RATIONALE AND DEVELOPMENT OF A SCALE TO COMMUNICATE ENVIRONMENTAL AND OTHER COMMUNITY RISKS

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Abstract: Efforts to secure any community from environmental and other community risks must be able to convincingly argue that:

1. The stressors impact the community's well being.
2. The community is ultimately responsible in the mitigation of these stressors.
3. Limited resources must be committed to manage this risk to an acceptable level.

Assuming any community has a fixed quantity of risk management funding, environmental security must compete for resources traditionally allocated to other well-recognized risks of war, terrorism, and natural disasters. Even if the quantity of funding is flexible, it must convincingly argue for the reallocation of scarce resources from the activities of consumption to investment. Economists refer to this discussion as "Guns or Butter."

Similarly, the Department of Homeland Security must allocate resources to many risks. Calculated from probable events, probable outcomes, and probable life and economic losses, a risk scale developed within one DHS-funded program uses the rationale of many successful threat and risk scales. It was suggested that this scale could be used to measure and rank the risk of all international events of terror, disaster, and calamity for the allocation of risk management efforts. This paper examines a few notable and successful scales of risk, the rationale for these and the development of the Security Assurance Index, and the recently proposed Global Risk Index and its application to environmental security.

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2. Background

As established by the Homeland Security Presidential Directive (HSPD-7), U.S. federal departments and agencies are directed to identify and prioritize critical infrastructure and key resources within the U.S. for protection from terrorist attack. Identifying 12 critical sectors and five key assets, HSPD-7 allocates this responsibility to the following departments and agencies:

- Agriculture & Food – Department of Agriculture
- Water – Environmental Protection Agency
- Public Health – Department of Health & Human Services
- Defense Industrial Base – Department of Defense
- Energy – Department of Energy
- Transport – Department of Homeland Security
- Telecommunications – Department of Homeland Security
- Postal & Shipping – Department of Homeland Security
- Banking & Finance– Department of Treasury
- Emergency Services – Department of Homeland Security
- Chemical & Hazardous Materials Industry – Department of Energy
- National Monuments & Icons – Department of Interior
- Nuclear Plants – Nuclear Regulatory Commission
- Dams – Department of Homeland Security
- Government Facilities – Department of Homeland Security
- Commercial Assets – Department of Homeland Security & the National Institute of Standards and Technology

In support of this national effort, the Idaho National Laboratory (INL) supports many Department of Energy (DOE), Department of Defense (DOD), and Department of Homeland Security (DHS) programs with engineering, science, and management expertise. One INL program is the DHS-funded Control System Security Program (CSSP) and the associated Control System Security Center (CSSC). Established to coordinate the efforts of control systems owners, operators, and vendors as well as the federal, state, local, and tribal governments, the CSSP's mission is to reduce the likelihood of success and severity of impact of cyber attacks on critical infrastructure. The primary objectives of the CSSP are:

- Enhance incident response capabilities
- Assess vulnerabilities and risk
- Enhance industry practices
- Enhance security awareness
- Recommend R&D needs

A significant problem for this program is the communication of risk from cyber vulnerabilities. Whether this risk is within the industry sector, between sectors, or between the sector and the general economy, parochial interests and information isolation usually result in underestimating or overestimating risk. However, even if risk is accurately evaluated, it is not effectively communicated due to personal perspectives of how great or insignificant this risk is on a national scale. For this reason, an INL economist and systems engineer developed a scale to effectively communicate risk.

From this beginning, it was suggested that a similar rationale for a risk scale could be applied to communicate risk at an international or global extent.

3. Problem Statement

Currently, the risk of cyber attacks is a difficult problem to manage due to its many complex aspects, including but not limited to:

- Constantly changing technology and their associated vulnerabilities
- Constantly changing threat actors
- Difficulty in predicting attack vectors
- Difficulty in predicting consequences and their impacts quantifiably
- Extremely low probability and extremely high consequence of a cyber attack

However, even if we can obtain the resources to manage these issues, communicating the calculated risk to individuals, communities, and agencies is difficult, ineffective, and inefficient. This is the result of many intermingled problems:

- Human behavior chooses to ignore risk if it was determined from the outside
- Human behavior chooses to ignore risk if it negatively impacts the community

- Human motivation chooses to overestimate risk if it results in increased funding
- Humans sometimes do understand large scale and large numbers

From our experience, the risk communication process was a review process where decision makers required a full understanding of the detail and methods of the assessment process. Often, calculations and methods were meticulously reviewed; and their derivations and assumptions questioned. Not only did this process require significant resources from the risk management process, it also resulted in a modified risk assessment process that would favor a community's desire. From the perspective of the risk assessors, these modifications were almost always motivated by outside decision makers who understood the risk management process and modified the assessment to a desired outcome. Bottom line: true risk reduction was not being achieved expeditiously, effectively, or efficiently. It became obvious to many that there needed to be a more effective and simple method to communicate cyber risk.

4. The Existing DHS Scale and Its Application to Cyber Security

After the establishment of DHS, Presidential Directive 3 required a: comprehensive and effective means to disseminate information regarding the risk of terrorist acts to Federal, State, and local authorities and to the American people.

What was presented is the Homeland Security Advisory System (HSAS), which consists of five color-coded levels to communicate the department's calculation of risk from and potential gravity of terrorist attack (Figure 1). Simple and visual, the colors are typical of those associated with threat or danger: deep reds are associated with fire or blood, yellows and orange with caution, and green or blue with calm and peace.

