELLENT (> 9)
Research & Argumentation				
• Work is placed within the context of the literature, filling an appropriate research gap • Goal & scope of paper is clearly identified • Limitations of paper are clearly described and linked to scope. Limitations do not prevent goal from being achieved. • Claims are supported by evidence and justification • Paragraphs are built around a single concept/theme • Relevant stakeholders are identified, and their influence on the project is stated and incorporated into analysis • Project recommendation or conclusions are clear and follow from evidence presented.				
Model Development, Sensitivity & Uncertainty Analysis				
• Model is appropriate for the environmental problem being analyzed • Model description is complete & accurate. All sources are referenced • Model identifies major sources of uncertainty, without over- or under- estimating the uncertainty bounds • Model parameter uncertainties are appropriately defined • Sensitivity analysis identifies variables most influential in modelled uncertainty • Model code is well commented & comprehensible • Model code is free of errors that would impact results				

Style & Formatting				
• Writing style is clear & concise • Uses explicit structure (sign posting) to direct audience throughout document • Organizational constructs (lists, paragraphs, tables) are appropriately selected & used • Journal’s style guide is followed & provided to the marking team • References are formatted appropriately according to the journal style guide • Tables & graphics are well rendered & organized				

Assignment 1: Project Proposal (10%)

Due Date: Friday, September 12th (1.5 weeks from now)

Introduction:

Over the course of this semester you will be working on an environmental engineering problem from the list provided in groups of 4-5. The final goal of this project is to provide a recommendation to the client based on modelling the problem, taking into account the uncertainty involved and therefore the level of confidence possible in your recommendation.

An important first step in any engineering problem is to outline what approach you are going to take to solve the problem. Often, this outline of your proposed approach is given to a client or some other reviewer who decides whether they will hire you to solve that problem for them. Many projects fail due to their inability to correctly define the bounds of the problem they are trying to solve, so taking the time to properly define a problem and brainstorm the important variables is not only critical to winning a project, but also critical to the project's success. For this assignment you need to:

1. Define the problem you wish to solve
2. Identify relevant stakeholders
3. Determine what the goal of the project is
4. Outline what the expected outcomes will be – is this a report, or a presentation? Who is your audience, and what are you trying to convey?
5. Determine a modelling approach that can be used to solve the problem
6. Brainstorm input variables that will be needed to solve the problem
7. Identify sources that can be used to parameterize these variables.

This proposal should be a 3 – 4 page report, with an introduction giving a brief description of your motivation for the project, an outline of the methods you will use, who the relevant stakeholders are and what some of the potential outcomes may be. Please take a look at the rubric on Page 2 for an indication of how you will be assessed. This assignment is worth 10-15% of your overall grade, depending on the strength of your interim proposal.

Learning Objectives:

- Define a problem from a case study
- Analyze problem to determine required problem scope
- Identify stakeholders
- Identify relevant variables for solving a problem
- Identify audience & genre for a technical report

Rubric

CATEGORY	BELOW EXPECTATIONS (< 7)	MEETS EXPECTATIONS (7-8)	VERY GOOD (8-9)	EXCELLENT (> 9)
Problem Definition				
• Problem statement is clearly defined • Relevant stakeholders are identified, and their influence on the project is stated • Project goal is clearly understood, and scope of problem definition matches with expected goal • Potential deliverables are identified, along with a clear understanding of the audience and genre required for that audience				
Variable Identification				
• Required variables are clearly identified • Potential models or modelling frameworks are clearly identified • Potential sources to parameterize the required variables are listed • Variables are linked to the problem definition • Identified modelling approach could achieve project goals				
Communications				
• Writing style is clear & concise • Uses explicit structure (sign posting) to direct audience throughout document • Organizational constructs (lists, paragraphs, tables) are appropriately selected & used • Paragraphs are organized around a central topic or theme • Sentences are clear and support paragraph topic or theme . Tables, graphics are well rendered & organized				

Case Studies (for groups who did not find an appropriate project):

1. Organophosphate esters (OPEs) are chemicals used as flame retardants and plasticizers [1] whose use has increased following the phase-out of polybrominated diphenyl ethers (PBDEs) as persistent organic pollutants (POPs), for which they were proposed as "safer" alternatives [2]. Unfortunately, it has become apparent that OPEs share several of the problematic characteristics of PBDEs, including high persistence in the environment and so the potential for long range transport [3], the potential to bioaccumulate in biota [4] and evidence of toxicity to humans [5] and the environment [6]. As such, the Canadian Chemicals Management plan has conducted reviews of several OPEs for potential listing, and have recommended some limits to their usage (e.g. Environment and Climate Change Canada, 2016).

