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A guide to making stochastic and single point predictions using the Cold Exposure Survival Model (CESM)

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Defence R&D Canada

Technical Memorandum

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Abstract

CESM is a commercially available, user-friendly PC application that predicts the status and survivability of hypothermic casualties based on biophysical and physiological principles. It has been calibrated against accidental and laboratory cold exposure data across a wide range of temperatures and is continuously refined as new knowledge emerges. Its advantage over other survival models lies in the fact that it can be customized to account for unique combinations of human, environmental and clothing characteristics present in any survival situation. In addition, it can be applied across a broad range of environmental conditions from air exposure, or partial to full water immersion. The stochastic upgrade enhances the prediction capabilities by offering a probability of survival when casualty information is not available or multiple casualties are involved. CESM was originally designed as a SAR decision aid, but it has proven to be a very effective education tool. Hypothetical scenarios may be examined, giving immediate feedback of the effect of such variable as wetness, wind, body fatness and various clothing items. Predictions assume that casualties are in a fixed, non-active position, and have a normal cooling response to cold.

Résumé

Le Cold Exposure Survival Model (modèle de survie à l'exposition au froid), ou CESM, est une application PC conviviale offerte sur le marché, qui permet de prévoir l'état et les chances de survie des victimes d'hypothermie à partir de principes biophysiques et physiologiques. Le modèle a été étalonné au moyen de données découlant d'expositions accidentelles et conduites en laboratoire, à une vaste fourchette de températures froides. Il est continuellement perfectionné au fil des connaissances nouvelles qui sont acquises. Son avantage par rapport à d'autres modèles de survie tient au fait qu'il peut être ajusté en fonction de la combinaison unique de facteurs en cause dans toute situation de survie, soit les caractéristiques de la victime, les vêtements qu'elle porte et l'environnement où l'incident se produit. En outre, il peut être appliqué à une vaste gamme de conditions environnementales, de l'exposition à l'air jusqu'à l'immersion partielle ou totale dans l'eau. L'ajout de la fonction stochastique a permis d'améliorer les capacités prédictives en calculant la probabilité de survie en l'absence d'information sur la victime ou en présence de plusieurs victimes. Le CESM a au départ été conçu comme outil de prise de décisions en recherche et sauvetage, mais il s'est avéré un outil éducatif très efficace. Des scénarios hypothétiques peuvent être étudiés, offrant un aperçu immédiat de l'effet de variables telles que l'humidité, le vent, la graisse corporelle et différents vêtements. Les prévisions sont fondées sur une victime inactive en position fixe, qui réagit normalement au froid.

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Executive summary

A guide to making stochastic and single point predictions using the Cold Exposure Survival Model (CESM):

Keefe, Allan A., Tikuisis, Peter.; DRDC Toronto TM 2008-061; Defence R&D Canada – Toronto; January 2008.

When previously confronted with Search and Rescue (SAR) operations in inclement environmental conditions, SAR personnel had very few resources to assist them in the prediction of a casualty's survivability or physiological status due to hypothermia. Limited hypothermia tables, consultation with experts or personal experience were the only means available. Unfortunately, these predictions could only be made with broad assumptions and limited certainty as there were no comprehensive tools to help account for the myriad of environmental and casualty combinations that can occur. In response to this need for an objective and robust method for estimating casualty survival time and status due to hypothermia, the Cold Exposure Survival Model (CESM) was developed.

Hypothermia occurs whenever an individual's body temperature drops by as little as 2°C from its daily normal of 37°C. Body temperature is normally maintained through a carefully controlled balance of heat production and loss. Body heat is produced through normal metabolism, shivering and exercise while it is lost to the environment through the avenues of conduction, convection, radiation and evaporation. This loss is minimized by an auto regulated decrease in blood flow to the body's periphery or through the insulation afforded by layers of body fat and clothing. When these mechanisms cannot compensate for the loss of heat to the environment due to cold, wind and wetness, body temperature begins to fall. The rate of this heat loss is influenced by numerous physical and physiological properties of the casualty as well as the nature and severity of the environment.

Historically, predictions of cold-water immersion survival were based upon incident reports from shipwreck rescues. When an incident occurred, measurements of water temperature, time of exposure and survival rate were recorded. As the amount of information grew, the relationship between survival time and water temperature could be deduced. While this method has the advantage of being based on actual incident data, it could not discern whether death was due to hypothermia or other events such as drowning or trauma, nor could it account for differences in survival time between individuals.

Recently, complex mathematical models have been developed that attempt to predict heat transfer between the human body and environment under various conditions. CESM is such a model and is based on known physiological and physical principles of heat transfer. It is capable of making either single point or stochastic (probabilistic) predictions of hypothermia survival and its validity has been demonstrated through extensive comparisons with known survival incident and laboratory experimental data. Its advantage over other models is its ability to be customized to each unique survival scenario, and may be applicable to both air and water exposure. CESM is constantly evaluated and improved as more data become available.

While CESM has a simple yet intelligent interface, it is necessary for the user to select the appropriate inputs that accurately represent the incident scenario to ensure a reasonable interpretation of the model output. In order to assist with this task, this guide has been developed to provide a fundamental understanding of the scope and limitations of hypothermia prediction models, as well as a comprehensive description of the model inputs and their impact on prediction times. Practical examples of the use of CESM are provided for both air exposure and water immersion, illustrating the robustness and versatility of the model.

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Auparavant, lors de leurs opérations de recherche et sauvetage (SAR) dans des conditions difficiles, les intervenants SAR disposaient de très peu de ressources pour les aider à prévoir les chances de survie d'une victime ou son état physiologique attribuable à l'hypothermie. Des tables d'hypothermie limitées, la consultation d'experts et l'expérience personnelle étaient les seuls moyens disponibles. Malheureusement, ces prévisions ne pouvaient être faites qu'à partir d'hypothèses larges et avec un degré de certitude limité, car il n'y avait aucun outil complet permettant de tenir compte de la myriade de combinaisons environnement-victime possibles. C'est en réponse à ce besoin d'une méthode objective solide pour estimer le temps de survie d'une victime et son état lié à l'hypothermie que le Cold Exposure Survival Model (modèle de survie à l'exposition au froid), ou CESM, a été mis au point.

L'hypothermie se produit dans tous les cas où la température corporelle d'une personne diminue d'aussi peu que 2 °C par rapport à la normale quotidienne (37 °C). Habituellement, la température du corps est maintenue par un équilibre soigneusement contrôlé entre la production et la perte de chaleur. La chaleur corporelle est produite par le métabolisme normal, le frissonnement et l'exercice, tandis qu'elle est libérée dans l'environnement par les mécanismes de conduction, de convection, de rayonnement et d'évaporation. Cette perte est minimisée par une diminution autorégulée de la circulation sanguine en périphérie du corps ou par l'isolation que procurent la graisse corporelle et les vêtements. Lorsque ces mécanismes ne parviennent pas à compenser pour la perte de chaleur attribuable au froid, au vent et à l'humidité, la température corporelle commence à chuter. La vitesse de cette perte de chaleur est influencée par les nombreuses caractéristiques physiques et physiologiques de la victime ainsi que par la nature et la rigueur de l'environnement.

Par le passé, les prévisions de la survie à une immersion en eau froide étaient fondées sur les rapports d'opérations de sauvetage en cas de naufrage. Lorsqu'un incident survenait, la température de l'eau, la durée d'exposition et le taux de survie étaient consignés. Avec l'accumulation des données, on est parvenu à établir le lien entre la durée de survie et la température de l'eau. Bien que cette méthode ait l'avantage d'être fondée sur des données issues d'incidents réels, elle ne faisait pas de distinction entre les décès attribuables à l'hypothermie et les décès liés aux noyades ou aux traumatismes, et elle ne tenait pas compte des différences individuelles quant à la durée de survie.

Récemment, des modèles mathématiques complexes ont été mis au point pour tenter de prévoir le transfert de chaleur entre le corps humain et l'environnement dans différentes conditions. Le CESM est au nombre de ces modèles. Il est fondé sur les principes physiologiques et physiques connus relatifs au transfert de chaleur. Il permet de faire des prévisions tant ponctuelles que stochastiques (probabilistes) de la survie à l'hypothermie, et sa validité a été démontrée au moyen de comparaisons approfondies avec des données issues des cas de survie connus et d'expériences

en laboratoire. Son avantage par rapport à d'autres modèles est qu'il peut être adapté selon le caractère unique de chaque scénario de survie, et peut s'appliquer à une exposition tant à l'air qu'à l'eau. Le CESM est constamment évalué et amélioré au fil des données nouvelles acquises.

Quoique le CESM ait une interface simple et intelligente, l'utilisateur n'en doit pas moins entrer les données appropriées qui représentent l'incident avec exactitude pour garantir l'interprétation raisonnable des résultats tirés du système. C'est pour faciliter cette tâche que le présent guide a été mis au point. Il offre une compréhension de base de la portée et des limites des modèles de prévision de l'hypothermie, et décrit en profondeur les données à saisir dans le système et leur impact sur le temps de prévision. Des exemples pratiques de l'utilisation du CESM sont fournis tant pour l'exposition à l'air que pour l'immersion en eau, ce qui illustre bien la solidité et la souplesse du modèle.

