6. POTENTIAL FOR HUMAN EXPOSURE

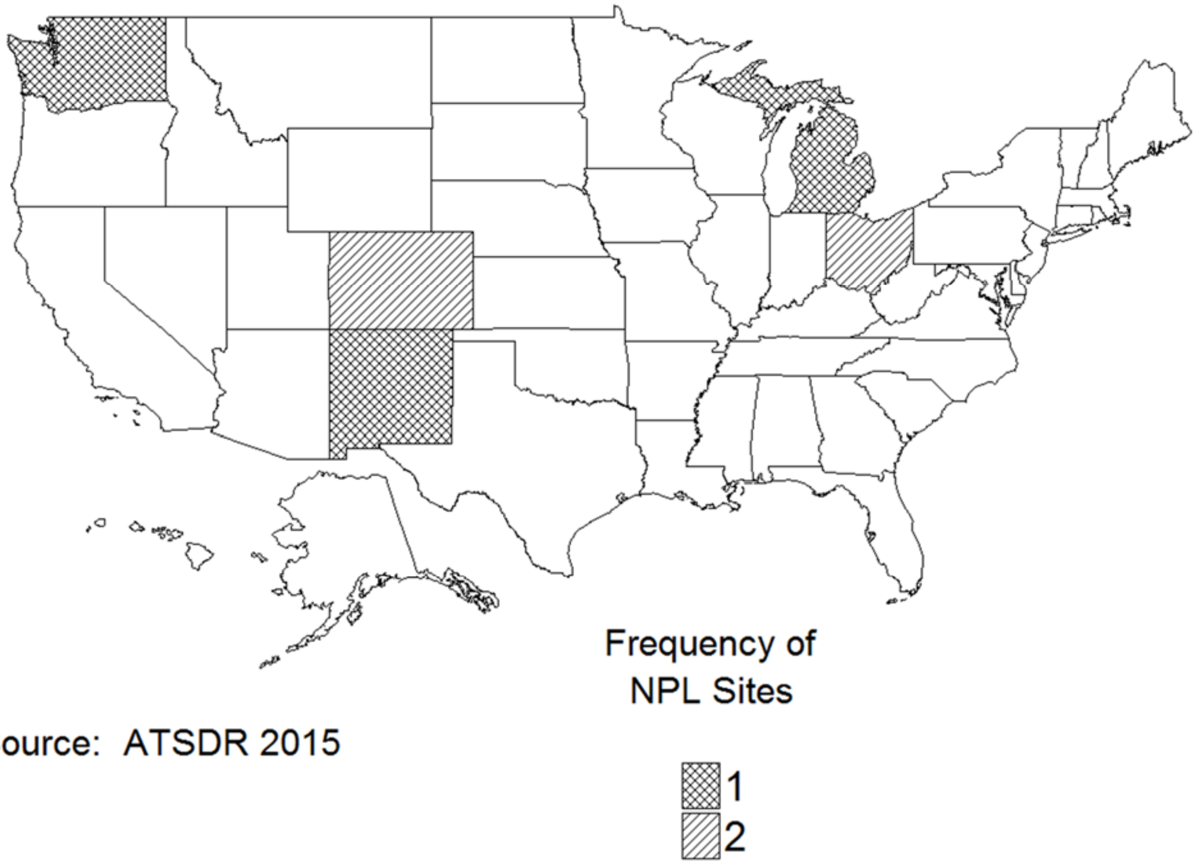
6.1 OVERVIEW

Nitrate and nitrite are ubiquitous in the environment. Specific salts have occasionally been identified in hazardous waste sites. Ammonium nitrate, sodium nitrate, and sodium nitrite were identified in 7, 3, and 2, of the 1,832 hazardous waste sites, respectively that have been proposed for inclusion on the EPA National Priorities List (NPL) (ATSDR 2015). However, the number of sites evaluated for these substances is not known. The frequency of these sites can be seen in Figures 6-1, 6-2, and 6-3.

Nitrate may enter the environment via natural and anthropogenic sources. Nitrate and nitrite occur naturally in the environments as a part of the earth's nitrogen cycle. A major source of anthropogenic nitrate and nitrite is artificial fertilizers, and various industrial processes also produce nitrate in their waste streams (Environment Canada 2012; WHO 1978). Inorganic fertilizer and nitrification of animal waste are the principal sources of nitrate in the environment (Environment Canada 2012; Nolan et al. 1997). However, contributions from human waste must be taken into account as well. Point and non-point anthropogenic sources that contribute include industrial waste water, mining (explosives) waste water, agricultural and urban runoff, feedlot discharges, septic system and landfill leachate, lawn fertilizers, storm sewer overflow, and nitric oxide and nitrogen dioxide from vehicle exhaust (Environment Canada 2012). Additionally, organic forms of nitrogen in the environment from various sources may undergo ammonification to form inorganic ammonia and ammonium, and nitrification to form nitrate, and have the potential to be released into surface waters (Environment Canada 2012). Inorganic nitrate and nitrite in soil and water can be taken up by plants used for human consumption (ATSDR 2013a).

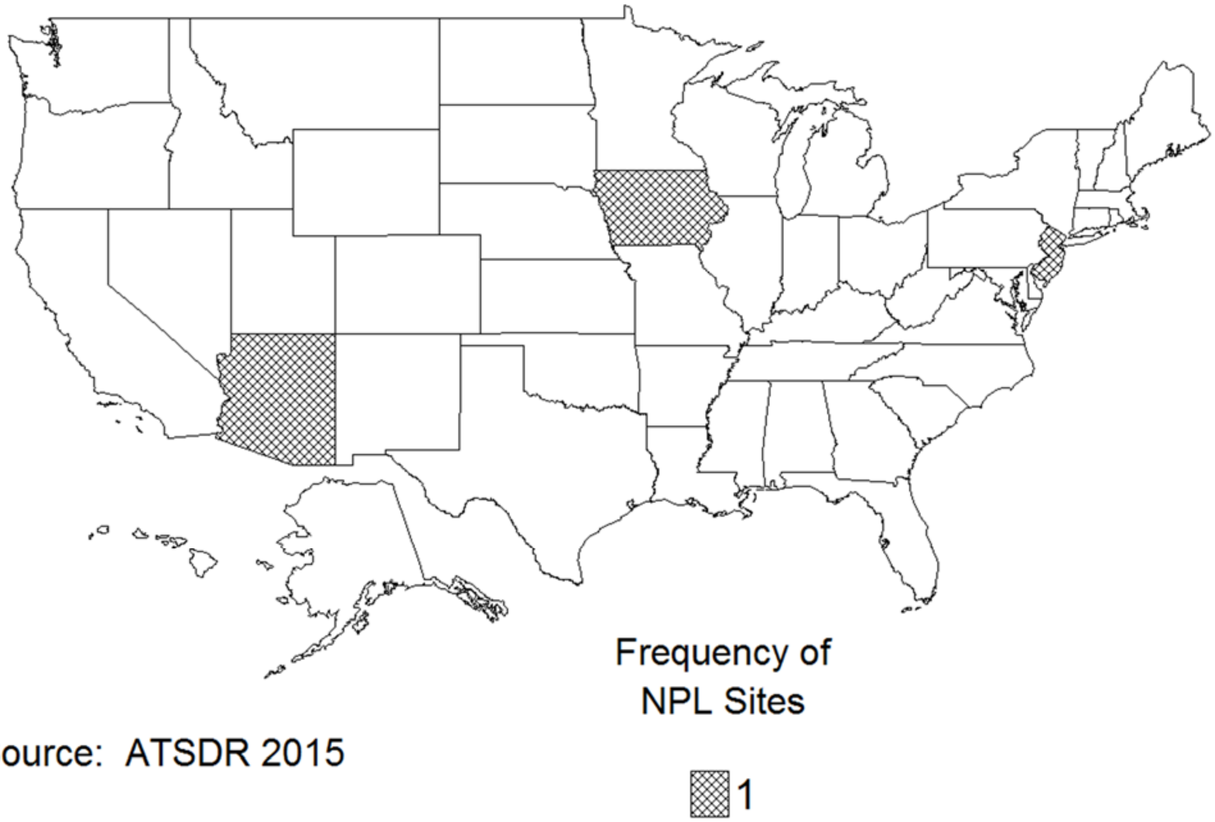
Exposure from drinking water of private wells is a source of concern as elevated concentrations have been reported in some wells, yet these water sources are not routinely tested, monitored, or regulated since they are not covered by the Safe Drinking Water Act (SDWA). About 15% of Americans use private wells as a source of drinking water and an important percentage of them may have a septic system serving their homes. Additionally, nitrate and nitrite exposure can occur from the ingestion of foods containing high levels of these chemicals (ATSDR 2013a).

Figure 6-1. Frequency of NPL Sites with Ammonium Nitrate Contamination



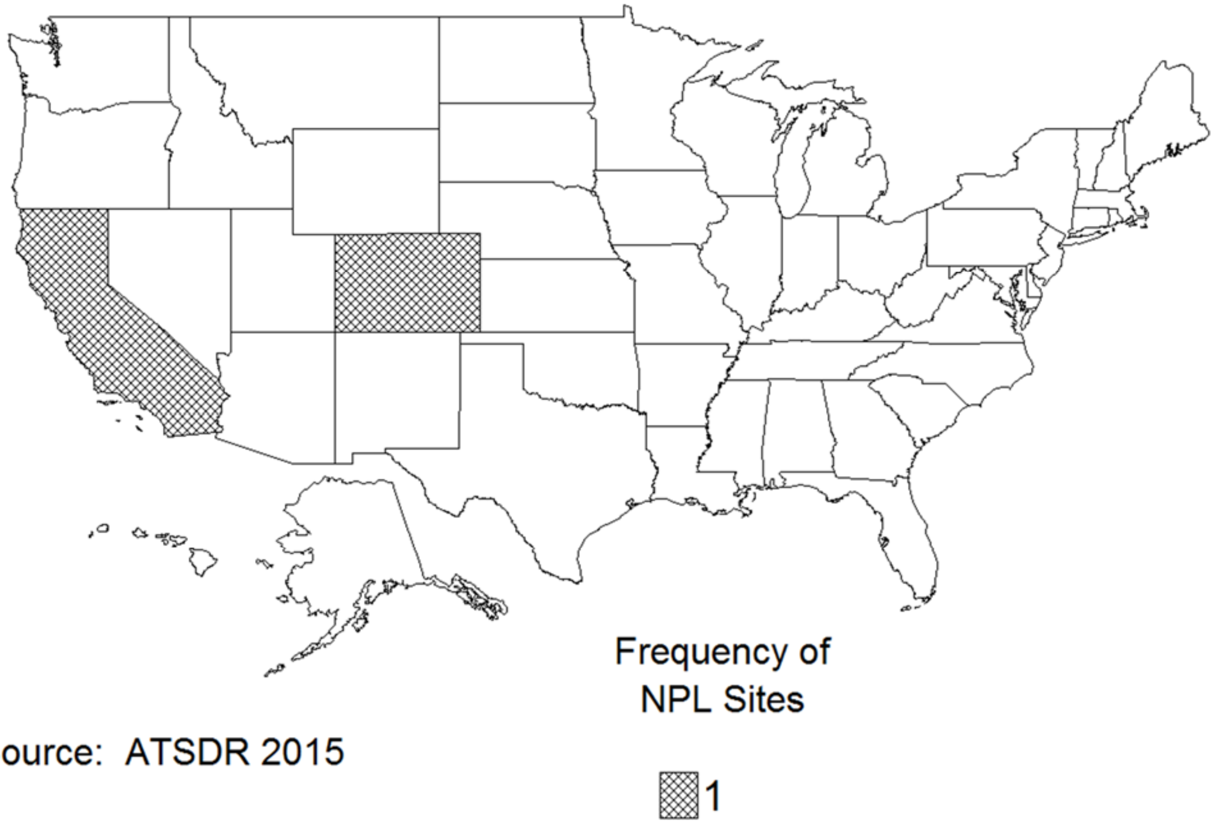
Source: ATSDR 2015

Figure 6-2. Frequency of NPL Sites with Sodium Nitrate Contamination



Source: ATSDR 2015

Figure 6-3. Frequency of NPL Sites with Sodium Nitrite Contamination



Source: ATSDR 2015

6.2 RELEASES TO THE ENVIRONMENT

The Toxics Release Inventory (TRI) data should be used with caution because only certain types of facilities are required to report (EPA 2005). This is not an exhaustive list. Manufacturing and processing facilities are required to report information to the TRI only if they employ 10 or more full-time employees; if their facility is included in Standard Industrial Classification (SIC) Codes 10 (except 1011, 1081, and 1094), 12 (except 1241), 20–39, 4911 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4931 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4939 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4953 (limited to facilities regulated under RCRA Subtitle C, 42 U.S.C. section 6921 et seq.), 5169, 5171, and 7389 (limited S.C. section 6921 et seq.), 5169, 5171, and 7389 (limited to facilities primarily engaged in solvents recovery services on a contract or fee basis); and if their facility produces, imports, or processes ≥25,000 pounds of any TRI chemical or otherwise uses >10,000 pounds of a TRI chemical in a calendar year (EPA 2005).