Though simple and similar to many other risk scales, this scale has received criticism from many quarters. The primary criticism is the lack of any criteria to define the threat level or a methodology for its calculation; thus, it is almost impossible to deduce the threat and determine possible actions in response. Without resolution, these issues create an environment of distrust. Furthermore, since the nation has been at an Elevated Alert since 2002, many have learned to mistrust this scale and its use as they have become numb to a threat that appears to be diminishing. Lastly, since blue and green levels have never been used, many argue that this is a three-level scale in practice. Bottom line: many critics argue that this scale has done more to create an environment of apathy, ignorance, and even suspicion due to its lack of transparency. The

Figure 1. Existing DHS scale.

only exception may be airport security, where increased levels always result in more intensive luggage and personal-effects searches.

For these reasons, relying on the HSAS for cyber security risk communication was seen to be difficult at best.

5. Development of CSSP Risk Scale

Given the history of the HSAS, the CSSP decided to develop its own scale for internal use, and if successful in communicating risk within the program, hoped it would be adopted informally between and within DHS and other federal agencies. From the outset, the goals of the CSSP scale were to communicate the assessed risk effectively, to require little interpretation, be easy to use, and avoid parochial interests through a transparent evaluation process. If these goals could be achieved, it was argued that the scale would become trusted and eventually codified through use.

The development strategy was simple. First, we assumed the HSAS scale would not go away; however, we believed that DHS would not resolve many of the problems as this would require a transparent methodology. Second, there appeared to be a large number of other threat and risk scales from which success and failure could be determined; we did not have to start this development from scratch. Lastly, when the attributes to success were identified, we would incorporate these when possible. In the end, our test for success was always:

- Easy to use
- Easy to communicate
- Easy to understand

6. Review of Existing Risk Scales

One will notice that risk scales are a relatively new phenomenon. Neither Columbus nor the generals of World War II benefitted from their use (though they would have). A lot of this is due to timing. First, using risk scales for communication is relatively new due to the assessment and communication technologies that enable them. However, risk scales have also been associated with the development of risk-averse and modern societies, which are primarily driven by the power of the individual. Whereas past societies were largely controlled by a king or queen whose primary responsibility was to oversee the protection of the kingdom, the path of a modern society is dominated by the well being of the individual and his or her influence on society. Thus, whether one is mitigating the risk of a flu outbreak, hurricane, earthquake, or terrorist attack, modern societies are motivated by the actions of the individual, which then determines the impact to the community. Fortunately, sufficiently robust communication tools are available to enable this *laissez-faire* in societal risk management.

It is important to note that many scales are available for inquiry. There are scales of Snowfall Impact, Volcanic Explosivity Index, Drought Indices, and the Beaufort Wave Index as well as traditional scales for noise and light. In summary, all of these have the identical objectives: to employ a quantifiable system of measure that is then communicated with ease and clarity to the audience. In the following review, many scales are presented. Some are common while others are less common yet used extensively in certain circles. In almost all cases, they are noted for their simple assessment, their ease of use and communication, and their effective communication.

6.1. FUJITA SCALE

The Fujita Scale (F-Scale) measures the damage from a tornado that is the result of wind intensity (Figure 2).

F-Scale Number	Intensity Phrase	Wind Speed	Type of Damage Done
F0	Gale tornado	40-72 mph	Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; damages sign boards.
F1	Moderate tornado	73-112 mph	Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	Significant tornado	113-157 mph	Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light object missiles generated.
F3	Severe tornado	158-206 mph	Roof and walls torn off well constructed houses; trains overturned; most trees in forest are uprooted, medium object missiles generated
F4	Devastating tornado	207-260 mph	Well-constructed houses leveled; structures with weak foundations blown off some distance; cars thrown and large missiles generated.
F5	Incredible tornado	261-318 mph	Reinforced concrete structures badly damaged, frame houses carried considerable distances; automobiles generated as missiles and thrown over 100 meters
F6	Inconceivable tornado	319-379 mph	Damage could not be differentiated from F4 or F5 winds. Possibly identified if cars and refrigerators were carried 1000s of meters or if ground swirls are found

Figure 2. F-scale.

Due to the nature of tornadoes, they are often rated after the fact, though forecasts and warnings will rate an approaching tornado to indicate the nature of the tornado and the risk of injury and death from this threat. Originally created by Tetsuya Fujita in 1971 as a 13-level scale, this design was driven by the objective to smooth the Beaufort Scale (which ranks violent storms) and the Mach Scale (which measures relative speed of wind as compared to the speed of sound in air). In practice, the Fujita scale contains only six levels (F0–F5); Fujita himself reserved an F6 ranking for a tornado of "inconceivable" magnitude and probable damage. Significant about this scale are:

1. Its simple design to warn of predicted tornado threat.
2. It incorporates only six color-coded levels.
3. Its popular adoption for the communication of tornado risk.

The simplicity of the scale corresponds easily to the number of digits on one hand. Additionally, the corresponding colors of cyan-blue to orange-red are typical of how people visualize threat or risk, where cool colors suggest serenity and red suggests blood and death. Lastly, the continued use of the F-Scale by the general public demonstrates its acceptance even though this scale was modified in 2007 as an EF-Scale (Enhanced Fujita) to reflect the current state of the science and art of predicting storm strength.

6.2. RICHTER MAGNITUDE SCALE

Also known as the Richter Scale, this scale assigns a single number to the maximum amount of seismic energy released by an earthquake using a base-10 logarithmic scale (Figures 3 and 4).

Originally developed by Charles Richter in partnership with Beno Guttenburg for an academic study of California earthquakes in 1935, it has been adopted worldwide due to its ease of assessment. Earthquakes of 10 or greater are conceivable; however, practice and physical maximums tend to keep earthquakes within the R-0 to R-8 range. Some people suggest the eventual occurrence of an R-9 earthquake—one of biblical proportions. However, earthquakes of R-10 or higher are thought to be impossible due to the stress or strain that rock is able to accept without failing. Additionally, one should be aware that a Richter Scale rating is applied after the fact; that is, earthquakes are rated after the released energy is measured. Richter ratings are not used for warning except in discussions of a scenario.

