C

Predictions of Daily Water and Sodium Requirements

To generate estimates of water and sodium losses at different energy expenditure levels and thus work rates, the U.S. Army Research Institute of Environmental Medicine (USARIEM) model was adapted for the four levels of energy expenditure identified in the Dietary Reference Intakes report on energy expenditure (IOM, 2002/2005). The USARIEM Heat Strain model is an empirical model that includes an equation to predict sweating rate during work (Moran et al., 1995, Shapiro et al., 1995). This algorithm has been used in the past to prepare military guidance for water needs during training and deployment.

The following is a description of the application of the model:

- Variables
  - Water requirements (L/d)
  - Sodium requirements (g/d)
- Prediction ranges
- Four energy expenditure levels (1,900; 2,400; 2,900; and 3,600 kcal/d)
- Temperature ranges (15°–40°C)

ANALYSIS

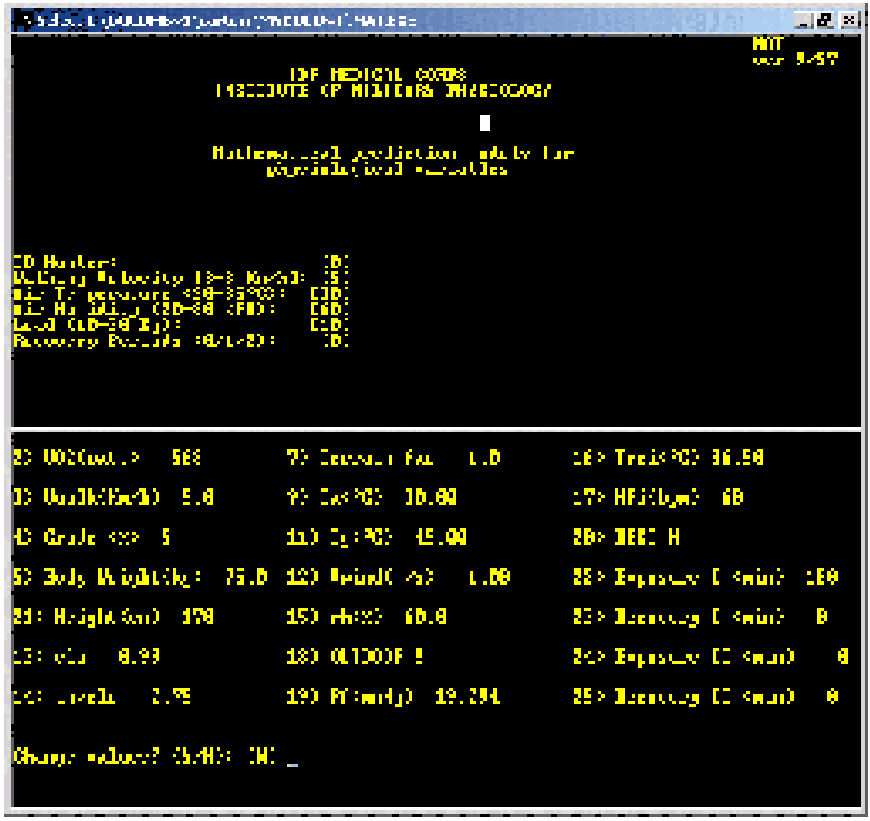
As shown in the example, the environmental, physiological, and individual information was inputted into the model. For any given individual, physiological, or environmental condition, the model predicted expected water losses. These data were then put into an

Excel 4.0 spreadsheet and used to generate the dataset of estimated water and sodium requirements at varying energy expenditure levels and temperatures. Environmental and individual assumptions are listed below. These data were then plotted using Sigma Plot 9.0 to generate a graphical display.

ASSUMPTIONS

- Individual
  - 70-kg person
  - Height = 170 cm
  - Walking velocity = 5 km/h
  - 0% grade
  - Clothing = 1.0 (cotton)
- Environmental
  - Partly cloudy day
  - Wind speed = 1 m/sec
  - Relative humidity = 50%
  - Outdoor
  - Water vapor pressure = 19.094 mm Hg
  - Load = 0 kg
  - Dry bulb temperature = 30°C
  - Black globe temperature = 45°C
- Physiological
  - Skin body temperature = 35.0°C
  - Rectal body temperature = 36.5°C
  - Initial heart rate = 60 bpm
  - Rest (N)
  - Exposure I = 720 min (= 12 h)
  - Exposure II = 720 min (= 12 h)
  - Exposure III (min) = 0
  - Exposure IV (min) = 0
- 1.0 L/d minimal requirements for survival:
- Sodium concentration of sweat (≈ 35 mmol/L), that of a partially acclimated person

Example (not used in this analysis):



The version of the program used was MAT version 9/97. Figures C-1a and C-1b describe the approximate daily water (Figure C-1a) and sodium (Figure C-1b) lost due to sweating as a function of dry bulb temperature and level of physical activity derived from modeling data (Table C-1).

