3.

WATER REQUIREMENTS, IMPINGING FACTORS, AND RECOMMENDED INTAKES

Ann C. Grandjean

The Center for Human Nutrition
University of Nebraska
Omaha, Nebraska USA

I. INTRODUCTION

Water is an essential nutrient for all known forms of life and the mechanisms by which fluid and electrolyte homeostasis is maintained in humans are well understood. Until recently, our exploration of water requirements has been guided by the need to avoid adverse events such as dehydration. Increasing appreciation for the impinging factors that must be considered when attempting to establish recommendations of water intake presents us with new and challenging questions.

This paper, for the most part, will concentrate on water requirements, adverse consequences of inadequate intakes, and factors that affect fluid requirements. Other pertinent issues will also be mentioned. For example, what are the common sources of dietary water and how do they vary by culture, geography, personal preference, and availability, and is there an optimal fluid intake beyond that needed for water balance?

II. ADVERSE CONSEQUENCES OF INADEQUATE WATER INTAKE, REQUIREMENTS FOR WATER, AND FACTORS THAT AFFECT REQUIREMENTS

1. Adverse Consequences

Dehydration is the adverse consequence of inadequate water intake. The symptoms of acute dehydration vary with the degree of water deficit (1). For example, fluid loss at 1% of body weight impairs thermoregulation and, thirst occurs at this level of dehydration. Thirst increases at 2%, with dry mouth appearing at approximately 3%. Vague discomfort and loss of appetite appear at 2%. The threshold for impaired exercise thermoregulation is 1% dehydration, and at 4% decrements of 20-30% is seen in work capacity. Difficulty concentrating, headache, and sleepiness are observed at 5%. Tingling and numbness of extremities can be seen at 6%, and collapse can occur at around 7% dehydration. A 10% loss of body water through dehydration is life-threatening (2). During the Six-day War of 1967, more than 20,000 Egyptian soldiers died from heat stroke. Egyptian troops were following practices of strict water rationing. During the same time, Israeli troops with abundant field water supplies and command-enforced water policies had minimal heat casualties (3)

While the vague discomfort that accompanies a 2% dehydration may not have a significant impact, the 20 – 30% reduction in work capacity seen at 4% can have a significant negative impact on productivity. Negative health consequences of chronic dehydration are covered later in this paper.

2. Minimum Water Requirements

The minimum requirement for water is the amount that equals losses and prevents adverse effects of insufficient water, such as dehydration. There are numerous limitations associated with the requirement estimates used to make recommendations. A review of the research designed to define fluid requirements of humans increases one's appreciation of the complexity of the issue. A multitude of intra- and inter-individual factors influence water requirements. As stated in the 1989 Recommended Dietary Allowances (4) establishing a recommendation that meets the needs of all is impossible:

- The primary determinant of maintenance water requirement appears to be metabolic, (Holliday and Segar, 1957) but the actual estimation of water requirement is highly variable and quite complex. Because the water requirement is the amount necessary to balance the insensible losses (which can vary markedly) and maintain a tolerable solute load for the kidneys (which may vary with dietary composition and other factors), it is impossible to set a general water requirement.
- The impracticability of establishing a general water requirement was reiterated in the Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate(5):
- Given the extreme variability in water needs which are not solely based on differences in metabolism, but also in environmental conditions and activity, there is not a single level of water intake that would ensure adequate hydration and optimal health for half of all apparently healthy persons in all environmental conditions.

Thus, the Panel determined that an Estimated Average Requirement (EAR), and therefore a Recommended Dietary Allowance (RDA), could not be established. Hence, an Adequate Intake (AI) was established as the reference value for water intake for healthy U.S. and Canadian individuals and populations.

3. Factors That Affect Requirements

For sedentary to moderately active individuals under temperate conditions, water is lost from the body via urine, feces, respiration, and evaporation. During increased physical activity and in conditions other than temperate, sweat loss contributes to body water loss. The minimal amount of fluid loss that can occur is referred to as the obligatory water loss. However, a variety of factors can affect obligatory loss. For example, obligatory urine loss occurs because of the need to remove various solutes from the body. The minimum water required for urine is dependent on the daily solute excretory load, primarily determined by diet, and the maximum urinary concentration achievable (6;7). Urinary concentrating ability varies with age (8;9) and with renal disease. Normally, fecal water loss is small, estimated at about 100 mL/day (4;10).

Water that passes through the skin (transepidermal diffusion) and is then lost by evaporation, and water that is lost from the respiratory tract, is collectively referred to as insensible water loss. Insensible water correlates with metabolic heat dissipation (11;12). The estimate of insensible water loss has been shown to vary more in infants than in adults (13), but Holliday and Segar (14) proposed an average water loss of 50 mL/100 kcal to apply to all ages. Even when caloric expenditure and body surface area are equal, however, insensible water loss through the skin and lungs varies. Environmental temperature and humidity, altitude, volume of air inspired, air currents, clothing, blood circulation through skin, and water content of the body can all affect insensible water loss (15).

A study published in 1930 (16) is the only identified primary reference reporting total water output in a healthy adult under temperate conditions. Five days of total intake and output data were reported on one sedentary 60-kg male subject confined to the laboratory. The average output was 2675 mL, ranging from 2227 mL to 3205 mL. Insensible loss remained fairly constant (1073–1213 mL), whereas urine water ranged from 1149 to 2132 mL. Some of the commonly referenced average output values are much lower than this 60-kg male's documented output. Nonetheless, the wide range of average daily output reported appears to capture the variability within and among individuals.

Another study assessing the effect of two diets on hydration was conducted on 27 healthy, sedentary, male subjects using a crossover design (17). During the trial that provided water as a portion of the beverage allotment, subjects consumed one-third of their beverages as plain drinking water. In the "without water" trial, no plain drinking water was consumed. Subjects were confined to a metabolic unit during the study and physical activity, sleep/wake cycle, and heat and humidity were controlled. Results showed no difference in the effect on hydration between the two diets, and subjects maintained euhydration on both trials. The mean total water from food and beverages, consumed by subjects in this study, was 1.1 mL/kcal.

