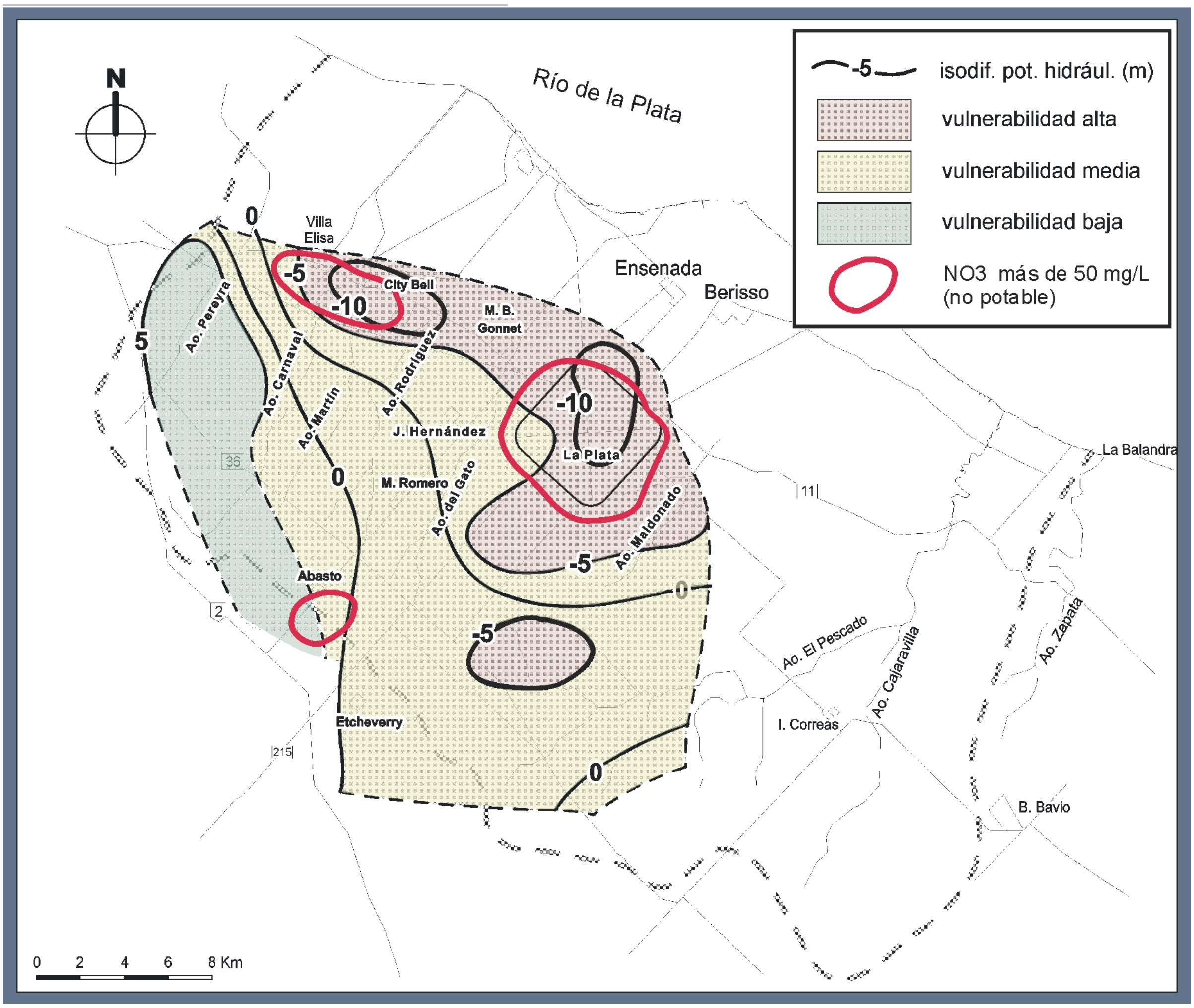
AGUA SUBTERRÁNEA DETERIORO DE CALIDAD Y RESERVA

VULNERABILIDAD ACUÍFERO PUELCHE



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1. INTRODUCCIÓN

El agua en general y la subterránea en particular es un recurso limitado en nuestro planeta, donde más del 97% es salada y se concentra en mares y océanos. Del resto, alrededor del 2% constituye los casquetes polares en forma de hielo. Le sigue en magnitud el agua subterránea, cuya reserva hasta 1.000 m de profundidad se estima en el 0,5% del total, mientras que el volumen instantáneo de agua superficial llega a sólo el 0,02% y entre el agua del suelo y la atmosférica, componen algo más del 0,01% de la total (1.383 x 10^6 km3).

El incremento en la demanda y la disminución en la disponibilidad, particularmente por deterioro en su calidad, han generado y generan problemas cada vez más graves para el abastecimiento tanto a nivel local como regional y continental. Esta problemática, que se ha manifestado en forma creciente durante el siglo 20, es previsible que mantenga su tendencia en el presente, especialmente debido al crecimiento poblacional mundial que dará lugar a un aumento en la demanda de alimentos, bienes y servicios. Por ello, considero apropiado calificar al 21 como el **Siglo del Agua.**

2. GENERALIDADES

Los conceptos **sobre-explotación y contaminación**, poseen variadas acepciones y alcances de acuerdo al enfoque particular de los especialistas y/o a la finalidad que se persiga con el aprovechamiento del agua subterránea.

Así, por **sobre-explotación** suele entenderse un exceso en la explotación que afecta las reservas permanentes, debido a que supera con amplitud y durante lapsos prolongados a la magnitud de las reservas renovables (recarga). Esto se traduce en una disminución del potencial hidráulico, que se manifiesta por un descenso apreciable de los niveles piezométricos y puede generar o acelerar otros procesos indeseables como contaminación y/o salinización. En definitiva, la sobre-explotación siempre causa una disminución marcada en la disponibilidad y productividad de los acuíferos.

En el concepto de **contaminación** se incluye a todo proceso que genere un deterioro apreciable en la calidad física, química y/o biológica del agua subterránea. Generalmente la contaminación deriva de acciones artificiales (polución), aunque a veces tiene origen natural (disolución de sustancias nocivas como flúor y arsénico en el Loess Pampeano, o metales pesados en yacimientos metalíferos) y en otras, si bien observa una génesis natural, es inducida artificialmente (salinización por sobre-explotación de acuíferos costeros).

