Developing Effective Dialogue between Practitioners of Climate Change Vulnerability-Risk Assessments

A Primer for Understanding Concepts, Principles and Language Use Across Disciplines

B.C. Ministry of Transpiration and Infrastructure

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Notice to Reader

This Primer outlines concepts, principles and language terms used across disciplines that have led to communication issues on climate change vulnerability-risk assessment projects. This Primer is not intended to be a glossary of technical expressions and terms but indicates where misunderstanding in communication can occur and where definitional clarity may be required. We anticipate that the list will grow over time as practitioners continue to work together on assessing climate change vulnerability risks.

Practitioner teams are encouraged to openly discuss the use of concepts, principles and language by the various professionals on the team as early in the project as possible. Furthermore, as interdisciplinary teams expand to include additional professional groups such as architects, accountants, lawyers, asset managers and others, we recommend expanding this document to include concepts, principles and language used by these professionals in their execution of vulnerability-risk assessments.

Over the course of an assessment it is common for communication issues to arise amongst team members. In our experience, much of this can be resolved by examining how the team members involved may be applying concepts, principles and language in differing ways.

This Primer is intended as a resource in discussions, and to be consulted as to individual topics, when situations arises that require understanding where communication may require clarity. Teams must be comfortable to challenge each other to define the meaning of their concepts, principles and language as applied within the context of the assessment.

Many generalizations are used to simplify and accentuate communication contrasts that may be encountered with multi-disciplinary teams involved in climate vulnerability risk work.

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1 Introduction

The BC Ministry of Transportation and Infrastructure (BCMoTI) has engaged in a number of projects to determine vulnerability-risk to transportation infrastructure in BC from future changes in climate. The intent of these projects is to understand potential risks to the transportation system and develop adaptation measures to address potential issues. During these projects, misunderstanding sometimes arose when communicating information because of cross discipline use of concepts, principles and language. These sometimes have differing interpretations depending on the practitioner, profession and discipline involved.

This project benefited from partnering with Natural Resources Canada under their Adaptation Platform intended to advance adaptation to climate change in Canada.

One element of this initiative was to develop a guideline to help communicate effectively when working on climate change engineering vulnerability-risk assessments. Experience has shown that individuals may understand concepts, principals and language differently across disciplines. While individuals may be comfortable with the use of concepts, principals and language within their own discipline, issues can arise without an understanding of how these concepts, principles and language may be used by others. Understanding these differences can improve discussions, teamwork and results.

Previous experience has shown that misunderstandings in concepts and language can lead to delays, scope creep and other issues. While it can be a challenge for risk assessment participants to develop communications early in a project, it is critical that those involved develop an understanding of each other's concepts, principles and language, as this is a key ingredient for a successful project. Once parties understand the vernacular of other participants, progress is easier to achieve. To facilitate this, we have developed this document to help focus discussions and come to a common understanding of concepts, principles and language used by various groups engaged in a climate change vulnerability-risk assessment.

It is clear that many players are required to execute a climate change vulnerability-risk assessment. For example, the engineering professional brings experience in designing, managing, operating and maintaining infrastructure systems under various climate conditions especially extreme weather conditions. They know how a particular facility will respond to extreme weather events and they have a fundamental knowledge of what kind of climate and weather information they need to evaluate infrastructure responses to these events.

Another group, the climate scientists, have expertise in working with climatic data and the various models and statistical approaches that are necessary to ensure that robust climate projection information is applied within an assessment. They are key players in ensuring that climate data integrity is maintained throughout the project leading to robust and scientifically defensible assessment outcomes.

Clearly groups must learn to communicate their needs and approaches to each other in a timely and efficient manner. We have no expectation that disciplines change their internal use of concepts and language. However, we suggest that practitioners must be sensitive to the nuances of how others may use similar concepts, principles and language and how these nuances may lead to differing interpretations and meanings.

This Primer attempts to address these issues and offer concepts, principles and language and approaches to clarify and streamline communication for vulnerability-risk assessment teams.

2 Disciplinary Cultures

Each discipline operates under its own unique set of professional expectations. These may or may not be codified in standards and guidelines, but they are nonetheless very real and place upon the professions cultural demands that translate into accepted behaviours, jargon and standards. To individuals within these areas of practice, these cultural values are transparent and they may consider them to be the very definition of professionalism, not only within their own profession, but generally.

In the following sections we outline the underlying cultural values that can operate within different groups involved in a climate change vulnerability-risk assessment process. With a clearer understanding of the cultural milieu within which individuals within disciplines operate, it will be easier for practitioners on climate change vulnerability-risk assessments to better cope with the diverse sets of pressures and expectations that may apply.

2.1 Engineering

Engineers, for the most part, are ***applied scientists***. Applied scientists use the results from basic research to develop practical solutions for identified problems. Engineers work in a world where almost everything must be translated into pragmatic application of:

- Science;
- Management; and
- Social, environmental and economic analysis.

They are very practiced at balancing competing pressures but uppermost in their mind is assurance of the public welfare.

Engineers Canada defines the practice of engineering as follows:

> *The "practice of professional engineering" means any act of planning, designing, composing, evaluating, advising, reporting, directing or supervising, or managing any of the foregoing, that requires the application of engineering principles, and that concerns the safeguarding of life, health, property, economic interests, the public welfare or the environment.*[1]

[1] Canadian Engineering Qualifications Board, ***Guideline on the Practice of Professional Engineering in Canada***, Engineers Canada, 2012

These factors have a significant bearing on the way engineers practice their profession and the language that they use to communicate with each other.

As members of a regulated profession, engineers must adhere to a written code of ethics. Engineers Canada provides guidance on the content of this code and the provinces and territories adopt the code, sometimes with modifications to accommodate regional considerations. The Engineers Canada Guideline on professional practice provides the code presented in **Table 2.1**.

Table 2.1: The Engineer's Code of Ethics[2]
1. Hold paramount the safety, health and welfare of the public and the protection of the environment and promote health and safety within the workplace; 2. Offer services, advise on or undertake engineering assignments only in areas of their competence and practice in a careful and diligent manner; 3. Act as faithful agents of their clients or employers, maintain confidentiality and avoid conflicts of interest; 4. Keep themselves informed in order to maintain their competence, strive to advance the body of knowledge within which they practice and provide opportunities for the professional development of their subordinates; 5. Conduct themselves with equity, fairness, courtesy and good faith towards clients, colleagues and others, give credit where it is due, and accept, as well as give, honest and fair professional criticism; 6. Present clearly to employers and clients the possible consequences if engineering decisions or judgments are overruled or disregarded; 7. Report to their association or other appropriate agencies any illegal or unethical engineering decisions or practices by engineers or others; 8. Be aware of and ensure that clients and employers are made aware of societal and environmental consequences of actions or projects and endeavor to interpret engineering issues to the public in an objective and truthful manner; and 9. Treat equitably and promote the equitable treatment of all clients, colleagues and coworkers, regardless of race, religion, gender, sexual orientation, age, physical or mental ability, marital or family status, and national origin.