It is of interest that the Richter scale is one of the oldest threat scales in existence; possibly, for this reason it was never color-coded. Also of interest is the fact that earthquake frequency has a logarithmic relationship, similar to the logarithmic energy designed into the scale. Lastly, the logarithmic relationship between each classification has similar logarithmic effects on the number of people killed and injured.

Earthquake Description	Richter Scale Number	Human Impact	Frequency
Micro	**Less than 2.0**	People cannot feel these	~ 8,000 /day
Very minor	**2.0-2.9**	People cannot feel these, but inexpensive seismological tools can record them	~ 1,000 / day
Minor	**3.0-3.9**	People often feel these, but they rarely cause damage	~ 135 / day
Light	**4.0-4.9**	People will notice objects shaking with noise, yet little or no damage	~ 17 / day
Moderate	**5.0-5.9**	Poorly constructed buildings can be damaged to significantly damaged, well built and designed buildings are not, injury and possible death noted	~ 2 / day
Strong	**6.0-6.9**	Damage and possible death may be noted over an area of 100 square miles with damage to well constructed buildings and possible failures	~ 0.3 /day
Major	**7.0-7.9**	Major to significant damage is noted over an even larger area with damage to significant damage to very well designed and constructed buildings	~ 0.05 / day
Great	**8.0 or greater**	Substantial damage to all structures and failure to all poorly designed or constructed buildings over several hundred square miles; expect tremendous injury and loss of life	~ 0.003 / day

Figure 3. Richter scale.

Earthquake Description	Richter Scale Number	Human Impact	Frequency
Micro	**Less than 2.0**	People cannot feel these	~ 8,000 /day
Very minor	**2.0-2.9**	People cannot feel these, but inexpensive seismological tools can record them	~ 1,000 / day
Minor	**3.0-3.9**	People often feel these, but they rarely cause damage	~ 135 / day
Light	**4.0-4.9**	People will notice objects shaking with noise, yet little or no damage	~ 17 / day
Moderate	**5.0-5.9**	Poorly constructed buildings can be damaged to significantly damaged, well built and designed buildings are not, injury and possible death noted	~ 2 / day
Strong	**6.0-6.9**	Damage and possible death may be noted over an area of 100 square miles with damage to well constructed buildings and possible failures	~ 0.3 /day
Major	**7.0-7.9**	Major to significant damage is noted over an even larger area with damage to significant damage to very well designed and constructed buildings	~ 0.05 / day
Great	**8.0 or greater**	Substantial damage to all structures and failure to all poorly designed or constructed buildings over several hundred square miles; expect tremendous injury and loss of life	~ 0.003 / day

Figure 4. Richter scale.

6.3. SAFFIR-SIMPSON SCALE

The Saffir-Simpson Scale has received an unlikely amount of use recently due to the number of deadly and damaging hurricanes in the U.S (Figure 5). Developed in 1969 by a civil engineer and the Director of the National Hurricane Center (NHC) for the purpose of warning the public of possible storm danger, this system warns the public about sustained winds, likely flooding, and probable damage when a hurricane landfalls. Due to the lengthy name of the scale, hurricanes are simply described by *category*, thus a *Category 2* or *Category 3* storm.

Per *Wikipedia*:

> the initial scale was developed by Saffir while on commission from the United Nations to study low-cost housing in hurricane-prone areas. While performing the study, Saffir realized there was no simple scale for describing the likely effects of a hurricane. Knowing the utility of the Richter Magnitude Scale in describing earthquakes, he devised a 1–5 scale based on wind speed that showed expected damage to structures. Saffir gave the scale to the NHC where Simpson added in the effects of storm surge and flooding.

Of interest about this scale are:

1. The number of categories
2. Its use in every day communication
3. Its color coding

Category	Sustained Wind	Storm Surge	Central Pressure	Potential Damage
1	74-95 mph 119-153 km/h	1.2-1.5 m 4-5 ft	28.94 inHg 980 mbar	No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Also, some coastal flooding and minor pier damage.
2	96–110 mph 154-177 km/h	1.8–2.4 m 6-8 ft	28.50–28.91 inHg 965–979 mbar	Some roofing material, door, and window damage. Considerable damage to vegetation, mobile homes, piers and small craft in unprotected boats may break their moorings.
3	111–130 mph 178-209 km/h	2.7–3.7 m 9-12 ft	27.91–28.47 inHg 945–964 mbar	Some structural damage to small residences and buildings, some curtainwall failures. Mobile homes are destroyed. Coastal flooding destroys small structures, floating debris damages large structures. Local terrain flooded.
4	131–155 mph 210–249 km/h	4.0–5.5 m 13-18 ft	27.17–27.88 inHg 920–944 mbar	More extensive curtainwall failures with some complete roof structure failure on small residences. Major erosion of beach areas. Terrain may be flooded well inland.
5	≥156 mph ≥250 km/h	≥5.5 m ≥19 ft	<27.17 inHg <920 mbar	Complete roof failure on many residences and industrial buildings. Some complete building failures. Flooding causes major damage to lower floors of all structures near the shoreline. Massive evacuation may be required.

Figure 5. Saffir-Simpson scale.