La contaminación del agua subterránea está estrechamente ligada a los procesos de degradación ambiental y en este sentido, resulta conveniente aplicar el **concepto de interacción global de los recursos naturales**, desarrollado por los investigadores soviéticos, que señala la imposibilidad de preservar la calidad de uno de los recursos, si el resto está deteriorado o en vías de deterioro. Como ejemplo, se puede mencionar que la contaminación del aire por la actividad industrial o urbana, se trasladará al agua superficial y al suelo, a través de la acción gravitatoria o el arrastre, producido por la lluvia y de éste, mediante el proceso de infiltración efectiva, podrá alcanzar al agua subterránea si la sustancia contaminante es móvil y persistente.

Otro elemento que tipifica el comportamiento dinámico del agua subterránea es su escasa movilidad, con bajas velocidades de flujo que, en condiciones de equilibrio natural, o sea cuando no existe alteración por explotación, normalmente varían entre algunos cm y decímetros por día, particularmente en acuíferos con porosidad primaria o intergranular. Esto hace que los procesos de degradación, particularmente los vinculados a la contaminación, se produzcan muy lentamente por lo que resulta difícil detectarlos, especialmente en las fases iniciales. **Este comportamiento que aparece como beneficioso para la preservación en realidad no lo es, pues la baja actividad dinámica deriva en lapsos muy prolongados para la restauración o descontaminación.** Respecto a esto último, conviene aclarar que es prácticamente imposible restaurar la calidad de un acuífero a su condición natural previa a la contaminación y en este sentido, en la generalidad, sólo pueden lograrse mejoramientos parciales, mediante tecnologías que requieren elevados costos. Por ello, resulta **perfectamente aplicable a los recursos naturales en general y al agua subterránea en particular, el apotegma de la medicina: "es preferible prevenir que curar"** (Auge, 1990).

3. HIDRÓSFERA

En la tabla 1 se indica la distribución del agua en el planeta, sobre la base de los trabajos de Lvovitch (1967) y Nace (1969)

TABLA 1

	AGUA EN LA TIERRA			
	Area km2.10^6	**Volumen km3.10^6**	**%**	**Altura equivalente (m)**
Océanos y Mares	362	1.350	97,6	2.650
Casquetes polares	17	26	1,9	50
Subterránea	131	7	0,5	14
Superficial	1,5	0,3	0,02	0,6
del Suelo	131	0,2	0,01	0,4
Atmosférica	510	0,02	0,001	0,04
Total	510	1.383	100,03	2.715

Del mismo se desprende el neto predominio de las aguas marinas (más del 97% del total), **que evidentemente constituyen la reserva futura más importante para los usos corrientes del agua (consumo humano, riego, industria).**

En los casquetes polares se almacena el mayor volumen de agua dulce existente en la hidrósfera, pero se ubican a distancias considerables de los sitios más densamente poblados, lo que restringe su aprovechamiento.

De los 7 millones de km3 que constituyen el volumen de agua subterránea almacenada hasta 1.000 m de profundidad (Lvovitch, 1967), sólo una fracción es potable y ésta no siempre se ubica en o cerca de los centros de mayor demanda. Además, la degradación del recurso por explotación excesiva y contaminación en las zonas urbanas y rurales, ha generado un grave problema que se ha incrementado notoriamente en los últimos 60 años, debido al aumento de la población, al fuerte crecimiento industrial, y al uso intensivo de plaguicidas y fertilizantes en la agricultura.

La notable incidencia de las actividades humanas, derivó en la formulación de una nueva disciplina dentro de la Hidrogeología denominada **Hidrogeología Ambiental, cuya finalidad es estudiar las características y el comportamiento del agua subterránea y las alteraciones que sobre la misma generan las acciones artificiales, para controlar la degradación, prevenirla y, dentro de lo posible, mejorar sus efectos.**

Si bien el volumen almacenado en los lagos e instantáneamente en los ríos del mundo sólo alcanza al 0,02% del total, algunos ríos tienen caudales sorprendentes como el Río de la Plata que, con un módulo de 20.000 m3/seg, sería hábil por sí solo para abastecer a la población mundial (6.500 millones), a razón de 265 L/día por habitante. Sin embargo, el agua superficial está más expuesta a la contaminación y generalmente es mucho más cara que la subterránea por el tratamiento que necesita para su potabilización.

4. USO DEL AGUA

En virtud de lo expuesto, en la mayoría de los países desarrollados, que se caracterizan por optimizar el uso de los recursos naturales, el empleo de agua subterránea para consumo humano, supera apreciablemente al del agua superficial (tabla 2).

TABLA 2

EXTRACCIÓN DE AGUA EN EUROPA		
	total km3/año	agua subterránea para uso humano %
Alemania	6,24	67
Bélgica	0,57	76
Dinamarca	0,70	98
Francia	5,00	50

Holanda	1,15	63
Inglaterra	2,50	32
Italia	9,95	36

Del cuadro se desprende el notorio predominio del agua subterránea respecto a la superficial para abastecimiento humano. Esto se debe a varias causas, entre las que se destacan su menor costo pues no necesita tratamiento y su mejor calidad porque está más protegida de la contaminación.

En la tabla 3 se reproduce la distribución en el consumo por uso y su variación mundial en este siglo (Kozlovsky, 1984).

TABLA 3

USO DE AGUA EN EL MUNDO							
	Consumo total	**Agricultura**		**Industria**		**Agua potable**	
año	**km3/año**	**km3/a**	**(%)**	**km3/a**	**(%)**	**km3/a**	**(%)**
1900	400	350	87,5	30	7,5	20	5
1950	1.100	820	74,5	220	20	60	5,5
1975	3.000	2200	73	650	22	150	5
2000	5.000	3400	68	1250	25	350	7

En el cuadro se aprecia que el aumento en el consumo total es del 1.150% entre 1900 y el año 2000 y que la incidencia respecto al agua potable, se ha mantenido con muy poca variación (5 al 7%). El uso industrial, como contraparte, creció notablemente del 7,5 al 25% y para el riego, que continúa siendo el mayor consumidor mundial, disminuyó del 87,5 al 68%.

Seguidamente se indican los consumos en el Conurbano de Buenos Aires y en La Plata, sobre la base de los datos obtenidos en el censo nacional de 1990.

En el Conurbano, el mayor volumen de agua se destinó en 1990 al consumo humano (739 hm3) sobre un total de 1.259 hm3; o sea el 59%, seguido por la industria (400 hm3, el 32%) y finalmente el riego (120 hm3, el 9%). De la demanda total, un 62% se cubrió con agua subterránea y un 38% con agua superficial.

Algo parecido sucedió en relación al empleo de agua subterránea en La Plata, con un índice del 66% respecto del total. Aquí, el volumen para riego (108 hm3) fue prácticamente igual al utilizado para consumo humano (107 hm3) y ampliamente superior al empleado para la industria (32 hm3).

