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4. DRINKING WATER INGESTION

4.1 INTRODUCTION

Drinking water is a potential source of human exposure to toxic substances among children. Contamination of drinking water may occur at the water supply source (ground water or surface water); during treatment (for example toxic by-products may be formed during chlorination); or post-treatment (such as leaching of lead or other materials from plumbing systems). Estimating the magnitude of the potential dose of toxics from drinking water requires information on the quantity of water consumed. The purpose of this section is to describe key published studies that provide information on drinking water ingestion among children (Section 4.2) and to provide recommendations of ingestion rate values that should be used in exposure assessments (Section 4.3).

Currently, the U.S. EPA uses the quantity 1 L per day for infants (individuals of 10 kg body mass or less) and children as a default drinking water ingestion rate (U.S. EPA, 1980; 1991). This rate includes drinking water consumed in the form of juices reconstituted in the home and other beverages containing tapwater. The National Academy of Sciences (NAS, 1977) estimated that daily consumption of water may vary with levels of physical activity and fluctuations in temperature and humidity. It is reasonable to assume that children engaging in physically-demanding activities or living in warmer regions may have higher levels of water ingestion.

Two studies cited in this chapter (US EPA, 2004 and EPA Analysis of CSFII) have generated data on drinking water ingestion rates. In general, these sources support EPA's use of 1 L/day as an upper-percentile tapwater ingestion rate for children under 10 years of age. The respondents recorded the source and type of water ingested at home and away from home. The respondents had several choices for the source of water ingested at home. These included community water supply, household well or rain cistern, household or public spring, bottled water and other. Similarly, the respondents had several choices for the source of water ingested away from home. The choices included tap/fountain, bottled, other, don't know, and not ascertain. Values associated with "don't know" and "not ascertain" were referred to as "missing" in Table 4-2. U.S. EPA 2004 and the subsequent analysis by EPA of the CSFII data classified water ingestion rates as direct and indirect. *Direct ingestion* is defined as direct consumption of

plain water as a beverage at home and away from home from all sources including tap/fountain water from community water supply, household well or rain cistern, household or public spring, and bottled. It does not include water used for preparing beverages such as coffee or tea. *Indirect ingestion* includes water added during food preparation, but not water intrinsic to purchased foods. Indirect water includes for example, water used to prepare baby formulas, cake mix, and concentrated orange juice. In addition to presenting data on direct and indirect water ingestion, data for consumption of water from various sources (i.e., the community water supply, bottled water, and other sources) are also presented. For the purposes of exposure assessments involving site-specific contaminated drinking water, ingestion rates based on the community supply are most appropriate. Given the assumption that bottled water, and other purchased foods and beverages are widely distributed and less likely to contain source-specific water, the use of total water ingestion rates may overestimate the potential exposure to toxic substances present only in local water supplies; therefore, tapwater ingestion of community water, rather than total water ingestion, is emphasized in this section.

The studies on drinking water ingestion that are currently available are based on short-term survey data (two days). Although short-term data may be suitable for obtaining mean or median ingestion values that are representative of both short- and long-term ingestion distributions , upper and lower -percentile values may be different for short-term and long-term data. It should also be noted that most drinking water surveys currently available are based on recall. This may be a source of uncertainty in the estimated ingestion rates because of the subjective nature of this type of survey technique.

The actual percentile distributions for water ingestion are presented in this handbook, where sufficient data are available. To facilitate comparisons between studies, the mean and the 90th percentiles are given for all studies.

Other drinking water studies based on older data were presented in the *Exposure Factors Handbook* (U.S. EPA, 1997a).