Similar to the Fujita and Richter Scales, the Saffir-Simpson Scale has five categories which are easy to remember and rank on one hand. Note that a Category 6 has been discussed to signify a hurricane storm of biblical proportions; and though not recognized, many believe that such a ranking would garner the attention of the media and convey the threat to the public better than a Category 5 ranking, which is at times ignored. Also of interest is how the scale is communicated. The scale is rarely referenced as the Saffir-Simpson; rather, the hurricane and its warning are simply described with a category number. In fact, the word category has almost become synonymous with hurricane due to its common use during the summer storm season.

6.4. TORINO SCALE

The Torino Scale is scarcely mentioned in general conversation, which is fortunate because it measures the risk of near-earth objects such as comets or asteroids striking the earth (Figures 6 and 7). Intended as a tool for astronomers, governments, and the public to assess the seriousness of collision predictions, this scale combines probability statistics and kinetic damage potential into a single risk value.

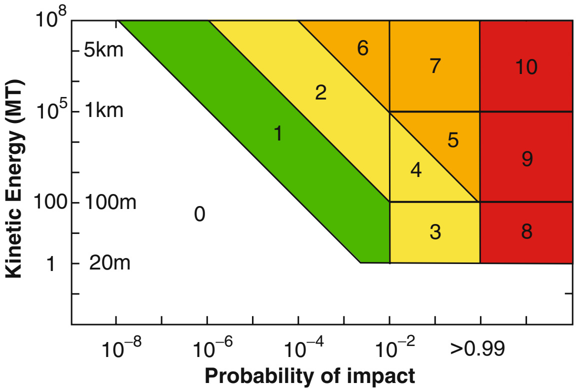

Figure 6. Torino scale.

	NO HAZARD (white)
0	The **likelihood of a collision is zero**, or is so low as to be effectively zero. Also applies to small objects such as meteors and bodies that burn up in the atmosphere as well as infrequent meteorite falls that rarely cause damage
	NORMAL (green)
1	Near Earth pass is predicted with no unusual level of danger. Current calculations show the **chance of collision is extremely unlikely** with no cause for public attention or public concern
	MERITING ATTENTION BY ASTRONOMERS (yellow)
2	An object making a somewhat close but not highly unusual pass near the Earth. While meriting attention, there is no cause for public attention or public concern as an **actual collision is very unlikely**
3	A close encounter, meriting attention. Current calculations give a **1% or greater chance of collision capable of localized destruction.** Most likely, telescopic observations will lead to re-assignment to Level 0. Attention is merited if the encounter is less than a decade away
4	A close encounter, meriting attention. Current calculations give a **1% or greater chance of collision capable of regional devastation.** Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention is merited if the encounter is less than a decade away
	THREATENING (orange)
5	**A close encounter posing a serious but uncertain threat of regional devastation**. Critical attention by astronomers is needed whether or not a collision will occur. If the encounter is less than a decade away, governmental contingency planning may be warranted
6	**A close encounter by a large object posing a serious but uncertain threat of a global catastrophe**. Critical attention by astronomers is needed to determine whether or not a collision will occur. If the encounter is less than three decades away, governmental contingency planning may be warranted
7	**A very close encounter by a large object posing an unprecendented threat of a global castastrophe.** For such a threat, international contingency planning is warranted, to determine conclusively whether or not a collision will occur
8	**Collision is certain with localized destruction on land or shoreline if ocean, sea, or lake landing. Events occur on average between once per 50 years and once per several 1000 years**
9	**Collision is certain and capable of causing unprecendented regional devastation Such events occur on average between once per 10,000 years and once per 100,000 years**
10	**Collision is certain, capable of causing global climatic catastrophe that may threaten the future of civilization as we know it, whether impacting land or ocean. Such events occur on average once per 100,000 years or less**

Figure 7. Key to the Torino scale.

Of particular interest to our efforts, this scale is notable in communicating a wide array of possible scenarios, simplified by the number of categories and their color coding. Similar to the Fujita, Richter, and Saffir-Simpson scales, the Torino Scale has five probability categories within a matrix of three categories for object size and implied kinetic energy. As a result, there are ten risk categories, which are then allocated into five color categories. Also of interest is the scale's global perspective in communicating the threat of worldwide catastrophe. Lastly, the color coding of cool to hot colors is similar if not identical to other threat scales.

6.5. UV INDEX

The UV Index is an international standard measurement of the strength of ultraviolet (UV) radiation from the sun at a particular place on a particular day (Figure 8). The primary purpose of this scale is to communicate the threat of a sunburn or sunstroke to the general public. Originally developed in Canada in 1992, this index has been adopted by many countries due to its effectiveness in communicating the risk from sunburn. The UV index is a calculated prediction of how strong the actual UV intensity will be at the sun's highest point in the day, which typically occurs during the 4-h period surrounding solar noon. This prediction is made by calculating the impact of latitude and local altitude, weather, and pollution to determine UV intensity at the earth's surface. The calculations are weighted in favor of UV wavelengths to which the human skin is most sensitive. The date, the most severe UV warning has been an UV Index rating of 17.

UV Index	Description	Recommended Mitigation
0–2	low risk from sun to the average person	Wear sunglasses if there is snow on the ground
3–5	moderate risk from unprotected sun exposure	Wear sunglasses and use sunscreen, cover body with clothing and hat, seek shade from midday sun
6–7	high risk from unprotected sun exposure	Wear sunglasses and use sunscreen of SPF-15 or greater, cover body with clothing and hat, seek shade from midday sun, reduce to time in sun to 2 hours before noon and 3 after noon
8–10	very high risk from unprotected sun exposure	Identical to actions above but wear more protective sunscreen, clothing. and hat. Reduce time in sun as required
11+	Certain risk from unprotected sun exposure	Take all precautions as possible with long sleeved shirts and long pants, sunscreen of SPF-50 or greater, broad hat. Reduce time in sun as practical

Figure 8. UV index.