En lo referente a los servicios sanitarios, en el ámbito de todo el país, el porcentaje de población abastecida con agua potable creció del 29 al 57% desde 1920 a 1990, mientras que la beneficiada con cloacas lo hizo del 17 al 30%.

En el Conurbano la situación es mucho más desfavorable, pues se pasó del 76% de la población con agua potable en 1940, a solamente el 39% en 1990.

5. APTITUD

La aptitud de un recurso natural, en este caso del agua subterránea, depende de su calidad y también de la disponibilidad y productividad respecto del uso requerido. Así por ejemplo un acuífero de baja salinidad (apto por su calidad) resulta inapto para regar, por aspersión o surco, si tiene muy baja productividad, lo que deriva en pozos de escasos caudales.

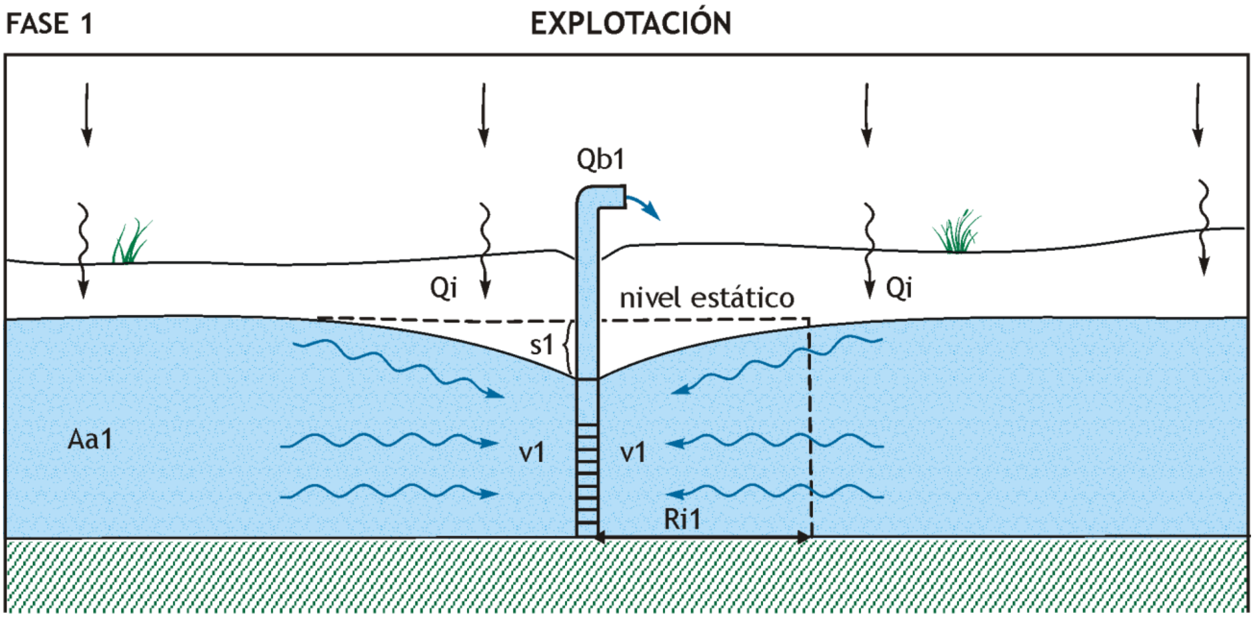
El manejo inadecuado de un acuífero mediante una extracción muy elevada (sobre-explotación), afecta su reserva y productividad, generando un deterioro hidráulico al que generalmente se le asocian otros procesos de degradación como salinización, contaminación artificial, asentamiento del suelo, pérdida de surgencia, desecamiento de humedales, etc.

6. SOBRE-EXPLOTACIÓN

En la figura 2 se esquematiza el concepto de sobre-explotación mediante un procedimiento comparativo respecto a la figura 1, que representa un estadío previo de explotación.

La fase 2 se caracteriza por un incremento en el caudal y en el tiempo de extracción respecto a la fase 1. En 2, el caudal bombeado (Q_{b2}) también supera con amplitud al que recibe el acuífero como recarga por infiltración (Q_i).

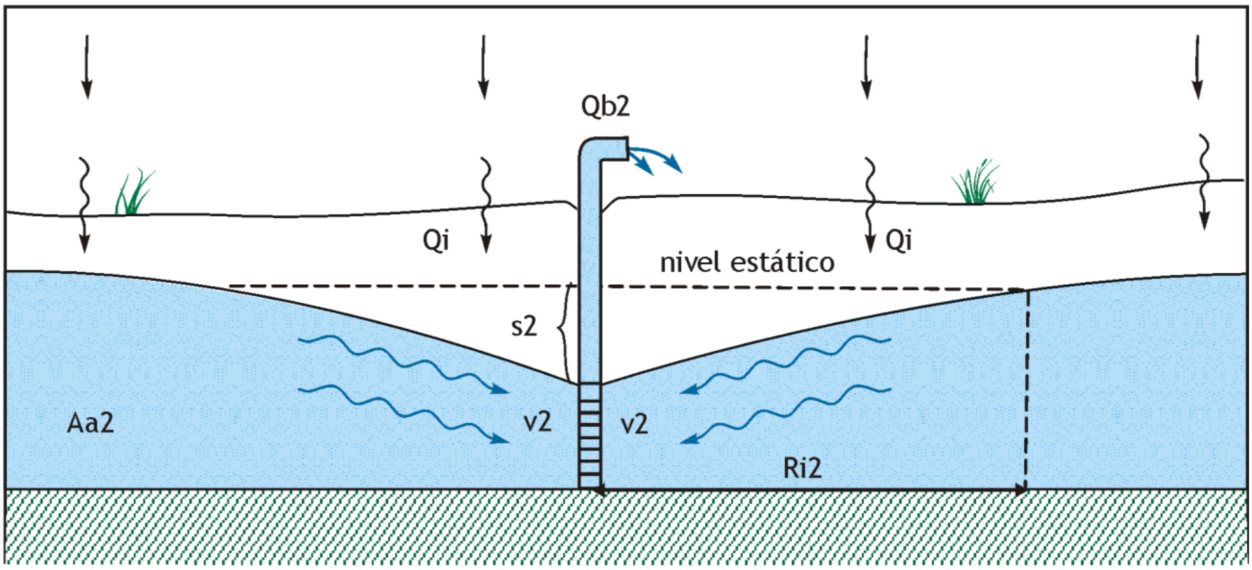
FIGURA 1



Qb1(Caudal bombeado ≅ Qi (Caudal infiltrado o recarga) Aa1 (Agua almacenada)
Ri1 (Radio del cono de depresión) v1 (Velocidad de flujo)

FIGURA 2

FASE 2 SOBRE-EXPLOTACIÓN



$Qb2 \gg Qi \quad Aa2 \ll Aa1 \quad s2 \gg s1 \quad Ri2 \gg Ri1 \quad v2 > v1$

La sobre-explotación esquematizada en esta fase, además de la disminución de la reserva (A_a), origina un descenso mayor del nivel dinámico o de bombeo (s_2 » s_1), un incremento en la velocidad de flujo ($v_2 > v_1$) y un aumento en el área afectada por la extracción (R_{i2} » R_{i1}), respecto a la fase de explotación.

