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Toward a New Conceptual Framework for Teaching About Flood Risk in Introductory Geoscience Courses

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ABSTRACT

An analysis of physical geology textbooks used in introductory courses shows that there is a systematic lack of clarity regarding flood risk. Some problems originate from confusion relating to statistical terms such as "100-year flood" and "100-year floodplain." However, the main problem is conceptual: statistics such as return periods and annual probabilities do not portray the variability inherent in flood recurrence and lead to misconceptions. An alternative conception of risk is proposed based on the analogy between playing a game of chance and living in a hazardous situation. This concept leads to the introduction of statistical ensembles as a means to characterize risk as a function of the duration of exposure to a hazardous situation. Presenting risk in relation to exposure time places floods in the framework of planning and problem-solving: how does the risk that arises from where we build relate to how long we want to be there? Methods and materials in the paper show how game play and ensembles can be introduced in the classroom. A supplemental Excel spreadsheet provides the means to generate ensemble diagrams from commonly available stream data and gives instructors the potential to customize their course materials by using data from local streams. © *2011 National Association of Geoscience Teachers.*

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INTRODUCTION

The geosciences have an important role to play in educating the public about risks from natural hazards. According to The Geological Society of America's position statement on Natural Hazards (Geological Society of America, 2008), "Geoscientists have a professional responsibility to inform the public about natural hazards and the need to build an increasingly natural hazard-resilient society, thereby enabling more responsible actions and decisions." According to a National Research Council report on flood risk reduction (National Research Council, 2000, p. 37): "Identifying sound, credible, and effective risk reduction priorities and solutions depends greatly on a well-informed public. The public should be knowledgeable about risk issues and should be given opportunities to express opinions and become involved in risk assessment and risk management activities."

Within the college curriculum geoscience courses have a key role to play in shaping public knowledge of natural hazards. The GSA's Natural Hazards Policy Statement "emphasizes the crucial role of geoscience education and outreach in broadening the public's understanding of their risk from natural hazards and the available options to reduce risk" (Geological Society of America, 2008). Introductory courses have considerable potential to affect the public's knowledge of risk issues. The majority of those who need to understand and interpret a flood insurance rate map (FIRM) will be home owners, architects, planners, insurers, loan officers, and emergency managers, who may depend on one introductory geoscience course for their knowledge of floods. Furthermore, these courses have the capacity to teach large numbers. For example, at West Chester University, a public, comprehensive, predominantly undergraduate institution, a physical geology course, Introduction to Geology (ESS101), has the potential to influence the level of risk comprehension of 860 students each year.

Analyzing risk involves jointly taking into account two aspects of any natural hazard, the hazardous phenomenon itself and its recurrence characteristics. The first aspect, providing an understanding of hazardous phenomena and the natural processes that cause them, is a traditional strength of geoscience. For example, knowing about the destructive power of floods and their origin within the hydrologic system is essential to evaluating the risk they pose. The recurrence characteristics of natural hazards are equally important. H.G. Wells is said to have predicted early in the 20th century, "Statistical thinking will one day be as necessary for efficient citizenship as the ability to read and write" (e.g., Campbell, 2004; Gigerenzer, 2002). This quote appears in modern works on risk and numeracy because there is an unfulfilled need for greater public understanding of risks for which recurrence is understood in terms of probabilities, and most natural hazards are prime examples. Fischoff *et al.* (1981) make the point that all hazards lead to decision problems, or in their terms, "acceptable risk problems." To make the best decision, each projected outcome and its probability have to be taken into account in assessing costs and benefits.

Making risk-based decisions is scientifically and technically challenging and the process is difficult even for experts to understand and communicate. With regard to flood risk, a report by the National Research Council (2000 p. 38–39) states: "The methods for analyzing the complexities of floodplain management are not simple to understand. This makes it difficult to communicate with citizens who are unfamiliar with scientific principles (e.g., hydrology, structural design) necessary to design floodplain management facilities. Indeed, few of the individuals involved in floodplain management understand all these principles well."

In this paper, I develop an improved conceptual framework to educate about flood risk.

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TABLE I. Coverage of Floods, Characteristics, Causes, and Mitigation.