4.2 DRINKING WATER INGESTION STUDIES

4.2.1 U.S. EPA, 2004

The U.S. EPA analyzed the combined 1994-96 and 1998 Continuing Survey of Food Intake by Individuals (CSFII) data sets to examine the ingestion of water by various segments of

the U.S. population. The CSFII is a continuing survey of food consumption habits in the U.S. In the initial 1994-96 survey, over 15,000 respondents provided data on what they ate and drank over two non-consecutive days; a 1998 supplement using the same methodology added several thousand children to the database. The 1994-96 survey and 1998 supplement are referred to collectively as CSFII 1994-96, 1998. Each individual in the survey was assigned a sample weight based on his or her demographic data; these weights were taken into account when calculating mean and percentile water ingestion from various sources. The U.S. EPA used the drinking water ingestion data in the CSFII 1994-96, 1998 to derive estimates of consumption rates by age groups. The ingestion rates are expressed in both milliliters per day (mL/day) and milliliters per kilogram body weight per day (mL/kg/day). Table 4-1 presents the estimated mean, 90^{th}, and 95^{th} percentile ingestion of water, including both direct and indirect sources.

The principal advantages of this study are (1) that the survey was designed to obtain a statistically valid sample of the entire United States population that included children and low income groups ; (2) sample weights were provided that facilitated proper analysis of the data and accounted for non-response; and (3) that the sample size (more than 20,000 persons) is sufficient to allow categorization within narrowly defined age categories. However, the design of the survey has some weaknesses, including the practice of surveying each participant on only two days; this reduces the precision of the measurement for each individual and may tend to exaggerate the effects of persons on both extremes of the distribution of ingestion, although the degree to which this may happen is unknown. Also, the design of the study, while being well-tailored for the overall population of the United States and conducted throughout the year to account for seasonal variation, is of limited utility for assessing small and potentially at-risk subpopulations based on ethnicity, medical status, geography, or other factors such as activity level.

4.2.2. EPA Analysis of CSFII (USDA, 1998)

The water ingestion study described in the previous section yielded useful results for direct and indirect water ingestion (Table 4-1). However, the age categories used by the investigators were not compatible with the standardized age categories used in this Handbook. Water ingestion for the target age groups of this Handbook were derived from the CSFII.

In the analysis of the CSFII 1994-96, 1998, data (US EPA, 2004) total water ingestion was defined as consisting of community water supply, bottled water, other sources, and missing sources. Missing sources represent water sources that the survey respondent was unable to identify. In addition to these sources, the data also distinguish between direct and indirect water consumption. Direct consumption is water consumed directly from the tap while indirect consumption is water added during final food or beverage preparation in the home or food establishment (e.g., restaurants, school cafeterias). In this Handbook, indirect and direct water use were not distinguished. Table 4-2 provides the estimates for the mean direct and indirect water consumption, broken down by water source, for the entire U.S. population, including both children and adults. Also included are estimates of the 90^{th} percentile and the 95^{th} percentile ingestion rates. Tables 4-3 through 4-6 show mean and percentile consumption, expressed as mL/day and ml/kg/day, of all water, community water, bottled water, and other water, respectively, for each of the target age categories.

The data show that the quantity of water ingested per unit mass of body weight is at a maximum in the first month of life and decreases with increasing age (Table 4-3). The significance of this finding is that the younger, vulnerable ages (i.e., infants) have higher dose rates per unit of body weight. The pattern of higher dose rate per unit of body weight is similar for individual sources of water (e.g., community water, bottled water, and other water (Tables, 4-4, 4-5, and 4-6.)

The CSFII 1994-96, 1998 data have both strengths and limitations with regard to estimating water ingestion. These are discussed in some detail in Chapter 8 of US EPA (2004). The strengths lie in the design of the survey in that it was constructed to collect a statistically representative sample of the U.S. population (i.e., obtain data from a sufficiently large and varied sample set) and the survey was specific in detailing types and composition with respect to water of food and drink. The large size of the sample population (> 20,000) total and over sampling of children enhances the precision and accuracy of the estimates for the overall population and child population subsets. Data were collected for only 2days and does not necessarily represent "usual intake." "Usual dietary intake" refers to the long-run average of daily intakes by an individual. Thus, upper percentile estimates may differ between short term and long-term data because short-term food consumption data tend to be inherently more variable. However, that variability due to short term duration of the survey does not result in bias of estimates of overall mean