Of particular interest:

1. The number of color codes
2. The speed of its adoption
3. Its quantitative approach to a relatively innocuous subject

First, it is important to notice that though UV Index ratings of 17 are possible, these ratings are communicated within five risk classifications, again, probably due to ability of the common individual to identify and remember levels of threat. Additionally, the colors are similar if not identical to other previously discussed scales while being representative of an outcome from unprotected sun exposure. Also noteworthy is the scale's rate of adoption; it has been adopted in most developed countries where skin cancer is a serious health issue and is often broadcast along with weather predictions. Lastly, it is important to note that although every person reacts to UV intensity differently, this quantitative scale allows the user to interpret his or her risk based on experience in its use.

6.6. DEFCON

Applicable only to the U.S. military, DEFCON measures defense readiness (Figure 9). Similar to all other scales discussed, this scale provides a

Description	Recommended Mitigation
DEFCON 5	This is the condition used to designate normal peacetime military readiness. An upgrade in military preparedness is typically made by the Joint Chiefs of Staff and announced by the United States Secretary of Defense.
DEFCON 4	This refers to normal, increased intelligence and the heightening of national security measures.
DEFCON 3	This refers to an increase to force readiness above normal. Radio call signs used by American forces change to currently-classified call signs.
DEFCON 2	This refers to a further increase in force readiness just below maximum readiness. Declared during the Cuban Missile Crisis, although limited to Strategic Air Command only. It is not certain how many times this level of readiness has been reached.
DEFCON 1	This refers to maximum readiness. It is not certain whether this has ever been used, but it is reserved for imminent or ongoing attack on US military forces or US territory by a foreign military power.

Figure 9. DEFCON scale.

quantitative measurement of the risk of attack from a hostile armed force. Of interest is the use of five levels on an inverted scale to the degree of risk. Also notable is the lack of color coding.

6.7. HOWE-DEVEREUX FAMINE SCALE

The Howe-Devereux Famine Scale is one of the newer scales for threat or risk (Figures 10 and 11). Introduced in 2004 by Paul Howe and Stephen Devereux at the University of Sussex, this scale measures the risk of famine according

Intensity	Phrase	Crude Mortality Rate (CMR)	Livelihood
0	Food Secure	CMR < 0.2/10,000/day and/or Wasting < 2.3%	Cohesive social system; food prices stable; Coping strategies not utilized
1	Food Insecure	0.2 <= CMR <0.5/10,000/day and/or 2.3% <= Wasting < 10%	Cohesive social system; Food prices unstable; Seasonal shortages; Reversible coping strategies taken
2	Food Crisis	0.5 <= CMR < 1/10,000/day 10% <= Wasting < 20%, and/or prevalence of oedema	Social system stressed but largely cohesive; Dramatic rise in food and basic items prices; Adaptive mechanisms fail; Increase in failed coping strategies
3	Famine	1 <= CMR < 5/10,000/day 20% <= Wasting < 40% and/or prevalence of oedema	Clear signs of social breakdown; markets begin to collapse, survival strategies initiated; migration begins, weaker family members abandoned
4	Severe Famine	5 <= CMR <15/10,000/day Wasting >= 40% and/or prevalence of oedema	Widespread social breakdown; markets close; survival strategies widespread; affected population identifies food scarcity as the major societal problem
5	Extreme Famine	CMR >= 15/10,000/day	Complete social breakdown; widespread mortality; affected population identifies food scarcity as the major societal problem

Figure 10. Howe-Devereux famine scale—intensity rating.

Magnitude	Phrase	Mortality range
A	Minor famine	0-999
B	Moderate famine	1,000-9,999
C	Major famine	10,000-99,999
D	Great famine	100,000-999,999
E	Catastrophic famine	1,000,000 and over

Figure 11. Howe-Devereux famine scale—magnitude rating.

to its intensity and magnitude. This scale replaced prior famine scales due to a more quantitative approach in measuring social and human conditions. Thus, while many organizations will continue to have their own qualitative interpretation as to the specific indicators, this scale requires quantitative data to assess a famine's magnitude (individual impact of nutrition provisions and death rates) and intensity (its impact on social functioning).

6.8. INTERNATIONAL SCALE OF RIVER DIFFICULTY

This scale is an international standard to rate and convey the dangers and potential risks of a river or a single rapid (Figure 12). In summary, this scale provides a rating to reflect the river's technical difficulty, skill level requirements for safe passage, and the associated risks of failure. Six nonlinear and nonfixed class ratings are provided with the option of plus (+) and a minus (−) to denote added ease or difficulty.

Similar to the scales discussed previously, this scale is simplified into six categories of simple threat descriptions. At this time, there are no color codes to visually signal danger or risk, though certain books on river running as well as local signing have incorporated a nonstandard color code similar to the previously discussed scales where red is associated with the most dangerous level, orange and yellow with less danger, and green and blue with the least danger.

		Description of Risk	**Probability of Injury or Death**
Class I	Easy	Waves small; passages clear; no serious obstacles	Risk to swimmers is slight
Class II	Medium	Rapids of moderate difficulty with passages clear. Requires experience plus suitable outfit and boat.	Swimmers are seldom injured and group assistance is seldom needed
Class III	Difficult	Waves numerous, high, irregular; rocks; eddies; rapids with clear passages, requires expertise in maneuvering; scouting usually needed. Requires good operator & boat.	Injuries are rare and group assistance not necessary but avoids long swims
Class IV	Very Difficult	Long rapids; waves high, irregular; dangerous rocks; boiling eddies; best passages difficult to scout; scouting mandatory first time; powerful and precise maneuvering required. Demands expert boatman & excellent boat	Swimmers are in moderate to high danger, probable injury, rescue difficult
Class V	Extremely Difficult	Exceedingly difficult, long and violent rapids, following each other almost without interruption; riverbed extremely obstructed; big drops; violent current; very steep gradient; close. Requires the best person & boat. All possible precautions must be taken.	Swims are definitely at risk of injury, death very possible, rescue very difficult
Class VI	Not runnable	Luck rules the day for any level of expertise.	Definite risk to life in and out of watercraft, rescue almost impossible

Figure 12. International scale of river difficulty.