[2] Canadian Engineering Qualifications Board, ***Guideline on the Code of Ethics***, Engineers Canada, 2012

Engineers' formative training included many sessions on the code of ethics. They are required to complete written examinations on these matters as part of their registration into the profession. As a consequence, the average engineer fundamentally believes that every professional, regardless of their discipline, must adhere to the same standards of practice.

Engineers are very comfortable with the concept of peer review. However, as applied scientists, they are not as interested in the purity of the science, that is, getting the precisely correct answer. Within engineering practice, peer review is generally applied in the sense of improving the quality of a design or report, assurance of compliance with codes and standards, or providing certification.

This is much more a process of assessing the professional practices applied to a project and much less one of proving a scientific principle. It is common for engineers to go over each other's work and sign-off on the professional integrity of the process. When they do so, they are staking their license on their opinion and are therefore very careful about what they offer as professional judgement. In essence, engineers are looking for a scientific foundation that is ***good enough*** to support their activities and assure public wellbeing.

As long as they understand the strengths and weaknesses of a particular scientific fact, or have assurance from others who are qualified to offer these judgements, engineers are very comfortable with proceeding on an initiative while adding appropriate safety margins and contingencies. These processes are ingrained in the professional culture. In day-to-day practice some engineers may not immediately identify that other professionals may be operating within completely different professional/cultural environments.

Ultimately, engineers are driven by a number of principles that can be simply stated. Engineering initiatives should be:

- Safe;
- Environmentally sound;
- Functional;
- Reliable;
- On time; and
- On budget.

While the engineer's practice is founded on science, the fundamental characteristic of the profession is application and, provided that appropriate safeguards are employed, they will accept less than perfect information to advance a project to completion.

2.2 Climate Science

Climate scientists, for the most part, are ***pure or basic scientists***. They pursue development and establishment of information to aid understanding. In essence, their primary mission is the pursuit of truth. Climate scientists work in a world where everything must withstand the scrutiny of their colleagues, not only within their own institutions, but also throughout the entire community of climate experts. They are very practiced at balancing competitive or alternative interpretations of their data and comfortable with processes that scrutinize every nuance of their work. In the end, they are pursuing the right answer to the questions they are evaluating. Timelines and budgets, although a normal part of their institutional culture, will often take a back seat to the pursuit of truth and correctness.

As a result, peer review for a climate scientist is a very different process than it would be for an engineer. For a climate scientist, peer review is the process of subjecting an author's scholarly work, research, or ideas to the scrutiny of others who are experts in the same field, before a paper describing this work is published in a journal. The review evaluates the basic, fundamental, correctness of a piece of work based on differing perspectives throughout the community of experts. The process does not evaluate, to the same extent, the overall veracity of the scientific method applied or the economic and social implications of the findings. It is sufficient to prove that the findings are generally correct.

Generally, climate scientists do not work within a regulated profession. For example, there are strict codes of conduct for a scientist regarding plagiarism, but they are not generally codified in an overarching standard that applies uniformly across the entire discipline. More commonly, codes of conduct are stated as policies of the institutions for which they work.

Climate scientists develop information to aid understanding, prediction and perhaps explanation of phenomena in the natural world as opposed to engineers who develop interventions to alter events. In essence, scientists deal with concepts while engineers deal with the material word. Ultimately, climate scientists are driven by a number of principles that can be simply stated. Climate information should be:

- Correct;
- Defensible;
- Reproducible;
- Scientifically based;
- Robust in peer review; and
- Conceptually sound.

The climate scientist’s practice is based on scientific method. They work in a world where new discoveries or theories can fundamentally change the interpretation of their results and, for the most part, they are comfortable with this possibility, provided that they have followed a process that is founded on pure science and peer review.

2.3 Sources of Conflict and Misunderstanding

The cultures within disciplines can sometimes lead to conflict and misunderstanding among vulnerability assessment team members. Engineers will bring to bear on any project a sense of urgency based on schedules and budgets. They are willing to make concessions on the overall correctness of climate information provided that they receive information that is sufficient for the purposes of the assessment at hand. That is, they do not see climate information as a universal set of results that all meet the highest standards of precision and accuracy. They may sacrifice a certain amount of precision in aid of getting to reasonably accurate information that is of sufficient quality for the present project.

Experience has shown that some climate scientists may not appreciate the engineer's approach towards data and vice versa. Given time and resources climate scientists can provide much higher quality information that may be much more scientifically defensible. It can be a mystery to them that engineers on the team, operating under different drivers and circumstances, may not view this with the same level of enthusiasm.

Engineers, for their part, may struggle with the climate scientist's approach to schedules and budgets. They want the climate information within a very strict project schedule and it can be a mystery to them that the climate scientist is seemingly unwilling or unable to provide it in that fashion.

The result can be a bit of a push and pull regarding development and delivery of information and can create issues between team members.

These tensions can be avoided by encouraging teams to initially discuss concepts, language, principles, practices and timelines as applied to their project. The teams will operate better if there is an understanding of overall expectations and project requirements.

For the benefit of the project, it is helpful if early on, the team discusses these issues and establishes project guidelines that are explicitly understood by everyone on the team.