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Introduction to the Cold Exposure Survival Model (CESM)

In all but the warmest of regions, Search and Rescue (SAR) operations must consider hypothermia as a factor in a casualty's survival outcome. When faced with this threat, the SAR team must estimate; "how long can the casualty survive, and if successfully rescued, what state of health can they be expected to be found?" These estimates might impact the urgency of the operation and allocation of required resources. In the past, these decisions were based on the combined use of hypothermia tables, consultation with subject matter experts or reliance on the wealth of knowledge and intuition garnered by years of experience. Unfortunately, multiple factors including the casualty's physical characteristics, clothing insulation and wetness influence the rate of hypothermia's progression. As a result, it has been almost impossible to accurately predict survivability across the myriad of all of possible conditions. This need for an objective and robust method for estimating casualty survival time and status due to hypothermia, has led to the development of the Cold Exposure Survival Model (CESM) [1, 2, 3].

Introduction to hypothermia

Hypothermia is clinically defined as a drop in body core temperature greater than 2°C below the daily norm of approximately 37°C. This occurs whenever the body loses heat to the environment at a rate greater that can be generated from normal metabolism, shivering, or exercise.

Heat is lost from the body through convection, conduction, radiation, and evaporation. Since water conducts heat approximately 25 times faster that air, conduction is the primary means of heat loss during water immersion, exacerbated by turbulent (i.e., convective) conditions. In air exposure, wet and windy conditions maximize evaporation and convection to form a potentially dangerous combination.

In an attempt to decrease the transfer of heat from its warm interior to the environment, the body's initial response to cooling is to constrict the blood vessels in the skin and extremities. If body cooling progresses, heat production is further increased through shivering. Maximal shivering can increase metabolic heat production by up to fivefold. This might appear high but is considerably less than can be achieved through short bouts of exercise. Heavy exercise produces sweat which then increases heat loss through evaporation. Moreover, the accumulation of sweat in clothing decreases its insulation value. Excessive movement in cold water can be especially counterproductive due to higher convective heat loss. This is the why Heat Escape Lessening Posture (H.E.L.P.), which mimics a compact fetal position, is encouraged as opposed to attempting to swim to safety. During prolonged survival situations, unnecessary exercise might result in a premature depletion of valuable body energy stores.

Symptoms associated with a decreasing body temperature from a normal 37°C down to severe hypothermia at 26°C are summarized in Table 1. Following this downward progression, CESM predicts the point at which Functional Time (FT) and Survival Time (ST) are attained.

FT is defined by the deep body temperature when cognitive functions such as decision-making, planning, and judgment would be adversely affected. This is defined as the limit of (cognitive) self-help and is reached at a body temperature of 34°C. It is assumed that a casualty at this stage of hypothermia would be conscious, but unable to make sound decisions. Performance of self-rescue activities such as climbing into a life raft, holding on to a life buoy, building a shelter and fire to keep warm, or signalling for help are usually impaired much earlier, and are based on how quickly the casualty's arm and hand temperatures decrease. Currently, CESM does <u>not</u> provide a prediction of the limit of physical self-help. However, is can be assumed that physical self-help is compromised well before cognitive self-help during cold exposure.

ST is defined as the limit of survival and is based on when core temperature reaches 28°C. In this circumstance, an individual would most likely be unconscious and not shivering. At this point, death would be imminent due to drowning, cardiac instability, or other associated complications from continued cooling.

Table 1 Stages and symptoms of progressive hypothermia [4]. CESM provides prediction times to functional (FT) and survival (ST) times respectively.

STAGE	•C	•F	SYMPTOM
Normal	37	98.6	None
	36	96.8	Early shivering; increased blood pressure
Mild	35	95.0	Maximum shivering; increased heart rate
(FT)	34	93.2	Poor judgement; amnesia
Moderate	32	89.6	Stupor; shivering, and heart rate decrease
(ST)	28	82.4	Decreased ventricular fibrillation threshold; unconsciousness likely
Severe	26	78.8	Unresponsive; acid-base disturbance

Hypothermia risk factors

When imagining a situation where the risk of hypothermia would be great, one might think of hikers caught on a windy, rainy hillside or someone falling through thin ice into frigid water. Surprisingly, the risk of hypothermia is present even in relatively temperate climates. For example, during the period from 1987 to 1998, the hypothermia-related death rate in the southern U.S. state of Alabama was a relatively high 0.43 per 100,000 population as compared to the United States average of 0.30 [5]. While this statistic may be counter intuitive to the thought that severe cold is necessary to induce hypothermia, it clearly demonstrates that factors such as old age, lower socio-economic status, and inadequate preparedness can compromise an individual's ability to maintain thermoneutrality; even in temperate climates.

Humans are warm-blooded mammals, and without the ability to create clothing, shelter, and fire, would still be confined to living within a narrow temperate zone about the equator. Unclothed, the thermoneutral temperature for an average individual is approximately 20-25°C in air, and 33-35°C in water. Once the ambient temperature falls below these ranges, physiological mechanisms such as shivering and vasoconstriction, or behavioural activities such as the wearing of clothing and seeking external heat sources are required to prevent an imbalance between heat loss and heat production. Water immersion, wind and rain may also increase the rate of heat loss from the body. Hunger and physical fatigue result in decreased fuel stores necessary for shivering and working muscles. Eventually cognitive processes are affected, leading to impaired judgment and decision making. Exhaustion was a contributing factor in a well-publicised incident in 1995, when five U.S. Army Ranger candidates died from hypothermia while on a strenuous training exercise in the Florida swamps [6]. All deaths occurred during a swamp patrol exercise that required soldiers to traverse knee to neck deep 14°C water.

Recently, the proliferation of wilderness activities such as mountain climbing, backcountry skiing and adventure racing have led to an increased potential for hypothermic casualties. While they may be adequately trained and equipped, physical exhaustion and rapidly changing weather place them at risk. During the 2001 first annual Discovery Channel World Championship Adventure Race in Switzerland, the canyoneering section was closed due to proliferation and severity of hypothermia amongst competitors. Despite the skill and experience of the competitors, exhaustion, temperature changes and inadequate clothing combined to create a potentially dangerous situation.

Hypothermia must be considered to be a risk in any environment where the temperatures are below the thermoneutral range, and the rate of heat loss to the environment is greater than what can be produced through metabolism, shivering and exercise. These conditions are a fact of life in Canada where lakes and rivers never reach thermoneutral temperatures, even in the summer. A recent report by the Canadian Red Cross reveals that 40% of all immersion deaths occurring from 1991 to 2001 were associated with cold water [7]. Therefore, the potential for hypothermia must always be considered in any incident involving water immersion.

Modeling of hypothermia survival

While the risk and danger of hypothermia has been long known, it was not until the Second World War (WWII) that a concerted effort was made to better understand hypothermia in order to predict casualty survival. Previously, the primary knowledge available was based on accidental exposures as scientific research regarding human tolerance to cold and survival modeling had not been well established.

One of the earliest attempts at predicting survival of hypothermia was the post WWII work of Molnar [1] who examined hundreds of U.S. Navy shipwreck reports. Only those cases where water temperature or the location and date of shipwreck existed, and the duration of neck level ocean immersion could be determined, were selected. Unknown water temperatures were estimated from the World Atlas of Sea Surface Temperatures. These data are plotted in Figure 1, where each point represents at least 1 survivor for the given water temperature and duration of immersion. While this work provides interesting survival outcome data, it is inadequate for prediction involving complex conditions, and is thus ineffective for SAR resource management.

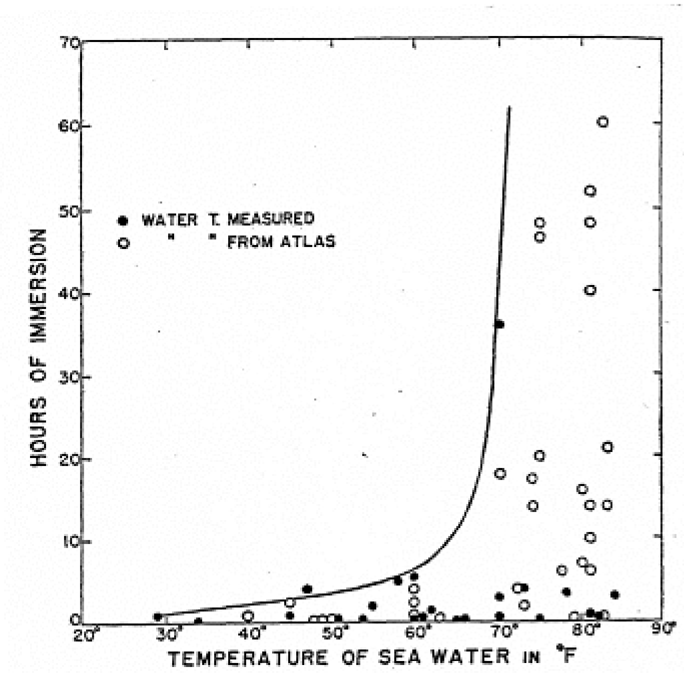

Figure.1Immersion survival time as a function of water temperature (from Molnar [1]).