It is notable that this scale was devised by the river running community to describe rivers and rapids with ease. All river runners know to scout a river or rapid of Class IV or higher, regardless of their level of technical ability.

6.9. APGAR SCALE

The APGAR Scale measures the relative health and immediate risk of newborns immediately after birth (Figure 13). What is most notable about this scale is its impact on society in general; the scale has been described as "the most important medical practice or technology in reducing infant mortality."

Developed in 1952 by anesthesiologist Virginia Apgar, it is best known by its mnemonic reference:

- **A**ctivity
- **P**ulse
- **G**rimace
- **A**ppearance
- **R**espiration

Designed to be administered by any hospital staff person twice after birth of the newborn (at 1 min and at 5 min), this evaluation provides an immediate assessment of risk to the infant. Like other successful scales, it is quantitative in nature, evaluating newborn health attributes on a scale of 0–10.

An APGAR 0 requires immediate response whereas an APGAR 10 requires no attention from medical staff. Newborns with an APGAR 7 or

	APGAR Score		
APGAR Sign	**2**	**1**	**0**
Heart Rate	Normal (above 100 beats per minute)	Below 100 beats per minute	Absent
Breathing	Normal rate and effort	Slow or irregular breathing	Absent (no breathing)
Grimace or reflex irritability	Pulls away, sneezes, or coughs with stimulation	Facial movement only (grimace) with stimulation	Absent (no response to stimulation)
Activity or muscle tone	Active, spontaneous movement	Arms and legs flex ed with little movement	No movement, "floppy" tone
Appearance by skin coloration	Normal color all over (hands and feet are pink)	Normal color (but hands and feet are bluish)	Bluish-gray or pale all over

Figure 13. APGAR scale.

above 1 min after birth are generally considered in good health; however, a lower score doesn't necessarily mean that your baby is unhealthy or abnormal. APGAR scores between 4 and 6 may simply demonstrate the need for some immediate, low-technology care such as suctioning of the airways or oxygen to help him or her breathe. At 5 min after birth, the APGAR score is reassessed and recalculated and if the baby's score hasn't improved to 7 or greater, doctors and nurses will continue medical care as required and closely monitor the newborn.

What is significant in developing trust of this scale and its ranking are the ease of calculating an APGAR score and its timeliness for mitigating newborn health issues. For this reason, it is very transparent. Also, it is interesting that this score is determined with five variables that are easy to remember with a mnemonic device. Response is simply a test of whether the newborn exceeds a minimum score rating of 6.

7. Security Assurance Index

The Security Assurance Index (SAI) was developed at INL for the CSSP using many of the attributes that we felt contributed to the successful risk scales (Figure 14). This included ease of use, communication, and understanding as well as a transparent, understandable, and quantifiable risk methodology. It is believed that these attributes, plus successful use, build trust—trust from the user that the index accurately reflects risk and trust from the risk manager that the users will respond appropriately. Thus, trust is an important outcome of this risk communication process.

expected life event	**life loss assurance level**	low-end	**median**	high-end
Total loss of US civilization	**SAL 10**	300,000, 000		
significant loss of US civilization	**SAL 9**	30,000,000	**95,000,000**	300,000,000
Loss of regional civilization	**SAL 8**	3,000,000	**9,500,000**	30,000,000
loss of metropolitan area	**SAL 7**	300,000	**950,000**	3,000,000
loss of city	**SAL 6**	30,000	**95,000**	300,000
loss of town	**SAL 5**	3,000	**9,500**	30,000
loss of community	**SAL 4**	300	**950**	3,000
loss of neighborhood	**SAL 3**	30	**95**	300
loss of family of related group	**SAL 2**	3	**9.5**	30
loss of individual	**SAL 1**	0.3	**0.9**	3

Figure 14. Security assurance index.

With respect to the CSSP, it is important to understand the program's mission, and what is considered to be at risk. First, DHS and CSSP have identical missions: the protection of U.S. infrastructure and population from terrorists' threat. The only difference is that the CSSP manages risk specific to control systems. Second, DHS clearly states that 300,000,000 people, a $12 trillion annual economy, and $120 trillion in capital investment are at risk. This is not to say that DHS does not recognize other equally important and intangible measures such as social, political, religious, economic, and psychological freedoms as well as cultural confidence, national influence, and morale. However, it simply recognizes that people and material wealth enables many other aspects of social welfare.

Given these maximum risk conditions, a scale was drafted of reasonable dimensions using the logarithmic logic of some of the scales we reviewed. As for those scales that did not incorporate this logic, this scaling often reflected event probability, probable death, and economic loss (Figure 15). Thus, a rating of 3 or 4 often suggests loss of 1,000 people and 10,000, respectively, without mitigation efforts.