Nitrate is released into the environment through both natural and anthropogenic sources. Naturally occurring nitrate and nitrite are part of the earth's nitrogen cycle. Anthropogenic sources, including animal and human organic wastes as well as nitrogen-containing fertilizers, increase the concentrations of nitrate in the environment. Nitrate and nitrite are present in the environment, in soils and water, and to a lesser extent, in air, plant materials, and meat products. Concentrations of nitrite in plants and water are low relative to nitrate concentration due to the fact that nitrite is easily oxidized to nitrate (WHO 1978).

Nitrate is the ion detected in the majority of groundwater and surface water samples because the nitrite ion is easily oxidized to nitrate in the environment; the nitrate ion is stable and is chemically unreactive under most environmental conditions (IARC 2010; WHO 2011b).

6.2.1 Air

Estimated releases of 301,654 pounds (~137 metric tons) of nitrate compounds to the atmosphere from 2,110 domestic manufacturing and processing facilities in 2013, accounted for about 0.1% of the estimated total environmental releases from facilities required to report to the TRI (TRI13 2014). These releases are summarized in Table 6-1. Estimated releases of 65,201 (~30 metric tons) pounds of sodium nitrite were released to the atmosphere from 363 domestic manufacturing and

Table 6-1. Releases to the Environment from Facilities that Produce, Process, or Use Nitrate Compounds[a]

		Reported amounts released in pounds per year[b]							
							Total release		
State[c]	RF[d]	Air[e]	Water[f]	UI[g]	Land[h]	Other[i]	On-site[j]	Off-site[k]	On- and off-site
AK	2	0	310,000	0	1,730,003	0	2,040,003	No data	2,040,003
AL	56	5	10,970,520	5,000	589,240	1,003	11,012,324	553,444	11,565,768
AR	26	0	3,776,021	0	14,399	4,217	3,790,167	4,470	3,794,637
AZ	32	3,295	0	0	39,894	78	43,189	78	43,267
CA	139	7,172	1,967,150	20,684	956,477	65,682	2,831,868	185,297	3,017,165
CO	39	1	1,850,266	0	54,944	50	1,904,854	407	1,905,261
CT	26	58,098	202,953	0	698	54,000	261,051	54,698	315,749
DC	4	0	0	0	0	0	0	No data	0
DE	6	0	2,850,359	0	0	0	2,850,359	No data	2,850,359
FL	36	479	850,888	23,373,722	264,705	0	24,261,115	228,680	24,489,794
GA	57	511	12,284,962	0	352,756	196,086	12,573,225	261,090	12,834,315
GU	1	0	181,244	0	196	0	181,440	No data	181,440
HI	7	0	439,915	0	0	0	439,915	No data	439,915
IA	46	23,005	6,737,465	0	133,387	28	6,886,605	7,280	6,893,885
ID	25	53	2,462,856	0	1,590,643	0	4,021,989	31,564	4,053,553
IL	108	28,202	6,428,670	14,007	454,232	2,346	6,875,892	51,565	6,927,456
IN	62	439	19,965,218	0	3,287,114	12,527	19,965,662	3,299,636	23,265,298
KS	27	38,262	108,068	340,905	98,569	21	585,186	639	585,825
KY	44	990	5,031,265	0	313,935	532	5,305,617	41,104	5,346,721
LA	48	4,502	10,169,890	1,576,528	55,015	0	11,753,676	52,259	11,805,934
MA	42	10	115	25,928	27,091	217,377	145	270,376	270,520
MD	21	0	739,290	0	84,199	35	739,687	83,837	823,524
ME	12	1,209	2,854,965	0	63	0	2,856,209	28	2,856,237
MI	103	10,021	1,714,827	0	228,050	33,121	1,732,091	253,928	1,986,019
MN	53	1,076	1,471,856	0	78,276	250	1,536,094	15,364	1,551,458
MO	37	2,852	1,752,877	0	241,834	5,100	1,977,139	25,524	2,002,663
MS	28	372	6,495,644	0	329	0	6,496,345	No data	6,496,345
MT	10	0	234,169	0	43,891	0	272,860	5,200	278,060
NC	41	1	6,563,023	0	236,361	236,692	6,793,505	242,572	7,036,077
ND	10	0	113,400	0	15,640	0	129,040	No data	129,040
NE	25	187	11,785,649	0	243,650	40	12,022,108	7,418	12,029,526
NH	7	125	0	0	0	39	125	39	164
NJ	40	0	5,313,118	0	41,966	376	5,354,858	602	5,355,460
NM	14	55,000	42,240	0	662,620	0	406,331	353,529	759,860
NV	27	6	2,800	0	3,947,279	2	3,729,262	220,825	3,950,087
NY	73	5,337	5,797,905	0	437,314	28,473	5,804,333	464,696	6,269,029
OH	111	1,987	6,081,057	134,614	182,994	64,665	6,219,720	245,598	6,465,318
OK	37	13,010	4,246,811	534,620	180,969	0	4,970,061	5,349	4,975,410
OR	40	1,000	542,093	0	6,833	0	545,071	4,855	549,926

Table 6-1. Releases to the Environment from Facilities that Produce, Process, or Use Nitrate Compounds[a]

		Reported amounts released in pounds per year[b]							
							Total release		
State[c]	RF[d]	Air[e]	Water[f]	UI[g]	Land[h]	Other[i]	On-site[j]	Off-site[k]	On- and off-site
PA	67	9,139	7,212,765	0	66,541	2,428	7,224,885	65,988	7,290,874
PR	7	0	0	1,465	120	34	1,465	154	1,619
RI	6	0	121	0	0	20,098	121	20,098	20,219
SC	43	3,001	2,346,088	0	178,745	458	2,376,696	151,596	2,528,293
SD	8	0	2,995,074	2,000	338,782	6	3,280,324	55,538	3,335,862
TN	45	270	2,748,175	470,956	125,258	1,678	2,772,445	573,892	3,346,337
TX	131	788	14,234,564	7,762,004	876,395	7,165	21,822,716	1,058,200	22,880,916
UT	37	329	97,000	0	1,282,016	29	714,559	664,815	1,379,374
VA	42	3,558	10,978,189	0	4,587	1	10,981,823	4,511	10,986,334
VT	6	0	124,890	0	57,395	0	124,890	57,395	182,285
WA	46	8,770	1,190,505	0	981,730	0	1,631,774	549,231	2,181,004
WI	127	591	2,162,376	0	2,339,390	31,174	3,734,315	799,216	4,533,531
WV	18	18,000	2,140,714	0	2,138	0	2,160,673	179	2,160,852
WY	5	0	633	6,569,900	249	0	6,570,782	No data	6,570,782
Total	2,110	301,654	188,570,641	40,832,332	22,848,913	985,811	242,566,590	10,972,761	253,539,351

[a] The TRI data should be used with caution since only certain types of facilities are required to report. This is not an exhaustive list. Data are rounded to nearest whole number.
[b] Data in TRI are maximum amounts released by each facility.
[c] Post office state abbreviations are used.
[d] Number of reporting facilities.
[e] The sum of fugitive and point source releases are included in releases to air by a given facility.
[f] Surface water discharges, waste water treatment-(metals only), and publicly owned treatment works (POTWs) (metal and metal compounds).
[g] Class I wells, Class II-V wells, and underground injection.
[h] Resource Conservation and Recovery Act (RCRA) subtitle C landfills; other onsite landfills, land treatment, surface impoundments, other land disposal, other landfills.
[i] Storage only, solidification/stabilization (metals only), other off-site management, transfers to waste broker for disposal, unknown
[j] The sum of all releases of the chemical to air, land, water, and underground injection wells.
[k] Total amount of chemical transferred off-site, including to POTWs.

RF = reporting facilities; UI = underground injection

Source: TRI13 2014 (Data are from 2013)

processing facilities in 2013, accounted for about 0.8% of the estimated total environmental releases from facilities required to report to the TRI (TRI13 2014). These releases are summarized in Table 6-2. Estimated releases of 125,680,001 pounds (~57,007 metric tons) of ammonia were released to the atmosphere from 2,292 domestic manufacturing and processing facilities in 2013, accounted for about 77% of the estimated total environmental releases from facilities required to report to the TRI (TRI13 2014). These releases are summarized in Table 6-3.

6.2.2 Water

Estimated releases of 188,570,641 pounds (~85,534 metric tons) of nitrate compounds to surface water from 2,110 domestic manufacturing and processing facilities in 2013, accounted for about 74% of the estimated total environmental releases from facilities required to report to the TRI (TRI13 2014). These releases are summarized in Table 6-1. Estimated releases of 2,472,668 pounds (~1,122 metric tons) of sodium nitrite compounds to surface water from 363 domestic manufacturing and processing facilities in 2013, accounted for about 30% of the estimated total environmental releases from facilities required to report to the TRI (TRI13 2014). These releases are summarized in Table 6-2. Estimated releases of 4,221,440 pounds (~1,914 metric tons) of ammonia to surface water from 2,292 domestic manufacturing and processing facilities in 2013, accounted for about 2.6% of the estimated total environmental releases from facilities required to report to the TRI (TRI13 2014). These releases are summarized in Table 6-3.

EPA (2009d) reported that the Mississippi River drains >40% of the area of the contiguous 48 states and carries roughly 15 times more nitrate than any other river in the country. EPA (2009d) noted that the nitrate load in the Mississippi rose from 200,000 to 500,000 tons per year in the 1950s and 1960s to an average of approximately 1,000,000 tons per year during the 1980s and 1990s; the data indicate that the nitrate load decreased slightly in the early 2000s.