En la práctica resulta muy difícil y a veces imposible establecer el límite por encima del cual la explotación se transforma en sobre-explotación. A este caudal normalmente se lo denomina **de seguridad, seguro, o safe yield** y su determinación es sumamente complicada pues no sólo debe estar en equilibrio con la recarga, cuya cuantificación también es muy difícil de establecer, sino que además no debe generar otros efectos indeseables como: salinización, por ascenso o invasión lateral; contaminación por migración descendente, como sucede con los NO3; subsidencia por compactación de suelos arcillosos; interferencia con otras baterías de extracción; etc.

Margat (1991) considera que en el término **sobre-explotación** se incluye a veces, a un estadío de desequilibrio hidráulico con disminución de reservas y en otras, al resultante de una explotación excesiva con consecuencias indeseables para el sistema hidrológico subterráneo (salinización). Además sostiene que la noción de sobre-explotación de un acuífero “es ambivalente, es decir ambigua” y que “su apreciación no puede ser independiente de los objetivos perseguidos con la explotación ni de las condiciones hidrogeológicas”.

Custodio (1991), entiende que la sobre-explotación (over-exploitation) constituye un concepto relativamente nuevo en hidrogeología y lo vincula fundamentalmente con los efectos adversos en la explotación del agua subterránea. Dice que es lo opuesto a caudal seguro (safe yield) y que el diseño y la distribución temporal de la extracción juegan un rol importante en los resultados de toda explotación. Refiere que su cotejo con la recarga constituye una tarea dificultosa, debido a: la incertidumbre que generalmente enmarca la cuantificación de esta última; la importancia y duración de los procesos en estadíos transitorios, o sea en desequilibrio dinámico; los cambios en la recarga derivados de las actividades humanas y a la posibilidad de modificarla por métodos artificiales. También cita que los cambios en la calidad, principalmente debidos a la mezcla con agua salada, constituyen factores importantes que deben considerarse al evaluar el caudal seguro respecto a la sobre-explotación de un acuífero, especialmente por el posible retardo en la manifestación de consecuencias indeseables y en la dificultad para identificarlos (monitoreo).

En virtud de lo expuesto, se puede concluir en que, si bien la sobre-explotación implica un concepto de marcado desequilibrio hidrodinámico, como consecuencia de una extracción que supera con amplitud y durante lapsos relativamente prolongados a la recarga natural, sus consecuencias suelen generar, además de la disminución de la reserva y de la productividad, otros efectos perjudiciales como salinización, contaminación, subsidencia, desecamiento, etc.

Seguidamente se mencionan algunos ejemplos de sobre-explotación de acuíferos en el mundo y en la Argentina.

- En Texas (EUA), el Acuífero Olgallala fue explotado intensivamente para riego entre 1940 y 1980, habiéndose extraído más del 40% de sus reservas permanentes. Esto derivó en descensos de los niveles piezométricos del orden de 50 a 60 m, con una reducción de 2/3 del espesor saturado del acuífero. El aumento de la potencia necesaria para bombear el agua hasta la superficie, generó un incremento de costos de alrededor del 600%.

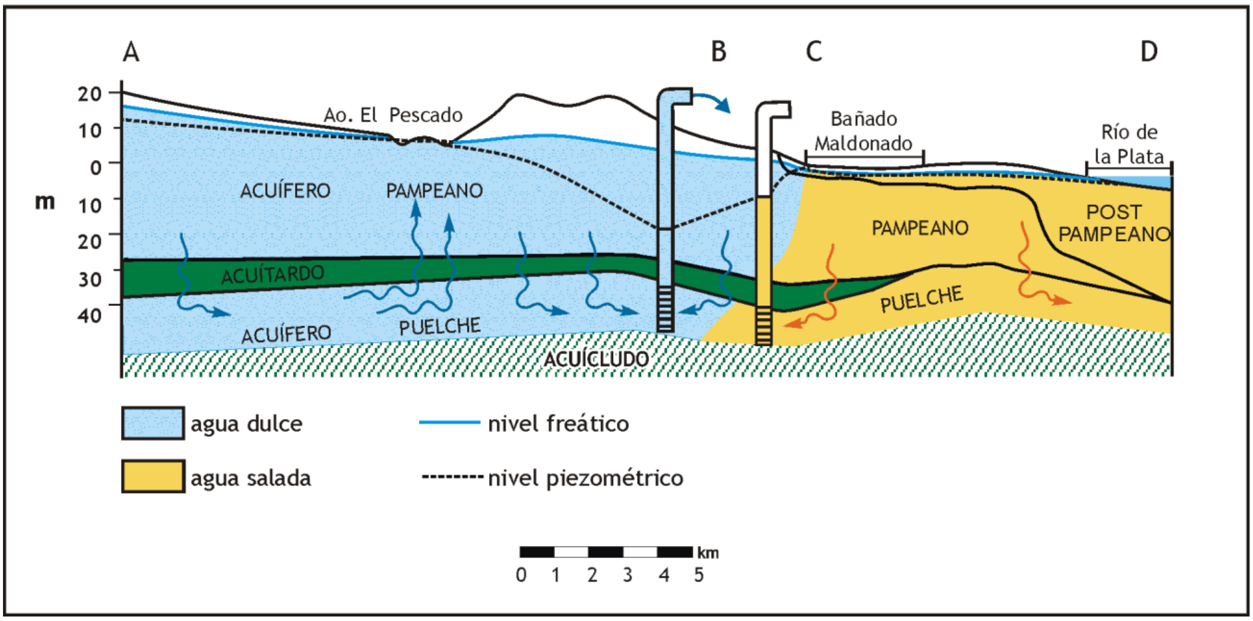
- La sobre-explotación del Acuífero de Lima, constituido por depósitos aluviales de piedemonte, generó un descenso promedio del nivel hidráulico de 2 m por año, con una reducción del espesor saturado original (300 m) de alrededor del 50%. Aquí, la recarga por infiltración de la lluvia es prácticamente nula, pues la precipitación media en Lima es menor a 50 mm/año y el mayor aporte lo generan dos ríos influentes. El exceso de extracción respecto a la reposición, es de unos 35 hm3/a que en definitiva se captan de la reserva, cuya disminución es la causa del descenso en el potencial hidráulico. Además de este efecto perjudicial, la sobre-explotación generó invasión de agua subterránea salada de origen marino.