Perhaps the most significant conclusions that can be drawn from an examination of water requirements are the limited scientific data, and the magnitude of the variability within and among individuals (16-18). This is important to keep in mind when considering recommendations, because recommendations are not necessarily requirements.

4. Factors that Increase Water Requirements

While young children, pregnant and lactating women, the elderly, and people with certain illnesses may have increased fluid requirements, and/or present additional challenges in meeting their requirements (19), space limitations prevent adequate review of such specific populations. Requirements and recommendations for fluid intake in hot and humid environments will be reviewed here because of the inordinate increase in fluid requirements that can result in such conditions and the large number of people worldwide who perform work in such environments.

5. Thermal and physiological stress

Water lost via sweating is usually low in temperate, sedentary conditions, but profuse sweating can be a major source of water and electrolyte loss for persons exercising or laboring in extreme heat and/or humidity. In physically active individuals, sweating presents the most highly variable water loss. Sweat rates can reach 3 to 4 L/hour, with variation in sweat rate depending upon exercise intensity and duration, age, gender, training, heat acclimatization, air temperature, humidity, wind velocity, cloud cover, clothing, and individual sweat rate (20). Total daily fluid requirements have been shown to range from as little as 2 liters per day to 16 liters per day pending on the work load and the level of heat stress (21).

It has long been known that persons under thermal and physiologic stress need to pay special attention to fluid and salt intake (2,22-24). Military personnel have been studied extensively in this regard. Monographs and scientific publications present some of the extensive research conducted by the United States for purposes of survival and endurance during the Second World War (2,25,26). Scientific findings from the research on military and aerospace personnel continue to provide essential and fundamental information on fluid requirements under conditions of thermal and physiologic stress (27-30). Collectively, research has shown progressive decrements in work performance with increasing levels of dehydration, and inter- and intra-individual variation in sweat rates, water intake, and water requirements.

A study on the effects of heat stress on the health and productivity of forest workers using manual working methods in temperate conditions was conducted in North East Zimbabwe (31,32). The forest workers were given either 0.17 or 0.6 liters of water each half hour. Based on the findings of dehydration and reduced productivity, the researcher concluded that International

Labour Organization recommendations for the consumption of at least 5 liters of fluid per day during heavy forestry work should be extended to work under temperate conditions.

Investigators conducting a field study to assess dehydration in 39 male underground miners concluded that workers who were educated about the need to drink small amounts frequently did not suffer from "voluntary dehydration" (33). The average fluid consumption per shift was 6.48 ± 2.41 L, with a range of 2.40 – 12.50 liters. The mean full shift average consumption rate was 0.8 ± 0.27, liters per hour, with a range of 0.32 – 1.47. Urinary specific gravity was used to determine hydration status. Start, mid, and end of shift, mean specific gravity were 1.0252, 1.0248 and 1.0254 respectively. However, specific gravity has been shown to be a somewhat unreliable measure of hydration status (34,35).

A study designed to determine if the Zimbabwe National Army rations are adequate for soldiers doing strenuous physical work, or even for those doing normal work in hot dry conditions, compared energy expenditure, and total body water on 12 soldiers (36). Eight soldiers were randomly assigned to the test group (strenuous work), and four were assigned to the control group (normal work). The study period lasted for 12 days. The average daily fluid intake for the test group was 11 liters per day compared to approximately 7 for the control group. The investigators concluded that the standard ration is inadequate.

The United States Army revised their fluid replacement guidelines in 1999. A study to compare the revised guidelines with the previous guidelines was conducted on soldiers engaged in outdoor military combat training in hot weather (37). The revised guidelines effectively reversed the decrease in serum sodium, reduced the increase in body mass, maintained hydration, and minimized overdrinking compared to the previous guidelines.

Table 1 shows the previous guidelines and Table 2 the revised.

Table 1. Previous Army Fluid Replacement Guidelines for Hot Weather Training [a]

Criteria		Controls	
Heat Condition/ Category	**WBGT* Index (°F)**	**Water Intake (qt/h)**	**Work-Rest Cycle (min)**
1	78-81.9	At least 0.5	Continuous
2	82-84.9	At least 0.5	50/10
3	85-87.9	At least 1	45/15
4	88-89.9	At least 1.5	30/30
5	90+	More than 2	20/40

[a]: Adapted from: Montain SJ, et al. Fluid Replacement Recommendations for Training in Hot Weather. *Military Medicine*, 164,7:502-508, 1999.
* WBGI = Wet Bulb Globe Temperature

It was determined that the Army's guidelines may need revision after 190 military personnel were hospitalized for water intoxication (hyposmolality/hyponatremia) between 1989 and 1999 (38). Hyponatremia should be considered a risk when large volumes of plain drinking water are consumed, especially when combined with a diet low in salt (sodium chloride).

Table 2. Revised Fluid Replacement Guidelines for Hot Weather Training (Average Acclimated Soldier Wearing Battle Dress Uniform, Hot Weather) [a]

		Easy Work		Moderate Work		Hard Work	
Heat Category	WBGT* Index (°F)	Work-Rest Cycle (min)	Water Intake (qt/h)	Work-Rest Cycle (min)	Water Intake (qt/h)	Work-Rest Cycle (min)	Water Intake (qt/h)
1	78-81.9	NL**	0.5	NL	0.75	40/20	0.75
2	82-84.9	NL	0.5	50/10	0.75	30/30	1
3	85-87.9	NL	0.75	40/20	0.75	30/30	1
4	88-89.9	NL	0.75	30/30	0.75	20/40	1
5	>90	50/10	1	20/40	1	10/50	1

[a] Adapted from: Montain SJ, et al. Fluid Replacement Recommendations for Training in Hot Weather. *Military Medicine*, 164,7:502-508, 1999.
* WBGI = Wet Bulb Globe Temperature
** NL, no limit to work time per hour

6. Recommendations and Estimates of Requirements

The amount of water needed to replace losses is the absolute requirement. Whereas requirements are impossible to predict precisely, except under controlled conditions, recommendations are standards to be used in the assessment and planning of diets for individuals and for groups, and for establishing policy.