Nitrate is commonly detected in various surface waters and groundwaters such as shallow, rural domestic wells. Contamination of water systems is a consequence of inorganic fertilizer use, animal manures, septic systems, and waste water treatment (ATSDR 2013a; Nolan 1999; WHO 2011b). Ammonium ions in sludge from waste water treatment plants, as well as effluents from those plants and septic systems, are rapidly converted to nitrate (WHO 1978). Various industrial process produce nitrate in their waste streams. For example, potassium nitrate, calcium nitrate,

Table 6-2. Releases to the Environment from Facilities that Produce, Process, or Use Sodium Nitrite[a]

		Reported amounts released in pounds per year[b]							
							Total release		
State[c]	RF[d]	Air[e]	Water[f]	UI[g]	Land[h]	Other[i]	On-site[j]	Off-site[k]	On- and off-site
AL	7	0	0	0	360	0	0	360	360
AR	7	0	254	0	0	0	254	No data	254
AZ	3	0	0	0	9,117	0	9,117	No data	9,117
CA	11	7	0	0	5	0	7	5	12
CO	2	255	0	0	0	0	255	No data	255
FL	1	0	0	0	0	0	0	No data	0
GA	11	98	648,256	0	101,148	68	749,502	68	749,570
IA	3	0	2,517	0	0	0	2,517	No data	2,517
ID	1	0	0	0	0	0	0	No data	0
IL	32	1,637	18,600	0	90,065	15	20,237	90,080	110,317
IN	20	1	1,130,853	0	3,312,017	4,896	1,130,854	3,316,913	4,447,767
KS	2	0	0	0	0	0	0	No data	0
KY	10	1,016	0	0	41,435	36,320	27,291	51,480	78,771
LA	9	0	48,000	1,500,000	107	0	1,548,000	107	1,548,107
MA	5	0	0	0	0	0	0	No data	0
MD	1	16	0	0	0	103	16	103	119
MI	42	12,992	4	0	181,207	2,490	18,745	177,948	196,693
MN	6	0	194,173	0	0	0	194,173	No data	194,173
MO	13	2,871	0	0	412	3,685	2,871	4,097	6,968
MS	6	8,489	7,895	0	26,296	3	16,384	26,299	42,683
NC	4	0	4,455	0	0	0	4,455	No data	4,455
NE	4	0	21,200	0	1,182	1,637	21,467	2,552	24,019
NJ	9	200	68,032	0	2,898	0	68,290	2,840	71,130
NM	1	0	0	0	0	0	0	No data	0
NV	1	2	0	0	33,641	0	33,642	No data	33,642
NY	8	11,807	4,925	0	2,800	220	16,732	3,020	19,752
OH	35	13,067	731	0	77,303	1,134	13,798	78,437	92,235
OK	3	289	9,010	0	17,405	0	9,299	17,405	26,704
OR	2	0	0	0	430	0	0	430	430
PA	15	250	0	0	7	0	250	7	257
RI	1	0	0	0	0	0	0	No data	0
SC	19	1,530	69,403	0	787	190	70,933	977	71,910
SD	3	6	121	25	5,500	0	5,652	0	5,652
TN	5	239	0	0	153	0	239	153	392
TX	38	34	199,659	198,969	54,487	0	449,818	3,331	453,149
UT	1	No data	No data	No data	No data	No data	No data	No data	No data
VA	4	0	0	0	40	0	0	40	40
WA	1	No data	No data	No data	No data	No data	No data	No data	No data

Table 6-2. Releases to the Environment from Facilities that Produce, Process, or Use Sodium Nitrite[a]

		Reported amounts released in pounds per year[b]					Total release		
State[c]	RF[d]	Air[e]	Water[f]	UI[g]	Land[h]	Other[i]	On-site[j]	Off-site[k]	On- and off-site
WI	13	10,231	28	0	69,018	0	10,259	69,018	79,277
WV	4	165	44,552	0	3	0	44,717	3	44,720
Total	363	65,201	2,472,668	1,698,994	4,027,823	50,760	4,469,774	3,845,673	8,315,446

[a] The TRI data should be used with caution since only certain types of facilities are required to report. This is not an exhaustive list. Data are rounded to nearest whole number.
[b] Data in TRI are maximum amounts released by each facility.
[c] Post office state abbreviations are used.
[d] Number of reporting facilities.
[e] The sum of fugitive and point source releases are included in releases to air by a given facility.
[f] Surface water discharges, waste water treatment-(metals only), and publicly owned treatment works (POTWs) (metal and metal compounds).
[g] Class I wells, Class II-V wells, and underground injection.
[h] Resource Conservation and Recovery Act (RCRA) subtitle C landfills; other onsite landfills, land treatment, surface impoundments, other land disposal, other landfills.
[i] Storage only, solidification/stabilization (metals only), other off-site management, transfers to waste broker for disposal, unknown
[j] The sum of all releases of the chemical to air, land, water, and underground injection wells.
[k] Total amount of chemical transferred off-site, including to POTWs.

RF = reporting facilities; UI = underground injection

Source: TRI13 2014 (Data are from 2013)

Table 6-3. Releases to the Environment from Facilities that Produce, Process, or Use Ammonia[a]

		Reported amounts released in pounds per year[b]							
							Total release		
State[c]	RF[d]	Air[e]	Water[f]	UI[g]	Land[h]	Other[i]	On-site[j]	Off-site[k]	On- and off-site
AK	6	23,099	7,012	136	24,075	0	54,323	No data	54,323
AL	70	4,060,001	209,278	9,343	43,646	294	4,287,915	34,647	4,322,563
AR	47	1,837,750	114,277	0	5,499	511	1,956,076	1,961	1,958,037
AS	1	20	0	0	0	0	20	No data	20
AZ	20	336,273	0	0	722	0	336,989	6	336,995
CA	118	2,801,456	26,830	2,870	165,409	369	2,978,123	18,811	2,996,934
CO	19	269,063	17,833	0	101,218	2,430	385,942	4,602	390,544
CT	15	74,775	155	0	0	0	74,930	No data	74,930
DC	2	165	0	0	0	0	165	No data	165
DE	7	58,659	6,071	0	23	0	64,730	23	64,753
FL	63	5,607,959	244,014	464,183	960,078	0	6,343,579	932,655	7,276,234
GA	81	12,615,696	268,976	0	166,494	153	12,967,436	83,883	13,051,319
HI	9	100,496	1,000	1,200	0	0	102,696	No data	102,696
IA	79	7,333,058	108,999	0	210,562	6,621	7,545,358	113,882	7,659,240
ID	19	2,844,444	27,824	0	167,548	0	3,023,068	16,749	3,039,817
IL	112	3,081,028	110,035	0	69,293	4,620	3,246,667	18,309	3,264,976
IN	64	1,600,854	45,833	707,485	77,195	0	2,423,117	8,250	2,431,367
KS	37	3,056,601	6,490	38,214	49,185	15,483	3,130,592	35,381	3,165,972
KY	47	971,022	55,064	0	48,663	1,845	1,036,520	40,073	1,076,593
LA	72	13,461,749	585,745	4,582,747	326,520	0	18,630,317	326,444	18,956,761
MA	30	178,727	41	0	1,622	0	178,768	1,622	180,390
MD	16	523,890	48,675	0	2	0	572,565	2	572,567
ME	10	753,203	89,718	0	0	0	842,921	No data	842,921
MI	70	1,681,959	36,582	9,790	7,181	7,875	1,731,377	12,010	1,743,387
MN	61	1,870,843	49,112	0	35,092	2,270	1,938,690	18,627	1,957,317
MO	46	422,032	228,193	0	44,490	251	654,800	40,166	694,966
MS	34	4,700,259	188,194	0	2,181	0	4,889,803	830	4,890,633
MT	10	449,711	5,420	0	264,118	0	719,205	44	719,249
NC	86	2,661,108	85,427	0	73,410	110	2,781,752	38,302	2,820,054
ND	13	16,199,585	4,476	11,500	474,130	0	16,689,625	66	16,689,691
NE	44	974,508	26,655	0	162,935	4,643	1,021,771	146,970	1,168,741
NH	9	127,211	447	0	0	2	127,658	2	127,660
NJ	43	527,774	9,790	0	24,984	74	537,605	25,017	562,622
NM	6	98,819	0	2,300	11,561	0	112,680	No data	112,680
NV	12	132,670	560	0	228,759	1	361,989	1	361,990
NY	50	687,039	50,197	0	974	274	737,570	915	738,485
OH	115	6,430,630	100,258	1,715,361	76,575	2,560	8,244,156	81,229	8,325,384
OK	24	5,433,575	18,832	696,880	137,282	0	6,282,692	3,877	6,286,569
OR	31	1,156,034	35,599	0	9,980	0	1,192,997	8,616	1,201,613

Table 6-3. Releases to the Environment from Facilities that Produce, Process, or Use Ammonia[a]

		Reported amounts released in pounds per year[b]							
							Total release		
State[c]	RF[d]	Air[e]	Water[f]	UI[g]	Land[h]	Other[i]	On-site[j]	Off-site[k]	On- and off-site
PA	95	1,739,875	77,649	59	710,403	4,905	1,829,424	703,467	2,532,891
PR	10	366,211	0	0	1,499	0	366,211	1,499	367,710
RI	10	7,130	0	0	0	2,500	7,130	2,500	9,630
SC	54	3,581,123	163,436	0	15,085	60,935	3,747,126	73,453	3,820,579
SD	10	102,302	1,809	1	21,448	0	104,819	20,741	125,560
TN	70	2,512,358	418,374	0	90,697	0	2,932,376	89,053	3,021,430
TX	209	4,853,142	297,133	17,187,730	397,858	468	21,789,218	947,114	22,736,332
UT	27	520,482	1,484	8	1,162,922	120	1,684,865	151	1,685,016
VA	49	4,358,663	105,431	0	30,198	32,318	4,471,823	54,787	4,526,610
VT	2	4,543	5,357	0	76	0	9,900	76	9,976
WA	29	878,866	55,744	0	100,110	3,880	940,195	98,405	1,038,600
WI	81	593,142	45,129	15,241	14,091	0	640,527	27,076	667,603
WV	34	332,238	227,614	137,238	47,192	13	602,602	141,693	744,294
WY	14	686,181	8,666	297,557	2,791	0	995,195	No data	995,195
Total	2,292	125,680,001	4,221,440	25,879,844	6,565,774	155,524	158,328,597	4,173,986	162,502,583

[a] The TRI data should be used with caution since only certain types of facilities are required to report. This is not an exhaustive list. Data are rounded to nearest whole number.
[b] Data in TRI are maximum amounts released by each facility.
[c] Post office state abbreviations are used.
[d] Number of reporting facilities.
[e] The sum of fugitive and point source releases are included in releases to air by a given facility.
[f] Surface water discharges, waste water treatment-(metals only), and publicly owned treatment works (POTWs) (metal and metal compounds).
[g] Class I wells, Class II-V wells, and underground injection.
[h] Resource Conservation and Recovery Act (RCRA) subtitle C landfills; other onsite landfills, land treatment, surface impoundments, other land disposal, other landfills.
[i] Storage only, solidification/stabilization (metals only), other off-site management, transfers to waste broker for disposal, unknown
[j] The sum of all releases of the chemical to air, land, water, and underground injection wells.
[k] Total amount of chemical transferred off-site, including to POTWs.

RF = reporting facilities; UI = underground injection

Source: TRI13 2014 (Data are from 2013)

silver nitrate, and sodium nitrate used in several industrial applications have waste waters with high-nitrate concentrations (Environment Canada 2012). Discharges of these waste streams increase the concentrations of nitrate and nitrite in surface waters. Treatment of these waste streams may only remove a portion of nitrogen. Factors such as nitrogen loading, population density, soil drainage characteristics, and woodland to cropland ratios, affect the transport of nitrogen from land to water (Nolan et al. 1997; Zhang et al. 1998). Increased levels of nitrite in drinking water may also be a consequence of contamination by boiler fluid additives (ATSDR 2013a). High risk waters for nitrate contamination include areas having soils with high permeability, high-nitrogen input, and low woodland to cropland ratios (Nolan et al. 1997; Zhang et al. 1998).

Natural sources of nitrate and nitrite include wet and dry deposition of atmospheric nitric acid and nitrate ion. These are formed in the atmosphere as a result of nitrogen cycling. Atmospheric deposition is a factor for nitrate concentrations in water systems (Momen et al. 1999). Atmospheric nitrogen (NO_3^-, NO_2^-, and NH_4^+), mainly from natural sources but a result of anthropogenic sources as well, have been estimated to contribute 182 kilotons of inorganic nitrogen per year to Canadian surface waters via wet and dry deposition (Environment Canada 2012). In the United States, deposition contributes an estimated 3.2 million tons (3,200 kilotons) of nitrogen per year to watersheds (Momen et al. 1999; Nolan 1999; Nolan et al. 1997). Owens et al. (1994) reported that nitrogen input to a grass pasture from precipitation was equivalent to 10% of the nitrogen fertilizer applied during a 5-year period. The concentration of nitrate-nitrogen in the precipitation during 1975–1980 was reported as 1.1 mg/L (ppm), which correlated to an input of 12.0 kg nitrate-nitrogen/hectare. A 10-year average was also evaluated for the years 1980–1990, which resulted in an input of 8.9 kg nitrate-nitrogen/hectare (Owens et al. 1994).