- El efecto de subsidencia o hundimiento del suelo por extracción de agua subterránea, generalmente se produce por consolidación de sedimentos arcillosos, al perder presión hidráulica poral por descenso de la superficie piezométrica. Existen numerosas ciudades importantes en el mundo afectadas por este problema (Berlín, Londres, Houston, San Francisco, Venecia, Milán) pero el caso más grave se da en México DF, donde en algunos sitios del centro urbano la subsidencia supera los 10m.

- En Argentina, tiene antigua data la sobre-explotación en La Plata, que fue la primer ciudad importante del país en abastecerse exclusivamente con agua subterránea, habiéndose habilitado el servicio de agua potable en 1885. Hacia la década de 1950 debieron abandonarse 15 pozos de alta productividad, debido al avance de agua salada subyacente a la Planicie Costera del Río de la Plata (figura 3); la traza del perfil hidrogeológico se indica en la figura 22.

FIGURA 3

PERFIL HIDROGEOLÓGICO



En 1970 el desplazamiento del frente salino se producía a razón de unos 70 m por año hacia el centro de la ciudad. Hoy, el problema se ha atenuado en parte, pues muchos pozos emplazados dentro del ejido urbano no funcionan y en los activos se redujo el caudal (Auge y Bucich, 1996). Otro inconveniente tan o más grave que el anterior, es la contaminación con NO3 provenientes del acuífero libre superior, cuya migración descendente se origina en la disminución del potencial hidráulico del acuífero semiconfinado inferior (Puelche), que es el que provee de agua a la ciudad (Auge, 1997).

- Algo similar ocurrió en el Conurbano de Buenos Aires, aunque aquí, en algunos sitios, el agotamiento de la reserva fue significativamente mayor que en La Plata, lo que derivó en la transformación del Acuífero Puelche en libre, por el descenso de la superficie piezométrica por debajo de su techo semiconfinante (Quilmes, Berazategui, San Martín, Caseros). Salinización por invasión lateral se produjo en Lanús, Lomas de Zamora, San Martín, Olivos, Tigre, etc. En el Conurbano también es grave el problema generado por el alto contenido en NO3, que acceden al Acuífero Puelche por un proceso similar al citado para La Plata.

En los últimos 15 años, la detención del bombeo en numerosos pozos; algunos afectados por salinización, otros por contaminación y otros por el reemplazo del abastecimiento mediante agua potabilizada del Río de la Plata, generó otro problema por el ascenso de la superficie hidráulica y el afloramiento, o la ubicación a poca profundidad del agua freática (Hernández y González, 1997). Esto afecta la estabilidad de las edificaciones por la sobrepresión y corrosión de las armaduras de los cimientos, produce el anegamiento de sótanos y cocheras, construidos cuando el agua estaba más profunda, da lugar a roturas en calles y veredas por falta de sustento y sifonaje y, en las zonas que carecen de cloacas, el afloramiento de agua contaminada, genera focos de grave deterioro ambiental, altamente peligrosos para la salud de la población. La situación mencionada afecta a la mayor parte del Conurbano (9 millones de habitantes) de los cuales alrededor de un 50% sufre los efectos del ascenso freático. Otras actividades que aún no han tenido manifestaciones nocivas respecto a la disponibilidad y a la calidad del agua subterránea, por lo recientes, son: la extracción para uso industrial y para riego.

En el primer caso, en la zona de Zárate y alrededores, se han concentrado varios establecimientos cerveceros que requieren grandes volúmenes de agua para la producción de malta y cerveza. Evidentemente esta concentración de la explotación derivará en un estadío de sobre-explotación, que afectará significativamente al Acuífero Puelche en poco tiempo, dado que la recarga es significativamente menor que la demanda.

Respecto al riego, se lo ha implementado en forma indiscriminada, en gran medida para cultivos extensivos, debido a la disminución de la lluvia en los últimos años, particularmente en las provincias centrales (Córdoba, Santa Fe, La Pampa y Buenos Aires) y en la Mesopotamia (Entre Ríos y Corrientes). Las consecuencias de este mal manejo, no sólo afectarán a la reserva sino a la calidad del agua subterránea debido a que gran parte de la región considerada es semiárida o árida y los acuíferos dulces conforman lentes de poca extensión y volumen, rodeados y subyacidos por agua salobre o salada, cuya recarga está muy limitada por el déficit en el balance hídrico y el tamaño de las lentes.

Tanto en éste, como en el caso de las cerveceras, evidentemente no primó el criterio de es **preferible prevenir que curar**.

Otro caso de deterioro en la calidad del agua subterránea es el que se produjo en Mar del Plata, donde la sobre-explotación del Acuífero Pampeano originó la intrusión de agua salada de origen marino y obligó al abandono de numerosos pozos en los barrios Casino y Puerto. Por ello y para atender la demanda de agua potable, debió construirse una nueva batería de pozos a la vera de la Ruta Nacional 2, entre el Aeropuerto de Camet y el periurbano Norte de la ciudad.

Otros ejemplos conocidos de sobre-explotación para riego afectan al Valle de Tulún en San Juan, al del Río Mendoza en Mendoza y a los valles Calchaquíes (Cafayate-Salta y Santa María-Catamarca) y de Lerma en Salta.

Existen variadas técnicas y métodos destinados a revertir los efectos nocivos producidos por la sobre-explotación, pero estos dependen en gran medida de las características que presenten dichos efectos, del comportamiento del sistema subterráneo y de las posibilidades técnicas y económicas.

Si el daño producido es la disminución de la reserva, las técnicas para su corrección deben apuntar a favorecer la recarga. Esto puede lograrse: disminuyendo el caudal total extraído, cosa que no se puede practicar cuando la demanda es fija y no se dispone de fuentes alternativas; ampliando el área y el número de captaciones y reduciendo el caudal individual; o efectuando recarga artificial, para lo cual debe disponerse de un volumen suficiente de agua de buena calidad.