The Tropical Agriculture Association has published water requirements for humans, animals and irrigated crops, given as liters per year (http://www.taa.org.uk). The minimum water requirement for fluid replacement for a 70kg human in a temperate zone equates to 3L per day, or 42.9mL/kg. Minimum requirements for an individual the same size but in a tropical zone equates to 4.1 to 6L/day, or 58.6 to 85.7mL/kg.

The Recommended Dietary Allowances (RDA), the dietary standards for the United States civilian population, have their roots in national defence. The Food and Nutrition Board (FNB), a part of the National Research Council, was established in 1940 "to advise on nutrition problems in connection with National Defense (39)." The amount of 1 mL water/kcal of energy expenditure has been the recommendation since 1945 (40). In 1989 the FNB added a higher amount, stating, "…there is so seldom a risk of water intoxication that the specified requirement for water is often increased to 1.5 mL/kcal to cover variations in activity level, sweating, and solute load (4)."

Age and gender specific Adequate Intakes (AI) for water were established in 2004 by the Food and Nutrition Board (5). The Dietary Reference Intakes (DRI) for water are shown in Tables 3 and 4.

Table 3. AI for Boys and Girls Birth to Eight Years of Age

0 – 6 months	0.7 L/day of water, assumed to be fromhuman milk.
7 – 12 months	0.8 L/day of water, assumed to be from human milk and complementary foods and beverages
1 – 3 years	1.3L/day
3 – 8 years	1.7 L/day

Table 4. AI for Ages Nine and Older

9 – 13 years	**Boys**	2.4 L/day
	Girls	2.1 L/day
14 – 18 years	**Boys**	3.3 L/day
	Girls	2.3 L/day
19 – 70+	**Men**	3.7 L/day
	Women	2.7 L/day

Athletes, like military personnel, are a population wherein hydration status is critical to performance. Considerable research has been conducted to explore the measurement and the consequences of dehydration during physical performance, as well as strategies andrecommendations for fluid intake. Athletes are commonly instructed to replace body water lost (measured by change in body weight) during training and competition with an amount of fluid that is equal to the amount lost, using the guideline that 1 kg equals 1 L. Numerous monographs and papers have been published on fluid needs of physically and environmentally stressed individuals (41-47).

7. Water Intake and Sources

Water intake includes that which is consumed as food and beverage, along with relatively small volumes of water created by oxidation of food (metabolic water) and breakdown of body tissue. Metabolic water is about 350 to 400 mL/d. Determining actual water consumption is difficult for a variety of reasons, one being that many of the published reports are for total water use (drinking water, water used for basic hygiene, etc.). Additionally, some reports on water intake report only tap water, and therefore, water provided as other beverages are not included in the calculations. Williams, et. al. (48) reported that estimates of mean water intake rates reported in the literature range from 1.04 to 1.63 L/person/day.

Humans ingest water as plain drinking water, as beverages, and in food. Water in food can be inherent or added during preparation, and also produced by metabolism. All contribute to the “total water intake.” Unfortunately, there is a paucity of data on total water consumption. The data that do exist show considerable variation in intakes both within and between individuals.

Studies in humans have shown that numerous factors affect fluid intake (49;50). Availability, ambient temperature, flavor, flavor variety, beverage temperature, proximity of the beverage to the person, and even beverage container have all been shown to impact intake. Cultural variations have been reported, although the data is limited (See Table 5).

Table 5. Market Shares (liter per capita) of Beverages in Various Countries [a,b]

Beverage	United States of America	Great Britain	Federal Republic of Germany	Italy	Finland
Soft drinks	173	91	78	47	31
Milk	102	126	55	68	104
Beer	89	108	147	2	63
Mineral water	?	2	62	50	8
Fruit juice	28	16	27	4	29
Wine[c]	16	11	23	80	5
Liquors[d]	–	5	19	11	35
Coffee[d]	98	13	96	57	156
Tea[d]	25	40	5	2	3

[a] Adapted from Tuorila, H. Individual and cultrual factors in the consumption of beverages. *In*: Ramsay and Booth, eds. *Thirst: physiological and psychological aspects*. London, Springer-Verlag, 1991.

[b] The USA consumption from 1985 (Bunch 1987; Putnam 1987), European figures from 1986 (Euromonitor 1988).

[c] In the US data includes liquors.

[d] Volumes estimated from dry substance with dilution ratios given

Water content of beverages varies. Plain drinking water and diet soft drinks are 100% water, whereas coffee and tea are 99.5%, and sport drinks are 95%. Fruit juices vary from 90 to 94% water. Skim milk, 2% fat milk, and whole milk are 91%, 89%, and 87% respectively. While not consumption data, the market share data in Table 5 reflects consumption patterns. Water intake from these beverages could be estimated with the possible exception of beverages containing alcohol.

Researchers described the diuretic action of alcohol as early as 1932 and subsequent studies substantiated a diuretic effect (51-54). A formula proposed by Stookey (55) applied quantitative estimates of the effects of alcohol to determine the retention of the water consumed. Making numerous assumptions, Stookey estimates water losses of 10 mL/g alcohol. Eggleton, in 1942, found that the diuresis following an alcoholic drink is roughly proportional to the amount of alcohol present and suggested that the ingestion of drinks containing small quantities of alcohol did not impair rehydration in dehydrated individuals (51). A 1995 study supported this notion. Taivainen and colleagues (56) found that while diuresis occurred after healthy adult males consumed a beverage of fruit juice and alcohol (1.2 g alcohol/kg of body weight), there was a subsequent antidiuretic phase that lasted up to 12 hours post alcohol ingestion. The researchers concluded that consuming fluids immediately following alcohol consumption (800 ml over 4 hours) and then 6 hours later (20 ml/kg) will, for the most part, offset the water lost from the alcohol induced diuresis. Thus, assuming adequate fluid intake following acute alcohol ingestion, it appears that alcohol-induced diuresis is transient and will not result in appreciable fluid losses over a 24 hour period.