Stagnation of nitrate-containing and oxygen-poor drinking water in galvanized steel pipes and chlorination disinfectant residues can lead to conditions where nitrite is formed via chemical reactions in the distribution pipes by *Nitrosomonas* bacteria (WHO 2011b).

A U.S. Geological Survey (USGS) study across the United States showed that 7% of 2,388 domestic wells and about 3% of 384 public-supply wells were contaminated with nitrate levels above the EPA drinking water standard of 10 mg/L (10 ppm) (ATSDR 2013a). Between 1994 and 1996, 24 lakes in the Adirondack Park, United States, were studied to assess the contribution of in-lake processes, atmospheric deposition, and watershed cover on the lakes' nitrate concentrations (Momen et al. 1999). Weighted means for nitrate concentrations as a result of precipitation near the lakes were reported for all seasons during the study period and ranged from 13.86 to 35.52 μeq/L. Nitrogen concentrations throughout the study period ranged from 2.1 to 22 μmol/L. Both atmospheric deposition and average lake depth were considered strong factors in concentrations of nitrate in lakes. It was concluded that the average lake depth was the most important factor; greater average depths correlated to higher nitrate concentrations. This was attributed to decreased contact time with lake sediment, decreasing the potential for removal processes (Momen et al. 1999).

Concentrations of nitrate in freshwater downstream from an open-pit coal mining operation have been reported to exceed 44 mg nitrate/L (Nordin and Pommen 1986). This is attributed to high nitrate levels in waste streams due to explosive residues. Monitoring studies conducted by the USGS indicate that nitrate and nitrite levels are several times greater in streams and groundwater in areas classified as agricultural use rather than as urban use, mixed use, or undeveloped land (USGS 2010a, 2010b).

Policies implemented by the European Union (EU) to reduce nitrogen emissions from agricultural point sources were reviewed by Velthof et al. (2014). The Nitrates Directive (ND) was implemented to protect water quality across Europe by inhibiting nitrates released by agricultural sources from leaching into groundwater and surface waters through the use of good farming practices. Although regional differences in emissions were large throughout the entire EU, nitrate leaching into groundwater and surface waters was estimated to decrease by 16% in nitrate leaching vulnerable zones over the period of 2000–2008, primarily as a result of lower nitrogen emissions from fertilizers and manures (Velthof et al. 2014).

Seawater nitrate concentrations that occur naturally due to nitrification processes can be as high as 2.4 mg nitrate/L (Environment Canada 2012). Assimilation into biological systems can deplete nitrate concentrations in marine environments, causing seasonal variations in nitrate concentrations. Winter concentrations off the Canadian Atlantic coast were reported to be 0.54 mg nitrate/L, a magnitude higher than summer concentrations of <0.03 mg nitrate/L (Environment Canada 2012).

6.2.3 Soil

Estimated releases of 22,848,913 pounds (~10,364 metric tons) of nitrate compounds to soils from 2,110 domestic manufacturing and processing facilities in 2013, accounted for about 9% of the estimated total environmental releases from facilities required to report to the TRI (TRI13 2014). An additional 40,832,332 pounds (~18,521 metric tons), constituting about 16% of the total environmental emissions, were released via underground injection (TRI13 2014). These releases are summarized in Table 6-1. An estimated release of 4,027,823 pounds (~1,826 metric tons) of sodium nitrite were emitted to soils from

363 domestic manufacturing and processing facilities in 2013, accounted for about 48% of the estimated total environmental releases from facilities required to report to the TRI (TRI13 2014). An additional 1,698,994 pounds (~771 metric tons), constituting about 20% of the total environmental emissions, were released via underground injection (TRI13 2014). These releases are summarized in Table 6-2. An estimated release of 6,565,774 pounds (~2,978 metric tons) of ammonia were emitted to soils from 2,292 domestic manufacturing and processing facilities in 2013, accounted for about 4% of the estimated total environmental releases from facilities required to report to the TRI (TRI13 2014). An additional 25,879,844 pounds (~11,739 metric tons), constituting about 16% of the total environmental emissions, were released via underground injection (TRI13 2014). These releases are summarized in Table 6-3.

In 2012, 13.5 million tons of nitrogen was added to soils as fertilizer (TFI 2014). Therefore, it should be noted that the totals provided here, for nitrate compounds, ammonia, and ammonium nitrite alone, may be insignificant, yet contribute to and are representative of, nitrogen releases to the environment.

6.3 ENVIRONMENTAL FATE

Nitrate and nitrite occur naturally in water and soils as part of the nitrogen cycle. Plants and mammals naturally contain nitrate and nitrite (WHO 2011b). Nitrate is the primary source of nitrogen for plants (EPA 2009a). Assimilation of nitrite from soils occurs via reduction of nitrate to nitrite, which is facilitated by various bacteria and catalyzed via nitrate reductase (WHO 1978). The most common forms of nitrogen that plants assimilate include ammonium (NH_4^+), nitrate (NO_3^-), and urea ($(NH_2)2CO$) (Cornell University 2009). Transport, partitioning, and transformation are controlled by various physicochemical properties, degradation, and other loss processes. Mammals endogenously produce nitrate and excrete them in their waste products (WHO 1978). Anthropogenic and natural sources of ammonia in the environment, such as fertilizers or animal waste products, are converted to nitrite via *Nitrosomonas* bacteria and then to nitrate via *Nitrobactor* bacteria. These products may be assimilated into plants and subsequently the atmosphere, or may leach into groundwater when they are present in excessive amounts (WHO 2011b).

Nitrate is the most oxidized form of nitrogen present in the environment (oxidation state of +5) and accounts for the majority of the total available nitrogen in surface waters (Environment Canada 2012). Nitrate is the conjugate base of nitric acid, HNO_3, a strong acid with pKa of -1.37 (WHO 1978). Nitric acid and salts of nitric acid completely dissociate in aqueous solutions (Environment Canada 2012; WHO 1978). Nitrite is the conjugate base of nitrous acid, HNO_2, a weak acid with a pKa of 3.37; nitrite readily decomposes to yield water and dinitrogen trioxide or nitric acid, nitric oxide, and water (WHO 1978; WHO 2011b).

6.3.1 Transport and Partitioning

Nitrate and nitrite are inorganic water-soluble salts with the potential for rapid migration through soils to surface water and groundwater (Nolan 1999; Taylor 2004; EPA 2009a). Sorption of anions such as nitrate is insignificant in most soils; therefore, leaching of excess soil nitrate into oceans, lakes, streams, and groundwater is an important consideration (Taylor 2004). Drainage characteristics of soils are strongly related to nitrate levels in shallow wells near agricultural areas (Nolan et al. 1997; Zhang et al. 1998). Other factors affecting leaching potential include the texture of the soil, pH, precipitation rates, tillage, and the types of crops or vegetation that may be planted in the soils.

The mobility of nitrate in a mid-European semi-natural grassland ecosystem as a function of plant diversity was investigated (Scherer-Lorenzen et al. 2003). The greatest leaching was observed in bare ground plots as well as plots planted only with legumes. Experiments with plots containing a wider variety of plant species indicated that total nitrate plant uptake increased and leaching losses decreased with increasing plant diversity due to greater root biomass within the soils. The leaching of nitrate decreased in the following order: bare plots > pure legumes > legumes + grasses > legumes + grasses + herbs (Scherer-Lorenzen et al. 2003). Annual nitrate leaching in an apple orchard was 4.4–5.6 times greater in plots treated with conventional farming practices (calcium nitrate fertilizer) as compared to plots treated by organic farming practices, in which nitrogen application was accomplished by loadings of chicken manure and alfalfa meal (Kramer et al. 2006). Reduced leaching was accompanied by increased denitrification in the organic treatment areas. Kitchen et al. (2015) investigated groundwater nitrate as a result of leaching due to agriculture cropping systems over time (1994–2004) and found the greatest decreases in groundwater nitrate concentration occurred as groundwater moved through an in-field tree line or through a riparian zone.

Nitrate leaching from croplands with high fertilizer use is a major source of groundwater nitrate concentrations. In Nebraska, groundwater concentrations of nitrate have been correlated with nitrogen-containing fertilizer application rates and residual nitrogen in surface soils (Schepers et al. 1991). The reduction of nitrate concentrations in groundwater through agricultural management practices was assessed in Nebraska’s central Platte River valley (Exner et al. 2010). Groundwater nitrate concentration reports were studied from 1986 to 2003. Peak levels, during 1988, in the primary aquifers were

26.8 mg nitrate-nitrogen/L. A gradual decline was observed with the implementation of fertilizer management regulations. In 2003, nitrate-nitrogen levels in the aquifer averaged 22.0 mg/L.

Nitrate in soils and surface water are susceptible to denitrification resulting in gaseous losses to the atmosphere (Taylor 2004). Nitrate in the atmosphere, emitted by denitrification, industrial processes, and vehicle exhaust, is deposited on land and water in precipitation, gases, and dry particles (Nolan 1999; Taylor 2004). Atmospheric deposition is a factor for nitrate concentrations in water systems (Momen et al. 1999; Nolan 1999; Nolan et al. 1997).

6.3.2 Transformation and Degradation

Nitrate and nitrite has the potential to move into various environmental compartments and are subject to abiotic and biotic degradation processes. Transformation and degradation processes include denitrification to atmospheric nitrogen and plant uptake (Newton 2005; Nolan 1999). Conversion is achieved via biotic process carried out by auto- and heterotrophic bacteria (Hammerl and Klapotke 2006). Under aerobic conditions in aquatic systems, ammonia and nitrite are converted to nitrate via nitrification. Conversion is achieved through a biotic process carried out by autotrophic nitrifying bacteria. Under anaerobic conditions in aquatic systems, bacteria convert nitrate to nitrite, which is further reduced to the gaseous compounds nitric oxide (NO), nitrous oxide (N_2O), and N_2 (nitrogen). These compounds are subsequently released to the atmosphere. Results from a study of denitrification in riverbed sediments found that potential rates for denitrification are limited by environmental conditions such as available organic carbon and temperature, rather than concentration of nitrate itself (Pfenning and McMahon1997). Higher rates were demonstrated in experiments with added carbon sources. Additionally, higher rates of denitrification were measured at 22°C compared to those at 4°C (Pfenning and McMahon1997).

6.3.2.1 Air

Nitrogen compounds are formed in the air by natural phenomena such as lightning (Hord et al. 2011), or may be discharged into air from industrial processes, motor vehicles, agricultural practices, or emitted by denitrification processes. Nitrate is present in air primarily as nitric acid and inorganic aerosols, as well as nitrate radicals and organic gases or aerosols (WHO 2011b). Nitrate in the atmosphere is subject to wet and dry deposition and are deposited on land via precipitation, gases, and dry particles (Nolan 1999; Taylor 2004).

6.3.2.2 Water

In surface waters, assimilation by plants and algae accounts for the majority of nitrate loss. Reducing conditions of water system including dissolved oxygen (DO) and dissolved organic carbon (DOC), as well as temperature and pH, influence the extent of bacterially mediated nitrate loss processes in water systems (Nolan 1999; WHO 2011b). Biologically mediated reduction processes of nitrate and nitrite were found to be positively related to DO and inversely related to iron, manganese, ammonium, and DOC concentrations (Nolan 1999).

Rates of denitrification were examined by measuring N_2O production using riverbed sediment and groundwater or surface water collected from the South Platte alluvial aquifer in Colorado, an area with high nitrate levels due to anthropogenic activity such as fertilizer use, farming practices, and septic drainage and runoff (Pfenning and McMahon 1996). The greatest N_2O production was observed in microcosms containing high levels of organic carbon. The type of organic carbon source was also shown to be correlated with the denitrification rate. Higher N_2O production rates were observed with acetate-amended sediments as compared to sediments amended with fulvic acids. Surface water-derived fulvic acids resulted in higher denitrification rates as compared to groundwater-derived fulvic acids. Reduction in microbial activity due to temperature gradients was also investigated. Denitrification rates decreased by nearly 80% in laboratory experiments when the temperature was lowered from 22 to 4°C.