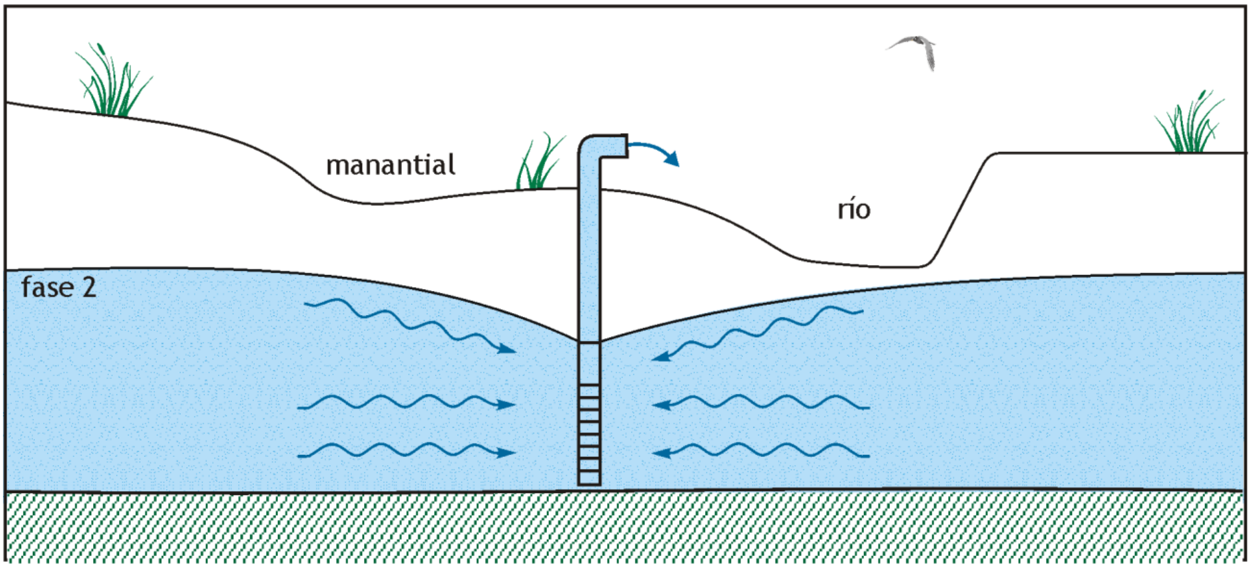
Si el problema es la intrusión de agua salada en un acuífero costero, las técnicas más empleadas para su remediación son: la dilución natural; la recarga por gravedad; el bombeo en la cuña salina para detener su avance; o la inyección de agua dulce para cortarla. Esto último se ha practicado con éxito en los acuíferos costeros de California, pero con elevados costos, que derivan del agua utilizada y de la energía necesaria para la inyección, dado que a mayor grado de confinamiento, más alta es la presión necesaria para lograr la inyección.

La subsidencia resulta irrecuperable en la práctica, particularmente donde existen sobrecargas importantes, como sucede en las ciudades. En ámbitos rurales, donde se restituyó la presión hidráulica por ascenso de la superficie piezométrica, se han registrado recuperaciones en los niveles de los suelos, pero las magnitudes no son trascendentes. En el caso de la subsidencia, el objetivo es lograr una explotación bajo la cual se minimice o se detenga el proceso de hundimiento.

En relación a la desaparición de fuentes de surgencia natural (manantiales), el desecamiento de terrenos anegadizos (humedales) y aún la pérdida de flujo superficial (ríos) (figura 4), su restauración dependerá de la posición de la superficie hidráulica, pues estos cuerpos, particularmente en

FIGURA 4

PERDIDA DE LA SURGENCIA Y DESECAMIENTO POR SOBRE-EXPLOTACIÓN

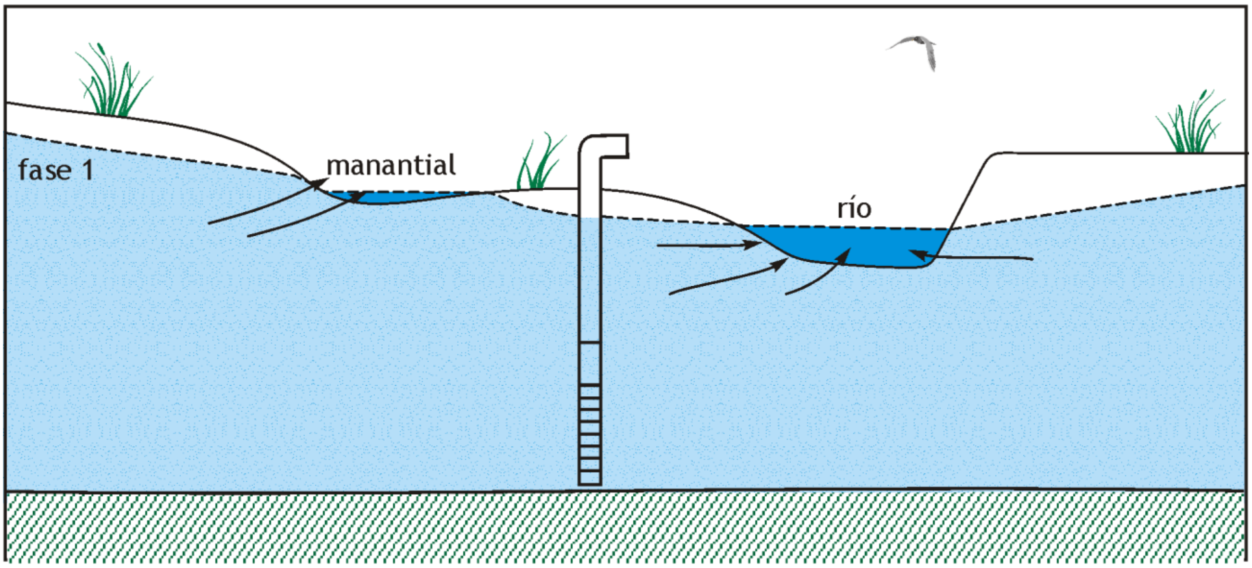


FASE 2: Pérdida de la surgencia y secamiento del río, por descenso de la superficie freática.

regiones húmedas, se originan en el afloramiento de agua subterránea. Por lo tanto volverán a aparecer cuando la disminución en el caudal extraído, o el aumento relativo de la recarga, hagan que el nivel piezométrico retome la posición que le permitía la descarga en superficie (figura 5)

FIGURA 5

SURGENCIA NATURAL



FASE 1: Surgencia natural

7. CONTAMINACIÓN

Ya se mencionó que es la alteración de las propiedades físicas, químicas y/o biológicas del agua, por la acción de procesos naturales o artificiales que producen resultados indeseables.