   However, these limits were not as stringent as some would prefer, and the City of Toronto is considering the best methods that they can use to reduce the emissions of OPEs to the environment through controls on their use within the city. Rodgers et al. (2018) conducted a modelling exercise to quantify the overall emissions of OPEs from the City of Toronto and found that there were ~3,300 kg yr^{-1} of air emissions from non-point sources within the city, which they stated came from sources "such as indoor air or traffic". In order to effectively reduce Toronto's OPE emissions, the City of Toronto has tasked you with determining what portion of Toronto's emissions come from indoor sources, and has provided you with data on the levels of OPEs in 51 Ontario homes [9]. This task will involve multimedia modelling [10] of OPE fate and emissions from indoors to outdoors, and should provide a recommendation to the City of possible measures they could use to decrease or mitigate OPE emissions from indoors.

2. Rapid urbanization and increased population growth have caused significant changes in urban watersheds. These changes have affected both storm and surface water quantity and quality in terms of flooding and impacts to aquatic biota, respectively. These impacts are known collectively as "Urban Stream Syndrome" (USS) [11]. To mitigate USS, low impact development (LID) technologies have been developed to restore or retain the pre-development hydrology of an affected area [12]. LID design is intended to retain stormwater, allowing runoff to infiltrate or evaporate in order to reduce the total volume of water delivered to urban streams or combined sewers.

   Older stormwater management systems relied on combined storm and sanitary sewers to prevent flooding and move stormwater from streets into receiving bodies. In these systems, stormwater is taken from urban areas and routed through wastewater treatment plants (WWTPs), where it is treated along with sanitary waste. WWTPs do not have the capacity to treat an unlimited quantity of influent, and so during large storms these combined sewers will be routed around the WWTP directly into the environment, in an event known as a "combined sewer overflow" (CSO). CSOs are problematic because they introduce raw sewage into the environment, which increases pathogen levels and can lead to negative health impacts or waterways and beaches being closed due to high bacteria indicator levels.

   The City of Toronto Wet Weather Flow Management Plan [13] has identified eliminating CSOs as a priority, and has several projects underway to meet this goal. LIDs, by reducing the total quantity of runoff delivered to combined sewers, work to prevent CSOs and have been identified by the City as an important part of the CSO solution. Modelling of CSO reduction through the use of LIDs is able to identify what LID technologies should be installed and prioritize watersheds where LID installation would be particularly effective [14]. This task will involve stormwater modelling to identify how the City of Toronto can use LID technologies to reduce CSOs and provide an estimate of the overall cost-benefit analysis of these projects. The report should also provide a recommendation of how the City can best eliminate CSOs.

References

[1] I. van der Veen and J. de Boer, “Phosphorus flame retardants: Properties, production, environmental occurrence, toxicity and analysis,” *Chemosphere*, vol. 88, no. 10, pp. 1119–1153, Aug. 2012.

[2] H. M. Stapleton *et al.*, “Novel and high volume use flame retardants in US couches reflective of the 2005 PentaBDE phase out,” *Environ. Sci. Technol.*, vol. 46, no. 24, pp. 13432–13439, 2012.

[3] R. Sühring *et al.*, “Organophosphate esters in Canadian Arctic air: occurrence, levels and trends,” *Environ. Sci. Technol.*, vol. 50, no. 14, pp. 7409–7415, Jul. 2016.

[4] J. Guo, M. Venier, A. Salamova, and R. A. Hites, “Bioaccumulation of Dechloranes, organophosphate esters, and other flame retardants in Great Lakes fish,” *Sci. Total Environ.*, vol. 583, pp. 1–9, 2017.

[5] C. C. Carignan *et al.*, “Urinary Concentrations of Organophosphate Flame Retardant Metabolites and Pregnancy Outcomes among Women Undergoing in Vitro Fertilization for the EARTH Study Team,” *Environ. Health Perspect.*, vol. 125, no. 8, p. 8, 2017.

[6] M. Behl *et al.*, “Use of alternative assays to identify and prioritize organophosphorus flame retardants for potential developmental and neurotoxicity,” *Neurotoxicol. Teratol.*, vol. 52, no. September, pp. 181–193, 2015.