6.3.2.3 Sediment and Soil

In soils, nitrite is oxidized to nitrate and the majority of nitrate is assimilated by plants and algae (WHO 2011b). Under aerobic conditions, residual or excess nitrate is expected to leach into groundwater and is not expected to undergo considerable degradation and/or denitrification. Under anaerobic conditions degradation of nitrate into atmospheric nitrogen is an important removal process (WHO 2011b). Poorly drained soils, which lack oxygen, promote nitrate conversion to gaseous nitrogen (Nolan et al. 1997).

Denitrification rates were examined using soil samples obtained from different areas of an apple orchard and measuring the rates of gaseous nitrogen and N_2O production as well as nitrate leaching (Kramer et al. 2006). Specifically denitrification rates were measured at different locations of the orchard treated with organic farming practices, conventional farming practices for orchards in the state of Washington, and integrated treatments from horticultural and pest management practices of conventional and organic farming practices. Nitrogen application in the conventional plots used calcium nitrate based fertilizer, while the organic plots used chicken manure and alfalfa meal. The integrated plots used equal parts of calcium nitrate fertilizer and chicken manure. Nitrogen emissions were higher in the organically treated plots, as compared to the conventional and integrated plots. Nitrate leaching was much greater (4.4–5.6 times higher) in the conventional plots as compared to the organically treated plots.

6.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to nitrate and nitrite depends in part on the reliability of supporting analytical data from environmental samples and biological specimens. Concentrations of nitrate and nitrite in unpolluted atmospheres and in pristine surface waters are often so low as to be near the limits of current analytical methods. In reviewing data on nitrate and nitrite levels monitored or estimated in the environment, it should also be noted that the amount of chemical identified analytically is not necessarily equivalent to the amount that is bioavailable. The analytical methods available for monitoring nitrate and nitrite in a variety of environmental media are detailed in Chapter 7.

Nitrate occurs naturally in the environments as a part of the earth's nitrogen cycle. Elevated levels may be present due to anthropogenic sources such as fertilizers, and human or animal wastes. High levels of nitrate in drinking water pose a health risk to infants, children, and pregnant or nursing women (EPA 2009a).

6.4.1 Air

Anthropogenic emissions of nitrogen oxides (NO_x) are now of the same order of magnitude as natural emissions (Hammerl and Klapotke 2006). Air pollution is considered a minor source of exposure to nitrate (WHO 2011b). Nitrate in the atmosphere is generally a result of nitrogen oxides released into the atmosphere that are oxidized to nitric acid, in turn forming nitrate particles (Matsumoto and Tanaka 1996). Atmospheric levels of particulate nitrate are highly dependent on temperature and the chemical composition of aerosol and gases in the atmosphere, especially particulate ammonium nitrate and gaseous nitric acid (Matsumoto and Tanaka 1996). Reported atmospheric nitrate concentrations range from low concentrations of 0.1–0.4 $\mu g/m^3$ up to higher-level concentrations ranging from 1 to 40 $\mu g/m^3$ (WHO 1978, 2011b). Concentrations in Netherland air samples have been reported to range from 1 to 14 $\mu g/m^3$. Indoor nitrate aerosol concentrations of 1.1–5.6 $\mu g/m^3$ appear to be related to outdoor concentrations (WHO 2011b). Zhuang et al. (1999) evaluated the concentrations of fine and coarse particle nitrate in the atmosphere over Hong Kong. The average daily concentrations for fine and coarse particle nitrate were found to be 0.583 and 1.663 $\mu g/m^3$, respectively.

6.4.2 Water

Nitrate and nitrite concentrations in water are typically expressed as either mg nitrate/L (ppm nitrate) and mg nitrite/L (ppm nitrite), or mg nitrate as nitrogen (nitrate-nitrogen/L) and mg nitrite as nitrogen (nitrite-nitrogen/L) (IARC 2010). The federal drinking-water standard maximum contaminant level (MCL) for nitrate is 10 mg nitrate-nitrogen/L and the MCL for nitrite is 1 mg nitrite-nitrogen/L (EPA 2009c; USGS 2010a; WHO 2011b). Inorganic nitrate and nitrite are very soluble in water and occur naturally in groundwater and surface water as a result of the earth's nitrogen cycle. Naturally occurring background levels of nitrate (concentrations expected if there were no effects of human development and anthropogenic sources) have been estimated as 1.0 and 0.24 mg nitrate-nitrogen/L for groundwater and streams, respectively, in the United States (USGS 2010a).

A comprehensive report analyzed nutrient levels in 5,101 wells from 51 different study areas (Burow et al. 2010; USGS 2010a). Monitoring data from 1993 to 2003 indicated that nitrate levels in groundwater varied widely across the nation, with some of the highest levels observed in the Northeast (particularly southern Pennsylvania), the Midwest, the state of California, and select regions of the Northwest (Washington state and Idaho). The report concluded that nitrate levels in deep aquifers were likely to continue to increase as shallow groundwater with high levels of nitrate gravitate downward (USGS 2010a). The highest levels of nitrate were observed in oxic groundwater (water containing >0.5 ppm DO) as opposed to anoxic groundwaters and shallow wells in agricultural areas, which tended to have greater levels than in urban areas (USGS 2010a). Burow et al. (2010) analyzed these data and reported that nitrate concentrations exceeded the MCL (10 mg nitrate-nitrogen/L) in 437 wells (8%). Levels exceeded the MCL in 20% of wells classified as agricultural land-use setting, and 3% were above the MCL in wells classified as urban use. In monitoring data from bank and in-stream wells in the San Joaquin River in California, collected between 2006 and 2008, the concentration of nitrate exceeded the detection limit (0.01 mg/L) in 5% of the groundwater samples and the concentrations in surface waters ranged from 1 to 3 mg/L. It was reported that 17 of the 26 nested monitoring wells, along the river bed and river bank, had no detectable concentrations of nitrate during the monitoring period (USGS 2013a).

Monitoring data obtained from 1991 to 1995 in shallow groundwater of coastal plains in the Albemarle-Pamlico Drainage Unit, in North Carolina and Virginia, have indicated the presence of increased nitrate concentrations as a result of agriculture and anthropogenic sources. Shallow groundwater concentrations are higher at inner coastal sites with well-drained soils compared with outer coastal sites. Areas with anthropogenic nitrogen sources, such as fertilizer and manure, had aquifer concentrations >3 mg nitrate-nitrogen/L. Levels <2 mg nitrate-nitrogen/L were reported in aquifer waters with greater DOC concentrations. Groundwaters from areas having well-drained soils had a median concentration of approximately 0.4 mg nitrate-nitrogen/L. Two of the 20 inner coastal wells had levels >10 mg nitrate-nitrogen/L. Groundwater concentration of nitrate was nearly undetectable in waters underneath poorly drained soils in the outer coast (median 0.05 mg nitrate-nitrogen/L). The North Carolina Division of Water Quality (NCDWQ) selected groundwater samples susceptible to contamination; 40% of the 15 wells in the inner coastal plain of the Albemarle-Pamlico Drainage had levels >10 mg nitrate-nitrogen/L (USGS 2012).

Nitrate and nitrite were the two most detected inorganic chemicals reported in public water systems (PWSs) in an analysis supporting the U.S. EPA's second Six-Year Review of National Primary Drinking Water Regulations. Occurrence data for nitrate from a Six-Year Review-ICR Dataset include 1,052,487 analytical results from 119,537 public water systems (groundwater 114,764; surface water 4,773) across 44 states during the time period from 1998 to 2005 (EPA 2009a). These water systems are reported to serve a combined population of 229,508,036. Nitrate was detected in approximately 70% of the water systems (groundwater 69.4%; surface water 81.3%) at a median concentration of 1.8 mg nitrate-nitrogen/L (groundwater systems 1.6 mg nitrate-nitrogen/L; surface water systems 2.71 mg nitrate-nitrogen/L). Maximum concentrations detected in groundwater and surface water systems were 99 and 48.5 mg nitrate-nitrogen/L, respectively. Seven states in the review reported at least one detection of nitrate greater than the MCL of 10 mg nitrate-nitrogen/L in >5% of their systems. Overall, the 2,973 systems with detections exceeding the MCL serve a combined population of 16,777,093 (EPA 2009a). Occurrence data for nitrite from the Six-Year Review-ICR Dataset includes 397,175 analytical results from 86,313 public water systems (groundwater 82,738; surface water 3,575) across 44 states during the time period from 1998 to 2005 (EPA 2009a). These water systems are reported to serve a combined population of 207,984,813. Nitrite was detected in approximately 22% of the water systems (groundwater 22%; surface water 23%) at a median concentration of 0.02 mg nitrite-nitrogen/L. Maximum concentrations detected in groundwater and surface water systems were 13 and 8.68 mg nitrite-nitrogen/L, respectively. Four states in the review reported at least one nitrite detection greater than the MCL (1 mg nitrite-nitrogen/L) in more than 1% of their systems. Overall, the 635 systems with detections exceeding the MCL serve a combined population of 10,067,031 (EPA 2009a).

In 1991, 12% of 631 private wells located on farmlands across 18 states in the United States reported concentrations >10.2 mg nitrate-nitrogen/L (Bruning-Fann et al. 1994; IARC 2010). Additionally, in 1994, levels of nitrate found in drinking waters across nine mid-western U.S. states ranged from 0.01 to

266 mg nitrate-nitrogen/L, with a mean value of 8.4 mg nitrate-nitrogen/L and 10% of the water supplies had concentrations >10 mg nitrate-nitrogen/L (CDC 1998). California groundwater is relied on for drinking water in 70% of its cities. A study in 1987 indicated that ~10% of the sampled California wells and >7% of the public water systems in Tulare County, California had levels >45 mg nitrate/L (>10 mg nitrate-nitrogen/L) (Zhang et al. 1998).

Studies regarding nitrate levels in drinking water outside the United States were summarized (IARC 2010). Zhang et al. (1996) reported that several cities in China (with populations between 10,000 and 100,000) had water supplies with concentrations >11.3 mg nitrate-nitrogen/L. Twenty-eight percent of public wells monitored in India and 13% in Saudi Arabia had reported levels >11.2 mg nitrate-nitrogen/L as well. In 1990, average concentrations in Canadian municipal drinking waters were reported to range from 0.1 to 3.3 mg nitrate/L (0.02–0.75 mg nitrate-nitrogen/L) (Environment Canada 2012). It has been estimated that 2% of the European population receive their drinking water from private wells and an estimated 2.4 million people are exposed to water supplies containing nitrate concentrations above guideline levels (Gangolli et al. 1994). Nitrate concentrations in many European countries have been reported to be gradually increasing over the last few decades. An average annual increase of 0.7 mg nitrate/L (0.2 mg nitrate-nitrogen/L) has been observed in some rivers of the United Kingdom (WHO 2011b). Nitrate levels in drinking water in Denmark have increased about 400% over the period from 1940 to 1983 (Moller et al. 1989).

Nitrate was reported to be the most frequently detected nutrient in U.S. streams that exceeded its MCL. It exceeded the MCL in 2% of all samples obtained (566 out of 27,555) and in at least 1 sample of 50 of the 499 streams surveyed from 1992 to 2001 (USGS 2010a). Many of the streams with levels above the MCL were located in the upper Midwestern Corn Belt where application rates of fertilizer and manure are high. Nitrite samples from five streams exceeded the nitrite MCL (USGS 2010a). Flow-adjusted nitrate concentrations decreased in 25% of 166 streams and rivers sampled by the USGS over the period 1993–2003; however, concentrations increased over this time period in 20 of the 166 sites (12%) surveyed (USGS 2009). Decreases in levels were attributed to changes in nitrogen use patterns and implementation of pollution control strategies. Multiple factors such as land use, nitrogen loading from fertilizer, manure use, and atmospheric deposition affected the trends observed.