Text	Chapter Title or Heading[a]	Images[b]	Causation and Hazard	Mitigation
American Geological Institute (2009)	Stream processes, landscapes, mass wastage, and flood hazards	0	Floodplains	Floodplain management, flood insurance
Carlson *et al*. (2008)	Streams and floods	7	Floodplains, heavy rainfall, urban development	Dams, levees, floodwalls, floodplain management
Jordan and Grotzinger (2008)	The development of cities on floodplains	1	Floodplains, urban development	Dams, levees, floodplain management
Marshak (2009)	Running water: The geology of streams and floods	5	Floodplains, precipitation, snow melt, dam failure, urban development, etc.	Dams, levees, floodwalls, floodplain management
Murck *et al*. (2008)	Water as a hazard and resource	3	Floodplains, precipitation, coastal storm surge, urban development, subsidence	Dams, channelization
Reynolds *et al*. (2008)	What is and is not a flood? How do we measure floods? How would flooding affect this place?	3	Floodplains, rainfall, snowmelt, dam failure, urban development, volcanic eruption	Levees, floodplain management
Tarbuck and Lutgens (2008)	Floods and flood control	7	Floodplains, precipitation, snowmelt, urban development, dam failure, ice jams	Dams, levees, channelization, floodplain management
Wicander and Monroe (2009)	Can floods be predicted and controlled?	4	Floodplains, rainfall, levee failure	Dams, levees, floodwalls

[a] Chapter titles or major headings that indicate treatment of floods.
[b] The number of images used to show the size or destructiveness of floods.

ANALYSIS OF THE EXISTING CONCEPTUAL FRAMEWORK FOR FLOOD RISK

Floods are standard content for books suitable for introductory geosciences courses. In this section I analyze the content and concepts used in seven recent (2008 or 2009 copyright date) physical geology textbooks from a range of publishing houses as well as the widely-used American Geological Institute lab manual. Table I shows that these publications typically:

- Devote a chapter or a chapter section to floods, as indicated by chapter titles and headings.
- Use case studies, statistics, or images of floods or flood damage to demonstrate the societal importance of floods.
- Explain the factors that can lead to floods or increase human exposure to flooding (e.g., heavy rainfall, snowmelt, urban development, levee, or dam failure).
- Describe human responses to floods (floodplain management, channelization, dams, flood walls, or levees).

In other words, the books are designed to tell students that floods are societally important hazards studied by geoscientists and that by understanding the factors that cause them we can design responses that minimize risk.

Learning to understand the likelihood or probability of hazardous conditions, not just the magnitude of the hazard, is another important component of risk analysis. The books approach this from the perspective of uniformitarianism—using past stream behavior to establish models for future flooding. They cover a range (see Table II) from a general statement of the magnitude-frequency relationship (Jordan and Grotzinger, 2008), through verbal definitions of recurrence intervals and annual probabilities (e.g., Tarbuck and Lutgens, 2008), to more complete descriptions of how stream data are converted to flow-probability graphs (e.g., American Geological Institute, 2009; Carlson *et al*., 2008).

The likelihood of extreme stream flow is typically conveyed by the terms "annual probability" and "recurrence interval" or "return period." These terms are defined by authoritative sources on flood risk. For example:

- "An annual maximum event has a return period (or recurrence interval) of T years if its magnitude is equaled or exceeded once, on the average, every T years. The reciprocal of T is the exceedance probability… of the event, that is, the probability that the event is equaled or exceeded in any one year." (Bedient and Huber, 2002, p. 188).
- "Return period—the average time interval between occurrences of a hydrological event of a given or greater magnitude, usually expressed in years" (National Research Council, 2000, p. 179).
- "Recurrence interval (return period, exceedance interval): In an annual flood series, the average interval in which a flood of a given size is exceeded as an annual maximum" (United States Water Resources Council, 1981, p. 2–4)

Key aspects are that a return period is an average, and that it refers to a flow which exceeds a specified level.

TABLE II. Statements of Flood Risk and Qualifications.