Shirreffs and Maughan (57) conducted a study designed to determine whether alcohol exerts a diuretic effect when consumed by dehydrated individuals. After an exercised-induced dehydration, the subjects consumed a volume of fluid equal to 150% of the estimated sweat loss. The fluids consumed, in the four different trials, were alcohol-free beer, and alcohol-free beer to which 1, 2, or 4% alcohol was added. The results suggested that the diuretic effect of alcohol is substantially blunted when consumed by dehydrated individuals. Urine production increased as the quantity of alcohol consumed increased, and there was a significant reduction in the rate of recovery of blood volume when the 4 % alcohol beverage was consumed. It must be noted that in all of the trials in the Shirreffs and Maughan study, the subjects consumed 150% of the estimated sweat loss, leaving to question the results if subjects had consumed only 100%, or less than 100%, of sweat losses, or if the alcohol content of the beverage had been higher.

While research on acute alcohol consumption followed by adequate fluid intake supports a dose-response relationship with moderate intake causing no long-term effects on hydration status, elevated serum osmolality has been observed in chronic alcohol consumers, both at baseline and after ethanol ingestion (58). It is unclear if, and if so to what degree, alcohol induced diuresis, neurohormonal aberrations, perception of thirst, and/or fluid consumption habits, contribute to the dehydration (as determined by serum osmolality) observed in chronic alcohol consumers (58;59)

Further evaluation of alcohol's effect on fluid balance is warranted, especially in view of the numerous cultures that routinely consume alcoholic beverages as part of the daily diet. Chronic consumption, as part of the daily diet, verses acute high volume consumption, and dose response studies would provide useful information for determining how alcohol should be considered when calculating total water intake.

In the United States the majority of individuals' fluid intake is not consumed as plain water, but instead from a variety of foods and beverages as influenced by cultural, economic, social, environmental, and sensory factors (4;60). Ershow, Cantor, et al. (61) analyzed data from the 1977–1978 Nationwide Food Consumption Survey (NFCS). They found that water consumed as plain drinking water averaged 31.4% of total intake. Beverages other than plain water provided 43.6% and food provided 25% of total water intake. The water content of the food portion of the diet can vary widely. For example, whereas the mean intake of water from food for subjects of both sexes, 20 to 64 years of age participating in the 1977–1978 NFCS was 545 gm, the average for the 5th and 99th percentile were 223 and 1254, respectively (61).

Data from the USDA 1994–1996 Continuing Survey of Food Intakes by Individuals (CSFII) showed that approximately one-third of the total fluid intake of persons aged 20 to 64 years of age was consumed as plain water (62). The 1994–1996 CSFII (63) also showed that the average consumption of milk and other beverages totaled 1,115 grams/day for all subjects. Of that, 35% was coffee and tea, 30% was carbonated soft drinks, 17% was milk, 9% was alcohol, and 9% was fruit drinks and ades.

The perception exists that beverages vary in their capacity to maintain hydration status, with caffeine containing beverages purported to have a diuretic effect. This appears to be based on studies showing acute increased urine output after caffeine doses in caffeine naïve individuals (64-70). However, research shows that a tolerance to caffeine develops (71-76). As such, those who are not caffeine naïve do not experience increased urine output or altered indicators of hydration status after consuming caffeinated beverages (18;77).

In addition to unsubstantiated warnings about caffeine, unsubstantiated claims about the essentiality of plain water in meeting fluid requirements are also touted. Public perception in the United States is that plain drinking water is more "hydrating" than other beverages, even though it has long been put forth in medical, military, nutrition, and physiology texts that water from foods and beverages can meet fluid needs (4; 5; 78-82).

8. Is There an Optimal Intake?

While current knowledge allows us to determine insufficient and adequate fluid intake, our scientific knowledge base is inadequate to determine if there is an optimal fluid intake. However, there is a growing body of science indicating that an optimal intake level may indeed exist, and that such an amount is greater than current recommendations.

Research on the relationship of drinking water and the incidence of cancer has been an area of study for some time. For the most part, such studies have been concerned with contaminants in drinking water as a cause of cancer (83-86). More recently, studies have examined the relationship between beverage volume, and in some studies, the specific types of fluids consumed as related to the incidence of various diseases.

Studies examining the fluid-disease relationship have considered various combinations of variables including dehydration, hyperhydration, fluid volume consumed, and types of beverages, as they relate to the absence, presence, or treatment of certain diseases or conditions. For example, dehydration has been linked to increases in risk for urinary tract infections, dental disease, broncho-pulmonary disorders, constipation, kidney stones, and impaired cognitive function (87-92). A relationship between a high fluid intake and decreased risk of a variety of maladies including urinary tract stones, colon and urinary tract cancer, and mitral valve prolapse has been shown (83;87;93-104). Some studies examining the relationship between fluid intake and specific diseases have found no correlation with the types of beverages consumed (83;86;95;101;102), while others have (104-108). For example, one study (108) found an inverse correlation between water intake and risk of fatal coronary heart disease and a positive correlation between intake of other fluids other than water and risk. As the authors noted, however, potential confounding variables need to be considered. Perhaps the water drinkers were more health conscious. Moreover, subjects in the study had an intake of milk higher than the average United States population, and the type of milk consumed was not reported. Perhaps water drinkers consumed less total dietary fat. As with most epidemiology research, known and unknown confounding variables make it impossible to draw definitive cause-effect conclusions.

That fluoridated drinking water protects against dental carries is well documented. Results from a cross-sectional study on 499 Australian Army recruits showed a dose-response relationship, suggesting benefits of lifetime exposure to fluoridated drinking water through young adulthood (109).

Whereas the available information on a fluid-disease relationship is far from conclusive, current data indicates need for further study. Determining the amount of fluid necessary to maintain hydration is one concern when trying to discern recommendations on fluid intake; determining fluid intake necessary to treat or decrease risk of certain diseases or disorders is another.