To make more accurate, reliable and pertinent estimates of FT and ST which can individualized to account for a wide range of incident scenarios, mathematical modeling is required. This involves the formation of mathematical equations and constructs to simulate natural phenomena. It also helps us understand the behaviour of a complex system through the knowledge of subsystems or individual elements. In the case of thermoregulation in cold environments, it is through an thorough understanding of thermodynamic principles and physiological responses that an individual's thermal status may be determined. Careful extrapolation of the data permits reasonable predictions to be made for environmental conditions that are too extreme to permit laboratory validation. These extrapolations can be tested against well-documented case histories to verify their validity.

In recent decades, several cold water survival predictions models have been developed based on net effective clothing insulation [9], or direct measurements of human metabolic and temperature response to cold immersion [10, 11]. Results from this latter work were the basis for the development of the Canadian Red Cross Cold Water Survival Curves (Figure 2). While useful as a "rule of thumb" estimate of hypothermia survival, models such as Molnar's [8] are limited by their inability to account for specific casualty, environmental and clothing factors.

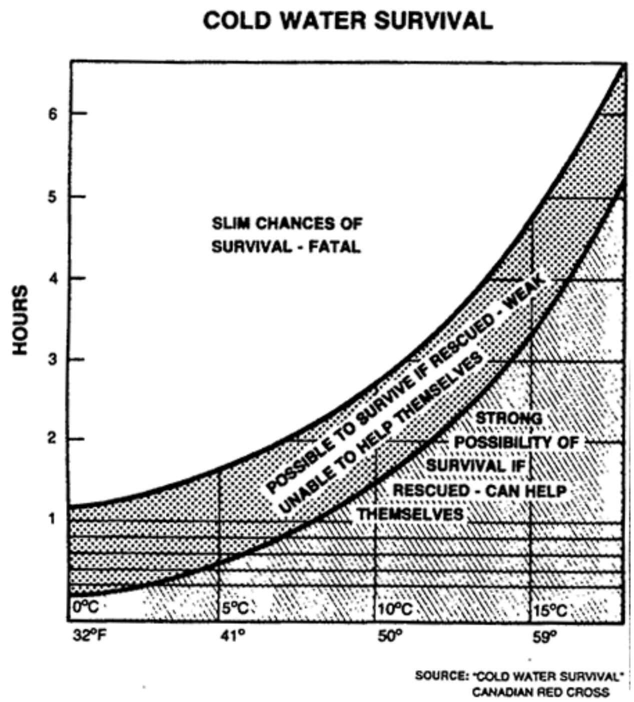

Figure 2 Red Cross of Canada cold water survival curves.

A more robust approach to hypothermia survival modeling has been facilitated by advances in the understanding of human response to cold and computing technologies. Complex, computer-based models such as Wissler's [12] and CESM, conceptualize the human body as a series of connected, cylindrical segments representing different regions of the body. Each segment is comprised of annular cylinders representing body core and muscle tissue, fat/skin, and clothing/still air layers (Figure 3a). Cylinders are modeled according to their unique physical and thermodynamic properties in order to determine temperature distribution and heat flow between the body and environment. A key advantage of this approach is that the model is not restricted to water immersion. Certain properties and cylinder geometry may be moderated to represent air exposure. Additionally, variable physiological parameters such as regional blood flow, metabolism and individual body composition can also be accounted for. For example, low body fat will result in less thermal resistance of the "skin + fat" cylindrical shell (i.e., smaller thickness) than an obese person. As physiological research improves our understanding of human response to cold, these data can be used to further refine model predictions. An integration of these physiological and physical principles is represented by the complex, mathematical formulae of CESM for situations which involve both air exposure [2] and water immersion [1].

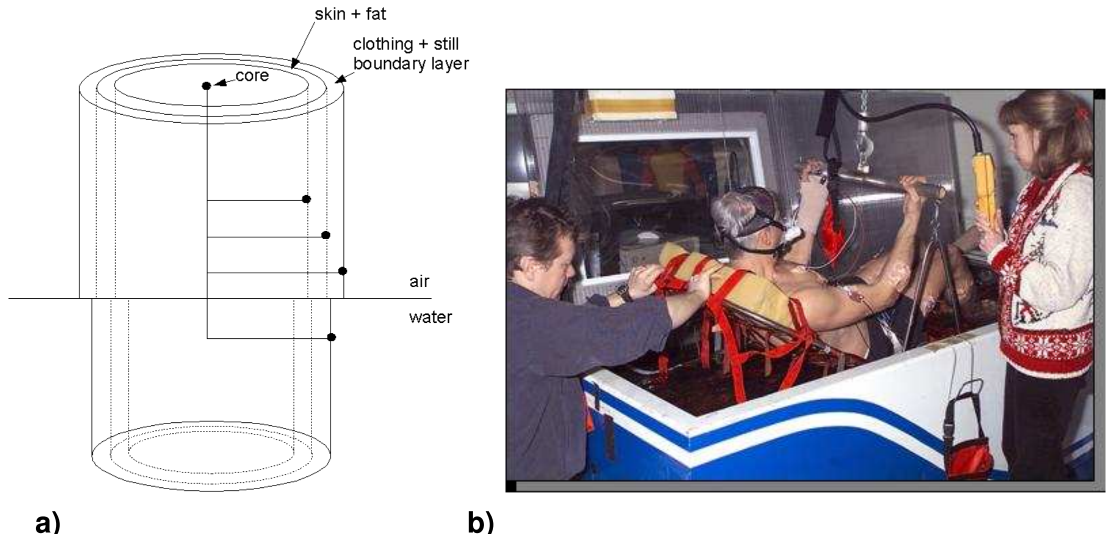

Figure 3 Biophysical models, such as CESM, represent the human as a set of concentric cylinders consisting of body core, skin, fat, clothing and still air boundary layers (a). Heat flow across these compartments is determined by their thermal property values, which may differ between air and water. These models are validated and enhanced by research into human's physiological response to cold (b).

CESM is constantly revised and improved as more laboratory and survival data become available. Reviewing model predictions against survival incident reports is necessary, and done periodically to further ensure the validity of the model. Any discrepancies between actual and predicted survival times are investigated to determine if model assumptions were violated, extenuating circumstances were involved or if an invalid scenario was used to represent the incident. If limitations to the model are identified, further research or experimentation may be required to generate new knowledge or refine certain elements of the predictive algorithms.

Assumptions and limitations of hypothermia models

Like all models, such those that predict weather systems or provide drift estimates, the CESM is a simulation of complex system which included human physiology, clothing and the environment. In order to develop a model, simplifying assumptions are made, boundary conditions must be defined and the range of applicability of the model must be understood. As a result, prediction models such as CESM must always be considered to be speculative as it is impossible to account for all possible events which may occur during a survival incident.

Predictions to FT and ST are based *solely* on the calculated deep body (core) temperature. This is important to note, as it has been shown that, due to cold shock and early drowning, the death rate of survivors immersed in water 10°C or cooler are about 25% upon initial immersion. This rate increases linearly until it reaches 100% in 20°C water [13]. Additional factors such as swim failure, trauma, blood loss, pre-existing medical conditions or alcohol and drug consumption increase the death rate but are *not* accounted for by CESM. Potentially life saving behavioural activities such as physical exercise, shelter building or lighting a fire may increase cold survival times, but their inclusion is beyond the scope of the CESM.

When performing predictions using CESM, it must be assumed that the casualty is in a fixed, non-active posture and has a normal cooling response to cold. Other caveats include the limitation of prediction times to a maximum of 36 hours as CESM is unable to account for unknown factors which may affect survival during prolonged exposure.

Since the output of the CESM is only a good as the information provided to it, misleading results will occur when inappropriate model inputs are selected or obtained from an uncertain or unreliable source. Comparison of the model's predictions against real life incidents is difficult because details such as relative humidity, clothing wetness, and body fatness are seldom reported as they are not considered essential medical or incident data. Survival end points are difficult to ascertain, as the exact time of death or loss of consciousness is unknown in most cases. It is unfortunate that better records are not obtained, as accidental exposure is the only context through which survival outcomes suitable for model calibration/validation can be ethically obtained.

CESM is a decision aid and the value of its predictions is dependent upon the user's ability to accurately represent the survival scenario through appropriate data inputs, and to interpret predictions within the constraint of the model's assumptions. The information provided in this guide is intended to provide the SAR expert with sufficient background and understanding of CESM to facilitate the development of accurate incident scenarios and interpret the model predictions for any SAR incident.