consumption levels (U.S. 2004). In addition, the survey was conducted on non-consecutive days, which improves the variance over consecutive days of consumption. The survey was administered such that an interviewer went through the data collection process for the initial day to show the participants the proper response methodology. The second day of the survey was reported by the participant. The two non-consecutive days of data collection, although an advantage over two consecutive days, provides limited information on individual respondents. The two-day mean for an individual can easily be skewed for numerous reasons. Estimation at the individual respondent level was not, however, an objective of the survey. The large sample does provide useful information on the overall distribution of ingestion by the population and should reflect adequately the range among respondent variability. Another limitation of these data is that the survey design does not support generating water consumption estimates for certain populations of interest, including Native Americans with traditional lifestyles, people who may consume large amounts live in hot climates, people who consume large amounts of water because of physical activity, and people with medical conditions necessitating increased water intake. While these individuals were participants in the survey, they are not present in sufficient numbers to support separate water ingestion estimates.

4.3 RECOMMENDATIONS

The studies described in this section were used in selecting recommended drinking water ingestion rates for children. A summary of the recommended values for drinking water ingestion rates is presented in Table 4-7. The ingestion rates, as expressed as mL/kg/day, generally decrease with age.

A characterization of the overall confidence in the accuracy and appropriateness of the recommendations for drinking water is presented in Table 4-8. The Exposure Factors Handbook (U.S. EPA, 1997a) gave this factor a medium confidence rating. However, the confidence score of the overall recommendations has been increased to high for this report because of the addition of newer data from the CSFII 1994-96, 1998.

4.4 REFERENCES FOR CHAPTER 4

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U.S. EPA. (1997a) Exposure Factors Handbook. Washington, DC: Office of Research and Development, (EPA/600/P-95/002F).

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Table 4-1. Estimated Direct and Indirect Water Ingestion for Selected Age Categories Derived from CSFII Data

Age Category	Sample Size (N)	Mean		Percentile Ingestion			
		mL/day	mL/kg/day	90th		95th	
				mL/day	mL/kg/day	mL/day	mL/kg/day
less than 6 months	772	448	77	957	174	1154	216
6 months to <1 year	714	530	59	1029	118	1278	148
birth to <2 years	2526	420	49	900	117	1079	150
1 to <4 years	3855	424	31	823	60	1029	75
4 to <7 years	3202	545	27	1053	53	1303	68
birth to <6 years	7973	470	36	937	76	1132	104
7 to <11 years	1100	607	20	1129	36	1418	45
11 to <15 years	816	811	16	1622	32	1961	40
15 to <20 years	825	991	15	1894	29	2385	38
20 years and older	9323	1460	20	2549	35	3194	44

Source: U.S. EPA, 2004

Table 4-2. Estimated Direct and Indirect Community Water Ingestion By Source for Entire U.S. Population (All Ages)[a]

Water Source	Sample Size	Mean[b]		90th Percentile[b]		95th Percentile[b]	
		mL/day	mL/kg/day	mL/day	mL/kg/day	mL/day	mL/kg/day
Community Water Supply	20,607	927	15	2,016	32	2,545	42
Bottled Water	20,607	163	3	473	11	911	22
Other Sources	20,607	128	2	296	7	947	18
Missing Sources[c]	20,607	16	0.3	0	0	0	0
All Sources	20,607	1,233	20	2,141	48	2,707	65

[a]Estimates are based on 2-day averages for non-consecutive days.
[b] "All Sources" may not be exactly the sum of the other sources in the table due to weighting factors applied to each individual in the survey.
[c] Missing sources are those sources of water that the survey respondent was unable to identify.

Source: U.S. EPA Analysis of CSFII 1994-96, 1998

Table 4-3. Estimated Direct and Indirect Water Ingestion, All Sources By Age Category for U.S. Children