9. Establishing Recommendations/Guidelines

It is important, for public health purposes, to estimate, as exactly as possible, the water requirements of a population. Doing so is an inordinate task, due to the numerous factors that effect requirements and the variances observed within each of those factors. Acknowledging the caveats, the World Health Organization, in their report, "Domestic Water Quantity, Service Level and Health" (19) estimated requirements. Based on a 70 kg adult male, and a 58 kg adult female, under average conditions, it was estimated that adult females needed 2.2L/day and males 2.5L/day. Manual labour in high temperatures increased requirements to 4.5L for both men and women. Recommendations for children were calculated using 1 liter per day for a 10 kg child and 0.75 liter for a 5 kg child, which resulted in 1.0L/day under average conditions and 4.5L for manual labour in high temperatures.

Table 6 shows the WHO requirements for adults (19) and also estimates from several the studies reviewed in this paper. While studies have shown that a low intake of fluid is associated with some chronic diseases, evidence is insufficient, at this time, to delineate specific amounts needed to prevent various diseases.

Table 6. Volume[a] of water recommended and/or found to support hydration under specific conditions.[bc]

	Sedentary, Temperate Environment		Physically Active and/or Increased Temperature		Optimal (Disease Prevention)
Female Adult	2.2	(19)	4.5	(19)	?
Male Adult	2.9	(19)	4.5 5.0 0.8/h 11.0	(19) (31) (33) (36)	?
Male & Female	2 – 4 0.5 qt/h	(21) (37)	8 – 16 ¾ - 1 qt/h	(21) (37)	?

[a] Volume is given as litres per day unless otherwise indicated.

[b] When reviewing this table, please keep in mind that data is not comparable in data collection methodology, subjects, environmental conditions, activity intensities (in reports on physically active), length of study/observation period, or purpose of study. Data are presented herein to demonstrate the ranges of recommendations/observations.

[c] The number in parentheses after the volume refers to the citation number in the reference list.

An incremental formula by which water requirements could be more precisely estimated for populations, groups of people, and perhaps even individuals would need to consider requirements under sedentary conditions at temperate environment with adjustments for altitude, heat, humidity, activity level, clothing, and other factors. While such a formula does not currently exist, development of such a formula could provide a point from which to more closely estimate requirements.

10. Future Challenges

For six decades, the driving force behind fluid and electrolyte research has been medical care, survival, and optimal physical performance. Empirical and clinical research, and field studies have been conducted on military personnel, athletes, and hospitalized patients. Missing, however, is comprehensive data more pertinent to “average” individuals who comprise the majority of many populations. Additionally, research is surfacing that moves beyond water requirements per se, and examines the relationship between optimal fluid intake and disease prevention, balancing requirements with availability, and exploring nutrients and other compounds (both beneficial and detrimental) that can accompany water. It is appropriate to move beyond the role of fluids in preventing dehydration and decrements in performance, and toward determining the contribution of fluids (and their mineral components) to longer, healthier, and more productive lives.

The current and future challenge is to continue research on topics such as fluid recommendations for various ages, the relationships between disease and the amount and types of fluids consumed, health-promoting properties of nutrients indigenous or endogenous to water, optimal intake levels, and consumption patterns. Additionally, guidelines or formulas that can more precisely determine the amount of water needed by individuals and/or populations would be advantageous.

Reference

1. Greenleaf J, Harrison MH. Water and electrolytes. In: Layman DK, editor. Nutrition and Aerobic Exercise, Washington, DC: American Chemical Society, 1986:107-124.
2. Adolph EF. Heat Exchanges, Sweat Formation, and Water Turnover. In: Adolph EF, editor. Physiology of Man in the Desert, New York: Interscience Publishers, 1947: 33-43.
3. Stewart C. The Spectrum of Heat Illness. In: Stewart C, editor. EnvironmentalEmergencies. Baltimore: Williams & Wilkins, 1990:1-27.
4. Food and Nutrition Board. Recommended Daily Allowances. 10 ed. Washington, DC: National Academy Press, 1989.
5. Food and Nutrition Board. Dietary Reference Intakes for Water, Potassium, Sodiu, Chloride, and Sulfate. Washington, DC: The National Academies Press, 2004.
6. Singer G, Brenner B. Fluid and electrolyte disturbances. In: Fauci A, Braunwald E, Isselbacher K, Wilson J, Martin J, Kasper D et al., editors. Harrison's Principles of Internal Medicine. NY, NY: McGraw-Hill, CD-ROM, 1998.
7. Howard L. Enteral and parenteral nutrition therapy. In: Fauci A, Braunwald E, Isselbacher K, Wilson J, Martin J, Kasper D et al., editors. Harrison's Principles of Internal Medicine. NY, NY: McGraw-Hill, CD-ROM, 1998.
8. Bergmann KE, Ziegler EE, Fomon SJ. Water and renal solute load. In: Fomon SJ, editor. Infant Nutrition. Philadelphia: W.B. Saunders, 1974: 245-266.
9. Phillips P, Rolls B, Ledingham D, Forsling M, Morton J, Crowe M, Wollner L. Reduced thirst after water deprivation in healthy elderly men. NEJM 1984; 311:753-759.
10. Alper C. Fluid and Electrolyte Balance. In: Wohl MG, Goodhart RS, editors. Modern Nutrition in Health and Disease, Philadelphia: Lea & Febiger, 1968: 404-424.
11. Benedict FG, Root HF. Insensible perspiration: Its relation to human physiology and pathology. Arch Intern Med 1926; 38(1):1-35.
12. Johnston M, Newburgh L. The determination of the total heat eliminated by the human being. Clinical Invest 1930; viii:147-160.
13. Levine S, Wheatley M. Respiratory metabolism in infancy and in childhood. American Journal of Diseases of Children 1936; 51:1300-1323.
14. Holliday M, Segar W. The maintenance need for water in parenteral fluid therapy. Pediatrics 1957; 823-832.
15. Newburgh L, Johnston M. The insensible loss of water. Physiological Reviews 1942; 22(1):1-18.
16. Newburgh L, Johnston M, Falcon-Lesses M. Measurement of total water exchange. J.Clin Invest 1930; 8:161-196.
17. Grandjean AC, Reimers KJ, Haven MC, Curtis GL. The effect on hydration of two diets, one with and one without plain water. JACN 2003; 22(2):165-173.
18. Grandjean AC, Reimers KJ, Bannick KE, Haven MC. The effect of caffeinated, non-caffeinated, caloric and non-caloric beverages on hydration. JACN 2000; 19(5):591-600.
19. Howard G, Bartram J. Domestic Water Quantity, Service, Level and Health. World Health Organization, 2003. Ref Type: Report