Using the Cold Exposure Survival Model

CESM requires data describing the casualty, clothing worn and the environment. Often, the information available is incomplete or inaccurate. By employing an intelligent interface (Figure 4), and providing an option of single point (deterministic) or stochastic (probabilistic) predictions, CESM provides the operator with the flexibility and guidance required to deal with such eventualities. Model inputs may be defined explicitly by the user entering data directly in the input fields or by selecting pre-defined descriptors. One may toggle between metric and imperial units, and look-up tips provide the user with additional information to assist in the selection of appropriate model inputs. As casualty or environmental data become available, pre-defined inputs may be replaced with known values. If all input parameters are not known, it is recommended that users manipulate the parameters to which survival time is most sensitive (e.g. wind speed, clothing, wetness and ambient temperature). This will produce best case and worst case scenarios and provide coverage against unanticipated events. This technique also illustrates the educational value of CESM, as the user can quickly visualize the effects of clothing or environmental conditions on survival outcome.

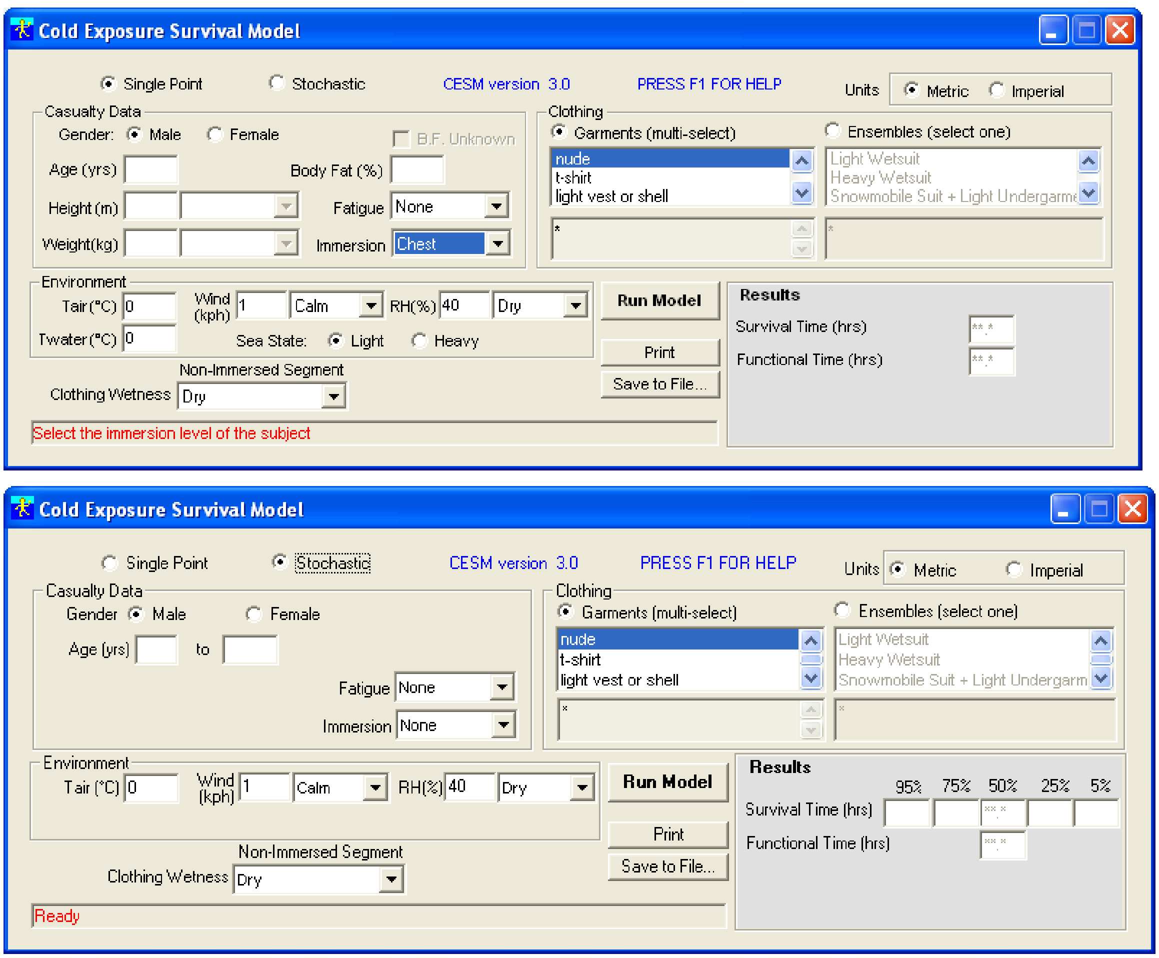

Figure 4 CESM model interface indicating both single point and stochastic modes.

Model Inputs

Prediction Mode

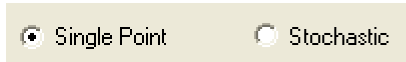

Figure 5 Selection options for Single Point or Stochastic prediction mode

When making survival predictions, the CESM user must take into consideration the amount of uncertainty in available incident data. Without proper knowledge of the effects of each parameter on survival outcome, large errors in survival time prediction may occur. For this reason, CESM provides the capability to make either a single point (deterministic) or stochastic (probabilistic) prediction.

Single point predictions provide one functional time (FT) and survival time (ST) for each scenario. While they are precise, they require an accurate knowledge of all model inputs. This affects the robustness of the prediction, as any uncertainty or error in any of the model inputs will limit the accuracy of the final result. Prediction times are particularly sensitive to clothing, wetness, wind speed and ambient temperature, especially in temperate conditions. As an example, in water temperatures of approximately 16-23°C, there is a fine balance between heat loss and metabolic heat production. This can be seen in Figure 1, where survival time increases dramatically between 65 and 75°C. A slight underestimation or overestimation of any of these key model inputs could result could result in a discrepancy in survival time of several hours. For this reason, it is recommended to use the single point prediction option only when all model input parameters are known with reasonable certainty.

Stochastic predictions provide an alternate approach to modeling survival time when casualty characteristics are not precisely known or when incidents involve multiple casualties. In contrast to the single point prediction, the stochastic process produces a probability distribution of survival times based on randomized, rational combinations of height and weight. Age is an third variable which can be fixed if the casualty's age is known, or randomized if an age range is entered. An age range is helpful when only generalized knowledge of the casualty is available (e.g. a young male, approximately 20-25 years old), or when a group of individuals are involved (e.g. a group of females between the ages of 30-45 years old). CESM randomly selects an age from within the given range and consults a population database to randomly select a plausible height and weight. When age is known, only height and weight are randomly determined. Body fat is then estimated from these data. All anthropometric information is derived from a 1981 survey of the Canadian population [14]. Once these data have been defined, a unique FT and ST are calculated for each pseudo casualty. This procedure is repeated many times, resulting in hundreds of FT's and ST's that are used to create a survival probability distribution. Figure 5 and 6 illustrate the stochastic distribution of height and weight inputs as well as the survival probability distribution of a hypothetical incident involving males and females between the ages of 20 to 60 years of age. While the mathematics of the CESM stochastic predictions are complex and beyond the scope of this document, they have been extensively documented for further reference [15].

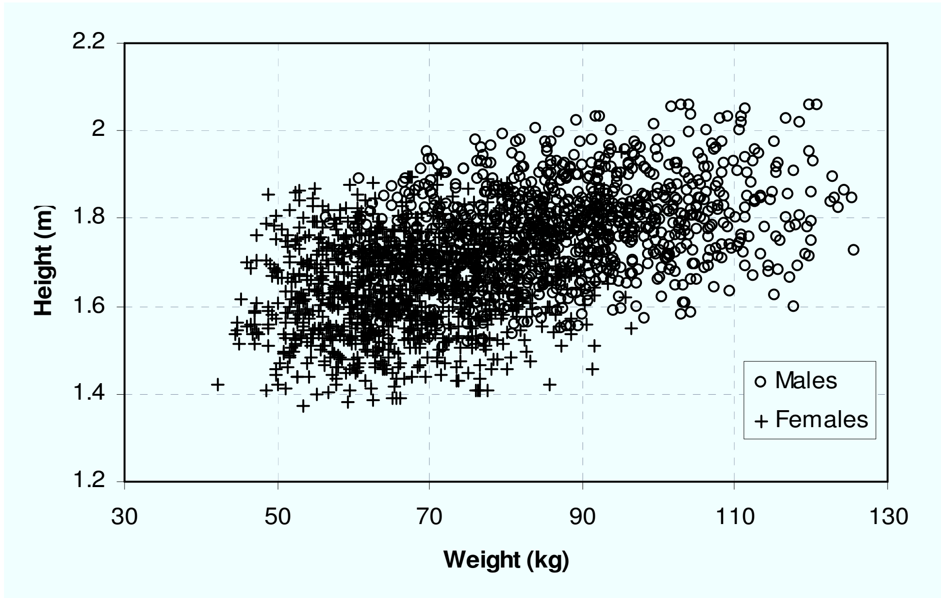

Figure 6 An example of the stochastic distribution of CESM height and weight inputs for 20-60 year old males and females.