[7] Environment and Climate Change Canada, “Risk Management Scope for 2-propanol, 1-chloro-, phosphate (3:1) (TCPP),” 2016.

[8] T. F. M. Rodgers, J. W. Truong, L. M. Jantunen, P. A. Helm, and M. L. Diamond, “Organophosphate Ester Transport, Fate, and Emissions in Toronto, Canada, Estimated Using an Updated Multimedia Urban Model,” *Environ. Sci. Technol.*, vol. 52, no. 21, pp. 12465–12474, Nov. 2018.

[9] C. Yang *et al.*, “Are cell phones an indicator of personal exposure to organophosphate flame retardants and plasticizers?,” *Environ. Int.*, vol. 122, no. May 2018, pp. 104–116, 2019.

[10] D. Mackay, *Multimedia Environmental Models: The Fugacity Approach*, Second. Boca Raton: Lewis Publishers, 2001.

[11] C. J. Walsh, A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan, “The urban stream syndrome: current knowledge and the search for a cure,” *J. North Am. Benthol. Soc.*, vol. 24, no. 3, p. 706, 2005.

[12] L. M. Ahiablame, B. A. Engel, and I. Chaubey, “Effectiveness of low impact development practices: Literature review and suggestions for future research,” *Water. Air. Soil Pollut.*, vol. 223, no. 7, pp. 4253–4273, 2012.

[13] Toronto Water, “2017 Wet Weather Flow Master Plan Implementation,” pp. 1–43, 2017.

[14] W. C. Lucas, “Design of Integrated Bioinfiltration-Detention Urban Retrofits with Design Storm and Continuous Simulation Methods,” *J. Hydrol. Eng.*, vol. 15, no. 6, pp. 486–498, 2009.

Understanding Uncertainty in Engineering – Known vs Unknown Unknowns

Learning Outcomes:
- **Learn to identify known-knowns, known-unknowns and unknown-unknowns**
- **Apply knowledge of problem type framework to solving a problem**
- **Identify and categorize important variables to a problem as known/unknown knowns**
- **Know the difference between variability and uncertainty**

Supplies list: Power Point slides, names of case studies & case studies describing situations (different environmental problems like ocean acidification, ozone layer depletion, etc.), chart paper, markers
Setting: Group-based lecture hall (akin to MY370) with students arranged at tables in groups of 7/8 for a total group size of ~ 50. 80-minute lecture.

Time	Activity/Topic
5 mins	**Review** (using Powerpoint): Review the Cynefin framework for classifying & solving problems: • Complex – solve through a “probe-sense-respond” framework • Complicated – sense-analyze-respond • Chaotic – act-sense-respond • Simple – Sense-categorize-respond Discuss how the different frameworks can apply to different environmental problems, and how each of them have different data requirements with different uncertainties.
15 mins	**Introduction** Introduce the concepts of “known-knowns, known-unknowns and unknown-unknowns”. Then, introduce an example problem – the room is too warm. Ask the students to identify what type (simple) of problem it is, then determine what the variables are that could impact the temperature – e.g. air exchange rate, thermostat set-point, distance of planet from the sun, time of year, number of people in the room. Have students classify these (mostly known-unknowns), then discuss what possible ranges could be for the input variables. Discuss that something like season might represent variability, while the accuracy thermometer in the thermostat is an example of uncertainty. Mention that we will focus on the most important variables – we will call back to this for a future discussion of model sensitivity
35 mins (~5 mins)	**Case Study** Have students look at the names of the case studies (place on tables before lecture) and have students brainstorm individually & silently as to what they think the important variables are for their case. Meanwhile, the instructor will hand out the chart paper and markers and at the end of the 5 minute brainstorming give each group the case study backgrounder, which will provide a little more information as to what is important for the cases.

(10 mins) (20 mins)	On one side of the chart paper, have the students write down all of the variables they can think of in three categories (known-knowns, known-unknowns and unknown-unknowns). On the other side of the chart paper, have them try to work out a rough model of how the system works, using the variables they have identified. How will variability or uncertainty in each of the input parameters impact the model result?
15 mins	**Group-to-group Discussion** Have each of the groups present their models to one other group, for ~5 minutes each. After each group presents, have them discuss the problem for ~2 minutes to try to see if they left anything out
10 mins	**Overall Discussion & Take-aways** Ask the students if anyone managed to identify any “unknown unknowns”. Talk about how these are the hardest to identify, and how by their very nature they often can’t be planned for. An example for the “room is too warm” problem could be a meteoroid strike – the room would get way too hot very quickly. Re-iterate how being able to quantify uncertainty is important, but show how you can only do a good job of quantifying uncertainty for some of the “known-unknowns”, while for others even if you know that you don’t know it, it can be hard to quantify. Re-iterate the importance of choosing the most important variables, which we will discuss in next week’s class on model sensitivity.