Características físicas: temperatura, pH, turbidez, olor, color. **Características químicas**: salinidad total (SDT), tipo y concentración aniónica, tipo y concentración catiónica, otros compuestos solubles, etc. **Características biológicas**: modificación de la composición biológica natural, ya sea introduciendo nuevos organismos o eliminando los existentes.

Además, la contaminación puede ser: **natural** y **artificial** y esta última, **directa o inducida** (Auge, 2004).

Natural. Es común la salinización del agua por contacto con sedimentos marinos y salinos, o la incorporación de sustancias que forman los yacimientos metalíferos (Pb, Hg, Zn y Cu), no metalíferos, radiactivos y petrolíferos y la disolución de oligoelementos como F y As, a partir de sedimentos de origen volcánico (Loess Pampeano).

Artificial directa. Es la más frecuente y se la puede clasificar de acuerdo al sitio donde se produce (**urbana** y **rural**) o a la actividad que la genera (**doméstica**, **industrial**, **agropecuaria**).

Urbana: vertidos domésticos; residuos de los escapes de los motores; pérdidas en las redes cloacales; lixiviados de basurales; humos y desechos líquidos, sólidos y semisólidos de la industria.

Rural: empleo de fertilizantes y plaguicidas, desechos humanos y animales.
Doméstica: vertido de jabones, detergentes, lavandina, materia orgánica (alimentos, fecal, basura en general). Cuando no se dispone de desagües cloacales, el resultado es la generación de ambientes propicios para la reproducción bacteriana y la formación de NH3, NO2 y NO3.
Industrial: Contaminación de la atmósfera por la eliminación de humos y otros compuestos gaseosos y del suelo y el agua, por vertidos líquidos, sólidos y semisólidos. Además por la infiltración de los contaminantes atmosféricos que caen solos o arrastrados por la lluvia.

La industria produce la gama más numerosa y variada de contaminantes. En los países desarrollados, a fines de la década de 1980, se estimaba en aproximadamente 1 millón la nómina de compuestos orgánicos. De estos, unos 40.000 se producen y se utilizan en forma corriente, pese a que un número significativo es tóxico en diferentes grados. A los citados hay que agregarle los metales pesados, fenoles, hidrocarburos, plaguicidas, etc. De los mencionados, algunos son altamente tóxicos, aún en concentraciones de millonésimas de gramo por litro de solución. En los anexos I, II, III y IV, se reproducen las normas de potabilidad establecidas en: Código Alimentario Argentino (CAA), Environmental Protection Agency (EPA), Ley 24051 de residuos peligrosos y Organización Mundial de la Salud (OMS).

En el anexo I se indican las características físicas, químicas y microbiológicas del agua potable, de acuerdo a lo establecido en el capítulo XII del CAA, actualizado al 2001. De los caracteres físicos resalta **turbiedad, olor y color**. A los caracteres químicos los subdivide en **sustancias inorgánicas y contaminantes orgánicos** y de los microbiológicos considera a las **bacterias coliformes, Escherichia coli, Pseudomona aerugionosa y mesófilas**.

Dentro de las sustancias inorgánicas, expresadas en mg/L, no diferencia a las **tóxicas** (As, Cd, CN, Hg, Pb) **del resto** como **Cl, SO4 y SDT**. Refiere 26 **contaminantes orgánicos**, entre ellos: THM, DDT, detergentes, Aldrín + Dieldrín, Lindano, Cl4C, Paratión, Malatión, con **límites máximos** expresados en microgramos por litro (µg/L).

El anexo II reproduce la norma de potabilidad para agua subterránea de EPA, traducida al español y actualizada a abril del 2000. Considera **contaminantes químicos inorgánicos, orgánicos, radionucleidos y micro-organismos**. Además del nivel máximo permitido del contaminante (NMC), su importancia radica en que indica los posibles efectos sobre la salud por exposición que supere el NMC y las fuentes de contaminación más comunes que afectan al agua subterránea.

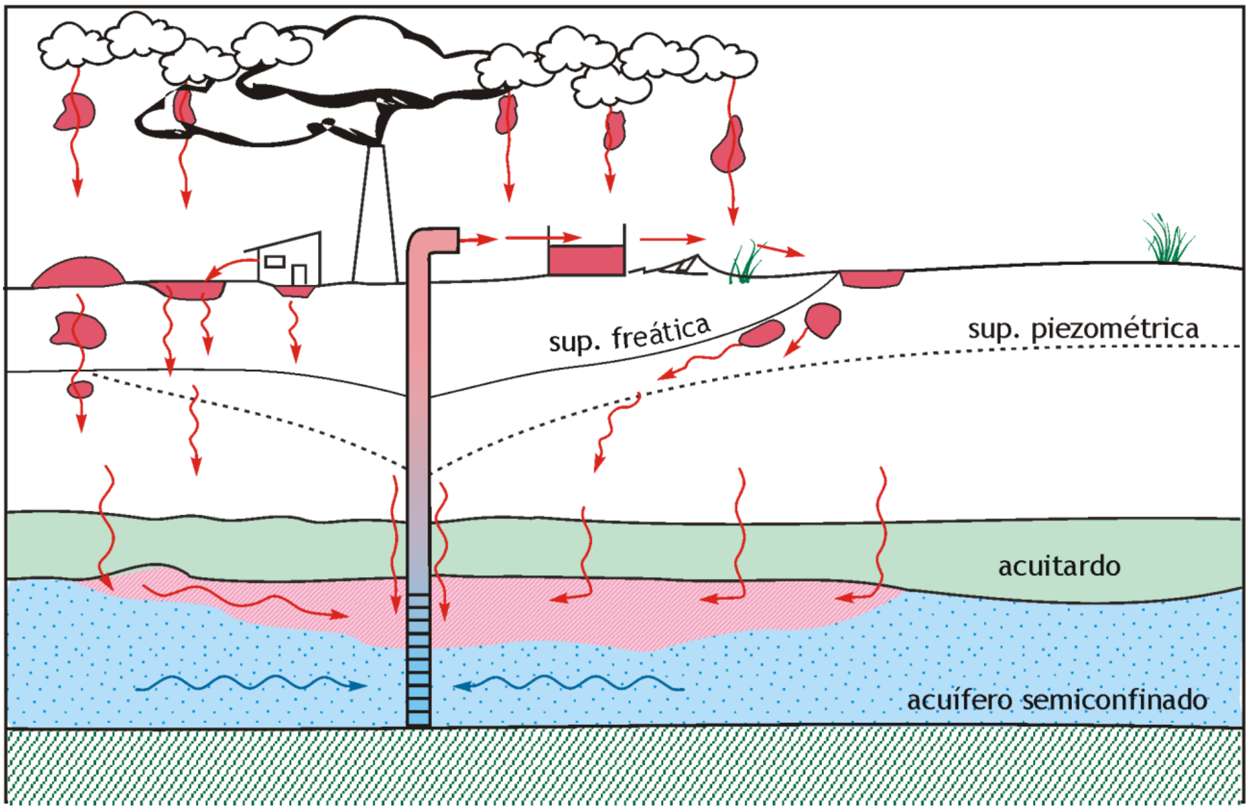
En el anexo III se indican los niveles guía (NG), de acuerdo al Decreto Reglamentario 831/93 de la Ley 24.051, que trata sobre el régimen de desechos peligrosos. En el Anexo II Tabla I de dicho Decreto, **se establecen los NG de calidad de fuentes de agua para bebida humana con tratamiento convencional, señalando el constituyente peligroso y el correspondiente NG expresado en µg/L.**