*The screen is an example of the input variable capabilities; however, actual data are not presented in the database.

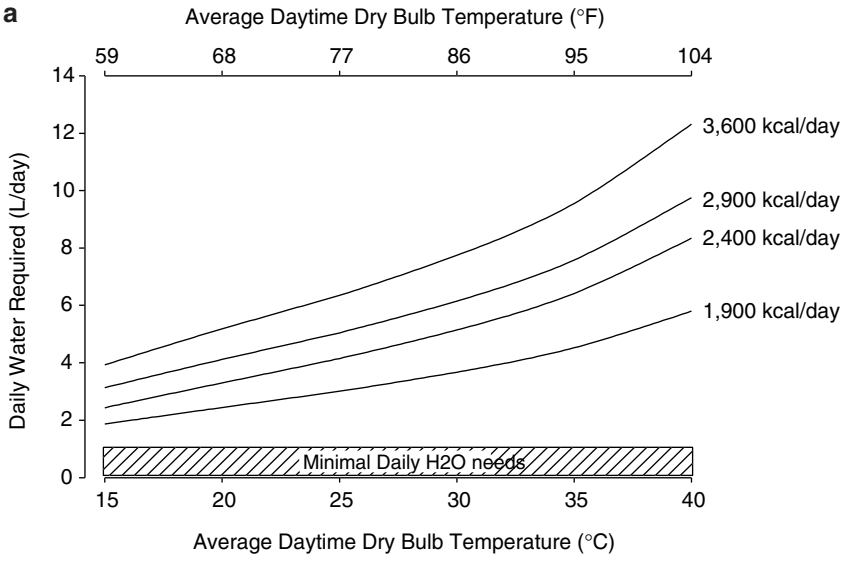
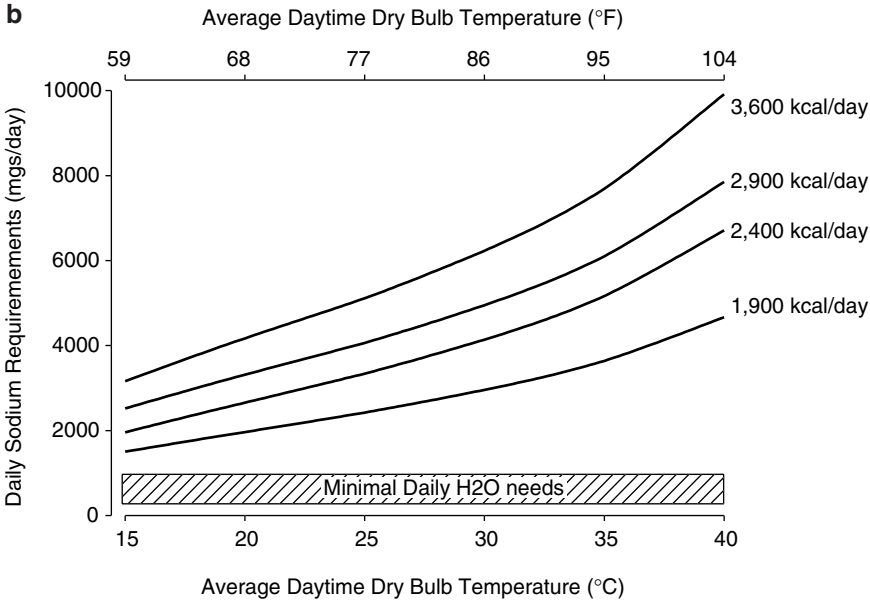


FIGURE C-1 Approximate daily water (Figure C-1a) and sodium (Figure C-1b) lost due to sweating as a function of dry bulb temperature and level of physical activity derived from modeling data (Table C-1). The hatched area indicates ≈ 1 L minimal water requirements. The y-axis represents the predicted water requirements that increase because of increased sweat losses to enable thermoregulation. The x-axis is the average daytime dry bulb temperature. The four lines represent the four levels of energy (in kcal/day) used in the model (1,900 kcal; 2,400 kcal; 2,900 kcal; and 3,600 kcal).



REFERENCES

IOM (Institute of Medicine). 2002/2005. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids.* Washington, DC: The National Academies Press.

Moran D, Shapiro Y, Epstein Y, Burstein R, Stroschein L, Pandolf KB. 1995. Validation and adjustment of the mathematical prediction model for human rectal temperature responses to outdoor environmental conditions. *Ergonomics* 38:1011–1018.