20. Gisolfi C. Water requirements during exercise in the heat. In: Marriott B, editor. *Nutritional Needs in Hot Environments*, Washington, DC: National Academy Press, 1993:87-96.

21. Sawka MN, Montain SJ. Fluid and electrolyte balance: effects on thermoregulation and exercise in the heat. In: Bowman BA, Russell RM, editors. Present Knowledge in Nutrition, Washington, DC: ILSI Press, 2001:115-124.

22. Council on Pharmacy and Chemistry. The addition of salt to drinking water. JAMA 1945; 129(2):131.

23. Johnson RE. Nutritional standards for men in tropical climates. Gastroenterology 1943; 1:832-840.

24. Strydom NB, Van Graan CH, Holdsworth LD. The water requirements of humans. J. Occup Med 1965; 7(11):581-587.

25. Adolph EF, Dill DB. Observations on water metabolism in the desert. Am J Physiol 1938; 123:369-378.

26. Pitts GC, Johnson RE, Consolazio FC. Work in the heat as affected by intake of water, salt and glucose. Am J Physiol 1944; 142:253-259.

27. Greenleaf JE, Harrison MH. Water and electrolytes. In: Layman DK, editor. Nutrition and Aerobic Exercise, Washington, D C: American Chemical Society, 1986:107-124.

28. Buskirk ER, Mendez J. Nutrition, environment and work performance with special reference to altitude. Fed Proc 1967; 26(6):1760-1767.

29. Mohlman HT, Katchman BJ, Slonim AR. Human water consumption and excretion data for aerospace systems. Aerosp Med 1968; 39(4):396-402.

30. Strydom NB, Wyndham CH, Van Graan CH, Holdsworth LD, Morrison JF. The influence of water restriction on the performance of men during a prolonged march. S. A. Medical Journal 1966; 539-544.

31. Wasterlund D. Heat stress in forestry work. Acta Universitatis Agriculturae Suecia, 200l.

32. Wasterlund D. A review of heat stress research with application to forestry. Applied Ergonomics 1998; 29(3):179-183.

33. Brake DJ, Bates GP. Fluid losses and hydration status of industrial workers under thermal stress working extended shifts. Occup Environ Med 2003; 60:90-96.

34. Grandjean AC, Reimers KJ. Urine specific gravity is not a reliable indicator of hydration status. MSSE 2000; 32[5], S197. Ref Type: Abstract

35. Popowski LA, Oppliger RA, Lambert GP, Johnson AK, Gisolfi CV. Is urine specific gravity a satisfactory measure of hydration status? MSSE 1999; 31[5], S323.
Ref Type: Abstract

36. Mudambo KSMT, Scrimgeour CM, Rennie MJ. Adequacy of food rations in soldiers during exercise in hot, day-time condictions assessed by doubly labelled water and energy balance methods. Eur J Apply Physiol 1997; 76:346-351.

37. Montain SJ, Latzka WA, Sawka MN. Fluid replacement recommendations for training in hot weather. Mil Med 1999; 164(7):502-508.

38. Kolka MA, Latzka WA, Montain SJ, Corr WP, O'Brien KK, Sawka MN. Effectiveness of revised fluid replacement guidelines for military training in hot weather. Aviat Space Environ Med 2003; 74(3):242-246.

39. Food and Nutrition Board. Recommended Dietary Allowances. Washington, DC: National Academy Press, 1943.

40. Food and Nutrition Board. Recommended Dietary Allowances. National Research Council, 1945.

41. Gisolfi C, Lamb D. Perspectives in exercise science and sports medicine. Vol. 3. Fluid homeostasis during exercise. Carmel (IN): Benchmark Press Inc, 1990.

42. Armstrong LE. Hubbard RW, Szlyk PC, Matthew WT, Sils IV. Voluntary dehydration and electrolyte losses during prolonged exercise in the heat. Aviat Space Environ Med 1985; 56:765-770.

43. Casa DJ, Armstrong LE, Hillman SK, Montain SJ, Reiff RV, Rich BSE, Roberts WO, Stone JA. National athletic trainers' association position statement: Fluid replacement for athletes. *Journal of Athletic Training* 2000; 35(2):212-224.

44. Convertino VA, Armstrong LE, Coyle EF, Mack GW, Sawka MN, Senay LC, Sherman WM. American College of Sports Medicine. Position Stand on Exercise and Fluid Replacement. Med Sci Sports Exerc 1996; 28(1):i-vii.

45. Epstein Y, Armstrong LE. Fluid-electrolyte balance during labor and exercise: concepts and misconceptions. Int'l J Sport Nutr 1999; 9:1-12.

46. Latzka WA, Montain SJ. Water and electrolyte requirements for exercise. Clinics in Sports Medicine 1999; 18:513-524.

47. Sawka MN, Francesconi RP, Young J, Pandolf KB. Influence of hydration level and body fluids on exercise performance in the heat. JAMA 1984; 252:1165-1169.

48. Williams B, Florez Y, Pettygrove S. Inter- and intra-ethnic variation in water intake, contact, and source estimates among Tucson residents: Implications for exposure analysis. Journal of Exposure Analysis and Environmental Epidemiology 2001; 11:510-521.

49. Ramsay DJ, Booth DA. International Life Sciences Institute. Thirst: physiological and psychological aspects. London: Springer-Verlag, 1991.