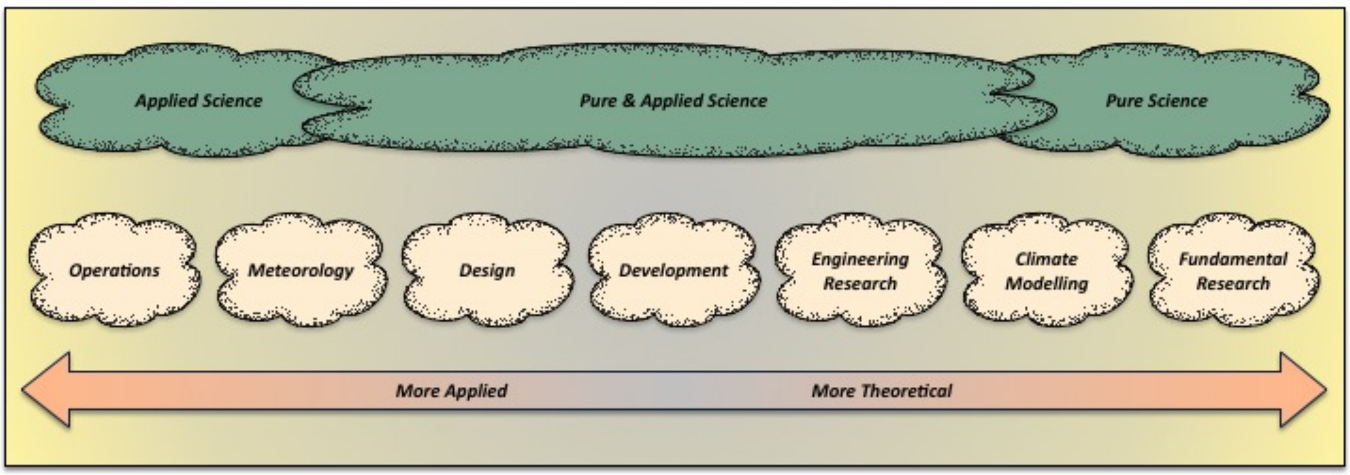
2.4 Boundary Conditions

This document identifies the communication boundary conditions often encountered within groups of professionals. Obviously, generalizing the use of language and behaviors attributed to a group as a whole may not be accurate when attributed to individuals, who are all unique in their use of language, behaviors and attitudes.

There are engineers who will exhibit attributes more like the characteristics we attribute to pure scientists. This may often be the case for engineering scientists, researchers or academics that work in professional environments within research institutions. Conversely, some climate scientists may be much more applied in their approaches to their discipline. This may be observed with meteorological specialists, who must generate daily weather forecasts within limited timeframes and within very tight budget constraints.

In this regard, the behaviors described within this document represent the boundaries of a continuum. This continuum is illustrated in **Figure 2.1**. The professionals that come together to form a vulnerability assessment team, may come from anywhere across the continuum outlined in **Figure 2.1**. Often, the use of language, concepts and approaches will overlap between members of the team, but this does not mean that every member of the team is fully conversant with these approaches. For example, individuals on the more applied end of the continuum may have very little difficulty communicating key technical issues with each other, but they may encounter significant difficulties fully communicating nuances of their technical activities with individuals on the more theoretical end of the continuum.

Figure 2.1: Continuum of Disciplinary Approaches



In this document we have used the terms ***"engineer"*** and ***"scientist"*** as a convenient categorization to describe the boundary conditions. We do this because many engineers tend to work on the more applied end of the continuum, while many scientists tend to work on the more theoretical end of the continuum.

These generalizations may or may not apply to the behaviour of individual practitioners within each group. Furthermore, we have observed that individuals may unintentionally shift from formally correct technical language to looser more common language dependent on the tasks they are performing.

The language described in the following sections may appear somewhat loose or informal to some readers. This looseness of language is driven by the phenomenon we are describing. We must describe how the language is used during informal conversation or differently between disciplines and this drives us to outline definitions that are not, in the strictest sense, correct. Common, informal, language often lacks the precision of strict, technical definitions.

It is precisely this lack of precision in language use and the different use of language across disciplines that we aim to address with this document.

The key is for practitioners to recognize that professional approaches and language use may vary across a team.

It is important to make an effort to identify where gaps in communication or professional culture can lead to conflict within the team.

This document is provided as an aid to communication within diverse teams. It is not a definitive description of definitions used in professions, cultural values or explicit approaches.

3 Common use of Concepts, Principles and Language within Disciplines

In aid of creating effective dialogue for team members, we have developed a lexicon of terms containing concepts, principles and language that may require examination for definitional differences among disciplines. By this, we hope to provide context for discussions aimed at identifying the differences in concepts, principles and language that may be encountered on a project.

For each term we provide a thumbnail sketch of how the terminology may commonly be used and the potential sources of confusion and conflict. ***We stress that these thumbnails are generalizations and that them may not reflect the actual technical definitions applied within professional groups.*** Not every practitioner may use the terms the way described and, when speaking formally, the actual definitions applied within a profession may be quite consistent. Rather, these thumbnails are presented to identify how the concepts, principles and language may be used in ***informal*** ways during discourse between professionals and how misunderstandings may result in communication breakdowns on vulnerability assessment teams.

The terms discussed in the following sections do not represent a set of technically accurate definitions.

They reflect observations of how members of vulnerability assessment teams have commonly used these terms during actual projects and how this informal use of language may have lead to misunderstandings between team members.

3.1 Accuracy

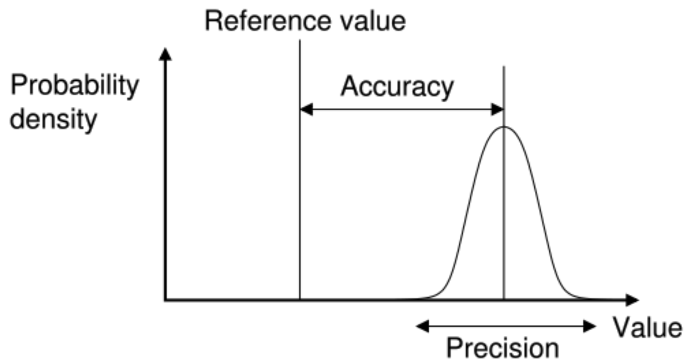
More Applied	More Theoretical
Typically engineers will use the words accuracy and precision interchangeably in their day-to-day work.	The degree of closeness of measurements to the actual or true value.

Potential Source of Confusion

An engineer may request precise information when they are actually requesting the scientist to provide accurate information. In most circumstances the engineer will actually be looking for data that is sufficiently accurate within the context of the whole range of data available to the assessment. They may not need very precise information at all and may be able to conduct their work with higher levels of uncertainty than the scientist may be comfortable providing. Generally, the engineer will be looking for information that is sufficient for their purpose, and will establish acceptable levels of precision and accuracy based on that purpose. Often increased precision comes at a cost that may well exceed the resources available to the assessment team.

In **Figure 3.1**, we present a strict definition of precision and accuracy. This is the way a scientist may more likely understand the terms, especially in professional discourse.

Figure 3.1: Statistical Definitions of Precision and Accuracy



On the other hand, engineers may more easily understand the use of the language based on the dartboard analogy presented in **Figure 3.2**.

Figure 3.2: Dartboard Analogy - Definition of Precision and Accuracy

3.2 Adaptation

More Applied	**More Theoretical**
An engineer may refer to adaptation with respect to adapting a specific engineered system or management process to anticipated	The scientist may think more broadly and include within their definition social and ecological adaptation processes.

changes. Broader social or ecological adaptation options may not explicitly be included, except under professional practice obligations, or if these are specifically included within the scope of a project.