Age (years)	Sample Size	Quantity, Percentiles (ml/person-day)													
		Mean	Min	1st	2nd	5th	10th	25th	50th	75th	90th	95th	98th	99th	Max
birth to <1 month	91	301	0	0	0	0	0	0	163	544	855	974	1076	1541	1541
1 to <3 months	253	368	0	0	0	0	0	0	268	696	891	1022	1177	1276	1941
3 to <6 months	428	528	0	0	0	0	0	89	550	812	1026	1303	1458	1516	2686
6 to <12 months	714	530	0	0	0	0	37	182	506	771	1032	1282	1523	1695	2034
1 to <2 years	1040	358	0	0	0	30	68	148	286	479	735	985	1188	1281	2008
2 to <3 years	1056	437	0	11	20	53	104	211	372	588	828	1008	1334	1681	2884
3 to <6 years	4391	514	0	4	22	67	126	251	439	682	980	1206	1535	1798	4081
6 to <11 years	1670	600	0	8	35	111	170	305	503	802	1132	1409	1704	2171	4281
11 to <16 years	1005	835	0	12	65	140	225	401	667	1100	1649	1962	2561	3194	6105
16 to <21 years	752	1027	0	0	6	104	207	403	770	1341	2014	2599	3860	4943	13358
		Quantity, Percentiles (ml/kg-day)													
birth to <1 month	91	88	0	0	0	0	0	0	19	171	236	269	332	485	485
1 to <3 months	253	75	0	0	0	0	0	0	42	134	172	247	298	375	534
3 to <6 months	428	72	0	0	0	0	0	7	70	117	149	187	214	224	288
6 to <12 months	714	56	0	0	0	0	0	15	50	84	117	145	171	195	254
1 to <2 years	1040	30	0	0	0	0	4	12	24	39	62	84	105	121	201
2 to <3 years	1056	30	0	0	0	0	4	13	25	40	59	72	94	129	173
3 to <6 years	4391	27	0	0	0	0	3	12	23	37	54	68	85	101	213
6 to <11 years	1670	20	0	0	0	0	3	9	17	26	38	48	63	75	110
11 to <16 years	1005	16	0	0	0	2	4	7	13	20	31	39	52	61	96
16 to <21 years	752	15	0	0	0	1	3	6	12	20	32	43	75	0	161

Source of Data: USDA Continuing Survey of Food Intakes by Individuals (CSFII), 1994-96, 1998

Table 4-4. Estimated Direct and Indirect Community Water Ingestion By Age Category for U.S. Children

Age (years)	Sample Size	Quantity, Percentiles (ml/person-day)													
		Mean [a]	Min	1st	2nd	5th	10th	25th	50th	75th	90th	95th	98th	99th	Max
birth to <1 month	91	297	0	0	0	0	0	0	0	353	709	856	859	957	957
1 to <3 months	253	359	0	0	0	0	0	0	0	459	815	918	1124	1177	1525
3 to <6 months	428	464	0	0	0	0	0	0	148	696	930	1056	1351	1443	2104
6 to <12 months	714	436	0	0	0	0	0	17	220	628	886	1056	1385	1523	2034
1 to <2 years	1040	303	0	0	0	0	0	60	188	404	632	842	1076	1216	2008
2 to <3 years	1056	351	0	0	0	0	0	79	246	480	684	879	1075	1393	2884
3 to <6 years	4391	409	0	0	0	0	4	98	291	548	834	1078	1387	1682	2963
6 to <11 years	1670	475	0	0	0	0	22	133	352	649	980	1237	1557	1974	2691
11 to <16 years	1005	656	0	0	0	0	31	182	473	829	1344	1619	2104	2589	6105
16 to <21 years	752	819	0	0	0	0	21	219	591	1049	1716	2299	3397	3883	13358
		Quantity, Percentiles (ml/kg-day)													
birth to <1 month	91	86	0	0	0	0	0	0	0	101	198	234	269	269	269
1 to <3 months	253	74	0	0	0	0	0	0	0	86	150	205	289	316	375
3 to <6 months	428	67	0	0	0	0	0	0	12	95	134	159	203	216	288
6 to <12 months	714	49	0	0	0	0	0	0	19	68	101	125	170	185	254
1 to <2 years	1040	26	0	0	0	0	0	4	16	34	52	70	96	107	177
2 to <3 years	1056	25	0	0	0	0	0	4	16	32	48	59	82	111	162
3 to <6 years	4391	24	0	0	0	0	0	4	15	30	46	60	79	93	213
6 to <11 years	1670	18	0	0	0	0	0	4	11	21	33	43	58	71	110
11 to <16 years	1005	13	0	0	0	0	0	3	9	16	25	33	42	54	96
16 to <21 years	752	12	0	0	0	0	0	3	9	16	25	33	45	63	161

Source of Data: USDA Continuing Survey of Food Intakes by Individuals (CSFII), 1994-96, 1998

[a] The mean values are for consumers only; while the percentiles referred to the whole population.