Annual trends of nitrate levels at eight sites along the Mississippi River Basin were studied by the USGS from 1980 to 2010 (USGS 2013b). Flow-normalized nitrate concentrations were generally reported to be level or increasing at all of the monitoring sites from 1980 to 2000; however, select locations showed greater increases or actual decreases in levels since 2000. The greatest increases over the 30-year period were observed in the upper Mississippi River (Clinton, Iowa) and Missouri River (Herman, Missouri). Decreasing flow-normalized nitrate levels over the 30-year period were observed at the Iowa River near Wapello, Iowa and Illinois River at Valley City, Illinois, suggesting that recent land management and farming practices may be reducing the nitrate fluxes in these areas (USGS 2013b).

Many surface water bodies in the United States have a large percentage of total nitrate load contributed by base flow (groundwater discharge, release from other watershed storages, and long-term interflow) in addition to surface runoff. Mean annual base-flow nitrate levels for 148 surface water and shallow groundwater sites in the United States from 1990 to 2006 were typically reported to be <1 mg nitrate-nitrogen/L; however, values as high as 8.48, 11.44, 8.29, and 8.25 mg nitrate-nitrogen/L were reported for Tulpehocken Creek, Pennsylvania; Indian Creek, Illinois; Salt Creek, Illinois; and Clifty Creek, Indiana, respectively (USGS 2010b). The highest levels typically were reported for agricultural land use sites that had frequent fertilizer and manure applications and highly permeable underlying bedrock.

Due to assimilation of nitrate by algae and other plant-life, concentrations of nitrate in surface water are typically lower than that detected in groundwaters (IARC 2010). Tables 1.4 and 1.5 in the IARC report summarize concentrations of nitrate from various regions around the globe. The global concentrations in groundwater were reported to range from 0.02 to 110 mg nitrate-nitrogen/L; mean values ranged from 2.2 to 42.9 mg nitrate-nitrogen/L. Global concentrations of nitrate in surface water were reported to range from 0 to 22 mg nitrate-nitrogen/L; mean values range from 0.1 to 8.3 mg nitrate-nitrogen/L). Nitrate levels in rainwater as high as 5 mg nitrate/L (1 mg nitrate-nitrogen/L) have been observed in various industrial areas (WHO 2011b).

6.4.3 Sediment and Soil

Levels of nitrate and nitrite in soil vary considerably as a function of soil properties, temperature, precipitation rates, nitrogen loadings, farming practices (tillage, crops planted), and seasonal changes. In well-drained aerobic soils, the conversion of ammonia into nitrate (nitrification) increases the soil-nitrate content and in anaerobic soils with high organic matter (such as waterlogged soils or wetlands), denitrification decreases the levels of nitrate and nitrite in soils. Acidic soils tend to have lower levels of nitrate since the nitrification process ceases at pH levels below 4.5 (USDA 2014). Typical nitrate levels in humid temperate soils fluctuate from about 20–65 kg-nitrogen/hectare in cropped soils and 25–150 kg-nitrogen/hectare in bare soils (USDA 2014). Certain locations near the South Platte River in northeastern Colorado had nitrate levels exceeding 500 kg-nitrogen/hectare (Shaffer et al. 1995).

6.4.4 Other Environmental Media

Nitrate and nitrite are common food preservatives. Levels of nitrite and nitrate were evaluated through several processing steps and storage conditions. Nitrite is oxidized to nitrate during storage. Nitrate remained relatively constant over a 2-week storage period, while nitrite levels declined over the same time period. The study also observed minimal influence of the nitrate levels formed from the amount of nitrite added. Additionally, using nitrate alone resulted in the formation of nitrite after thermal processing. Cooking resulted in losses of both nitrite and nitrate; 50% nitrite and 10–15% nitrate remained in the prepared sausage analyzed (Perez-Rodriguez et al. 1996).

Nitrate and nitrite are present in vegetables, fruits, cured meats, fish, dairy products, beers, cereals, and cereal products (Gangolli et al. 1994). Nitrate content of foodstuffs is typically higher than nitrite content (ATSDR 2013a; WHO 2011b). Cured meats have concentrations of <2.7–945 mg of nitrate/kg and <0.2–1.7 mg nitrite/kg (IARC 2010; WHO 2011b). Concentrations of nitrate in vegetables and fruit is strongly affected by processing of the food, fertilizer use, and growing conditions and range from 30 to 6,000 mg/kg (ppm) (IARC 2010; WHO 2011b). Celery, lettuce, red beetroot, and spinach have high levels of nitrate (200–>2,500 mg/kg [ppm]). Parsley, leek, endive, Chinese cabbage, and fennel have high levels of nitrate ranging from 100 to 250 mg/kg (ppm). Cabbage, dill, and turnips have medium levels of nitrate ranging from 50 to 100 mg/g. Vegetables with low levels of nitrate (20–50 mg/g) include broccoli, carrots, cauliflower, cucumber, and pumpkin. Very low levels of nitrate (<20 mg/g) are found in artichokes, asparagus, eggplant, garlic, onions, green beans, mushrooms, peas, peppers, potatoes, summer squash, sweet potatoes, tomatoes, and watermelons (ATSDR 2013a). Nitrite concentrations are typically <10 mg/kg (ppm) and rarely reach 100 mg/kg (ppm); however, exceptions include damaged, outdated, pickled, and fermented foods in which levels may be as high as 400 mg/kg (ppm) (WHO 2011b). Data for nitrate and nitrite in foodstuffs are not lacking and several papers have been published that summarize numerous studies, including IARC (94 2010) and Gangolli et al. (1994). Gangolli et al. (1994) cited a paper reporting the average daily intakes of nitrate and nitrite in the United States to be 106 and 4.1 mg/day, respectively.

Marshall and Trenerry (1996) analyzed several food types purchased from local supermarkets in Australia for both nitrate and nitrite. Nitrite was not detected in fruit juices in this study. Nitrate and nitrite was detected in various cheeses at levels <10 mg/kg (ppm). Canned meat products had small amounts of nitrite (<10 mg/kg [ppm]), while nitrate levels were higher (10–25 mg/kg [ppm]). Several samples of ice were also analyzed for the presence of nitrite and nitrate, and all samples were below Australian food standards (10 mg/L nitrate; 1 mg/L nitrite).

Nitrite and nitrate levels were determined in several whey-containing food products (Oliveira et al. 1995). In total, 231 samples from powdered modified milk, powdered non-fat milk, a dairy beverage, and strawberry- and chocolate-flavored instant mixes were evaluated. Mean nitrate levels ranged between 7.3 and 532 mg/kg (ppm). Mean nitrite levels ranged between 1.1 and 2.5 mg/kg (ppm). One serving of the product with the highest reported nitrate levels (a chocolate-flavored instant mix) was calculated to be 51.9 mg/serving. One serving of the product with the highest reported nitrite levels (powdered non-fat milk) was calculated to be 0.1 mg/serving.

From 1993 to 1997, nitrate and nitrite levels were monitored in Danish lettuce, leek, potato, beetroot, Chinese cabbage, and white cabbage, and spinach (Peterson and Stoltze 1999). Seasonal variation was observed in nitrate levels. Lettuce exhibited higher concentrations in winter as opposed to summer. Overall nitrite concentrations were low. Average nitrate concentrations were 2,760, 1,783, 198, and 158 mg/kg fresh weight for lettuce, fresh spinach, leeks, and potatoes, respectively. Average nitrite concentrations were 11, 0.91, 0.80, 0.15, and 0.14 mg/kg fresh weight for fresh spinach, beetroot, potatoes, leeks, and lettuce, respectively. The average daily intakes, estimated from consumption surveys of the vegetables in the study, were 40 mg/day nitrate and 0.09 mg/day nitrite.

Table 6-4 contains data on infant foods examined for nitrate and nitrite (Cortesi et al. 2015). Food samples of animal origin were composed of a variety of sources such as poultry, beef, rabbit, lamb, and turkey. Foods samples of plant origin were composed of a variety of sources such peas, legumes, vegetable broths, cream of pumpkin and carrots, and mixed vegetables. Mixed-origin samples were composed of both plant and animal sources. The highest average concentration of nitrate was found in foods of plant origin (45.5 mg/kg), while the highest average concentration of nitrite was found in foods of animal origin (14.82 mg/kg).

Jones et al. (2014) reported nitrate and nitrite concentrations in fresh breast milk, freeze-thawed breast milk, freeze thawed colostrum, and several commercially available infant formulas. Data are tabulated in Table 6-5. Fresh breast milk was collected from 11 mothers of term infants and 13 mothers of preterm infants. Samples of colostrum (milk expressed days 1–3), transition milk (expressed days 4–7), and

Table 6-4. Concentrations of Nitrate and Nitrite in Infant Food Products

Food type	Nitrate (mg/kg)	Nitrite (mg/kg)
Homogenized samples of animal origin	0.35–83.2	6.6–48.87
Freeze dried samples of animal origin	2.01–80.26	1.3–74.74
Homogenized samples of plant origin	4.82–131.68	2.26–20.71
Freeze dried samples of plant origin	19.41–85.03	1.34–6.62
Homogenized samples of mixed origin	3.77–67.31	1.98–80.22

Source: Cortesi et al. 2015

Table 6-5. Average Concentrations of Nitrate and Nitrite in Human Milk and Infant Formula

Milk type	Nitrate (μmol/L)	Nitrite (μmol/L)
Fresh breast milk	16	0.1
Freeze-thawed breast milk	20	0.04
Preterm fresh	12	0.07
Preterm freeze-thawed	22	0.03
Term fresh	11.5	0.13
Term freeze-thawed	12.5	0.04
Freeze-thawed colostrum	41	0.16
Infant formula	43	0.29
Freeze-thawed colostrum	44	0.15
Transition milk	Not reported	0.05
Mature milk	Not reported	0.025

Source: Jones et al. 2014

mature milk (expressed days >7) were analyzed. Concentrations of nitrate and nitrite in the 10 formulas evaluated were 9–61 and not detected–1.4 μmol/L, respectively.

6.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The general public is typically exposed to nitrate and nitrite via ingestion of water and foods that contain these chemicals. Inhalation and dermal exposure may be possible; however, these routes are not as prominent. Oral exposure to nitrate and nitrite from contaminated drinking water and food is the prominent route. Nitrate and nitrite overexposure may occur through ingestion of foods containing high levels of nitrate and nitrite (ATSDR 2013a). Inorganic nitrate and nitrite can be taken up by plants, especially leafy vegetables such as lettuce and spinach as well as beet root; vegetables account for about 80% of the nitrate in a typical human diet (ATSDR 2013a; Hord 2011; Lundberg et al. 2009; Peterson and Stoltze 1999). Contaminated foodstuffs from improper storage of commercial and prepared baby foods have caused overexposure in children (Dusdieker et al. 1994; Greer and Shannon 2005; Sanchez-Echaniz et al. 2001).

Iammarino et al. (2014) analysed 75 samples of spinach and 75 samples of lettuce, collected from June 2010 to December 2011, for nitrate and nitrite. Spinach had a greater number of detections compared with the lettuce samples. Mean nitrate concentrations ranged from 155.5 to 2,149.6 mg/kg; mean nitrite concentrations ranged from 16.3 to 101.6 mg/kg. Four spinach samples and five lettuce samples had concentrations of nitrate >2,000 mg/kg. Quantifiable concentrations of nitrite were detected in 15 samples of spinach (28.5–197.5 mg/kg) and one sample of lettuce (66.5 mg/kg).

The remainder of the nitrate in a typical diet comes from drinking water (about 21%) and from meat and meat products (about 6%) in which sodium nitrate is used as a preservative and color-enhancing agent (ATSDR 2013a; Lundberg et al. 2008; Saito et al. 2000). For bottle-fed infants, the major source of nitrate exposure is from contaminated drinking water used to dilute formula, especially when the water is boiled prior to use (ATSDR 2013a; Fewtrell 2004). A review by Jones et al. (2015) reported daily nitrate ingestion concentrations for adults. An intake of approximately 3 mg/kg/day for adults was based on a typical adult diet.