Text	Flood Risk Statement	Qualification of Risk Statement
American Geological Institute (2009)	"Recurrence interval (or return period) is the average number of years between occurrences of a flood *of a given rank or greater than that given rank*." (p. 233)	
Carlson *et al.* (2008)	"Hydrogeologists designate floods based on their recurrence interval, or return period. For example, a 100-year flood is *the largest flood expected to occur within a period of 100-years*." (p. 438)	"If a 100-year flood occurs this year on the river you live beside, *you should not assume* that there will be a 99-year period of safety before the next one." (p. 436)
Jordan and Grotzinger (2008)	"Small floods are more frequent, occurring every 2 or 3 years on average. Large floods are generally less frequent, usually occurring every 10, 20, or 30 years." (p. 320)	
Marshak (2009)	"The annual probability of flooding indicates the likelihood that *a flood of a given size or larger* will happen at a specified locality during any given year." (p. 397)	"Some floodplain residents have the impression that since a 100-year flood just happened, another won't happen for 100 years. *This is a false impression!* Two 100-yeards can happen in the same year, can happen 80 years apart, or can happen 210 years apart." (p. 397)
Murck *et al.* (2008)	"The average time interval between two *floods of the same magnitude* is called the recurrence interval." (p. 320)	
Reynolds *et al.* (2008)	"This term [a hundred year flood] signifies *the size of a flood that is predicted…*" (p. 493) Exceedance is defined accurately with regard to flow probability. (p. 493, 497)	"The term *does not imply* that such a flood will only happen every hundred years, because '100-year floods' can, and have, happened two or three years in a row along some rivers." (p. 493)
Tarbuck and Lutgens (2008)	"The flood discharge that has a 1 percent (1 in 100) *probability of being exceeded* in any one year is called a 100-year flood." (p. 448)	"This *phrase is misleading* because it leads people to believe that only one such flood will occur in a 100-year span or that such floods occur regularly every 100 years. *Neither is accurate*." (p. 448)
Wicander and Monroe (2009)	"So, a 20-year flood, for example, is the period during which *a flood of a given magnitude* can be expected." (p. 315)	"*It does not mean* that the river in question will have a flood of that size every 20 years, only that over a long period of time, it will average 20 years." (p. 315)

Likewise, the annual probability is the likelihood that a specified level of flow will be exceeded in any year. The statistical aspect of risk as an average time to exceedance is a fundamental aspect of formal statements of flood risk.

American Geological Institute (2009); Marshak (2009); and Tarbuck and Lutgens (2008) state the definition accurately (Table II). Murck *et al.* (2008) and Wicander and Monroe (2009) give the impression that a T-year flood corresponds to a flow of a single magnitude; Reynolds *et al.* (2008) give conflicting statements in different sections. Carlson *et al.* (2008) provide evidence for why there is confusion about the meaning of the T-year event. A focus box (p. 438–439) titled "Estimating the size and frequency of floods" demonstrates how annual maximum flow data can be used to estimate the magnitude of the 100-year flood; the magnitude determined by this procedure yields the flow which is exceeded in 100 years on average. However, Carlson *et al*., refer to a 100-year flood as "the largest flood expected to occur within a period of 100 years." That is, the flow is incorrectly stated to be a maximum (not to be exceeded), not a minimum (to be exceeded).

The origin of this error, and perhaps those in Murck *et al.* (2008) and Wicander and Monroe (2009), seems to originate from the confusing relationship between the 100-year flood and the so-called 100-year floodplain. Flood Insurance Rate Maps (CFR, 2002, Part 59.1, p. 235–236; FEMA, 1983) define rate zones of type A ("area of special flood hazard") based on the area "subject to a 1% or greater chance of flooding in any given year." Note that since the 100-year flood has a 1% chance of being exceeded in a year, the chance of any lesser flow occurring is greater than 1%. Thus, the margin of zone A, commonly termed the 100-year floodplain, is defined by inundation from the smallest possible 100-year flood (Fig. 1). In plain words, a 100-year flood, by definition, will exceed the bounds of the 100-year floodplain!