Shapiro Y, Moran D, Epstein Y, Stroschein L, Pandolf KB. 1995. Validation and adjustment of the mathematical prediction model for human sweat rate responses to outdoor environmental conditions. *Ergonomics* 38:981–986.

TABLE C-1 Generated Database from the USARIEM Prediction Model

Given:	kcal/h	watts	per 12 h (kcal)
Rest	76	88	912
Light	234	273	2,808
Mod	382	444	4,582
Hard	531	618	6,372

Assumption: 1.0 liter water essential (daily resp water loss and kidney loss)

Predicted Sweating Rates (mL/h)

Air Tdb	Rh	Rest	Light	Mod	Hard
10	50	32	100	355	628
15	50	65	204	456	722
20	50	108	339	618	911
25	50	151	473	763	1,069
30	50	201	629	938	1,263
35	50	265	829	1,168	1,524
40	50	361	1,129	1,524	1,934

12 h Air	Scenario Rest	Light	Mod	Hard	Kcal	Water Loss
10	0.95	0.05	0	0	1,006.8	425
15	0.95	0.05	0	0	1,006.8	867
20	0.95	0.05	0	0	1,006.8	1,440
25	0.95	0.05	0	0	1,006.8	2,009
30	0.95	0.05	0	0	1,006.8	2,672
35	0.95	0.05	0	0	1,006.8	3,522
40	0.95	0.05	0	0	1,006.8	4,796

WBGT	Rest	Light	Mod	Hard	Kcal	Water Loss
9.9	0.7	0.25	0.05	0	1,570	782
14.2	0.7	0.25	0.05	0	1,570	1,434
18.8	0.7	0.25	0.05	0	1,570	2,299
23.1	0.7	0.25	0.05	0	1,570	3,148
27.4	0.7	0.25	0.05	0	1,570	4,141
31.7	0.7	0.25	0.05	0	1,570	5,416
36.2	0.7	0.25	0.05	0	1,570	7,336

Hard	A:J13
khard	A:E7
klight	A:E5
kmod	A:E6
krest	A:E4
light	A:H13
mod	A:I13
Rest	A:G13
sr	A:E13.I20
WBGT	A:F13

ttl kcal	ttl water loss			
1,918.8	1.4	35	23	1,147
1,918.8	2.4	35	23	1,905
1,918.8	2.9	35	23	2,367
1,918.8	3.5	35	23	2,825
1,918.8	4.2	35	23	3,358
1,918.8	5.0	35	23	4,042
1,918.8	6.3	35	23	5,068

ttl kcal	ttl water loss			
2,481.5	2.3	35	23	1,837
2,481.5	2.9	35	23	2,362
2,481.5	3.8	35	23	3,058
2,481.5	4.6	35	23	3,742
2,481.5	5.6	35	23	4,541
2,481.5	6.9	35	23	5,568
2,481.5	8.8	35	23	7,113

continued

TABLE C-1 Continued

WBGT	Rest	Light	Mod	Hard	Kcal	Water Loss
9.9	0.65	0.15	0.15	0.05	2,020	1,445
14.2	0.65	0.15	0.15	0.05	2,020	2,130
18.8	0.65	0.15	0.15	0.05	2,020	3,115
23.1	0.65	0.15	0.15	0.05	2,020	4,047
27.4	0.65	0.15	0.15	0.05	2,020	5,148
31.7	0.65	0.15	0.15	0.05	2,020	6,578
36.2	0.65	0.15	0.15	0.05	2,020	8,754
WBGT	Rest	Light	Mod	Hard	Kcal	Water Loss
9.9	0.45	0.25	0.2	0.1	2,666	2,078
14.2	0.45	0.25	0.2	0.1	2,666	2,925
18.8	0.45	0.25	0.2	0.1	2,666	4,179
23.1	0.45	0.25	0.2	0.1	2,666	5,350
27.4	0.45	0.25	0.2	0.1	2,666	6,741
31.7	0.45	0.25	0.2	0.1	2,666	8,552
36.2	0.45	0.25	0.2	0.1	2,666	11,316

ttl kcal	ttl water loss			
2,931.9	2.9	35	23	2,371
2,931.9	3.6	35	23	2,922
2,931.9	4.6	35	23	3,715
2,931.9	5.5	35	23	4,465
2,931.9	6.6	35	23	5,352
2,931.9	8.1	35	23	6,503
2,931.9	10.3	35	23	8,254

ttl kcal	ttl water loss			
3,578	3.6	35	23	2,881
3,578	4.4	35	23	3,562
3,578	5.7	35	23	4,572
3,578	6.9	35	23	5,515
3,578	8.2	35	23	6,634
3,578	10.1	35	23	8,091
3,578	12.8	35	23	10,317