Case Study: A Silent Spring – Persistent Organic Pollutants & Bird Mortality

In the 1962 Rachel Carson published the novel “A Silent Spring”, describing a spring where no birds were singing due to chemicals pollution. This novel was based on problems associated with Dichlorodiphenyltrichloroethane (DDT); an insecticide widely used at the time the novel was published. DDT is an example of a persistent organic pollutant (POP), which are compounds that fit the PBT criteria: they are resistant to degradation (persistent, P), are lipid-soluble so tend to accumulate in living organisms (bioaccumulate, B) and have some toxic (T) effects. DDT caused the shells of birds eggs to thin, which caused them to be crushed by incubation. This devastated many species of birds including many of the larger raptors, such as bald eagles and peregrine falcons, as DDT bio-magnifies in food chains.

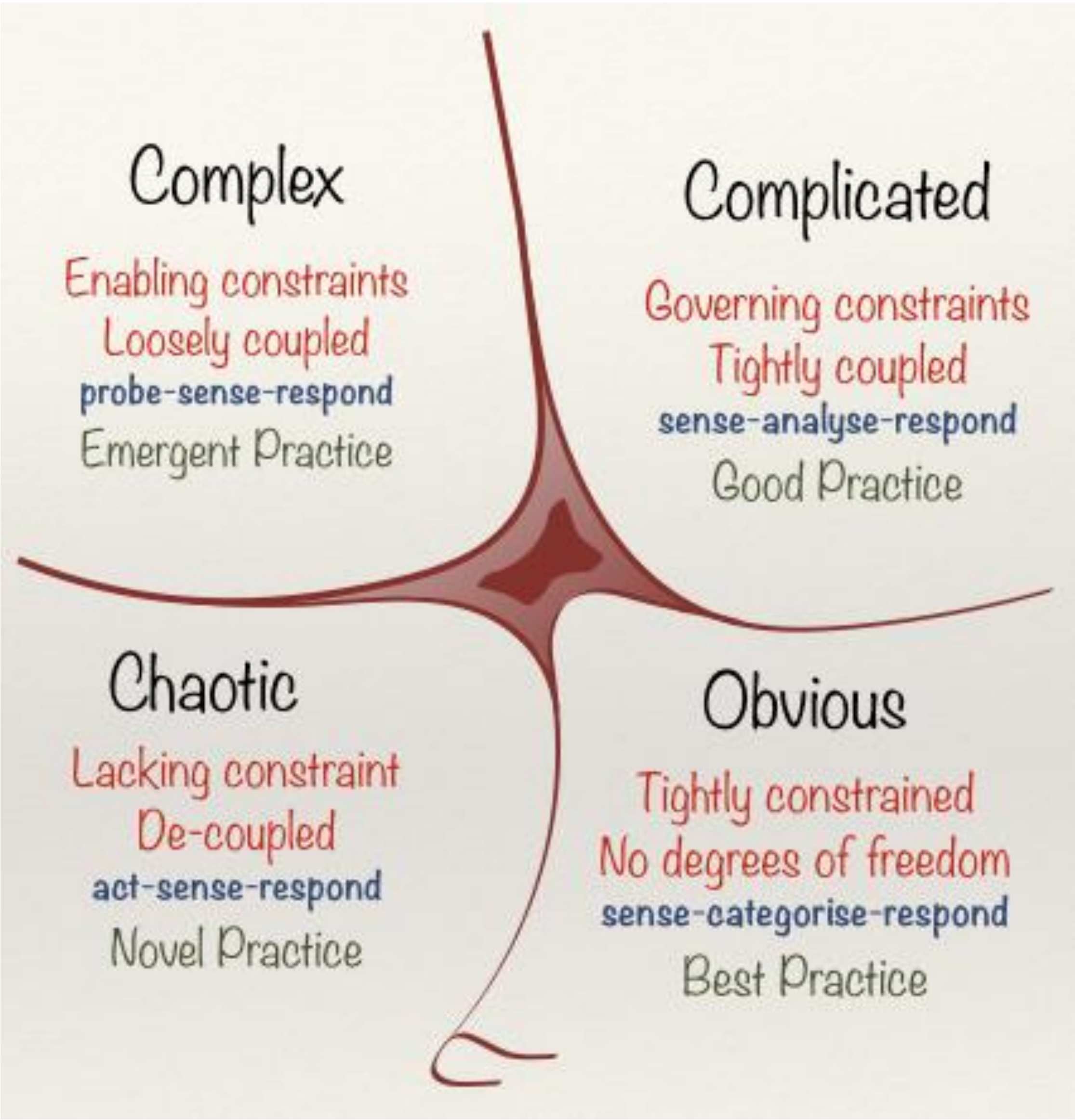
Know What you Don’t Know: Types of Uncertainty