Table 4-5. Estimated Direct and Indirect Bottled Water Ingestion By Age Category for U.S. Children

Age (years)	Sample Size	Quantity, Percentiles (ml/person-day)													
		Mean [a]	Min	1st	2nd	5th	10th	25th	50t0h	75th	90th	95th	98th	99th	Max
birth to <1 month	91	278	0	0	0	0	0	0	0	30	460	576	993	1541	1541
1 to <3 months	253	331	0	0	0	0	0	0	0	0	579	790	896	1070	1941
3 to <6 months	428	415	0	0	0	0	0	0	0	0	585	774	1164	1458	1516
6 to <12 months	714	355	0	0	0	0	0	0	0	59	506	762	1051	1338	1736
1 to <2 years	1040	246	0	0	0	0	0	0	0	0	216	355	635	810	1834
2 to <3 years	1056	319	0	0	0	0	0	0	0	0	281	495	750	1006	2737
3 to <6 years	4391	361	0	0	0	0	0	0	0	0	325	532	828	1045	2917
6 to <11 years	1670	425	0	0	0	0	0	0	0	0	340	532	850	1079	3808
11 to <16 years	1005	542	0	0	0	0	0	0	0	0	384	710	1183	1431	3135
16 to <21 years	752	650	0	0	0	0	0	0	0	0	473	946	1710	2366	4880
		Quantity, Percentiles (ml/kg-day)													
birth to <1 month	91	85	0	0	0	0	0	0	0	9	134	268	317	485	485
1 to <3 months	253	66	0	0	0	0	0	0	0	0	95	164	175	295	534
3 to <6 months	428	59	0	0	0	0	0	0	0	0	74	114	150	197	220
6 to <12 months	714	38	0	0	0	0	0	0	0	2	50	86	112	140	225
1 to <2 years	1040	21	0	0	0	0	0	0	0	0	18	28	55	67	184
2 to <3 years	1056	23	0	0	0	0	0	0	0	0	17	36	55	83	140
3 to <6 years	4391	21	0	0	0	0	0	0	0	0	17	29	45	58	147
6 to <11 years	1670	15	0	0	0	0	0	0	0	0	9	17	28	38	94
11 to <16 years	1005	10	0	0	0	0	0	0	0	0	6	13	22	33	54
16 to <21 years	752	10	0	0	0	0	0	0	0	0	7	14	27	30	63

Source of Data: USDA Continuing Survey of Food Intakes by Individuals (CSFII), 1994-96, 1998

[a] The mean values are for consumers only; while the percentiles referred to the whole population.

Table 4-6 Estimated Direct and Indirect Other Water Ingestion By Age Category for U.S. Children

Age (years)	Sample Size	Quantity, Percentiles (ml/person-day)													
		Mean [a]	Min	1st	2nd	5th	10th	25th	50th	75th	90th	95th	98th	99th	Max
birth to <1 month	91	166	0	0	0	0	0	0	0	0	0	0	353	422	550
1 to <3 months	253	276	0	0	0	0	0	0	0	0	0	397	560	691	1183
3 to <6 months	428	431	0	0	0	0	0	0	0	0	0	386	740	941	2597
6 to <12 months	714	342	0	0	0	0	0	0	0	0	32	411	720	963	1478
1 to <2 years	1040	253	0	0	0	0	0	0	0	0	0	118	412	482	1495
2 to <3 years	1056	342	0	0	0	0	0	0	0	0	54	347	587	739	1652
3 to <6 years	4391	396	0	0	0	0	0	0	0	0	59	345	660	831	4052
6 to <11 years	1670	440	0	0	0	0	0	0	0	0	181	470	843	1049	2015
11 to <16 years	1005	640	0	0	0	0	0	0	0	0	346	794	1183	1726	3244
16 to <21 years	752	598	0	0	0	0	0	0	0	0	118	446	857	1658	2729
		Quantity, Percentiles (ml/kg-day)													
birth to <1 month	91	49	0	0	0	0	0	0	0	0	0	0	130	130	173
1 to <3 months	253	55	0	0	0	0	0	0	0	0	0	55	110	149	237
3 to <6 months	428	64	0	0	0	0	0	0	0	0	0	53	106	170	260
6 to <12 months	714	37	0	0	0	0	0	0	0	0	1	34	79	95	171
1 to <2 years	1040	22	0	0	0	0	0	0	0	0	0	10	30	45	150
2 to <3 years	1056	26	0	0	0	0	0	0	0	0	3	22	39	60	173
3 to <6 years	4391	22	0	0	0	0	0	0	0	0	1	17	35	47	133
6 to <11 years	1670	16	0	0	0	0	0	0	0	0	5	15	29	36	73
11 to <16 years	1005	12	0	0	0	0	0	0	0	0	6	14	25	35	65
16 to <21 years	752	9	0	0	0	0	0	0	0	0	1	7	14	27	46