The Fourth National Report on Human Exposures to Environmental Chemicals, published and updated by the Centers for Disease Control and Prevention (CDC 2013), reported the following data from the National Health and Nutrition Examination Survey (NHANES) 1999–2008. Nitrate levels in the urine (see Table 6-6), and urine (creatinine corrected) (see Table 6-7) were evaluated for various ages and ethnicities. Mean values of nitrate in the urine were 42.7 and 46.3 mg/L for 7,697 members of the general U.S. population sampled during 2005–2006 and 7,629 members of the general U.S. population sampled during 2007–2008, respectively. The highest geometric mean (creatinine corrected) during 2001–2002 of 72.0 mg/L was determined from 374 samples from 6–11 year olds; the highest geometric mean (creatinine corrected) during 2005–2006 of 60.8 mg/L was determined from 1,054 samples from 6–11 year olds; and the highest geometric mean during 2007–2008 of 70.2 mg/L was determined from 1,143 samples from 6–11 year olds. Throughout all survey years, females had a higher geometric mean than males. In the survey years 2007–2008, 3,789 female samples yielded a mean of 51.0 mg/g, while 5,351 male samples yielded a mean of 44.6 mg/g (CDC 2013).

No information was located regarding absorption of inhaled inorganic nitrate or nitrite in humans or laboratory animals. Inhalation of inorganic nitrate or nitrite is not a likely exposure route of concern for the general population, although inhalation of dust from fertilizer products containing nitrate salts is possible.

Occupational exposure is primarily via inhalation and dermal routes. Industrial workers and farmers may be exposed via inhalation of dusts. Dusts may also dissolve in sweat on skin, increasing the potential for dermal exposure.

Vegetable consumption is a considerable source of nitrate, and drinking water with high levels of nitrate is also a major contributing factor. Several studies have been conducted assessing exposure to drinking waters with high levels of nitrate. In 1986 until 1987, Moller et al. (1989) studied 294 Danish adults between the ages of 20 and 64 years who were exposed to various levels of nitrate in their drinking water and diet. Twenty-one drinking water supplies contained low (0–5 mg nitrate/L [ppm nitrate]) intermediate (35–59 mg nitrate/L [ppm nitrate]) and high (≥60 mg nitrate/L [ppm nitrate]) nitrate levels, with mean concentrations of 0.3, 46.5, and 84.4 mg nitrate/L (ppm nitrate), respectively. The median exposures of total dietary nitrate for the low, intermediate, and high water categories were 37, 89, and 123 mg nitrate/day, respectively. Mean nitrate levels detected in the participant’s 24-hour urine samples for the low, intermediate, and high water concentration categories were reported as 36, 55, and 73 mg nitrate, respectively. Overall, the dietary contribution was calculated to be 17% from water and 83% from food for the low group, and increased to approximately 60% from water and 40% from food for the intermediate and high groups. Fifty-nine Canadian adults between the ages of 20–74 years used tap water with low (<3 mg nitrate-nitrogen/L) and high (>3 mg nitrate-nitrogen/L) concentrations of nitrate. The

Table 6-6. Geometric Mean and Selected Percentiles of Urine Concentrations of Urinary Nitrate (in mg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES)

	Survey years	Geometric mean (95% CI)	Selected percentiles (95% CI) 50th	75th	90th	95th	Sample size
Total	2001–2002	48.2 (46.2–50.3)	49.0 (46.0–52.0)	78.0 (73.0–83.0)	100 (100–130)	140 (130–150)	1,617
	2005–2006	42.7 (39.6–46.1)	47.8 (44.4–51.2)	74.6 (69.8–79.4)	108 (101–114)	133 (125–144)	7,697
	2007–2008	46.3 (44.6–48.1)	50.3 (48.4–52.0)	76.0 (72.7–79.1)	110 (104–116)	138 (132–146)	7,629
Age group							
6–11 years	2001–2002	62.2 (53.8–71.8)	68.0 (58.0–79.0)	94.0 (84.0–100)	130 (100–160)	150 (120–380)	374
	2005–2006	51.2 (47.4–55.4)	54.7 (51.9–58.2)	79.2 (72.8–87.2)	113 (101–128)	141 (120–158)	1,054
	2007–2008	55.2 (51.7–58.9)	60.2 (56.1–64.3)	84.5 (80.1–92.5)	117 (107–135)	149 (132–189)	1,143
12–19 years	2001–2002	57.4 (53.5–61.6)	66.0 (60.0–69.0)	91.0 (86.0–95.0)	120 (100–130)	150 (130–160)	827
	2005–2006	52.5 (48.5–56.8)	57.5 (52.3–62.6)	84.2 (79.9–88.4)	119 (111–124)	144 (129–153)	2,106
	2007–2008	55.5 (51.5–59.7)	56.8 (51.9–61.5)	84.1 (76.2–94.5)	119 (107–133)	144 (133–162)	1,135
≥20 years	2001–2002	45.4 (43.3–47.5)	49.0 (46.0–52.0)	78.0 (73.0–83.0)	100 (100–130)	140 (130–150)	1,617
	2005–2006	40.5 (37.4–43.9)	45.0 (41.3–48.3)	71.7 (67.1–77.4)	105 (98.0–113)	129 (122–142)	4,537
	2007–2008	44.2 (42.5–45.9)	48.1 (46.0–49.7)	73.2 (70.1–76.5)	107 (101–113)	135 (128–146)	5,351
Gender							
Males	2001–2002	57.5 (54.6–60.6)	63.0 (59.0–67.0)	89.0 (83.0–94.0)	130 (100–140)	150 (140–170)	1,335
	2005–2006	48.4 (44.6–52.6)	52.7 (48.3–57.8)	79.4 (72.8–86.5)	110 (103–121)	136 (123–152)	3,765
	2007–2008	51.9 (49.9–54.1)	56.1 (53.8–58.0)	79.5 (75.7–83.5)	112 (105–119)	137 (131–149)	3,839
Females	2001–2002	40.7 (38.4–43.2)	43.0 (41.0–48.0)	72.0 (68.0–76.0)	100 (98.0–120)	130 (120–150)	1,483
	2005–2006	37.9 (35.1–40.8)	42.0 (38.2–46.0)	69.2 (65.5–73.4)	104 (96.6–110)	130 (124–140)	3,932
	2007–2008	41.4 (39.3–43.7)	43.9 (41.5–46.3)	71.3 (67.5–74.8)	108 (99.8–115)	138 (132–149)	3,790

Table 6-6. Geometric Mean and Selected Percentiles of Urine Concentrations of Urinary Nitrate (in mg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES)

	Survey years	Geometric mean (95% CI)	Selected percentiles (95% CI) 50th	75th	90th	95th	Sample size
Race/ethnicity							
Mexican Americans	2001–2002	53.2 (48.7–58.2)	59.0 (52.0–66.0)	84.0 (79.0–91.0)	120 (100–150)	160 (130–180)	707
	2005–2006	47.8 (44.7–51.2)	52.4 (49.9–56.2)	77.9 (75.1–83.1)	113 (104–120)	148 (133–156)	1,972
	2007–2008	48.7 (45.0–52.6)	51.9 (47.4–56.7)	75.6 (69.7–81.3)	111 (100–122)	148 (127–164)	1,505
Non-Hispanic blacks	2001–2002	53.8 (47.8–60.5)	58.0 (51.0–64.0)	84.0 (77.0–93.0)	120 (100–130)	140 (130–170)	680
	2005–2006	45.9 (42.1–50.0)	50.4 (46.6–54.9)	75.0 (68.8–80.8)	101 (95.3–110)	127 (114–148)	2,078
	2007–2008	47.5 (45.0–50.3)	50.3 (48.6–52.5)	74.7 (71.9–77.3)	105 (97.1–116)	134 (125–150)	1,707
Non-Hispanic whites	2001–2002	46.3 (44.1–48.6)	51.0 (47.0–53.0)	81.0 (78.0–85.0)	120 (100–130)	140 (130–150)	1,228
	2005–2006	41.2 (37.6–45.2)	46.2 (41.3–50.6)	73.3 (67.3–80.1)	107 (98.2–115)	129 (122–142)	3,056
	2007–2008	45.0 (42.7–47.5)	49.2 (46.1–52.6)	75.5 (70.5–80.0)	108 (101–116)	134 (128–140)	3,190

CI = confidence interval

Source: CDC 2013

Table 6-7. Geometric Mean and Selected Percentiles of Urine Concentrations of Urinary Nitrate (Creatinine Corrected) (in mg/g of creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES)

	Survey years	Geometric mean (95% CI)	Selected percentiles (95% CI)				Sample size
			50th	75th	90th	95th	
Total	2001–2002	49.8 (47.7–51.9)	46.9 (44.2–49.6)	63.8 (61.2–67.7)	90.9 (84.3–98.8)	120 (111–128)	1,616
	2005–2006	42.6 (40.2–45.1)	42.4 (40.1–44.7)	59.7 (55.8–64.1)	85.5 (81.3–91.3)	113 (106–118)	7,697
	2007–2008	47.7 (45.9–49.7)	46.0 (44.0–48.3)	66.5 (62.4–70.5)	98.0 (92.3–102)	127 (119–135)	7,628
Age group							
6–11 years	2001–2002	72.0 (66.1–78.4)	66.0 (62.6–70.4)	87.0 (80.2–97.7)	129 (96.5–144)	144 (130–235)	374
	2005–2006	60.8 (57.4–64.5)	57.3 (53.6–60.6)	76.5 (70.9–82.1)	109 (95.0–123)	134 (121–164)	1,054
	2007–2008	70.2 (65.7–74.9)	65.9 (62.4–69.5)	89.0 (83.2–96.5)	128 (112–152)	173 (140–216)	1,143
12–19 years	2001–2002	44.8 (43.4–46.2)	43.8 (42.6–45.0)	56.2 (52.2–59.7)	73.2 (65.2–85.1)	93.4 (79.0–104)	826
	2005–2006	39.8 (37.8–41.9)	38.1 (36.3–40.3)	51.8 (47.7–56.0)	70.6 (63.1–78.8)	88.9 (79.4–103)	2,106
	2007–2008	43.4 (41.3–45.5)	40.5 (38.6–43.5)	56.0 (52.7–59.2)	76.6 (69.0–86.2)	98.0 (85.4–121)	1,134
≥20 years	2001–2002	48.3 (45.9–50.9)	46.9 (44.2–49.6)	63.8 (61.2–67.7)	90.9 (84.3–98.8)	120 (111–128)	1,616
	2005–2006	41.4 (38.9–43.9)	41.0 (38.8–43.7)	58.6 (54.8–63.1)	85.3 (80.2–91.0)	111 (105–116)	4,537
	2007–2008	46.5 (44.6–48.4)	44.7 (42.5–47.0)	65.0 (60.7–69.2)	96.1 (90.0–102)	125 (117–132)	5,351
Gender							
Males	2001–2002	47.6 (44.7–50.7)	46.1 (43.4–48.7)	61.3 (58.0–64.5)	86.7 (77.1–97.3)	114 (97.3–125)	1,335
	2005–2006	40.1 (37.5–42.9)	39.5 (36.7–42.8)	55.3 (51.6–59.5)	77.2 (70.7–83.0)	95.9 (89.6–102)	3,765
	2007–2008	44.6 (42.8–46.6)	42.8 (40.7–45.1)	60.6 (58.1–64.4)	85.6 (81.1–91.3)	111 (101–121)	3,839
Females	2001–2002	51.9 (49.9–54.1)	51.2 (48.4–53.0)	69.1 (66.7–71.2)	100 (91.7–111)	129 (118–140)	1,481
	2005–2006	45.1 (42.8–47.6)	45.0 (42.4–47.4)	64.4 (60.0–69.6)	96.8 (87.8–105)	128 (117–134)	3,932
	2007–2008	51.0 (48.9–53.2)	50.0 (47.5–52.7)	72.3 (67.8–76.8)	107 (101–116)	146 (129–163)	3,789

Table 6-7. Geometric Mean and Selected Percentiles of Urine Concentrations of Urinary Nitrate (Creatinine Corrected) (in mg/g of creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES)