Uncertainty in Environmental Engineering

Tim Rodgers

Review – Types of Problems

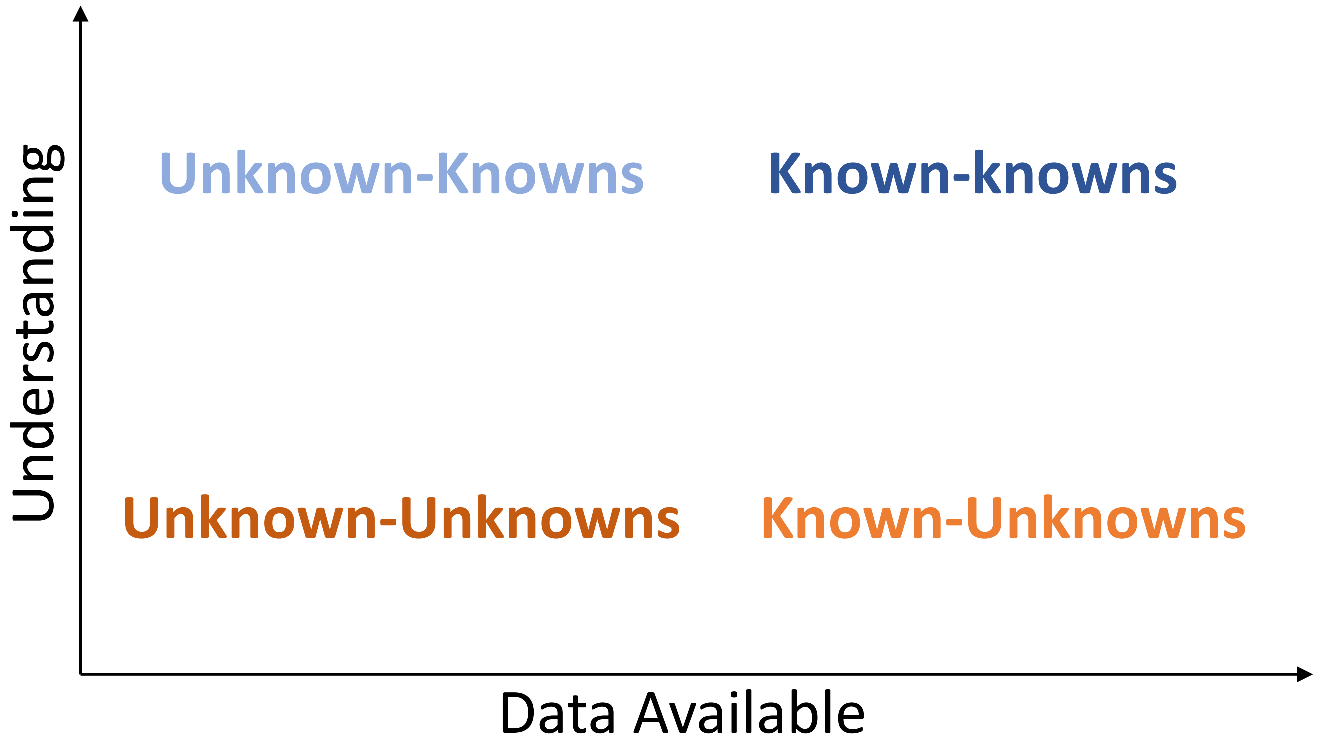
- Knowing the problem – first step towards a solution!
- Each type of problem has a type of solution
- To go from problem definition to a working solution need to determine what variables control the outcome
- Each variable is typically uncertain



https://upload.wikimedia.org/wikipedia/commons/1/15/Cynefin_as_of_1st_June_2014.png