Potential Source of Confusion

The engineer may perceive that the scientist is thinking too broadly and out of scope. The scientist may perceive the engineer to be too narrowly focussed. To avoid this confusion the assessment team should clearly define the overall scope of the project. Both views of adaptation are valid. Issues arise when team members make assumptions regarding what's in and what's out of the assessment processes.

3.3 "A Number"

More Applied

Often engineers will ask the scientist to provide them with one number that they can use to establish the climate threshold for an engineering design. They are seeking a parameter such as a 1 in 100 year storm event value or a percentage change that they can use in engineering calculations.

More Theoretical

The climate scientist works with multiple models and assumptions that all yield potentially reasonable results. Their work generates ranges of conditions that, within defined parameters, all provide rational trends of future climatic conditions. They may not be professionally comfortable with providing a single value to describe these potential future outcomes.

Potential Source of Confusion

While engineers may be looking for a single parameter to describe the future climate, the scientist may be very uncomfortable with synthesizing the outputs from multiple models into one single value.

Engineers have a great deal of experience working with ranges of numbers in other areas of their professional practice – consider, for example, the large number of iterations and sensitivity analyses that they will often employ to establish project economic forecasts based on varying market price analyses.

Engineers must incorporate different types of climate information in their work. Historically, climate design parameters have not been based on a single observation. Meteorological information is based on years of hourly observations and the profession applies a significant level of professional judgment to establish "safe" climate-based design margins. Engineers frequently use ranges and apply professional judgment to establish these margins – this is a standard professional engineering skill set.

On the other hand, the scientist will focus on providing a robust range of climate projections based on their knowledge of the strengths and weakness of the models they apply. Furthermore, they will assess assumptions based on the greenhouse gas projections used as inputs to the models. They will wish to ensure that they provide the engineer with a range of values that has the highest likelihood of containing the "true" future climate based on their professional assessment of the assumptions and computational methods imbedded in the models.

It is important to understand that each professional will apply the unique standard approaches of their disciplines. Teams must rely on the range of skill sets represented within the group. In this context, the scientist will normally be most comfortable providing ranges of future climate projections. The engineer will normally have the training and skills necessary to synthesize that information into parameters that are meaningful within the context of the particular engineering design and anticipated operating conditions.

It is not generally reasonable for the engineer to require the scientist to apply engineering judgment to establish these parameters, as the training necessary to do this rests with the engineers at the table. Conversely, the scientist must accept that the engineers will "manipulate" the climate information into formats that are relevant within the context of the current assessment or project.

Some confusion could be avoided here if scientists understood more about which number the engineer requires in a given circumstance. Scientists try to quantify uncertainty as a range of plausible values, sometimes with estimates of associated likelihoods. A more precise question might be to ask for a number that is unlikely to be exceeded with a specified likelihood.

3.4 Calibration

More Applied	**More Theoretical**
Creating a reproducible correlation between a reference point and a set of data or projections. Once calibrated, measured data may be used to extrapolate to a reference value.	The scientist will use the term calibrate to refer to specific activities involving impacts models or sub-grid parameterizations. Typically, they will refer to "validation" when they are discussing agreement between model outputs and the meteorological record.

Potential Source of Confusion

Climate models function in a way that is fundamentally different from most other types of models that engineers work with. The equations of motion do not change and do not require calibration.

It is not uncommon for an engineer to request that the outputs from climate models be calibrated. They are actually requesting that the outputs be "ground truthed" against the meteorological record at the infrastructure's location. They are hoping to gain some insight into the veracity of the model information based on the model's ability to "reproduce" the historical climate as documented in the meteorological record.

However, the scientist may actually hear a request that they provide information on the precision of the model runs. That is, do models agree with each other or can the same model provide the exact same outputs on multiple runs? The scientist will typically say that this cannot be done.

This comment will, more often than not, cause the engineer much concern. *"If the model cannot give a reasonable indication of the historic climate, how can we trust it to give a good prediction going forward?"* If both the scientist and engineer use expressions such as "ground truth" or "validate" they will find that they are both keenly interested in testing climatic models against the historic record. This is something the engineer wants to see and something that is also standard practice in climate science.

3.5 Climate

More Applied

Within professional practice engineers may not make clear distinctions between climate and weather. They tend to use the words interchangeably.

More Theoretical

Climate is the statistics of weather events. The term weather is used to describe discrete events in place and time.

Potential Source of Confusion

The engineer may request climate data when they actually need data for extreme weather events. Typically, the engineer will be looking for information on discrete weather events, such as extreme high temperatures that may be anticipated over a defined period in a particular location. They are interested in how the future climate will create discrete events that may exceed infrastructure design values or what future values may be in order to design for these events.

While means and variances may help the engineer put the information into context, ultimately they will focus on whether the infrastructure in question will experience conditions that will exceed physical threshold values over the anticipated useful life of the system.

3.6 Confidence

More Applied

The overall comfort with a set of data. This goes beyond the statistical variance and

More Theoretical

Typically, the scientist will rely on statistics to articulate their confidence in climate encompasses the entire process of generating the data, including the veracity of the stated and unstated assumptions. The less confidence the engineer has in a data set, the more safety margins and contingencies they will add to a project.

information. They are focussed on their ability to reproduce results and will tend to view confidence as a measure of whether or not multiple lines of evidence point to a consistent result.

Potential Source of Confusion

Experienced engineers will wish to evaluate the overall process of data creation with specific emphasis on the assumptions and professional qualifications of the individuals generating the data. They may actually ask the scientist to offer an opinion regarding the overall veracity of the data and may express frustration if the scientist points to the variance of the data set and the differences between the models used to arrive at the data.

The engineer wants to know if the scientist would trust a piece of infrastructure designed on the basis of the information the scientist has provided. The may ask – *"Would you stake the safety of your family on the veracity of the data?"* Generally, engineers are trained to evaluate information in this fashion, apply professional judgment, and state an overall level of comfort with the data, assumptions and resulting designs.

3.7 Confidence Interval

More Applied

Engineers will use the term confidence interval to describe the range of a data set based on statistical analysis. For example, they may refer to 95% confidence intervals for a particular data set.

More Theoretical

Scientists will typically use confidence intervals when reporting historical trends, and in that case use confidence intervals in a manner consistent with engineers. However, when a range of projected climate change is given, an engineer may interpret this as a confidence interval when instead what is being provided is a range of changes that are equally likely.

Potential Source of Confusion

Confusion may arise when the engineer applies traditional statistical approaches to climate forecast ranges, for example, averaging the results from an ensemble of climate forecasts. The scientist will object to this approach, as each model included within the ensemble represents one likely future climate condition. While simple statistical analysis may be appropriately applied to the meteorological record, it may not yield the robust future climate projection that the engineer expects if applied to climate change model ensembles. The scientist will object to this approach. This may turn into a circular argument as the engineer requires "a number" to work with while the scientist insists on providing ranges of equally likely future climate conditions.