If geoscientists authoring textbooks have difficulty reconciling the definitions of 100-year flood and 100-year floodplain, it is a near certainty that the students and teachers who use the books will also have difficulty. One option is to avoid using the term "100-year floodplain" and to use FEMA's flood zone terminology (e.g., zone A). The concept of an event which is exceeded every T years, on average, could then be reserved for stream flow, where existing usage supports it. However, even technically correct use of the "T-year flood" commonly leads to misunderstanding because it leads to an intuitive misinterpretation—a flood that occurs every T years—as discussed in (Lutz, 2001). Table II shows that most of the books that refer to the "100-year" or other flood also attempt to qualify the term to avoid such misconceptions, e.g., (Marshak, 2009, p. 397): "Some floodplain residents have the impression that since a 100-year flood just happened, another won't happen for 100 years. This is a false impression! Two 100-year floods can happen in the same year, can happen 80 years apart, or

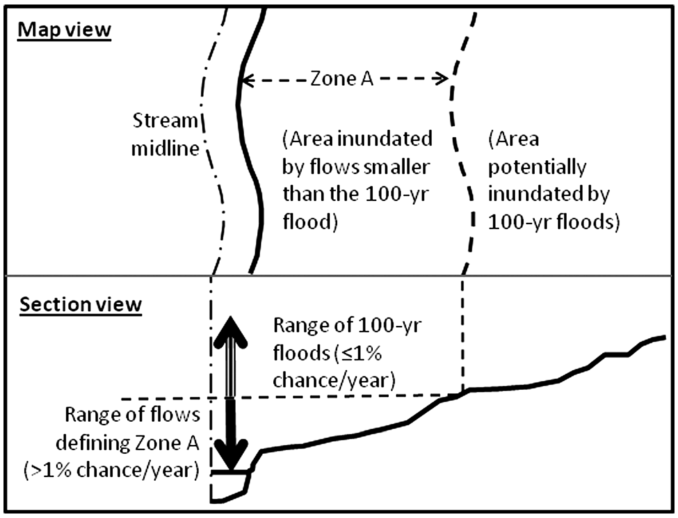

FIGURE 1: Bottom: Cross-section view of one half of a stream valley, to right of stream midline. Horizontal dashed line is elevation exceeded by 100-year floods. Top: map view; zone A (FEMA special hazard zone) is the land from the stream bank to limit of inundation corresponding to the elevation exceeded by 100-year floods (dashed line carried to the map from section view). Land farther from the stream than zone A will be inundated by any flood that qualifies as a 100-year flood.

can happen 210 years apart." A problematic aspect of this and other clarifications is that they identify a false impression but don't provide an accurate, concrete understanding of flood variability to displace the misconception.

A NEW CONCEPTUAL FRAMEWORK FOR FLOOD RISK

Risk analysts (e.g., Margolis, 1996; Gerstein, 2008) understand the difficulty of overcoming intuitive conclusions. Intuitive (and wishful) thinking is especially powerful when the risks are expressed in probabilities which do not lead to clear-cut conclusions. Margolis (1996 p. 52) claims that "it takes a cognitively effective rival intuition to challenge an intuition." To this end Hall-Wallace (1998) and Mattox (1999) present mechanisms for students to simulate the occurrence of natural hazards in the classroom. Lutz (2001) suggests a more general procedure to establish an analogy between hazard probabilities and playing a game of darts in which the sizes of the rings were based on the probabilities. In this paper, I use the framework of game play as an analogy to develop more concrete thinking about risk that leads to correct interpretations, not misconceptions. This approach builds on the use of scenarios and simulations in other work to communicate the possibilities in an uncertain future.

Scenarios developed from models can be effective to display future conditions and to show the variability that can result from different models and assumptions. For example, (Meehl *et al.*, 2007, Fig. 10.5) present scenarios for climate change in the 21st century that let an individual pick a point in the future and consider the conditions that might exist at that time, taking into account the differences among scenarios that reflect different model assumptions. Multiple scenarios for probability-based models, called statistical ensembles, reflect the random nature of risk; each individual scenario is referred to as a realization of the statistical model. The Army Corps of Engineers uses ensembles, developed from realizations of probability versus flow, flow versus stage, and stage versus damage models, to assess the expected annual damage from stream floods (National Research Council, 2000, p. 63–64). The Army Corps' assessment considers realizations as outcomes within a probability distribution. I have developed the concept of viewing successive realizations as outcomes in a time sequence. In this framework, ensembles become a means to visualize the unfolding of flood risk in the future.