Interestingly enough, such a concept in scale development was proposed by Gustav Fechner, a 19th century, German psychologist who advanced the theory that the intensity of a human sensation increases in arithmetical progression based on a geometric increase in stimulus. Describing human reaction to stimulus, Fechner's famous equation (the first to describe human psychology mathematically) is the basis of many scales that relate to human comfort and discomfort:

$$S = c \log R$$

expected life event	**economic loss assurance level**	low-end	**median**	high-end
total loss of US civilization	**SAL 10**	$3 Q		
significant loss of US civilization	**SAL 9**	$300T	**$1Q**	$3Q
loss of regional civilization	**SAL 8**	$30T	**$100T**	$300T
loss of metropolitan area	**SAL 7**	$3T	**$10T**	$30T
loss of city	**SAL 6**	$312B	**$1T**	$3T
loss of town	**SAL 5**	$31.2B	**$100B**	$312B
loss of community	**SAL 4**	$3.1B	**$10B**	$31.2B
loss of neighborhood	**SAL 3**	$312M	**$1B**	$3.1B
loss of family of related group	**SAL 2**	$31M	**100M**	$312M
loss of individual	**SAL 1**	$3	**10M**	$31M

Figure 15. Economic loss index.

Where:

S = sensation

R = numerically estimated stimulus

c = a constant that must be separately determined by experiment for each sensibility

This concept has been used to develop many human response scales to noise (decibel), light (lumens), and vibration (Richter). Interestingly, it appears that we have taken the liberty of applying this same concept to human sensation and response to threat, danger, risk to life and limb, and property loss. What this means is that humans, in general, will notice a perceptible difference (a doubling) in risk only if it increases by an order-of-magnitude. Thus, the risk of one to nine deaths is relatively the same; it is not until ten people are at risk that a human will notice the increase. It is from this observation that the SAI is developed.

Lastly, the SAI methodology scale was made to be transparent and reproducible to gain acceptance, trust, and usefulness for application to other risk scenarios. Accordingly, risk is calculated from the basic equation of risk under deliberate and targeted threat (versus the risk of statistically random threat):

$$Risk = Threat\ ^{*}\ Vulnerability\ ^{*}\ Consequence$$

Where

Threat = the probability of threat actor's capability to deliver an attack successfully

Vulnerability = 1 minus the probability of a target to protect itself from the attack threat

Consequence = the likey outcome or distribution of outcome of the specific attack

CSSP recognized the tremendous difficulty in obtaining data and then calculating risk; however, an evaluation process was established to calculate threat and vulnerability as a probability and consequence as a life and limb or economic statistic based on life loss and injury or loss of human and durable capital investment, inventory, S-T market disruption, and environmental loss. Thus, based on a maximum loss condition, the following SAI was developed:

First, one must note that an SAI level is referred to as a Security Assurance Level (SAL) since an index begs for a level or ranking. Also note that although life and economic losses of less than one and $1 million are calculable, they fall below the threshold level for risk management by DHS.

In practice, the greatest level attained on either scale would warrant the highest ranking.

As a test of reasonableness, two recent and well known events were used to demonstrate and understand the scale's usefulness. The 1992 World Trade Center (WTC) bombing resulted in 13 people killed, more than 1,000 injured, and $600 million in economic losses. In this event, a 600-lb car bomb was used within the WTC parking garage in hopes of destroying the structure from within. Though insufficient for the task, a bomb of this size could have delivered considerable loss of life (which it did not) and considerable facility loss (which it did). Prior to this event, when security was lax, one would have rated this scenario as a SAL 3 risk event. On the other hand, 9-11 presents a scenario of significantly higher risk. Although the final economic losses have not yet been tallied, we know that almost 3,000 people lost their lives, tens of thousands were injured, and there was a loss of more than $80 billion in structures and business to the local economy (and even more if one includes national economic disruptions). Prior to this event, the risk may have rated low since no one believed in such a strategy of execution; however, there would have been no argument that if a group of people possessed these characteristics, these buildings and the nation would have been vulnerable to a SAL 5 or SAL 6 event.

The SAI has proven to be just as valuable as hoped. The evaluation process is transparent as are the results; scenarios are given rankings based on the highest probable loss (economic or human life), organized according to the SAL levels, and if needed, are prioritized for a more intensive risk evaluation. Furthermore, this process has been adaptable for evaluating many risk scenarios, with little time, few resources, and for the purpose of ranking risk. This process has contributed significantly to ranking issues within and between industry groups; thus, scenarios are often compared, as in the example above.

Please note that a color schematic has yet to be assigned to any SAL level. This is in part due to the nature of the group, which is small, and the clear understanding of risk associated with each level. However, it may also be due to the sensitivity associated with any loss of human life. For example, it would not be politically or programmatically acceptable to associate the loss of one or even ten lives with a blue or green color. A warning color of at least yellow would have to be used to signal concern and action. It has been suggested that grouping these 10 SAL levels into five color groups would be easy for people to remember, similar to other scales … or possibly grading the 10 levels from yellow to magenta. Either way, such a ranking would help provide the necessary urgency for mitigating the possibility of such highly ranked scenarios.

8. Development of a Global Risk Index

Presentation of the SAI to the risk management community resulted in many suggestions that a scale of similar design could be applied to global-related risks as a Global Risk Index (GRI). A risk scale based on loss of life was presented at Risk Analysis 2006 (Malta 2006) (Figure 16). (A risk scale based on economic loss was not presented due to the inappropriateness of mapping material and financial losses across the many social, cultural, and economic environments of the world.)

Similar to the SAI development, objectives such as a transparent evaluation process, and ease of use, communication, and understanding continue to be paramount to developing trust in communicating risk. As to the logic of the scale, the logarithmic scale was again selected due the gravity and orders of magnitude it demonstrates in conveying the urgency of a risk scenario. Of note, similar to the Howe-Devereux Scale of Famine, a measure of global risk may find insignificant meaning in small numbers; that is, the possibility of death on a magnitude of 1,000 people or less. From a world health perspective where events of this size happen daily (such as famines, floods, earthquakes, and disease), they seem to be of a national interest and often allow only national response. Events that have a potential for crossing over into the hundreds of thousands to millions garner world interest, attention, and possibly response. Recent tsunamis, earthquakes, famines, and even global warming have resulted in responses of differing degrees due to the magnitude of resources required to react to and mitigate these events. However, for purposes of demonstration and consistency, the categories of 1, 2, and 3 are retained.