	Survey years	Geometric mean (95% CI)	Selected percentiles (95% CI) 50th	75th	90th	95th	Sample size
Race/ethnicity							
Mexican Americans	2001–2002	50.9 (45.7–56.8)	48.1 (44.9–51.4)	67.4 (60.3–77.6)	97.3 (85.7–117)	135 (100–161)	707
	2005–2006	44.6 (42.6–46.7)	44.0 (42.2–45.3)	60.4 (58.1–62.9)	89.9 (82.0–95.4)	120 (111–128)	1,972
	2007–2008	48.7 (45.1–52.7)	47.0 (43.5–50.5)	64.8 (59.7–69.9)	93.5 (88.9–101)	128 (108–156)	1,505
Non-Hispanic blacks	2001–2002	38.7 (36.3–41.3)	38.0 (34.6–41.3)	53.5 (50.3–57.4)	70.3 (64.9–79.3)	91.7 (78.9–100)	679
	2005–2006	32.9 (30.9–35.0)	31.9 (29.8–34.1)	45.4 (41.5–49.6)	64.0 (60.1–68.0)	81.2 (75.3–89.6)	2,078
	2007–2008	35.9 (34.2–37.7)	34.8 (33.3–36.6)	49.0 (44.8–53.6)	69.1 (63.5–77.4)	87.8 (78.1–97.4)	1,706
Non-Hispanic whites	2001–2002	51.4 (49.4–53.4)	49.1 (46.9–51.5)	66.9 (64.2–69.4)	95.2 (87.7–100)	124 (115–132)	1,227
	2005–2006	43.7 (40.8–46.8)	43.9 (40.8–46.8)	61.4 (56.5–66.2)	85.5 (80.6–91.9)	110 (102–116)	3,056
	2007–2008	49.0 (46.7–51.4)	47.4 (44.9–50.5)	68.2 (63.3–73.1)	98.3 (91.2–105)	126 (118–135)	3,190

CI = confidence interval

Source: CDC 2013

mean urinary nitrate excretion of the participants who consumed drinking water with low-nitrate levels was 15.0 mg nitrate-nitrogen/day, while the mean value for the participants who consumed drinking water with higher nitrate levels was 22 mg nitrate-nitrogen/day (Levellois et al. 2000). Higher correlations for total nitrate intake and urinary excretion were found with dietary nitrate intake as opposed to water nitrate intake.

Various scenarios for nitrate and nitrite intake have been considered and it has been found that dietary intake contributes the majority of exposure occurrences. Approximately 89–99% of an adult's daily intake of both nitrate and nitrite is from their food when an average to high vegetable diet is consumed with average water intake. The daily intake contribution from food decreases to 33–56% for nitrate and 7.7–14% for nitrite when average to high consumption of water with nitrate levels (50 mg nitrate/L [ppm nitrate]) is considered (IARC94_2010). Gangolli et al. (1994) also reported that 88–96% of the average dietary intake of nitrate comes from food sources (85% of which is attributed to vegetables), while 4–12% comes from drinking waters. Exposure to dietary nitrate may increase exposure to nitrite due to endogenous production. Ingested nitrate is readily absorbed from the upper gastrointestinal tract into the blood and is mainly excreted in the urine (Gangolli et al. 1994). Portions of blood nitrate are transported to human saliva where it is mostly metabolized to nitrite; approximately 5% of dietary nitrate is metabolized to nitrite (Gangolli et al. 1994). Gangolli et al. (1994) estimated that the human adult intakes of nitrate are 2.4 mg nitrate/kg (ppm nitrate) body weight/day from food and 0.33–4.1 mg nitrate/kg body weight/day from water; the human adult intakes of nitrite are 0.04–0.07 mg nitrite/kg body weight/day from food and <0.002–0.07 mg nitrite/kg body weight/day from water. These estimates do not account for the endogenous production of nitrite. Worldwide dietary exposures were estimated from data collected in the 1997 Total Diet Study in the United Kingdom and additional dietary studies. Representative exposure estimates for nitrate and nitrite were reported as 58–218 and 0.7–1.6 mg nitrite/day, respectively (IARC 2010).

Estimated daily intake values of nitrate and nitrite have been calculated based on data from the United Kingdom and the United States. An individual with an average water intake (1.4 L/day) and average food consumption or a high vegetable diet is estimated to consume levels 52–80 or 140–220 mg nitrate/day, respectively. An individual with an average water intake (1.4 L/day) and average food consumption or a high vegetable diet is estimated to consume levels 0.74 or 2.2 mg nitrite/day, respectively (IARC 2010).

Dermal exposure to inorganic nitrate or nitrite is not a likely route of concern for the general population, although absorption following dermal exposure to dust from fertilizer products containing nitrate salts is possible.

6.6 EXPOSURES OF CHILDREN

This section focuses on exposures from conception to maturity at 18 years in humans. Differences from adults in susceptibility to hazardous substances are discussed in Section 3.7, Children’s Susceptibility.

Children are not small adults. A child’s exposure may differ from an adult’s exposure in many ways. Children drink more fluids, eat more food, breathe more air per kilogram of body weight, and have a larger skin surface in proportion to their body volume than adults. A child’s diet often differs from that of adults. The developing human’s source of nutrition changes with age: from placental nourishment to breast milk or formula to the diet of older children who eat more of certain types of foods than adults. A child’s behavior and lifestyle also influence exposure. Children crawl on the floor, put things in their mouths, sometimes eat inappropriate things (such as dirt or paint chips), and may spend more time outdoors. Children also are generally closer to the ground and have not yet developed the adult capacity to judge and take actions to avoid hazards (NRC 1993).

Children will be exposed to nitrate and nitrite through ingestion of food and drinking water. Nitrate is commonly detected in various surface waters and groundwaters. High nitrate concentrations in drinking water are commonly found in privately owned wells, with shallow depths and permeable soils. It has been estimated that about 15 million families in the United States use private well drinking water. Based on monitoring data and birthrates from 2000, it was estimated that 40,000 infants <6 months old would be living in households using drinking water with nitrate levels that exceed the federal standard (10 mg nitrate-nitrogen/L) (Fewtrell 2004). Additionally, boiling water from private wells may concentrate nitrate in the water, which may lead to higher exposure of children whose infant foods are prepared using water that is boiled first (Fewtrell 2004). Gangolli et al. (1994) estimated that the infant intake of nitrate and nitrite from food is negligible, while the infant intakes of nitrate and nitrite from water are 1.7–8.3 mg nitrate/kg body weight/day and <0.02 mg nitrite/kg body weight/day, respectively. A review by Jones et al. (2015) reported dietary nitrate and nitrite concentrations for newborn infants. An intake of approximately 0.15 mg/kg/day for infants was based on a mean of reported concentrations in breast milk and formula. Ingestion based on breast milk intake of approximately 150 mL/kg/day, was reported as 0.12 mL/kg/day for nitrate and 0.0007 mL/kg/day for nitrite.

Infants may have higher exposures as compared to adults if the water source used for formula has high levels of nitrates and nitrites. Human breast milk has been shown to contain, although not concentrate, nitrate and is not considered a significant source of infant exposure (IARC 2010).

6.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Populations using well water in agricultural areas may be exposed to greater levels of nitrate and nitrite as compared to populations living in urban areas since groundwater in agricultural communities typically has greater levels of nitrate and nitrite than urban water (Burow et al. 2010). Furthermore, workers who are employed in occupations where fertilizer use is common (e.g., farming, greenhouse operations) may be exposed to nitrate and nitrite through dermal routes and inhalation of dust particles.

6.8 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of nitrate and nitrite is available. Where adequate information is not available, ATSDR, in conjunction with NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of nitrate and nitrite.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

6.8.1 Identification of Data Needs

Physical and Chemical Properties. The physical and chemical properties of nitrate salts are discussed in Chapter 4. These salts are highly soluble in water and dissociate under environmental conditions and exist as ions (WHO 1978, 2011b). No data needs are identified.

Production, Import/Export, Use, Release, and Disposal. According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit substance release and off-site transfer information to the EPA. The TRI, which contains this information for 2012, became available in November of 2013. This database is updated yearly and should provide a list of industrial production facilities and emissions. Import/export data are available for ammonium nitrate (USDA 2013). Data for the other compounds assessed in this profile would be useful.

Environmental Fate. The transport and fate of nitrate and nitrite compounds have been studied (Kramer et al. 2006; Pfenning and McMahon 1996; WHO 2011b). These substances are highly mobile in soils. Transformation and degradation processes include denitrification to atmospheric nitrogen and plant uptake (Newton 2005; Nolan 1999). Conversion is achieved via biotic process carried out by auto- and heterotrophic bacteria (Hammerl and Klapotke 2006). Under aerobic conditions in aquatic systems, ammonia and nitrite are converted to nitrate via nitrification. Conversion is achieved through a biotic process carried out by autotrophic nitrifying bacteria. Under anaerobic conditions in aquatic systems, bacteria convert nitrate to nitrite, which is further reduced to the gaseous compounds nitric oxide (NO), nitrous oxide (N_2O), and N_2 (nitrogen). No data needs are identified.

Bioavailability from Environmental Media. Nitrate and nitrite are readily absorbed following ingestion from water or food sources.

Data assessing absorption from intake of food sources and water containing nitrate and nitrite has been studied (Gangolli et al. 1994; Kortboyer et al. 1997b). Several reports have indicated the correlation of methemoglobinemia in adults and children and elevated nitrite levels in the blood (CDC 1997, 2002; Gautami et al. 1995; Gowans 1990; Greenberg et al. 1945; Sevier and Berbatis 1976; Ten Brink et al. 1982). Adequate data for intake of nitrate and nitrite from drinking water and food are available (ATSDR 2013a; Gangolli et al. 1994; Hord 2011; JECFA 2003c; Lundberg et al. 2009; Peterson and Stoltze 1999). Data are lacking for absorption from the lungs and skin. Further data may be useful to establish whether uptake via inhalation or dermal contact of dust is a notable source of exposure, since this may occur during application of fertilizers containing these chemicals.

Food Chain Bioaccumulation. Nitrate ion and nitrite ion are both a natural part of the earth's nitrogen cycle. Plants and mammals naturally contain nitrate and nitrite (WHO 2011b). Assimilation of nitrite from soils occurs via reduction of nitrate to nitrite, which is facilitated by various bacteria and catalyzed by nitrate reductase (WHO 1978). Data are available to indicate that nitrate and nitrite may be concentrated in several plants and waters intended for human consumption (JECFA 2003c; Peterson and Stoltze 1999; Zhang et al. 1996, 2003). No data needs are identified.

Exposure Levels in Environmental Media. Reliable monitoring data for the levels of nitrate and nitrite in contaminated media at hazardous waste sites are needed so that the information obtained on levels of nitrate and nitrite in the environment can be used in combination with the known body burden of nitrate and nitrite to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites.

Exposure Levels in Humans. Humans are exposed to nitrate and nitrite primarily through the ingestion of drinking water and consumption of food. Estimated intakes are available (Gangolli et al. 1994; IARC 2010). Biomonitoring data for nitrate levels in urinary samples have been reported (CDC 2013). Continued monitoring of nitrate and nitrite levels in humans is needed.

This information is necessary for assessing the need to conduct health studies on these populations.

Exposures of Children. Children are exposed to nitrate and nitrite by the same exposure routes as adults (e.g., ingestion of food and water). Data from the NHANES survey discussed in Section 6.5 indicated that higher urinary nitrate levels were typically observed in children as compared to adults. Continued monitoring of nitrate and nitrite levels in children is needed.

Child health data needs relating to susceptibility are discussed in Section 3.12.2, Identification of Data Needs: Children’s Susceptibility.

Exposure Registries. No exposure registries for nitrate or nitrite were located. This substance is not currently one of the compounds for which a sub-registry has been established in the National Exposure Registry. The substance will be considered in the future when chemical selection is made for sub-registries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to exposure to this substance.

6.8.2 Ongoing Studies

No ongoing environmental fate studies for nitrate or nitrite were identified using NIH RePORTER or the Defense Technical Information Center (DTIC) online database. Nitrate and nitrite levels and trends are monitored in major watersheds and drinking water by organizations such as the USGS and USDA. These reports are typically available from their websites.