Twenty-first century students may be better prepared to accept probabilistic scenarios than previous generations. Popular software-based games, whether run on a computer or specialized game "box," use elements of randomness to create novel and non-repeating patterns of play. Even traditional "analog" games of chance such as solitaire, hearts, and poker are simulated using software. Competitive poker, played on the web, shown on several television stations, and highlighted in *Sports Illustrated*, is surging in popularity (Croson *et al.*, 2008). The analogy between exposure to risk and time spent playing a game is also fruitful. For example, the chance of experiencing a low probability outcome in a typical game of chance depends on how long you play the game; the chance of experiencing a large flood depends on how long you live on the floodplain.

Students also are aware that games of chance, though there are strong elements of randomness, can be played skillfully, and that developing skill depends on understanding the underlying probabilities. I use the probabilities associated with dealing five-card poker hands to develop the principles of statistical recurrence. The result of a single deal can be simulated using a random number generator. A realization consists of a number of simulated results presented sequentially to portray one possible outcome of playing the game over time. Figure 2 shows a realization based on 100 simulated hands, the outcome of each

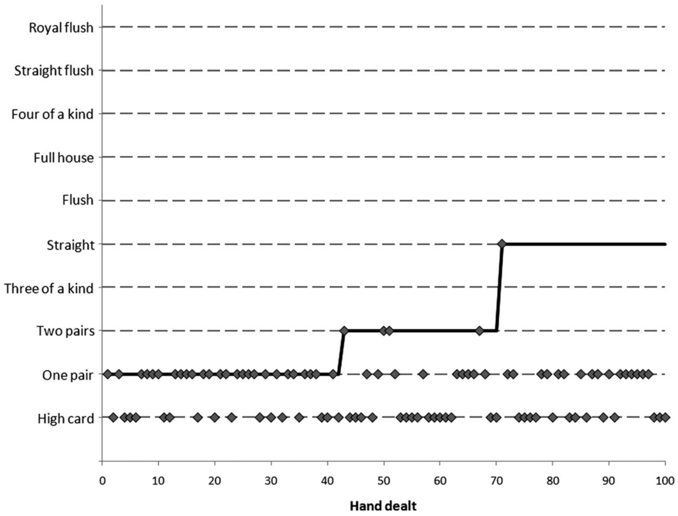

FIGURE 2: A single realization of the results of dealing 100 five-card poker hands. Symbols represent the outcome of each deal; the line tracks the cumulative maximum, which is the highest scoring hand dealt after a given number of hands.

hand represented by a symbol. The realization shows the basic magnitude-frequency structure of poker: low-scoring hands occur much more frequently than high-scoring hands. Students should understand that the probability of being dealt a given hand decreases upward along the vertical axis. It is not essential that students know the composition of each hand (e.g., flush = five cards of the same suit) or the underlying numerical probabilities.

When I introduce the poker simulation to students I ask them how good poker players learn the game, and the answer always is, "From playing poker," not "By looking up the probabilities." I quote John Dewey's maxim, "We don't learn from experience but from reflecting on experience," to make the point that to learn from the game we have to keep track of the important outcomes and to learn from them. In the context of natural hazards such as floods, the rare, large events are the most damaging, and the probability of their occurring within a given time frame is of greatest interest. The line in Fig. 2 indicates the cumulative maximum for that realization; it indicates the largest event experienced after a given number of hands have been dealt. For example, by the 71st hand a straight is the highest and is not exceeded in following hands.

Combining the cumulative maximum lines of many realizations creates a statistical ensemble that represents the distribution of the largest outcomes conditional on the number of hands played. Figure 3 is an ensemble based on 100 realizations of 100 hands each; note that each line has been slightly offset in the vertical direction to reduce overlap. For example, by the 70th hand one realization has not exceeded two pairs, two realizations have yielded four-of-a-kind, and the others are somewhere in between. I ask the students what they think are reasonable and unreasonable expectations for someone interested in playing from 1 to 100 hands of poker the ensemble diagram. To stimulate thinking about the extremes I provide two additional lines that bound the percentage of realizations in the center of the distribution (90% in Fig. 3). At least three categories result:

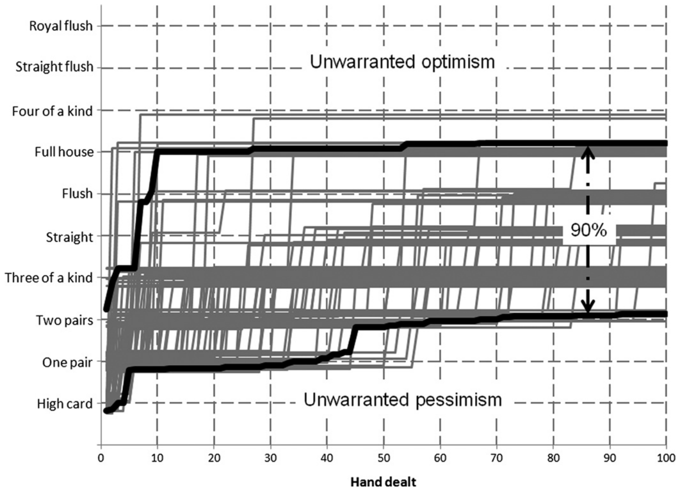

FIGURE 3: A statistical ensemble consisting of the cumulative maximum lines of 100 realizations such as that shown in Fig. 2. Heavy lines indicate the central 90% of the realizations at each hand dealt; i.e., 5% exceed the top heavy line; 5% are less than the lower heavy line.

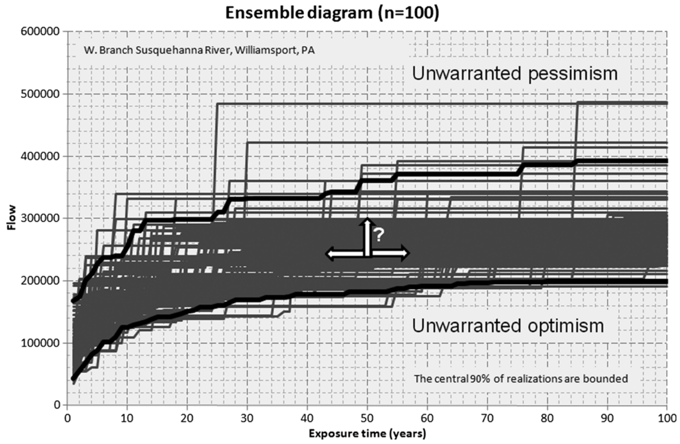

FIGURE 4: Ensemble diagram of 100 realizations of the cumulative maximum of annual peak streamflow (cfs) at Williamsport, PA. Heavy lines bound the central 90% of realizations. The vertical arrow indicates the flow exceeded by the 50-year flood; horizontal arrows indicate the large variability around the 50 year average recurrence interval.

- Unreasonable optimism— For example, if only 1% of the realizations yielded four-of-a-kind by the 20th hand, is it reasonable to think you'd do that well or better in 20 hands?
- Unreasonable pessimism—For example, if all realizations yielded at least one pair by the 20th hand, is it reasonable to think you'd do any worse in 20 hands?
- Reasonable expectations—By the 20th hand, 90% of the realizations range from one pair to a full house. Some students will point out that most of the realizations are on the low side of the 90% range, so it might be more reasonable to expect three-of-a-kind at best.

Ensemble diagrams for stream flow are made to appear as similar as possible to the diagram for the poker game, e.g., Fig. 4. Axis labels are modified: "Hands dealt" is replaced by "Exposure time (years)," indicating the time over which one is exposed to risk from the stream; stream flow replaces the poker hands. Because high poker hands are good but high floods are bad, the labels for unwarranted optimism and pessimism are swapped. Reading the graph is exactly analogous to the poker diagram. For example, what are the chances that someone living near the West Branch of the Susquehanna River at Williamsport, PA, for 30 years will not have experienced a flow of 150,000 cfs? Figure 4 shows that almost all the simulations exceed this value: it is very likely that a larger flow will occur in a 30 year span.