The key to solving this dilemma rests in professional dialogue and the application of robust professional judgment. The engineer will provide the intimate knowledge of engineering design to the dialogue and the scientist will provide the robust background in climate modelling.

The engineer must step away from applying simple statistical approaches and apply a considerable level of professional skill and experience to synthesizing the information into a format that is relevant within the context of the current project or assessment. The scientist must provide the insight into the nuances, strengths and weaknesses of each model projection to guide the engineer's professional judgment.

For example, in some cases the team may decide that the most appropriate parameter would be from the high end of an ensemble of projections while in other cases the team may choose parameters more in the mid-range of the ensemble. As well, as certain models project more robust results for particular climate parameters, the team may assign more weight to the projections from those models with respect to those parameters.

The professional judgment of the team must guide these deliberations. In the end, it is critical that the teams document the basis for their judgment and, in some cases, the ranges of parameters that were considered. It may be necessary to conduct sensitivity analysis to finally resolve a parameter, or in some cases, identify additional work outside of the current project or assessment that will be necessary to finally resolve the issue.

3.8 Conservative

More Applied	More Theoretical
A design or estimate that contains an explicit or implied factor that ensures that a system will perform according to specification under all reasonable conditions.	Selecting a value that is somewhat less than the highest point in a data range. A conservative estimate will ensure that the value is covered by entire range of data quoted. Where a scientific basis does not exist for an estimate, the scientist will tend to exclude that information.

Potential Source of Confusion

Typically, when an engineer is talking about conservative estimates, they are looking at the situation from the frame of reference of the infrastructure. That is, has the design provided sufficient safety margins to ensure that the infrastructure does not fail, even if operating conditions approach the design threshold? On the other hand, the scientist will typically discuss conservative from the frame of reference of the data. That is, can they be reasonably comfortable that the data that they provide is within the range of reasonable outcomes?

Scientists are much more concerned about the overall integrity of the data and not as much on the outcomes that may arise from using that data. In practice, an engineer may choose to use data on the extreme ends of a data set to cover worst-case scenarios while the scientist may choose data from the mid range to ensure that the value they provide is defensible within the overall range of data.

One major source of confusion is the scientist's tendency to exclude information where they have high levels of uncertainty or lack a precise basis for an estimate. For example, if the general consensus is that there will be sea level rise, engineers will almost always include a safety factor to accommodate that consensus within their design work. If they lack a clear basis for this factor, they will assign a value to account for the uncertainty based on professional judgment. On the other hand, the scientist having judged that there is insufficient evidence for an adjustment may simply be silent on the matter, as based on their expert judgment; the lack of sufficient evidence may preclude the use of such data in an analysis of "best estimate".

Once again the key to solving this impasse is communication amongst team members. The scientist must identify where they have excluded potentially relevant information. The engineer must learn to ask the scientist about areas where they might have excluded information. The engineer may be compelled to include arbitrary safety factors within their analysis and the scientist may be able to help guide the professional judgment necessary to arrive at these safety factors.

Both parties must work from the position that simply because a phenomenon is not measured does not suggest that it is not a real hazard leading to potentially significant risk outcomes. One clear outcome of this approach is that it will tend to identify where additional work or scientific study is necessary in order to better inform engineering decisions. In risk assessment, information gaps often represent significant risk drivers.

3.9 Correct Answer

More Applied	More Theoretical
A result that is sufficient for the purposes of the project.	An answer that is as close as possible to true.

Potential Source of Confusion

If an engineer can measure a critical parameter with accuracy and precision that is within required design requirements, results with higher degrees of precision and accuracy are typically of much less interest. For example, if they can measure temperature to ± 1 °C, they will not be particularly interested in spending time and resources to develop other data to ± 0.05 °C.

Generally, for engineers the question is whether the information is sufficiently precise for the intended purpose. For scientists, the purpose may not always be apparent, or there may be multiple potential purposes. A key consideration would be whether the "answer" is sufficient to allow a physical interpretation of the underlying causes of the phenomenon being investigated.

Another consideration might be whether the "answer" is good enough to determine, with reasonable confidence, that physical constraints (e.g., closure of energy and moisture budgets) are being satisfied, which in some circumstances might be what one wishes to know in order to conclude that the answer is "correct".

3.10 Data

<u>**More Applied**</u>	<u>**More Theoretical**</u>
Engineers will define almost any set of numbers and facts as data.	Values based on actual measurement. The scientist may call outputs from model runs "information" since these values are based on computational outputs and assumptions and not upon actual physical measurements.

<u>**Potential Source of Confusion**</u>

An engineer may ask for climate change data. This may create a sense of discomfort for the scientist, as they may have difficulty conceptualizing how they could extract actual, measureable, data from a model run.

3.11 Ensemble

<u>**More Applied**</u>	<u>**More Theoretical**</u>
Ensemble is not a word typically used in engineering practice. If the engineer contemplates the word, they would generally think of groups of performers. In terms of grouping results, engineers would be quite familiar with sets of data, but they would treat the set as a unified whole and would feel absolutely free to compute averages, interpolate and extrapolate within the data set.	The climate scientist will refer to an ensemble as a group of results from various different models and emissions scenarios. Ensemble averages may be used to report general changes. However, the scientist may advise practitioners to consider each model outcome individually and to be mindful of the influence of using ensembles that include different emissions scenarios.

<u>**Potential Source of Confusion**</u>

The engineer will want to crystalize information into a unique pattern or value. They are most concerned about particular parameters exceeding threshold values at some time during the anticipated service life of the infrastructure. They can find ensembles of results to be overly detailed and will ask for a "best estimate" for the parameters in question. This will be difficult for the scientist to provide, as each model and emissions scenario provides a unique, and equally likely, prediction of future climate. To compound matters, given the way that models are structured, it is possible that the same model, using identical input values, may provide slightly different projections of future climate conditions over a series of runs.

The members of an assessment team can alleviate some anxiety by having very explicit discussions regarding the assumptions inherent in different emissions scenarios and the strengths and weaknesses of the different models used to generate the ensemble. With this context, an experienced professional engineer can apply professional judgment to establish appropriate input information for an infrastructure assessment.

3.12 Forecast

More Applied

See Prediction

More Theoretical

See Prediction

3.13 Good Enough

More Applied

In engineering it is important that data be sufficient for its intended purposes. The pursuit of perfection in data can result in significant project delays and cost overruns. As a result, the engineer will consistently evaluate data to ensure that it meets the minimum quality requirements for a particular project. Once this is achieved they will constantly evaluate the cost and schedule implications of improving data beyond this point.