50. Rozin P, Cines BM. Ethnic differences in coffee use and attitudes to coffee. Ecology of Food and Nutrition 1982; 12:79-88.

51. Eggleton MG. The diuretic action of alcohol in man. J Physiol 1942; 101:172-191.

52. Murray MM. The diuretic action of alcohol and its relation to pituitrin. J Physiol (Lond) 1932; 76:379-386.

53. Roberts KE. Mechanism of dehydration following alcohol ingestion. Arch Intern Med 1963; 112:154-157.

54. Rubini ME, Kleeman CR, Lamdin E. Studies on alcohol diuresis. I. The effect of ethyl alcohol ingestion on water, electrolyte and acid-base metabolism. J Clin Invest 1955; 34:439-447.

55. Stookey JD. The diuretic effects of alcohol and caffeine and total water intake misclassification. European Journal of Epidemiology 1999; 15:181-188.

56. Taivainen H, Laitinen K, Tahtela R, Kilanmaa K, Valimaki MJ. Role of plasma vasopressin in changes of water balance accompanying acute alcohol intoxication. Alcohol Clin Exp Res 1995; 19(3):759-762.

57. Shirreffs SM, Maughan RJ. Restoration of fluid balance after exercise-induced dehydration: effects of alcohol consumption. J Appl Physiol 1997; 83(4):1152-1158.

58. Collins GB, Bronsnihan KB, Zuti RA, Messina M, Gupta MK. Neuroendocrine, fluid balance, and thirst responses to alcohol in alcoholics. Alcohol Clin Exp Res 1992; 16(2):228-233.

59. Oglivie KM, Lee S, Rivier C. Role of arginine vasopressin and corticotropin-releasing factor in mediating alcohol-induced adrenocorticotropin and vasopressin secretion in male rats bearing lesions of the paraventricular nuclei. Brain Research 1997; 744:83-95.

60. Rolls B. Homeostatic and non-homeostatic controls of drinking in humans. In: Arnaud MJ, editor. Hydration throughout life, London: John Libbey and Company Ltd. 1998:19-28.

61. Ershow AG, Cantor KP, Federation of American Societies for Experimental Biology, Life Sciences Research Office, National Cancer Institute (U.S.), Epidemiology and Biostatistics Program. Total water and tapwater intake in the United States population-based estimates of quantities and sources. Bethesda, MD: Life Sciences Research Office, Federation of American Societies for Experimental Biology, 1989.

62. Heller KE, Sohn W, Burt BA, Eklund SA. Water consumption in the United States in 1994-96 and implications for water fluoridation policy. J Public Health Dent 1999; 59(1):3-11.

63. United States Department of Agriculture. 1994-96 Continuing Survey of Food Intake by Individuals. http://www.barc.usda.gov/bhnrc/foodsurvey/Cd94-96.html. 1999.
Ref Type: Electronic Citation

64. Bellet S, Roman L, DeCastro O, Kim K, Kershbaum A. Effect of coffee ingestion on catecholamine release. Metabolism 1969; 18:288-291.

65. Dorfman LJ, Jarvik ME. Comparative stimulant and diuretic actions of caffeine and theobromine in man. Clin Pharmacol Ther 1970; 11(6):869-872.

66. Massey L, Wise K. The effect of dietary caffeine on urinary excretion of calcium, magnesium, sodium and potassium in healthy young females. Nutr Res 1984; 4:43-50.

67. Neuhäuser-Berthold M, Beine S, Verwied SC, Luhrmann PM. Coffee consumption and total body water homeostasis as measured by fluid balance and bioelectrical impedance analysis. Ann Nutr Metab 1997; 41(1):29-36.

68. Passmore AP, Kondowe GB, Johnston GD. Renal and cardiovascular effects of caffeine: a dose-response study. Clin Sci (Lond) 1987; 72(6):749-756.

69. Robertson D, Frölich JC, Carr RK, Watson JT, Hollifield JW, Shand DG, Oates JA. et al. Effects of caffeine on plasma renin activity, catecholamines and blood pressure. NEJM 1978; 298:181-186.

70. Wemple R, Lamb D, McKeever K. Caffeine vs caffeine-free sports drinks: effects on urine production at rest and during prolonged exercise. Int J Sports Med. 1997; 18:40-46.

71. Colton T, Gosselin R, Smith R. The tolerance of coffee drinkers to caffeine. Clin Pharmacol Ther 1968; 9:31-39.

72. Denaro C, Brown C, Jacob PI, Benowitz N. Effects of caffeine with repeated dosing. Eur J Clin Pharmacol 1991; 40:273-278.

73. Goldstein A, Kaizer S, Whitby O. Psychotropic effects of caffeine in man. IV. Quantitative and qualitative differences associated with habituation to coffee. Clin Pharmacol Ther 1969; 10:489-497.

74. Myers M, Reeves R. The effect of caffeine on daytime ambulatory blood pressure. Am J Hypertens 1991; 4:427-431.

75. Robertson D, Wade D, Workman R, Woosley RL, Oates JA. Tolerance to the humoral and hemodynamic effects of caffeine in man. J Clin Invest 1981; 67(4):1111-1117.

76. Eddy NB, Downs AW. Tolerance and cross-tolerance in the human subject to the diuretic effect of caffeine, theobromine and theophylline. J Pharmacol Exp Ther 1928; 33:167-174.

77. Armstrong LE. Caffeine, body fluid-electrolyte balance, and exercise performance. Int J Sport Nutr and Exer Metab 2002; 12:189-206.

78. Alper C. Fluid and Electrolyte Balance. In: Wohl MG, Goodhart RS, editors. Modern Nutrition in Health and Disease. 1968:404-424.

79. Bland JH. Basic physiologic considerations of body water and electrolyte. Clinical Metabolism of Body Water and Electrolytes. Philadelphia: Saunders, 1963: 10-53.