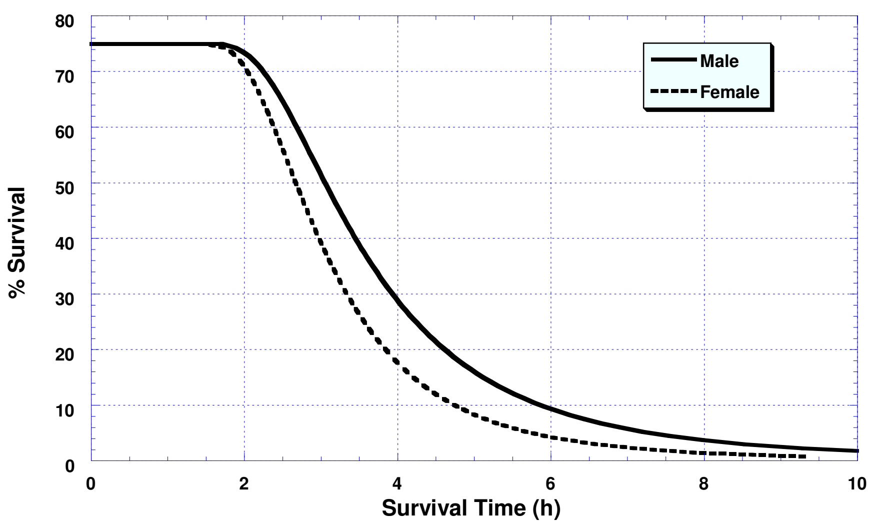

Figure 7 The stochastic distribution of survival times for 20-60 year old males and females exposed to 5°C, high seas, wearing a long sleeved t-shirt, light sweater and jacket.

Once calculated, the stochastic outputs are presented to the user in a tabular format listing STs from 5th (shortest) to the 95th (longest) survival time. A median or 50th percentile for FT is also provided. All percentiles are based on a normal distribution of survival times. Examples of these outputs are provided in greater detail in the "Model Outputs" section of this guide.

Due to the randomness of model inputs, the stochastic CESM will provide a slightly different result each time it is run. This may result in a variation in individual prediction times as well as the range from 5th to 95th percentile. This effect may be more pronounced in temperate waters as the difference in survival times between the very small (5th percentile) and very large (95th percentile) is exaggerated at these temperatures. For this reason, it is recommended to run the stochastic prediction two or three times to observe the sensitivity of the prediction to the model parameters. Prediction times can be honed by averaging the results of these runs.

Casualty information

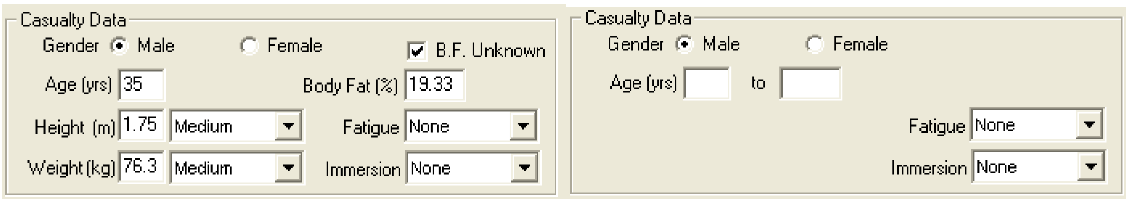

Figure 8 Casualty information input fields

Gender

Currently, CESM does not allow mixed gendered scenarios. This is a deliberate decision, as the distribution of survival times of a mixed gender prediction would be too wide for meaningful interpretation. For this reason, separate scenarios must be run for males and females.

When compared to males, females tend to have a lower resting metabolic rate, have a higher surface area to volume ratio, and higher body fatness. While body fatness conserves heat, the former two factors are disadvantageous to the maintenance of body heat content. Hence, when all other factors are held constant, females will generally have a shorter predicted survival time than males.

Age

Very young and elderly individuals are at a greater risk of hypothermia due to their high surface area to volume ratio, and normal age-related physiological processes. Resting metabolic rate also tends to decrease with increasing age, further compromising survival time. Unfortunately, there is a general lack of cold response data for these age extremes. Consequently, CESM limits predictions to individuals between 7 to 75 years of age.

When making a stochastic prediction, either one age or a range of ages may be entered. If the age of the casualty is known, then all that is required is to enter that value in one of the two age input fields. Conversely, if the age is not known, then enter the anticipated age range (e.g. 35 to 45 years for a middle-aged casualty).

When multiple casualties are involved, enter the age range for each gender separately. While CESM will accommodate ages from 7 to 75, tighter predictions will result with narrower age ranges. For example, depending on the population involved in the incident, one may wish to perform separate predictions for children, adults and elderly.

Height and weight

Height and weight are used to determine the mass, volume, and surface area of the individual. These values are regressed from a Statistics Canada database on the Canadian population based on the age and gender of the casualties if the pre-defined categories of height and weight are selected. To understand the effect of height and weight on hypothermia, consider a tall individual of medium weight. Such a person has a greater surface area to volume ratio as compared to a shorter individual of the same weight. As a result, all other things being equal, the tall person will have a proportionally larger surface area for heat loss to the environment.

With each degree drop in body temperature, heavy individuals must lose a greater total amount of body heat as compared to a smaller person. Therefore, as weight increases, so will thermal reserve and survival time. In addition, heavier individuals typically have a thicker layer of insulating fat to attenuate heat lost. Individuals with large muscle mass and low body fat (e.g. body builders) are an exception to this rule. The advantage of having a little more mass can be demonstrated by CESM by selecting a known height and percentage body fat, and stepping through weight from very light to very heavy (these categories represent the 5^{th}, 25^{th}, 50^{th}, 75^{th}, and 95^{th} percentiles of the population for the gender and age selected).

When performing stochastic predictions, height and weight are not enabled as user inputs. During the stochastic calculations, CESM will be run against hundreds of randomly selected combinations of height and weight, which will then be evaluated to produce the probability of survival results.

Body fat

Body fat, particularly the layer between the muscle and skin (i.e., the subcutaneous tissue), is a valuable source of insulation. In certain examples, the protection afforded by body fat can account for exceptional feats of cold tolerance. For example, Lynne Cox successfully swam 2.7 miles across the Bering Strait from the U.S. to the Soviet Union in water as cold as 4°C. Due to her high body fat (approximately 36%), she was able to withstand cold conditions that thinner individuals would quickly succumb to. As body fatness is rarely known without direct measurement, CESM provides a capability for its estimation based on age, gender, height, and weight.

Fatigue

Fatigue affects survival time by reducing an individual's energy stores and shivering endurance. For prediction purposes, the fatigue level is dependent on the intensity and duration of work or exercise that the individual would have undertaken prior to the incident. Individuals out for a day hike or sail might be tired, while more rigorous exercise or work such as mountain climbing or laborious fishing would result in a higher state of fatigue (exhausted). Increasing levels of fatigue lead to a decreased ability to generate heat through shivering and consequently, a shorter survival time.

Immersion

CESM is capable of predicting body cooling times due to full water immersion (neck) and air exposure (none), but also for incidents of partial immersion. Examples of partial immersion include sitting in a flooded life raft or being partially out of the water by holding onto floating debris. As water conducts heat away from the body at a much greater rate than air, the predicted survival time will decrease as more of the body is immersed in water. An exception to this rule might include conditions of high winds and very cold air temperatures that may actually result in greater cooling rates than immersion in temperate to warm water.

Air exposure is applicable to both land based operations such as hikers or mountain climbers lost in the wilderness and mariners who are still on their craft. The effects of wind, rain or sea spray are accounted for in the environmental conditions inputs.

Environmental conditions

Figure 9 Environmental conditions input fields

Environmental conditions refer to the air and water conditions applicable to the casualty. For example, if predictions are to be made for air exposure only, then the input options for sea state and water temperature will not be displayed. Conversely, in the event of full immersion, the air exposure input option will be disabled. Partial immersion conditions require the entry of all environmental inputs.

Wind speed

Wind accelerates cooling by compressing insulation, and increasing the convective and evaporative heat losses. Wind speed (khp or knots), if known, may be directly entered; otherwise an estimated value from the predetermined descriptive inputs may be selected. Lower wind speeds should be applied if the casualties are assumed to have found shelter or are in a heavily wooded area.

Air temperature

The immediate air temperature that the casualty is exposed to applies here. Lower air temperatures may be experienced if the casualty is in shade or in close proximity to a cold object such as a glacier. Although not accounted for in CESM, the radiant heat of sunshine can result in a higher effective ambient temperature.

Relative humidity

A dry condition will help maintain clothing insulation. Conversely, warm, dry clothing may be made damp and less insulative by high humidity or ingress of rain/snow. Select the appropriate level of humidity or enter the value if known. The clothing wetness value might require adjustment to reflect the added moisture if the rain/snow option is selected.

Water temperature

If unknown, the estimation of water temperature (either in °C or °F) can be obtained by consulting the appropriate meteorological resource. Water immersion results in much lower survival times than exposure to an equivalent air temperature. This is because water conducts heat away from the body approximately 25 times faster than air. In water colder than 10°C, shivering and metabolism have diminishing effects on survival time as the rate of cooling is so high due to the increased temperature difference between the water and individual resulting in indefensible heat loss.