More Theoretical

Science is a constant search for truth. It is important for a scientist to assure themselves and their peer group that the data is a close to perfect as possible. They will face challenges on their approaches and outputs based on this kind of constant assessment.

Potential Source of Confusion

The scientist may view the engineers' approach to the information to be quite different than their own. On the other hand the engineer can perceive the scientist's approach to providing information to be overly cautious at the expense of timeliness and resources. As the information provided by the scientist is being applied for engineering purposes it is only important that it is sufficient to the purposes of the project and it does not need to be "perfect".

This may require an ongoing dialogue amongst team members to ensure that the information deemed to be "good enough" also be scientifically defensible within the context of the particular project or assessment and within the timelines and budgets available to complete the work. If the information is deemed to be scientifically weak, this may drive the team to make recommendations regarding future work and scientific analysis outside of the context of the current work.

3.14 Index

More Applied

Generally, the engineer will use the term index in one of two ways. First, they may refer to the index of an article or book – an alphabetical listing of key words and page locations within a document. Second, they may think of unit-less number values such as the Dow Jones Index. In engineering it is quite common to generate unitless ratios that can be used in a variety of ways. For example, the Vulnerability Ratio outlined in Step 4 of the PIEVC Protocol is a unitless index that is used to determine the relative vulnerability of an infrastructure component.

More Theoretical

The scientist may have a broader definition of the word index. First, they would agree with the engineer with respect to an index of a document. However, in technical applications they may define index more holistically. For example, they may refer to CLIMDEX indices, which are more detailed and inclusive than a simple unitless ratio.

Potential Source of Confusion

The engineer may expect to see a unitless ratio while the scientist is presenting much more detailed information. This may come into play when a scientist offers indexed climate information. The engineer may assume that they are being offered less detailed information than they may perceive they need. Once again this confusion can be minimized if both parties clearly define the scope of the project and the content of the information packages being requested or offered.

3.15 Information

More Applied

Facts and ideas conveyed in non-numerical formats. This can include, but is not limited to, word of mouth, pictures and charts.

More Theoretical

Values output from mathematical models. This can be a set of numbers with stated means and variances.

Potential Source of Confusion

The engineer will often refer to forecast climate data while the scientist is actually being asked to provide projected climate information.

3.16 Likelihood

More Applied

The engineer will tend to use the term likelihood to refer to general, or non-numeric, matters and use the term probability to refer to computed, or numerical, values.

More Theoretical

The scientist may rely more on the statistical definitions of likelihood and probability, where the terms may be used interchangeably.

Potential Source of Confusion

The engineer may ask for the likelihood of an event and expect to receive comments such as "highly likely", "unlikely", etc. Conversely, the engineer may be looking for a value such as the 1:100 year event. The scientist may perceive this to be a request for a statistical value and may be somewhat reticent about providing a number based on an ensemble of data with a high range of variability or uncertainty.

In many cases, the engineer may not need to know the probability with computational certainty. Rather, they may simply need to know that a trend that they are presently observing will "likely" continue based on the scientist's professional judgement. Parties should clarify the nature of the data that is being requested.

3.17 Mitigation

More Applied

An engineer, especially one experienced with risk assessment processes, will use the term mitigation to refer to the process of taking action to reduce identified risks.

More Theoretical

The scientist may refer to mitigation in the sense that it is used generally in climate change literature. They may tend to refer to mitigation as activities related to reducing greenhouse gas emissions.

Potential Source of Confusion

This is quite a common communication gap in climate change adaption and risk assessment. Generally, throughout the climate change community, mitigation is understood to be any activity related to greenhouse gas management. The use of the term as an activity to reduce an identified and very specific risk is not as common in the scientific community. Thus, the engineer may refer to mitigation activities in response to a vulnerability assessment and the scientist can perceive this to mean a broadening of the scope to include greenhouse gas management issues relative to the contemplated actions.

What the average engineer considers to be mitigation would normally be called adaptation in the climate change literature. The parties can alleviate this by discussing and agreeing to the definitions that they will be using during the execution of the assessment and by revisiting these definitions if, and when, confusion arises.

3.18 Normalize

More Applied

The engineer may use the term normalize in a very general or non-technical fashion. They may use normalize in the sense of aligning measured and reference data points, in the same sense that they may refer to calibration or the scientist may refer to validation.

More Theoretical

The scientist may use the term normalize in the sense of statistical data management techniques aimed at reducing the error associated with a data set. They may also refer to processes that are used to align different sets of data to a common mean and variance. The latter is similar to the approaches that may be applied to grade results from a class to align those results with a pre-defined mark distribution.

Potential Source of Confusion

The engineer may ask for information to be normalized when they are actually asking the scientist to validate the model outputs. The scientist may perceive this to be a request to complete a variety of statistical operations on the information with the aim of reducing variances or adjusting data sets to pre-defined variance ranges and mean values. The scientist may not be able to actually do the tasks that they perceive the engineer to be requesting. In fact, the engineer may actually be asking the scientist to provide information on validation of the model outputs, an activity that the scientist may have completed already as part of their routine analysis.

3.19 Parameter

More Applied

Typically, the engineer may refer to design parameters. Generally, they would use the term to cover fixed design threshold values. Less commonly, they may refer to a parameter as a variable in a computation.

More Theoretical

The term can have broad range of interpretations in climate science. It can include something that is measure (eg., precipitation) and thus can be very close to the engineering concept. On the other hand, it can also include constants in climate models that are adjusted to change model behaviour and to "tune" it to current climatology, and constants used to describe statistical models (e.g., regression coefficients) and probability distributions (e.g., location, scale and shape parameters in the GEV distribution).

Potential Source of Confusion

The engineer may be referring to a specific design threshold value, while the scientist may perceive this to be a variable. Confusion in this regard is much less common, but does occur from time to time. The engineer should clarify whether they are referring to fixed or variable numerical values. The scientist should feel comfortable about asking the engineer to more clearly define the nature of the information they are requesting.

3.20 Precision

More Applied

Typically engineers will use the words accuracy and precision interchangeably in their day-to-day work.

More Theoretical

The degree of reproducibility of measurements under unchanged conditions.

Potential Source of Confusion

An engineer may request accurate information when they are actually requesting the scientist to provide precise information.

In fact, both precision and accuracy are desirable qualities. If the engineer knows that the information is accurate, but not precise, they will apply different safety margins and contingencies than when the information is precise, but not accurate. In an ideal situation, information will be both precise and accurate, but this may not be possible within the schedule and budget of a project.