Lastly, two notes of importance. The first note is that the original Malta presentation did not include colors to associate risk with the magnitude or urgency of a situation. This was probably an oversight on my part because it would have had a much more powerful impact in communicating risk. The second note is that if this were to be adopted as an index of world risk, there should be little discussion as to the description of risk. Thus, I would use a word such as "category" to describe world risk.

	GLOBAL RISK INDEX Category	lower bound	MEDIAN	Upper bound
total loss of civilizations	Category 10	312,000,000	**1,000,000,000**	3,120,000,000
significant loss of large civilizations	Category 9	31,200,000	**100,000,000**	312,000,000
loss of regional civilization	Category 8	3,120,000	**10,000,000**	31,200,000
loss of metropolitan area	Category 7	312,000	**1,000,000**	3,120,000
loss of city	Category 6	31,200	**100,000**	312,000
loss of town	Category 5	3,120	**10,000**	31,200
loss of community	Category 4	312	**1,000**	3,120
loss of neighborhood	Category 3	31	**100**	312
loss of family of related group	Category 2	3	**10**	31
loss of individual	Category 1	0	**1**	3

Figure 16. Global risk index, in terms of numeric impact.

Additionally, a scale of the same rationale was presented as a percentage of the population (Figure 17). This has the advantage of being applicable to any nation-state context; thus, if Malta were at risk of an event that could result in 200,000 lives lost (50% of its population), this "category 10" event could present as compelling a need for mitigation as a loss of 500 million people in China. Because of this, I prefer the scale of percentage to just numbers. Again, its use would be tailored to whether national or global concerns are at stake.

As a test of reasonableness, two worldwide flu pandemics were discussed. The Spanish Flu Outbreak of 1918 resulted in an estimated loss of 40–100 million human lives. Given the contemporary expert estimate of world population, this was a 2–5% reduction. Significant by any measure, this pandemic would have been labeled a Category 9 event. However, due to the state of the world's information, health, and pharmaceutical response at that time, it was not possible to predict a reasonable outcome for this scenario.

The current H5N1 flu strain presents a totally different scenario. The science concerning pathogens, medicine, and pharmaceutical products has progressed to a sufficiently advanced state that the outcome of the H5N1 flu strain can be predicted with some accuracy. Given this information, risk can be adequately evaluated to devote resources to mitigating the possible outcomes of scenarios concerning this pathogen. Currently, health organizations around world predict probable population reductions of between 15–150 million given the current state of the flu strain. Assuming this range of life loss (0.2–2.3% of the current world population), this pandemic would rank as a "Category 8" world event; still significant, but not as significant as the Spanish flu outbreak.

The response to this presentation was mixed, if not binomially distributed. It was obvious that more than half of the conference attendees

	GLOBAL RISK INDEX category	lower bound	MEDIAN	Upper bound
total loss of civilizations	Category 10	10.00%	31.60%	100.00%
significant loss of large civilizations	Category 9	1.00%	3.16%	10.00%
loss of regional civilization	Category 8	0.10%	0.32%	1.00%
loss of metropolitan area	Category 7	0.01%	0.03%	0.10%
loss of city	Category 6	0.001%	0.003%	0.010%
loss of town	Category 5	0.0001%	0.0003%	0.0010%
loss of community	Category 4	0.00001%	0.00003%	0.00010%
loss of neighborhood	Category 3	0.000001%	0.000003%	0.000010%
loss of family of related group	Category 2	0.0000000%	0.0000003%	0.0000010%
loss of individual	Category 1	0.00000000%	0.00000000%	0.00000010%

Figure 17. Global risk index, in terms of percentage impact.

found such a scale useful and beneficial in ranking risk scenarios. The other attendees were emotional about the issues of life, death, and life valuation techniques. Of particular concern was the depiction of the loss of one or even ten lives as being less significant than that 1,000 or even 10,000 lives. For this reason, caution must be taken anytime loss of life is predicted with acceptable levels.

9. Development of an Environmental Security Index

From the information presented, an index for environmental security would be larger in scope than any of the existing risk scales; however, it would be smaller in scope than the proposed world risk index. From these observations, there should be no doubt that such a scale would prove effective in communicating environmental security risk within a sphere of influence provided that the five identified factors are present:

- Easy to use
- Easy to communicate
- Easy to understand
- Transparent
- Trusted

I would propose an index with characteristics similar to the GRI. They are logical, easy to understand and use, easy to communicate, and transparent in derivation. Most importantly, a risk scale that could be used to communicate the risk of any scenario would significantly contribute to communicating the risks of any event. Thus, the risk of H5N1 would be able to be compared against the risk of global warming or the risks of nanomaterials, long-lived chemicals, or nuclear isotopes. The only recommendation is that a name or acronym that is easy to remember and say would be highly desirable. I would argue that “Category” be reserved for referencing risks that are global in significance.

Without a doubt, risk scales have found a place in modern societies. They are commonly used to communicate risks efficiently and effectively while being easy to replicate through a transparent evaluation process. Often, even if citizens know little of how the risk was determined, they seek paths of mitigation based on this communication. I believe that eventually a global risk index will become reality. This may be through the combination of other accepted risk scales such as the Howe-Devereux or Torino Scale. Or it may be through the effort of international groups who are working on developing a common language and response to world risk events.

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