While increased body fat is advantageous for cold survival, it is most apparent in moderate to temperate waters. In these conditions, metabolism and shivering play a greater role in maintaining body temperature. Figure 10 illustrates the difference in survival times between individuals with differing amounts of body fat. The vertical bars show the absolute difference in survival time between the two individuals as a function of water temperature.

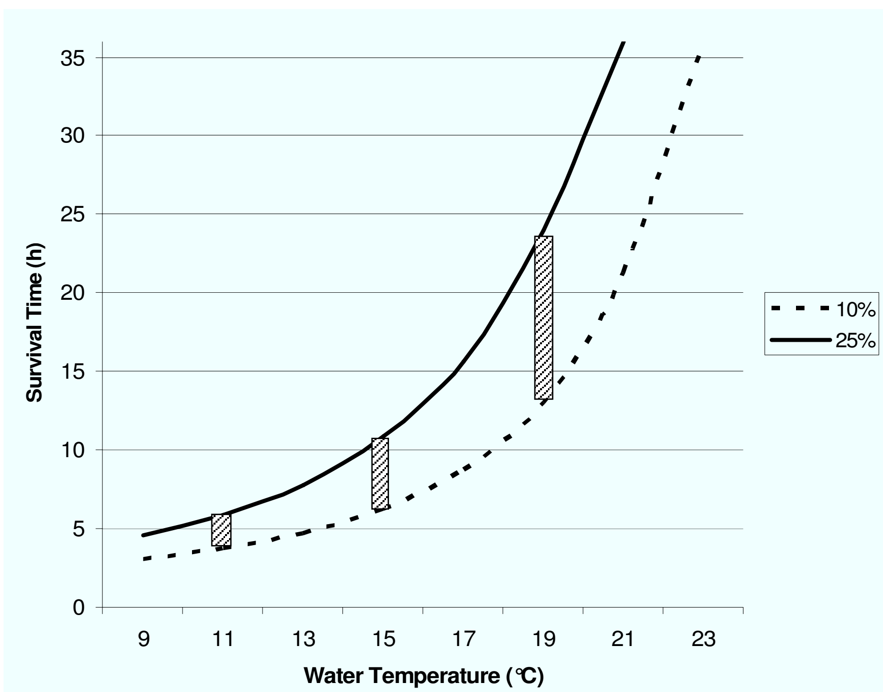

Figure 10 Effect of 10 and 20 % body fat on survival time at different water temperatures based on neck level, nude immersion of a 35 year old male, of average height and weight.

When performing stochastic predictions in temperate waters (16 to 23°C) it is important to remember that survival times are based on many samples of random individuals. This may result in a wide range of survival times from the 5th to 95th percentile due to differences in height, weight and body fat. For example, the predicted single point survival time prediction of the individual described in Figure 10 in 17°C water and a CESM estimated body fat of 19.3% is 13.9 hours. When a stochastic prediction is made based on the same 35 year old male, the 5th to 95th percentile survival times range from 8.3 to 31.5 hours. This is due to the stochastic prediction reflecting the wide range of characteristics of the population sampled. In general, the stochastic prediction works best when little knowledge of the incident data or multiple of casualties are involved. Single point predictions should only be used when accurate and detailed casualty information is available.

Sea state

Sea state refers to the movement of water immediately surrounding the casualty. Turbulent water increases convective cooling and reduces survival time considerably. If the water is reasonably calm, or the casualty is moving in rhythm with the water (e.g. bobbing in swells), then "Light Seas" would be appropriate. Conversely, "Heavy Seas" would be appropriate if the water is turbulent due to breaking waves or current.

Clothing

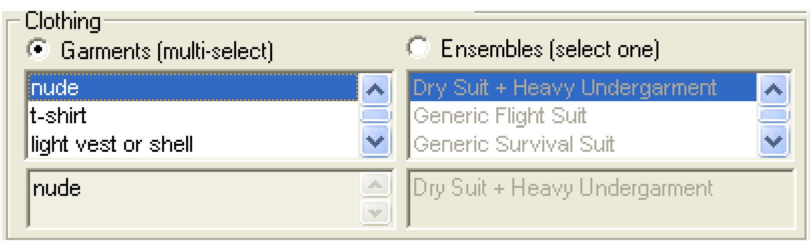

Figure 11 Clothing configuration input fields.

Clothing is critical to hypothermia predictions, as it is the barrier of insulation between the casualty and the environment. Common clothing items and ensembles, for which the insulation values have been determined, allow the user the ability to create a flexible, customized clothing configuration.

Garments

Individual clothing items may be multi-selected to create a customized clothing ensemble. This is accomplished by depressing and holding the ‘Ctrl’ key while selecting each garment with a left mouse click. Nude exposure, which implies a minimally clothed (e.g. bathing suit) individual, is the only exception and cannot be combined with other garments. Increasing the number of garment layers results in a greater overall insulation and survival time. All items pertain to the upper body, as this region is considered most critical for survival prediction. It is assumed that the clothing insulation selected for the upper body reflects the clothing worn for the entire body.

Ensembles

Ensembles are predetermined clothing configurations for which the insulation values are known under light and/or heavy sea states. Available options include commonly worn protective clothing such as snowmobile suit, coveralls, wet suits and dry suits. A particularly useful educational aspect of ensembles is the demonstration of the immense benefit of wearing a properly sealed dry suit when immersed in water as compared to wearing other clothing that allows water penetration.

Wetness of non-immersed and immersed clothing

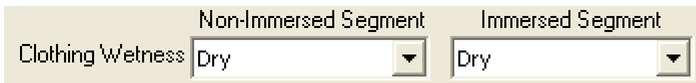

Figure 12 Clothing wetness input fields.

Moisture in clothing, whether from precipitation, condensation, immersion, splash or sweat significantly compromises the insulation value of the clothing and survival time. When selecting a non-immersed wetness value, consider the potential for water or moisture penetration. Prior heavy exercise or rain can result in a moderate to high wetness, while a humid environment may result in low wetness.

With the exception of dry suits, immersed clothing wetness defaults to "soaked" for all garments and ensembles. A properly fitted and zipped dry suit should be assigned a "dry" wetness level. A poorly sized suit or an improperly closed zipper will allow water leakage into the suit, reducing its insulation and effectiveness. Select the appropriate level of wetness that represents the amount of water ingress anticipated.

Model output

Functional and survival times

In review, functional time (FT) is attained when one’s body temperature decreases to a level where cognitive processes such as judgement, planning and decision-making are adversely affected. This represents a limit to an individual’s ability to perform self-help activities due to poor decision-making. Survival time (ST) involves further body cooling to the point when an individual would likely become unconscious and non-shivering. Death would be imminent without rapid medical intervention. As previously mentioned, CESM does *not* take into account premature death rate rates in cold water due to cold shock, drowning, injury or other debilitating factors. It has been shown that the death rates of water immersed survivors in water 10°C or lower are about 25% upon initial immersion. In water temperatures of 20°C and above, the initial survival rate increases to 100%. Initial survival rate appears to increase linearly between 10° and 20°C.

Single point calculations result in only one value for both FT and ST whereas stochastic predictions yield a normal distribution of times from which the 50th percentile for FT and percentiles ranging from the 95th to 5th for ST are displayed (Figure 13).

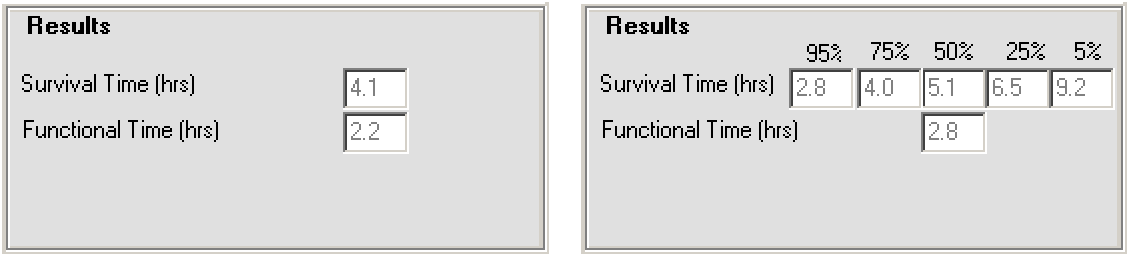

Figure 13 An example of the single-point and stochastic prediction outputs based on identical scenarios (35 year old male of average height and weight, neck level immersed in 10°C heavy seas, wearing a t-shirt + light vest or shell).

If one compares the two model outputs in Figure 13, one can see that the single-point prediction corresponds closely to the 75th percentile of the stochastic prediction. This demonstrates the importance of performing a single point prediction when detailed casualty information is known. In this case, the individual's characteristics differ from the average of the random population sample. One may still wish to perform a stochastic analysis as a contingency to compensate for any circumstances that may not have been anticipated.

The strength of the stochastic prediction is particularly evident with incidents involving multiple casualties. Instead of performing multiple single-point predictions to account for each casualty, only one stochastic prediction for each gender is required. The percentiles of survival time would then relate directly to the percentage of survivors predicted to survive to a given time. For example, if Figure 13 referred to an incident involving 10 males casualties, then the a 50% survival time of 5.1 hours would indicate that this is the time at which 50% of the casualties who survived the initial immersion would still be alive. Caution must be exercised if the anticipated age range is large as children, mature adults and elderly respond differently to cold. In this case, one may wish to categorize individuals into age groups representing young, middle aged and older individuals.