3.21 Prediction

More Applied

Future casting events. Almost every projection of future events may be referred to as a prediction or forecast. Typically, engineers will have experience with working with economic projections, which they refer to as predictions or forecasts.

More Theoretical

A prediction or forecast typically refers to anticipating the actual weather conditions in a particular place at a specific time. Most often, the term is used to refer to weather forecasts. Scientists also refer to seasonal and decadal predictions, but generally refer to long-term future casting as projections because these are dependent upon scenarios of how future greenhouse gas emissions and other forcing factors will evolve.

Potential Source of Confusion

The scientist usually distinguishes between forecast/predictions and projections on the basis of time frame. They may object to using the term forecast as they see it as a request to predict actual weather events at a particular date and time in a specified location. Outputs from climate modelling should not normally be used in this way. They are typically used to provide the range of anticipated weather conditions, the means and variances and the range of results from an ensemble of models.

The engineer must take this information and apply professional judgment to place the information in a context sufficient to establish a reasonable set of conditions that the infrastructure system may see over its useful service life. It is important that both parties be comfortable with the information provided by the scientist being assessed and massaged to put it into a form that is amenable to engineering design and judgment.

3.22 Projection

More Applied	More Theoretical
See Prediction	See Prediction

3.23 Probability

More Applied	More Theoretical
See Likelihood	See Likelihood

Potential Source of Confusion

There are occasions when the engineer may actually require a numerical value for the probability of an event. For example, they may request that data be presented in terms of 50 or 100-year return periods. Nonetheless, they may couch this request in terms of likelihoods. Once again, the parties should clarify the nature of the information that is being requested.

3.24 Professional Judgment

More Applied	More Theoretical
A level of competence and knowledge of	The scientist often sees professional judgment

technical standards obtained through many years of training and professional practice guided by practitioners with many more years of professional practice in a specific area of engineering practice. Typically, it takes four years of university, five years of practice under the guidance of licensed engineers and then many more years of professional practice as a licensed engineer before the profession would deem an individual fully qualified to express independent professional judgment.

as a subjective process. Where data is unavailable it would entail the application of assumptions, interpolations and extrapolations necessary to move forward. The scientist may be uneasy about applying judgment in this way and may wish to pursue additional work to test and/or replace judgment-based information with measured or computed results.

Potential Source of Confusion

During an assessment the engineer will typically be quite comfortable with applying professional judgment to move a project forward. They have trained their entire career to make these decisions based on a solid understanding of the technical standards of their discipline. On the other hand, the scientist may be quite uncomfortable with this process and may express concern that the process is being compromised with subjective, and untested, inputs.

The scientist may press for more work to confirm and measure the inputs while the engineer may be perfectly comfortable pursuing the project to completion without further data analysis. This can lead to conflict on assessment teams. It is important that both parties understand that professional judgment is not subjective and must only be applied within the bounds of the experience and training of the professionals who are offering their opinions.

One other outcome of this confusion is the tendency of the scientist to ask the engineer to provide a published reference for the basis of the judgment. While this is sometimes a possibility, in many more cases the judgment is based on a combination of schooling, on-the-job training and hands-on experience that is filtered through years of professional practice. This is not often simply reported in the literature.

While it may be foreign to some scientists, it is the basis for higher levels of compensation being afforded to senior members of the profession. Companies and clients are willing to pay a premium to professionals with a solid history of successfully applying professional judgment. Professional engineers can face disciplinary action for mistakes in professional judgment. As a result, the professional engineer will tend to be very careful in applying this judgment to situations where they do not have robust professional experience and training.

3.25 Resiliency

More Applied

The engineer will define resiliency in terms of the infrastructure's ability to absorb projected

More Theoretical

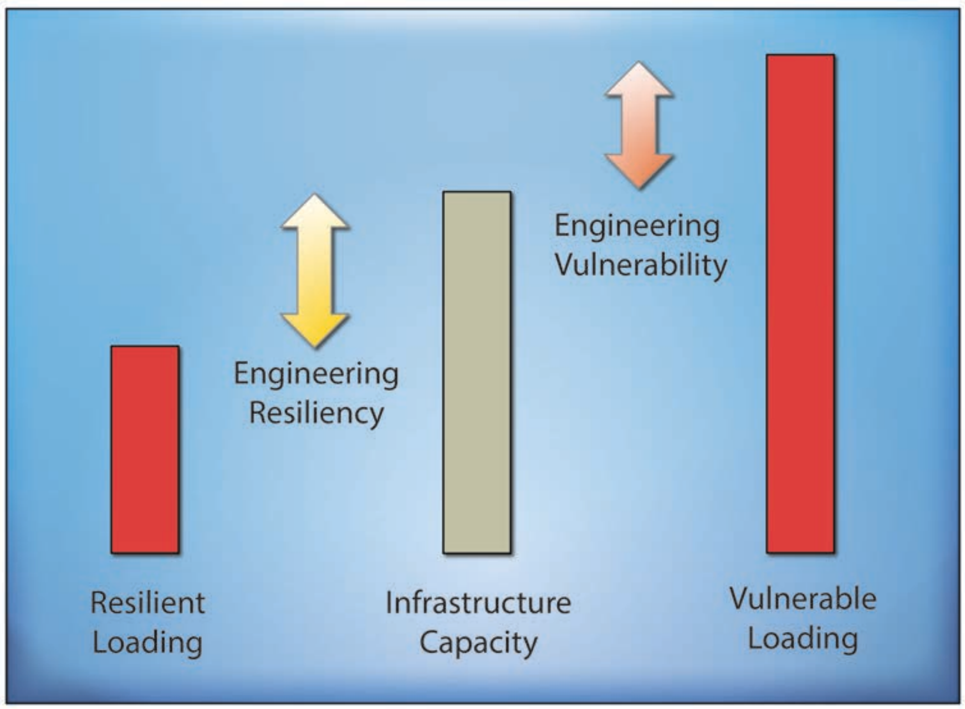
The scientist may define resiliency in much broader terms, including within their definition weather events. Typically, they will not include a broader definition of societal and ecological resiliency with respect to a population's or an ecosystem's ability to absorb and adapt to anticipated changes. The engineer's definition will tend to focus on the hardware and systems directly within their engineering or management control. They will be much less comfortable expressing opinions on broader social or environmental adaptive actions unless part of the project scope. social and ecological responses to anticipated changes. They will tend to see the issue in a more holistic way and may wish to contemplate adaptation considerations that are outside of the engineer's direct management or engineering control.