Thinking about probability in the context of a game calls attention to aspects of risk that are virtually inaccessible in traditional expositions. For example, the flow-probability graphs in textbooks (e.g., Carlson *et al.*, 2008, box 16.2, Fig. 3) are misleading because the graph indicates a unique peak flow for any T-year flood. Ensemble diagrams display the variability and make the variability a key aspect of decision-making.

More importantly, the T-year flood fails to communicate important information about risk that ensemble diagrams provide. Consider the knowledge of risk available to someone who plans a 50-year investment in Williamsport,

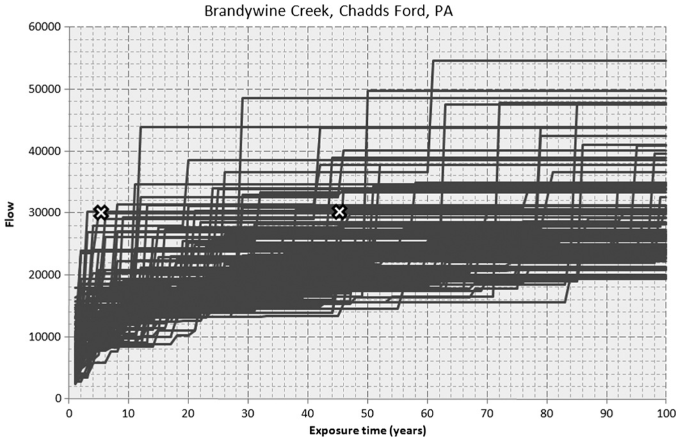

FIGURE 5: Ensemble diagram of 100 realizations of the cumulative maximum of annual peak streamflow (cfs) for Brandywine Creek at Chadds Ford, PA. Symbols indicate conditions specified in the text.

PA. The 50-year flood is approximately 223,000 cfs, meaning that this flow will be equaled or exceeded every 50 years on average. But this information does not answer these practical questions: "What is the effect of variability in time around the average of 50 years? How much variability in flow can be expected relative to the 50-year exceedance value? What is the largest flood that is likely within 50 years? What are the chances that a flood will not exceed the 50-year flow in 50 years?" The ensemble diagram (Fig. 4) shows that the nominal 50-year flood is just a single value in the midst of a broad distribution. The "50-year flood" actually has little meaning for evaluating the risk of floods over a 50-year span, and the same weakness pertains to any T-year flood statistic. The ensemble diagram creates the potential for students to think in more depth about flood risk and avoidance because it provides the entire distribution, which is more informative for making decisions about risk. For example, about 5% (5/100) of realizations exceed 350,000 cfs. If we were to plan mitigation measures for flows that large we might be prepared 95% of the time. Is that good enough? What would be the practical consequences of picking 90%, or 99%? Where does the region of unwarranted pessimism begin?

PRELIMINARY RESULTS AND ONGOING IMPLEMENTATION OF THE CONCEPTUAL FRAMEWORK

An important change in perspective brought about by ensemble concept is that the planning timeframe, represented by exposure time on ensemble diagrams, is explicit. As a result, students can put themselves in the roles of people who need to make decisions about flood risk. The following example is from an in-class exam given to mostly first-year, nonscience majors. It referred to an ensemble diagram for flow on Brandywine Creek at Chadds Ford, PA, a few miles from campus (Fig. 5):

16. (8 points) Answer the following questions based on the ensemble diagram below. Mark your diagram to help show your reasoning.

(a) A couple is thinking of buying a house on land which would be flooded if Brandywine Creek exceeded a flow of 30,000 cfs. They plan to live in the house for five years before they retire and move to North Dakota. Based on the diagram, explain how likely you think it is that they will be flooded out during the time they live in the house.

(b) When the couple move their daughter plans to buy the house and live there for 45 years until she retires. Is it more or less likely that she will be flooded? Explain.

Student responses reflected their abilities to translate verbal descriptions into the frame of the diagram, plot the information, interpret the meaning of the plotted information, and write an explanation consistent with the statistical ensemble. Correct answers recognized that for part (a), no simulations out of 100 exceeded 30,000 cfs at five years' exposure, with the interpretation that the chance of the house being flooded during five years is small (<1%); for part (b), 10–15 simulations exceed 30,000 cfs at 45 years' exposure, with the interpretation that there is a substantially greater, but still small, chance of flooding (10%–15%) during 45 years.