Risk of freezing

For scenarios not involving water immersion, high winds and cold air temperatures can create an environment suitable for the development of frostbite to exposed skin tissue. While predictions of frostbite are typically given for the face, it is recognized that hand function is critical to survival status and self-help. For this reason, whenever the risk of frostbite is present, CESM provides predictions for the level of freezing risk and time to freezing for both the cheek and finger. These are calculated according to the dynamic model of skin cooling described by Tikuisis and Keefe [16]. Risk of freezing is presented to the user in the form of freezing index captions ("no risk" to "extreme" risk) as well as a time to freezing prediction for both cheek and finger (Figure 14).

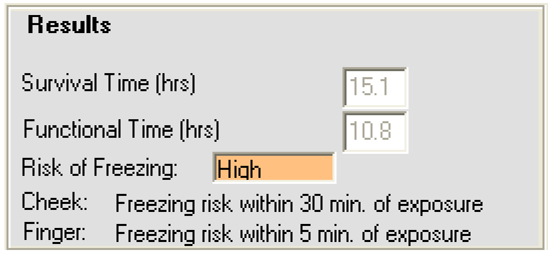

Figure 14 Risk of freezing prediction during air exposure.

CESM Example Usage

Predicting ST for any incident, involving either one or multiple casualties is always challenging as the factors that may influence the outcome are either unknown, or too numerous to realistically model. As a result, it is inevitable that certain assumptions or insight are necessary to select reasonable model inputs. Although the stochastic component of CESM attempts to address some of these uncertainties, there is no substitute for experience and a good understanding of how to apply the model in real life situations. The following examples are based on actual incidents and are designed to illustrate the application of the CESM to a variety of accident scenarios.

Air exposure

On October 30, 1991, a CC-130 Hercules crashed approximately 10 nautical miles south of Alert, North West Territories (now Nunavut). Fourteen of 18 crew and passengers survived the impact and retreated to the intact tail section of the aircraft. Two of the survivors were too injured to move, and remained outside, sheltered by a piece of wreckage and covered by snow. Due to the impact and subsequent fire, much of the survival gear was lost. As a result, the clothing worn by the individuals ranged from a basic flight suit to Arctic parka. Air temperature ranged from –20°C to –40°C and winds progressed from calm to around 30 knots. Approximately 33 hours after the initial impact, rescue arrived on the scene to find 13 semi-conscious survivors. The fourteenth individual, who was clad only in a flight suit and refused shelter, had succumbed to the cold and perished from hypothermia several hours earlier.

Considering that this is a multi casualty incident, the best strategy would be to proceed with a stochastic approach. While the age of the crew and passengers can be obtained from the flight manifest, calculating FT and ST for each one would be a time consuming task. At the time of the incident, protective Arctic clothing was on board, but it wasn't known if it was actually donned in time or lost in the crash. Second, if a substantial piece of the aircraft was intact, it could provide shelter for the survivors, protecting them from the wind and cold. As with most incidents, it is always best to consider a best and worst case scenario if all of the facts are not known.

The worst case would involve casualties wearing only their flight suit (winter equivalent = coveralls + medium undergarment) while being exposed to 15 knot wind and an average ambient temperature of -30°C. Assuming that most crew and passengers were male, 25-50 years of age, then the STs would range from approximately 15 to 21 hours.

At the other extreme, assuming that individuals were able to don their winter kit (heavy parka, light sweater, long sleeved shirt), find shelter from the wind (calm) and huddle together (increase effective temperature, say to – 25°C). In this case, STs increase to beyond 35 hrs.

Fortunately, the best-case scenario was true for most of the casualties and the CESM survival times are in reasonable agreement with the actual events. The sole individual who succumbed to the cold was well represented by the worst-case scenario. It must be noted, that in these extreme conditions and durations of survival, small discrepancies in wind speed, clothing insulation and/or wetness may substantially affect the prediction. Furthermore, as the model does not account for such variables as heat production due to physical work or insulation due to snow coverage or huddling, additional operator inferences must be made. For example, in the case of the lightly clad individual who had died of hypothermia after about 25 hours of exposure, his actual survival time being greater than the predicted duration of 15 to 21 hours may be attributed to the extra heat generated due to physical activity, as was the case shortly after the accident. As a reminder, CESM makes the assumption that survivors are in a fixed, non exercising posture.

Water immersion

Example 1

The 1990 sinking of the fishing vessel *Santa Barbara*, in 16.7°C water off Guaymas, Mexico, also provides good test data for CESM. Five individuals, four clad in pyjamas and one in a full wetsuit (6 mm thick), clung to a wooden door, awaiting rescue. The sixth individual, unknown to the others, swam 35 hours until he intercepted a ferry that requested a rescue boat. Four of the five individuals died at the sinking site and their times of death were recorded by the sole survivor. ST predictions shown in Table 2 are reasonably close to the observed values. Note that the average predicted ST of the four non-survivors corresponds exactly with the actual, observed ST. While this may be a fortuitous example, it is a testament to the power of the CESM

Table 2Casualty data from the Santa Barbara incident, compared with predicted survival times of CESM v2.2 (denotes survivor). Pyjamas were considered to be equivalent to a long sleeved t-shirt and the casualties were assumed not to be tired upon immersion in*

GENDER	AGE	HEIGHT	WEIGHT	% BODY FAT	CLOTHING	ST (ACTUAL)	ST (CESM)
		(m)	***(kg)***	***(estimated)***	***(observed)***	***(h)***	***(h)***
M*	62	1.78	91	24.6	wetsuit	38	31.9
M	63	1.83	83	21.6	pyjama	14	10.4
M	35	1.80	86	20.6	pyjama	12	13.7
F	56	1.68	73	27.4	pyjama	11	11
F	45	1.64	68	26.2	pyjama	9	10.8
				Average ST of non-survivors		11.5	11.5

Example 2

Carolyn Matthew's book "Heroic Rescues at Sea" [17], describes the co-ordinated rescue of a severely hypothermic sailor by the Joint Rescue Co-ordination Centre Halifax, and the Coast Guard crew of the Sambro lifeboat station. A report was received at 0400h regarding a young man lost and alone in small sailing boat in the fog of St. Margaret's Bay, Nova Scotia. He had left the previous morning and had not returned after being out on the water all day and evening. The late summer water temperature of the bay was around 64°F (18°C), and he was wearing only shorts and t-shirt. When he was located the following morning at approximately 1100h, he was found holding on to the side of his overturned boat, in a fixed posture with foot high waves crashing over his head. Rescuers were certain that they had arrived too late. Miraculously, he was still alive, and spent the next two days unconscious in hospital recovering from hypothermia. His watch had stopped at 0300h, indicating that he had been in the water a minimum of 8 hours.

Applying CESM in this example, a 25-year-old male of average height and weight, immersed to the neck in 64°F water wearing only a t-shirt is predicted to survive from 11.8 to 14.5 hours, depending on sea state. Allowing for fatigue, these predictions may be reduced by another 1 to 2 hours. Again, these predicted values agree favourably with his physical and mental status upon rescue, even in the absence of detailed incident data. In this instance, little information was known about the incident or casualty. As a result, assumptions regarding body type, clothing worn, and immersion level must be made. In the absence of firm data, it is best to run a stochastic prediction or make educated assumptions based on partial incident data and run several single point scenarios to build a range of survival predictions. As the search progresses, better information may become available, permitting the fine-tuning of the model inputs and hence, more accurate predictions.

Multiple casualty stochastic example

In 1994, the passenger vessel Estonia with 989 persons aboard, capsized and sank in less than 40 minutes off the coast of Sweden [18]. Weather conditions at the time were reported as being windy with an air temperature of approximately 10°C, 4 metre waves and a water temperature of only 11°C. In the course of the rapid evacuation, only 310 passengers made it to the outer deck and most of these were inadequately dressed for the conditions. Rescue vessels appeared rapidly on scene, and after 7.5 hours post sinking, the last survivor was finally rescued. In total, 137 individuals survived the incident. Very few were rescued from the water, with the majority of the survivors found in life rafts. Of the bodies recovered, hypothermia was determined to be the primary or contributing cause of death in almost every case.

Due to the sheer numbers of evacuees involved and the lack of precise information regarding their physical characteristics, a single point prediction would be impractical. A situation such as this is where a stochastic prediction is best applied. For example, Figure 15 illustrates reasonable model inputs for the female Estonia survivors who entered life rafts.