Potential Source of Confusion

The engineer will tend to work in ways to draw boundary conditions around the adaption analysis. They will ask questions about how they may redesign systems or adjust management and operation procedures to accommodate changing weather patterns. The scientist may wish to broaden the discussion to include many other factors that may be well outside of the engineer's direct control. Both approaches are equally valid. The issue in this case is that the engineer and scientist must agree on the overall scope of the assessment prior to entering into the debate.

Figure 3.3 provides a description of how the engineer would view resiliency and vulnerability. In the engineer's definition, a system will be considered to be resilient when there is sufficient capacity in the system to absorb the affects of anticipated weather events. Conversely, the system would be deemed to be vulnerable if the system did not have sufficient built-in capacity to absorb anticipated impacts. To clarify these matters we typically refer to these situations as "Engineering Resiliency" and "Engineering Vulnerability".

Figure 3.3: Engineering Resiliency and Vulnerability



3.26 Risk

More Applied

The engineer, especially one who has worked with risk management processes, will have a very technical definition of risk. They will consider risk to be the product of the probability of an event times the severity of that event, given that it has occurred. They treat probability and severity as mutually exclusive parameters. Risk can be quoted in whatever units are applicable to the question at hand. It is not uncommon to quote risk as a numerical, or economic value, or as unitless numerical values such as High, Medium or Low.

More Theoretical

Unless a scientist has worked with risk management processes, they may have a more generic definition of risk. Generally, the term risk can be used to imply probability, severity or some combination of the two that are not treated as mutually exclusive.

Potential Source of Confusion

Lack of agreement on the definition of risk can lead to considerable iterations during assessment processes. It is quite common for teams to get tied up in potential interactions between the probability of a risk event and the outcome of such an event when it DOES happen. It is common for individuals to call low likelihood events low risk when, in fact, the severity of the event may be such that the risk is actually quite high.

Conversely, it is common for individuals to call low severity events low risk when, in fact, the event may occur frequently enough to have significant economic or service disruption impacts over time. To avoid this confusion, teams should discuss the meaning of the terms that they are using prior to engaging in actual assessment work. Once again, having a discussion about language can alleviate many problems during the actual execution of an assessment.

3.27 Sufficient / Sufficiency

More Applied

See Good Enough

In engineering input data must be sufficient for the task at hand. This entails not only the level of precision of data but also covers data gaps and unknowns. The engineer will make assumptions, interpolations and extrapolations and use previous experience to cover gaps, but may decide that data is insufficient if they cannot base the assumptions on previous experience or other input information. In this case, they will undertake work to fill in the unknowns.

More Theoretical

See Good Enough

The scientist will tend to view sufficiency in terms of data being close to truth and with respect to levels of precision. They may be uncomfortable with addressing data gaps and unknowns through assumptions, interpolations and extrapolations. As well, they may tend to exclude information where they lack sufficient scientific basis to draw firm conclusions.

Potential Source of Confusion

Teams must agree on the approaches used to infill missing or imprecise data. The engineer will be very comfortable in applying professional judgment to address many of these issues, but the team must agree on the limits of this professional judgment. Where professional judgment cannot be used to fill in insufficient data, the team will need to define alternative processes. This may entail study work and research recommendations arising from the assessment.

3.28 Threshold

More Applied	**More Theoretical**
A value used in design that establishes a point beyond which a change in behaviour may occur, such as the failure of a component.	The scientist will typically look at threshold values within the context of the data. They may establish acceptable bands of data based on the variance of the data set. These thresholds will be consistent regardless of how the information may be applied.

Potential Source of Confusion

Engineers will look at climate information within the context of design or operating values for the infrastructure in question. It is not uncommon for engineers to apply different threshold values to the same climate information depending on the application. In this way, the same set of climate information may be applied to assess a range of threshold values that are all infrastructure specific.

As an example, a scientist will provide information on freeze-thaw cycles based on the freezing point of water being 0 $^{\circ}$C. However, from the engineer's perspective this may be incorrect. On a highway segment where salt is used for ice control, the impact is that the freeze-thaw cycles occur around -4 $^{\circ}$C. It is important that the engineer and scientist clearly communicate the application for the information and the assumptions that were used to generate it. This can avoid confusion during an assessment.

3.29 Trigger

More Applied	**More Theoretical**
See Threshold	See Threshold

Potential Source of Confusion

The engineer may refer to a design threshold value as a trigger.

3.30 Uncertainty

More Applied	**More Theoretical**
See Confidence	See Confidence
The engineer may often use the term uncertainty in a general, non-numerical,	Typically the scientist will be referring to the range of plausible data values spanned by the

fashion. When they refer to the uncertainty of information they may be asking about more than the accuracy and precision of the data set. Often, they are referring to all of the factors that went into the generation of the information. For example – How comfortable is the scientist with the assumptions used by the model? Would they suggest using a different emissions scenario? Etc.

data.

Potential Source of Confusion

When asked about uncertainty or confidence in data, the scientist may provide information about the range of the information set. This can lead to confusion as the engineer is really asking the scientist how much they would actually trust the model outputs. Model outputs can be very precise but completely inaccurate. The engineer may actually be asking about the overall veracity of the information and not about statistical measures of uncertainty.

3.31 Validation

More Applied

The engineer may use the term validation generically. They may refer to validating or endorsing a document. They would not typically use the term with respect to “ground truthing” information or calibrating measured data. Also, within engineering, the term validate may be used to establish that proper engineering analysis is being used in a calculation process. This is a common use of the term in greenhouse gas reduction activities, where greenhouse gas offset calculations are validated to ensure that proper analytical processes have been applied.

More Theoretical

Typically, the scientist will use the term validation to refer to the process of “ground truthing” climate model data or downscaling methods against historical meteorological data from a specific location.

Potential Source of Confusion

This is an example of one of the most common sources of confusion arising in discussions between engineers and scientists. Typically, the engineer will not fully understand the scientist’s intended meaning when they refer to validation. Once again, the parties must openly discuss the terms that they will be using during the course of an assessment and come to a common understanding of how the language will be applied during the work.

3.32 Vulnerability

More Applied	**More Theoretical**
See Resiliency	See Resiliency

3.33 Weather

More Applied	**More Theoretical**
Engineers like others, may not distinguish between climate and weather. Engineers are concerned with weather such as extreme weather events as they must design infrastructure to taking these and their frequency and intensity into account.	Meteorological conditions that occur at a specific location and time. Statistics may be computed from weather data to establish climatological norms.

Potential Source of Confusion

When the engineer is referring to climate or climate events, they may actually be referring to specific weather events such as extreme values (temperature, precipitation) at a particular location and time. In contrast, the scientist will use the term weather to refer to specific events and the term climate to refer to the tendency of events to occur over a specific time period.