In a recent class, 63% of students ($n = 77$) provided answers that I judged to be entirely or essentially correct using the rubric in Table III. In future classes I plan to test how student learning about risk develops by evaluating their understanding at different stages of introducing the

TABLE III. Rubric for Exam Question.

	Entirely Correct	**Essentially Correct**	**Substantial Errors**	**Major Errors**
Symbols	Concise symbols placed accurately	Large symbols possibly placed accurately	Symbols inaccurate on one axis or missing in one part	Symbols missing or inaccurate on both axes
Part a Part b	*Accurate characterization of the situation in relation to ensemble *Quantitative analysis of risk in terms of probability *Uses relevant terms (exposure time, risk, probability, unwarranted pessimism)	*Accurate characterization of the situation in relation to ensemble *Quantitative analysis not clear; or lacks probability *Uses some relevant terms (exposure time, risk, probability, unwarranted pessimism)	*Partial characterization of the situation in relation to ensemble *Quantitative analysis lacking *Uses few relevant terms (exposure time, risk, probability, unwarranted pessimism)	*Erroneous characterization of the situation in relation to ensemble *Quantitative analysis lacking *Uses no relevant terms (exposure time, risk, probability, unwarranted pessimism)
Part b Comparison	*Explicit comparison with Part a, including influence of exposure time	*Does not compare to Part a; or does not refer to influence of exposure time	*Does not compare to Part a. and does not refer to influence of exposure time	*Does not compare to Part a. and does not refer to influence of exposure time

ensemble approach, and I will continue this study throughout the course as students use the same conceptual framework and similar diagrams when seismic and volcanic risks are the subject. Further work of this sort is necessary to fully validate efficacy of the conceptual framework and ensemble diagrams in the classroom.

CONSTRUCTING ENSEMBLE DIAGRAMS FROM ANNUAL PEAK STREAMFLOW DATA

To make ensembles accessible to instructors I created an Excel workbook that can accept annual peak stream flow data that are available for over 27,500 surface water sites in the U.S. from USGS websites (http://waterdata.usgs.gov/nwis/sw). The workbook is available as a supplementary file. It will:

- Perform an analysis of the data modeled on regression of the log(peak flow) versus annual probability.
- Provide diagnostic charts to help determine whether the fit of the model to the data is satisfactory.
- Predict streamflow to be exceeded for any given return period.
- Graph a single realization over a 100-year period.
- Construct ensemble diagrams of 100 realizations over a 100-year period.

The first tab in the workbook contains instructions for using it.

The workbook is set up to automatically generate charts that can be used in classroom presentations and to provide material for student exercises and exams. For example, the ensemble diagrams in Figs. 4 and 5 were created using the spreadsheet. The diagnostic charts make it possible to screen data to avoid sites where the methods used don't model the data well. The workbook is easy to use and could be adapted for students to use in lab activities.

CONCLUSIONS

Introductory geoscience courses have a role to play in educating the American public about risk, particularly the risk of flooding, the most widespread and costly hazard (FIFMTF, 1992). Textbooks used in these courses provide valuable information about the causes, characteristics, and risk mitigation strategies for floods but are less successful in conveying the probabilistic nature of flood recurrence: about half the books convey incorrect or confusing definitions of parlance such as "the 100-year flood." Textbooks typically warn against intuitive misunderstandings of annual probabilities and return periods but fail to provide a strong, positive basis to counter misconceptions.

This paper develops an alternative conception of flood risk based on the analogy between playing a game of chance and living in a hazardous situation, leading to several improvements:

- "Playing the game" leads to a correct conceptual understanding of risk as an outcome of random events over time. The misconception of periodic recurrence is avoided.
- The time frame for exposure to a risk is represented straightforwardly, not by a probability or a statistical average.
- Ensemble diagrams display open-ended variability and confront students with an essential aspect of risk: how safe is safe enough? They can reason on their own about what constitutes an acceptable risk and can delineate undue optimism and undue pessimism.

An Excel workbook makes it easy to screen peak flow data and to create ensemble diagrams for any of the more than 25,000 stream gage stations for which annual peak flows are provided by the USGS.

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