Introduction - Types of Uncertainty

- Four classes of unknowns
  - Not always a clear line between



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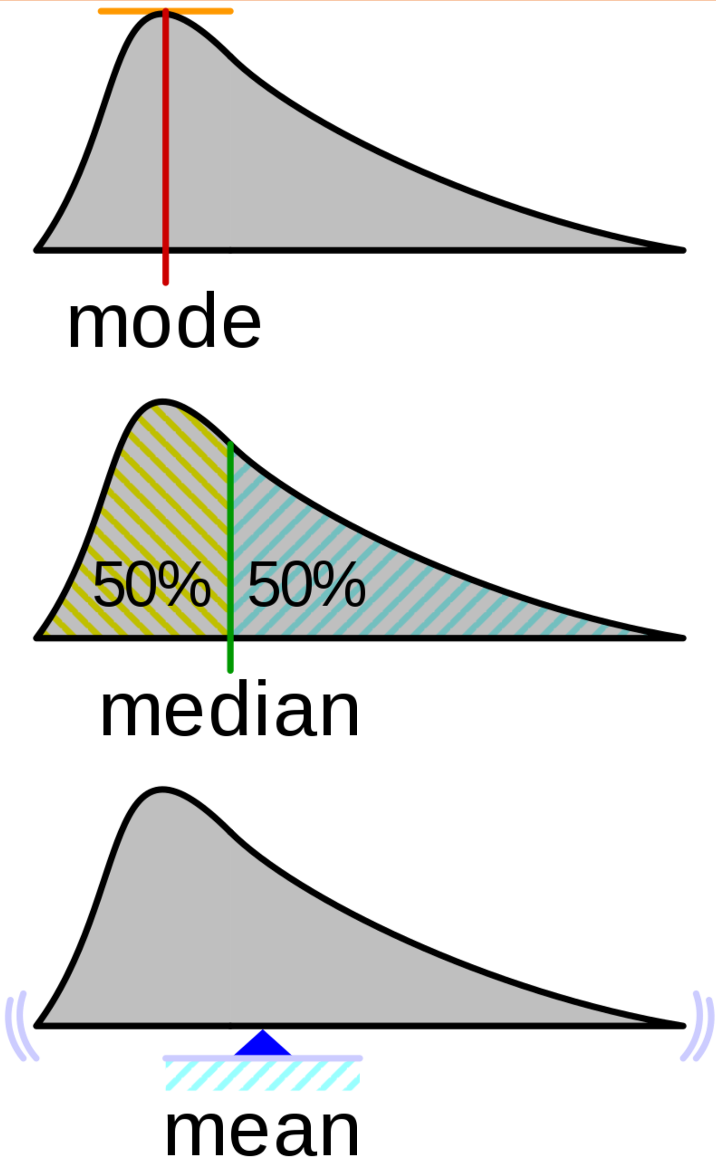
Types of Uncertainty "Known-Unknowns" & "Known-Knowns"

- Everything is uncertain!
  - Some things are more uncertain than others
- A **Probability Density Function** (PDF) contains all the information about the uncertainty of a variable
- If you can define the PDF – "**Known-Unknown**"
  - Sometimes you can only estimate the PDF
- If the uncertainty is negligible – "**Known-Known**"



https://upload.wikimedia.org/wikipedia/commons/thumb/3/33/Visualisation_mode_median_mean.svg/800px-Visualisation_mode_median_mean.svg.png

Types of Uncertainty “Unknown-Unknowns”& “Unknown-Knowns”

- **Unknown-Unknowns**
  - Difficult or impossible to define a PDF for an identified unknown
  - Impossible to account for
  - Only shown to matter in hindsight
  - Very hard to deal with

- **Unknown-Knowns**
  - Could be accounted for but were missed
  - Brainstorming & thorough problem definition helps minimize these

Example Problem – Warm Room

1. Define problem types

2. Determine relevant variables – build conceptual model

3. Classify variables – which ones are important?

Case Studies

1. Define problem types

2. Determine relevant variables – build conceptual model

3. Classify variables – which ones are important?

Case Studies – Present to you neighbours!

1. Find another group

2. Present your model & associated variables for 5 minutes

3. Discuss for 2 minutes – what did you miss?

4. Switch and repeat!

Take-Aways

- Important to quantify uncertainty
    - Impossible to be comprehensive

- Next lecture – determining the importance of variables to your model!