Source of Data: USDA Continuing Survey of Food Intakes by Individuals (CSFII), 1994-96, 1998

[a] The mean values are for consumers only; while the percentiles referred to the whole population.

Table 4-7. Summary of Recommended Community Drinking Water Ingestion Rates [a]

Age Category	Mean		Percentiles[b]						Reference
			50th		90th		95th		
	mL/day	mL/kg-day	mL/day	mL/kg-day	mL/day	mL/kg-day	mL/day	mL/kg-day	
birth to <1 month	297	86	0	0	709	198	856	234	Table 4-4
1 to <3 months	359	74	0	0	815	150	918	205	Table 4-4
3 to <6 months	464	67	148	12	930	134	1056	159	Table 4-4
6 to <12 months	436	49	220	19	886	101	1056	125	Table 4-4
1 to <2 years	303	46	188	16	632	52	842	70	Table 4-4
2 to <3 years	351	25	246	16	684	48	879	59	Table 4-4
3 to <6 years	409	24	291	15	834	46	1078	60	Table 4-4
6 to <11 years	475	18	352	11	980	33	1237	43	Table 4-4
11 to <16 years	656	13	473	9	1344	25	1619	33	Table 4-4
16 to <21 years	819	12	591	9	1716	25	2299	33	Table 4-4

[a] Community water includes both direct and indirect water consumption (e.g., plain water, water used to prepare foods and beverages)
[b] Lower percentiles are shown in Table 4-4.

Table 4-8. Confidence in Water Ingestion Recommendations

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	The CSFII 1994-96, 1998 had thorough SAB expert panel review. , The EPA analysis of the CSFII data used to estimate the recommended values in this Handbook used the same methodology as was reviewed and approved by the SAB, but the particular values have not been peer reviewed.	Medium
• Accessibility	The source data are available from the sponsoring agency.	High
• Reproducibility	Methods are well-described.	High
• Focus on factor of interest	The studies are directly relevant to tapwater, and data of similar quality were provided for other water sources	High
• Data pertinent to U.S.	See "representativeness" below.	NA
• Primary data	The CSFII 1994-96, 1998 contains primary data on recall of ingestion.	High
• Currency	Data were collected between 1994 and 1998.	Medium
• Adequacy of data collection period	These are two-day average ingestion data. However, long term variability may be small. Their use as a chronic ingestion measure can be assumed.	Medium
• Validity of approach	The approach was competently executed.	High
• Study size	The CSFII 1994-96, 1998 had sufficient sample populations (i.e., 11,000) for the study.	High
• Representativeness of the population	The CSFII 1994-96, 1998 was validated as demographically representative of the U.S. population, but may not be representative of specific segments of the population that may be of interest.	Medium
• Characterization of variability	The full distributions were given in the main study.	High
• Lack of bias in study design (high rating is desirable)	Bias was not apparent.	High
• Measurement error	No physical measurements were taken. The method relied on recent recall of standardized volumes of drinking water containers, and was not validated.	Medium
Other Elements		
• Number of studies	There was one key study for the recommendations.	High
• Agreement between researchers	N/A	Low
Overall Rating	The data are excellent and acceptably current. However, may not be representative of specific segments of the population.	**High**