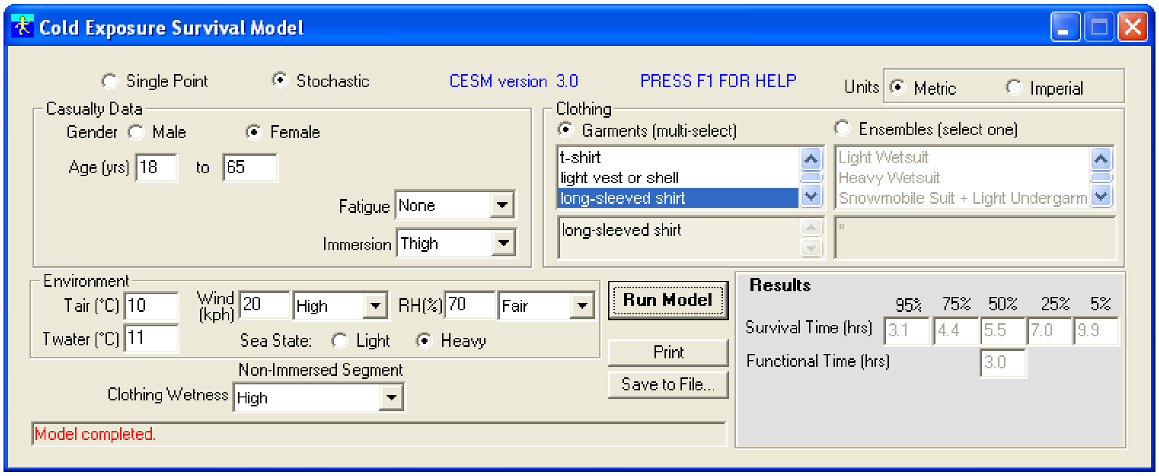

Figure 15 Example CESM inputs for predicting the ST of females in life rafts during the Estonia disaster.

Common sense and experience will typically guide the choice of inputs during the initial stages of rescue planning. Each parameter should be then be re-examined and adjusted as information becomes available. In the current example for adult female survivors, given the late hours and rapid sinking of the vessel, it was assumed that most passengers had little time to don protective clothing and would only be dressed in night or indoor clothing. Clothing wetness was high since they would most likely have been briefly immersed or soaked by high waves while boarding or once in the raft. Thigh level immersion was also selected to simulate partially swamped life rafts. These conditions were quite dire, resulting in an estimated 5% loss of life due to hypothermia after 3 hrs and 50% casualty rate after approximately 5.5 hrs for those that survived the initial cold shock. Note the functional time of 3 hrs; it was reported that survivors found after 3 hours in the life raft were exhausted and could not move into the rescue raft unaided.

Table 3 is a summary of the CESM stochastic predictions for males and females in both water immersed (neck) and life raft (thigh) conditions for this scenario. Based on these predictions, it is not surprising that the window of opportunity for finding survivors was so short and verified by the actual events. In total, only 5% of women and 22% of all male passengers were rescued, and of those, the majority were between the ages of 15 to 44 years old.

Applying an approximation of Wissler's statistic of a 25% death rate upon initial immersion in water 10°C or less, then it is revealed that a 22% male survival rate after 7.5 hours actually corresponds to 28% (22% x 1.25) of those surviving the initial immersion. By interpolating the results in Table 3 for neck level immersed males, 28% survivability corresponds very closely to 7.5 hours. A similar exercise applied to the female survivors reveals 5% x 1.25, or 7% survivability after 7.5 hours which also corresponds well with the actual event.

Table 3 ST prediction time (h) for age 18-65 years, neck and thigh (life raft) level immersion, wearing a long sleeved shirt in 10°C heavy seas.

MALES		95%	75%	50%	25%	5%
	Neck	3.3	4.7	6.0	7.7	11.0
	Thigh	4.0	5.8	7.5	9.7	14.0
FEMALES						
	Neck	2.3	3.4	4.4	5.6	8.1
	Thigh	3.1	4.4	5.5	7.0	9.9

Considerations in developing CESM scenarios

The above examples demonstrate the robustness of the CESM in its ability make accurate survival predictions across a wide range of individual, environmental and clothing configurations. While it is relatively simple to reconstruct a scenario based on incident report data, the reality is that obtaining real-time, accurate information can be exceedingly difficult. This can lead to a precarious situation, as the quality of its predictions is highly dependent upon obtaining accurate information. Improper use of the CESM could lead to misleading predictions which can adversely affect the planning or decisions made during a SAR operation.

In order to provide the SAR professional with sufficient insight into the use and limitation of the CESM and to assist with the development of plausible model scenarios, the following tips help to ensure that the CESM is used to the best of its potential:

- Early in the operation, when all incident information might not be available, develop multiple survival scenarios based on best and worse case scenarios. Always use the stochastic output during this phase and refine the predictions as further data become available.
- Pay particular attention to clothing wetness, water temperature and wind speed as survival outcome can be susceptible to minor variations in these parameters, especially in temperate conditions.
- Following the previous point, it is important to be cognisant of the fact that temperate water conditions are the most difficult in which to predict hypothermia survival time. Minor differences between individuals or their clothing may account for large differences in survival time.
- Expect the unexpected. CESM assumes that the casualties are in a fixed, non-exercising posture and have a normal cooling response to cold. Injuries, shock, or swimming may serve to decrease survival time while shelter, sources of warmth and exercise may extend survival time. These factors are not accounted for by CESM.
- Never lose sight of the fact that the CESM is designed to aid the SAR professional in making informed decisions while planning and conducting SAR operations. It should only

be used in conjunction with the SAR planning/management tools and professional experience at their disposal.

Conclusions

CESM is a commercially available, user-friendly PC application that predicts the status and survivability of hypothermic casualties based on biophysical and physiological principles. Both stochastic and single point prediction capability are available to the user. CESM has been calibrated against accidental and laboratory cold exposure data across a wide range of environmental conditions. Instances where survival predictions deviate from the actual survival outcome are often explained by violations of the model assumptions (e.g. a heat source may have been found or survival time was compromised by poor health). As modelling human cold survival is a complex and evolving science, CESM is continuously refined through the monitoring of scientific literature and conducting additional experiments.

CESM's advantage over other survival prediction tools lies in the fact that it is highly customizable and broadly applicable to air exposure and partial to neck-level water immersion. Hypothermia survival predictions may be made based on casualty information, environmental conditions, and clothing worn. While CESM was initially designed as a SAR decision aid, it has proven to be of great value as an education tool. Hypothetical scenarios may be applied, which give immediate feedback of the hazards of cold environments and the effectiveness of various clothing or survival strategies. Predictions assume that casualties are in a fixed, non-active position, and have a normal cooling response to cold. Finally, best results are obtained by running several "what if" scenarios to generate a survival window.

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List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
SAR	Search and Rescue
SARTech	Search and Rescue Technician
CESM	Cold Exposure Survival Model
ST	Survival Time
FT	Functional Time
WWII	World War Two

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CESM is a commercially available, user-friendly PC application that predicts the status and survivability of hypothermic casualties based on biophysical and physiological principles. It has been calibrated against accidental and laboratory cold exposure data across a wide range of temperatures and is continuously refined as new knowledge emerges. Its advantage over other survival models lies in the fact that it can be customized to account for unique combinations of human, environmental and clothing characteristics present in any survival situation. In addition, it can be applied across a broad range of environmental conditions from air exposure, or partial to full water immersion. The stochastic upgrade enhances the prediction capabilities by offering a probability of survival when casualty information is not available or multiple casualties are involved. CESM was originally designed as a SAR decision aid, but it has proven to be a very effective education tool. Hypothetical scenarios may be examined, giving immediate feedback of the effect of such variable as wetness, wind, body fatness and various clothing items. Predictions assume that casualties are in a fixed, non-active position, and have a normal cooling response to cold.

Le Cold Exposure Survival Model (modèle de survie à l’exposition au froid), ou CESM, est une application PC conviviale offerte sur le marché, qui permet de prévoir l’état et les chances de survie des victimes d’hypothermie à partir de principes biophysiques et physiologiques. Le modèle a été étalonné au moyen de données découlant d’expositions accidentelles et conduites en laboratoire, à une vaste fourchette de températures froides. Il est continuellement perfectionné au fil des connaissances nouvelles qui sont acquises. Son avantage par rapport à d’autres modèles de survie tient au fait qu’il peut être ajusté en fonction de la combinaison unique de facteurs en cause dans toute situation de survie, soit les caractéristiques de la victime, les vêtements qu’elle porte et l’environnement où l’incident se produit. En outre, il peut être appliqué à une vaste gamme de conditions environnementales, de l’exposition à l’air jusqu’à l’immersion partielle ou totale dans l’eau. L’ajout de la fonction stochastique a permis d’améliorer les capacités prédictives en calculant la probabilité de survie en l’absence d’information sur la victime ou en présence de plusieurs victimes. Le CESM a au départ été conçu comme outil de prise de décisions en recherche et sauvetage, mais il s’est avéré un outil éducatif très efficace. Des scénarios hypothétiques peuvent être étudiés, offrant un aperçu immédiat de l’effet de variables telles que l’humidité, le vent, la graisse corporelle et différents vêtements. Les prévisions sont fondées sur une victime inactive en position fixe, qui réagit normalement au froid.

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Cold Exposure Survival Model; CESM; cold; hypothermia; survival; Search and Rescue; SAR; modelling; immersion

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