80. Food and Nutrition Board. Water. 7 ed. Washington, DC: National Academy Press, 1968.

81. Food and Nutrition Board. Water. 8 ed. Washington, DC: National Academy Press, 1974.

82. Food and Nutrition Board. Water and Electrolytes. 9 ed. Washington, DC: National Academy Press, 1980.

83. Wilkens LR, Kadir MM, Kolonel LN, Nomura AM, Hankin JH. Risk factors for lower urinary tract cancer: the role of total fluid consumption, nitrites and nitrosamines, and selected foods. Cancer Epidemiol Biomarkers Prev 1996; 5(3):161-166.

84. Mirvish SS, Grandjean AC, Moller H, Fike S, Maynard T, Jones L, Rosinsky S, Nie G. N-nitrosoproline excretion by rural Nebraskans drinking water of varied nitrate content. Cancer Epidemiol Biomarkers Prev 1992; 1(6):455-461.

85. Vena JE, Graham S, Freudenheim J, Marshall J, Zielezny M, Swanson M, Sufrin G. Drinking water, fluid intake, and bladder cancer in western New York. Arch Environ Health 1993; 48(3):191-198.

86. Bruemmer B, White E, Vaughan TL, Cheney CL. Fluid intake and the incidence of bladder cancer among middle-aged men and women in a three-county area of western Washington. Nutr Cancer 1997; 29(2):163-168.

87. Borghi L, Meschi T, Amato F, Briganti A, Novarini A, Giannini A. Urinary volume, water and recurrences in idiopathic calcium nephrolithiasis: a 5-year randomized prospect study. J Urol 1996; 155(3):839-843.

88. Embon OM, Rose GA, Rosenbaum T. Chronic dehydration stone disease. Br J Urol 1990; 66(4):357-362.

89. Inouye SK. Prevention of delirium in hospitalized older patients: risk factors and targeted intervention strategies. Ann Med 2000; 32:257:263.

90. Lawlor PG, Gagnon B, Mancini IL, Pereira JL, Hanson J, Suarez-Almazor ME, Bruera ED. Occurrence, causes, and outcome of delirium in patients with advanced cancer. A prospective study. Arch Intern Med 2000; 160:786-794.

91. Read NW, Celik AF, Katsinelos P. Constipation and incontinence in the elderly. J Clin Gastroenterol 1995; 20(1):61-70.

92. Ship JA, Fischer DJ. The relationship between dehydration and parotid salivary gland function in young and older healthy adults. J Geronotology: Medical Sciences 1997; 52A(5):M310-M319.

93. Curhan GC, Willett WC, Knight EL, Stampfer MJ. Dietary factors and the risk of incident kidney stones in younger women. Nurses' Health Study II 2004; 64:885-891.

94. Rodgers AL. Effect of mineral water containing calcium and magnesium on calcium oxalate urolithiasis risk factors. Urol Int 1997; 58(2):93-99.

95. Bitterman WA, Farhadian H, Abu SC, Lerner D, Amoun H, Krapf D, Makov UE. Environmental and nutritional factors significantly associated with cancer of the urinary tract among different ethnic groups. Urol Clin North Am 1991; 18(3):501-508.

96. Braver DJ, Modan M, Chetrit A, Lusky A, Braf Z. Drinking, micturition habits, and urine concentration as potential risk factors in urinary bladder cancer. J Nat'l Cancer Ins 1987; 78(3):437-440.

97. Hosking DH, Erickson SB, Van den Berg CJ, Wilson DM, Smith LH. The stone clinic effect in patients with idiopathic calcium urolithiasis. J Urol 1983; 130(6):1115-1118.

98. Hughes J, Norman RW. Diet and calcium stones. CMAJ 1992; 146(2):137-143.

99. 99. Iguchi M, Umekawa T, Ishikawa Y, Katayama Y, Kodama M, Takada M, Katoh Y, Kataoka K, Kohri K, Kurita T. Clinical effects of prophylactic dietary treatment on renal stones. J Urol 1990; 144(2 Pt 1):229-232.

100. Lax D, Eicher M, Goldberg SJ. Mild dehydration induces echocardiographic signs of mitral valve prolapse in healthy females with prior normal cardiac findings. Am Heart J 1992; 12**4**(6):1533-1540.

101. Lubin F, Rozen P, Arieli B, Farbstein M, Knaani Y, Bat L Farbstein H. Nutritional and lifestyle habits and water-fiber interaction in colorectal adenoma etiology. Cancer Epidemiol Biomarkers Prev 1997; 6(2):79-85.

102. Michaud DS, Spiegelman D, Clinton SK, Rimm EB, Curhan GC, Willett WC, Giovannucci EL. Fluid intake and the risk of bladder cancer in men. NEJM 1999; 340(18):1390-1397.

103. Pohlabeln H, Jockel KH, Bolm-Audorff U. Non-occupational risk factors for cancer of the lower urinary tract in Germany. Eur J Epidemiol 1999; 15(5):411-419.

104. Slattery ML, Caan BJ, Anderson KE, Potter JD. Intake of fluids and methylxanthine-containing beverages: association with colon cancer. Int J Cancer 1999; 81(2):199-204.

105. Shannon J, White E, Shattuck AL, Potter JD. Relationship of food groups and water intake to colon cancer risk. Cancer Epidemiol Biomarkers Prev 1996; 5(7):495-502.

106. Geoffroy-Perez B, Cordier S. Fluid consumption and the risk of bladder cancer: results of a multicenter case-control study. Int J Cancer 2001; 93(6):880-887.

107. Slattery ML, West DW, Robison LM. Fluid intake and bladder cancer in Utah. Int J Cancer 1988; 42:17-22.

108. Chan J, Knutsen SF, Blix GG, Lee JW, Fraser GE. Water, other fluids, and fatal coronary heart disease: the Adventist Health Study. Am J Epidemiol 2002; 155(9):827-833.

109. Hopcraft MS, Morgan VM. Exposure to fluoridated drinking water and dental caries experience in Australian army recruits, 1996. Community Dent Oral Epidemiol 2003; 31:68-74.