En el anexo IV se vuelcan los niveles guía recomendados por la OMS, (actualización al 2004), obrantes en: Guidelines for Drinking-Water Quality – Third Edition. **Considera aspectos químicos, microbiológicos y radiológicos y, además de los NG recomendados**, incursiona en otros temas como: grado de precisión de las diferentes técnicas de laboratorio; tratamiento de aguas, indicando las técnicas más utilizadas (cloración, ozonación, filtración, aireación, coagulación, adsorción, intercambio iónico, ósmosis inversa); tratamiento para el control de la corrosión; NG de acuerdo a la categoría de la fuente (natural, industrial, doméstica, agrícola).

En la figura 6 se reproduce esquemáticamente la producción industrial de contaminantes, la emisión al aire y los vertidos sobre el suelo y el subsuelo. Los humos contienen contaminantes en diferentes estados (sólido, líquido, gaseoso) que deterioran al aire y luego llegan al suelo por su propio peso o arrastrados por la lluvia. Generalmente tienden a concentrarse en las depresiones topográficas (ríos, lagos, lagunas), llevados por el escurrimiento superficial, o a infiltrarse y pasar al subsuelo, si existen condiciones favorables para la recarga. En la figura, se aprecia también la migración a través de capas de baja permeabilidad (acuitardos), favorecida por el bombeo del acuífero semiconfinado subyacente, lo que genera una sobrecarga favorable al acuífero libre sobrepuesto. Este proceso fue el que permitió la migración de los NO3 contenidos en el Acuífero Pampeano hacia el Puelche infrapuesto, con el consecuente deterioro en la calidad de este último.

FIGURA 6

CONTAMINACIÓN AÉREA, SUPERFICIAL Y SUBTERRÁNEA

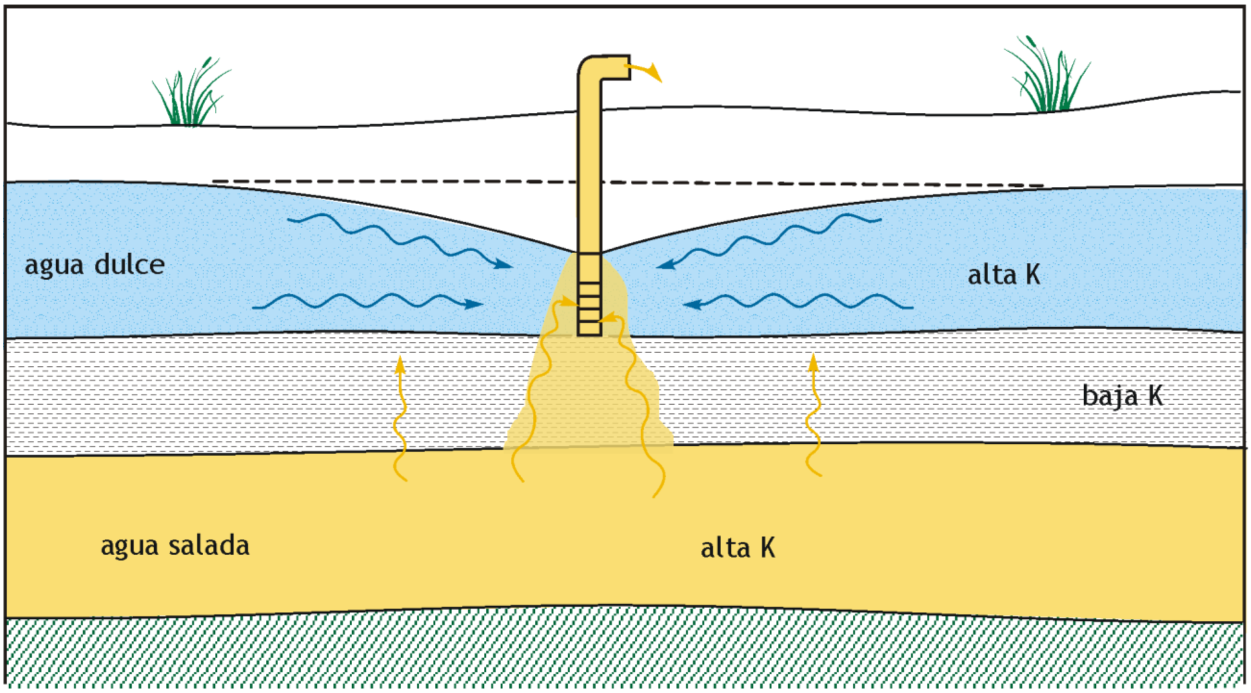


Agropecuaria: Se origina por el empleo de plaguicidas y fertilizantes para mejorar la productividad. Los primeros (organoclorados y organofosforados), son altamente tóxicos como DDT, Aldrín, Dieldrín, Paratión, Malatión, Heptacloro, etc. Los carbamatos también son plaguicidas, aunque mucho menos tóxicos que los anteriores. Los fertilizantes más comunes son: materia orgánica y nitrogenada, fósforo y potasio. La materia nitrogenada se oxida a NO3 que son muy solubles, estables y móviles, mientras que el P y el K, y sus derivados, son fijados con facilidad por las partículas arcillosas del suelo. El comportamiento del contaminante, en relación a su solubilidad, movilidad y degradabilidad, condicionan su permanencia y perdurabilidad en el medio. Así, las bacterias provenientes de los vertidos fecales, rara vez subsisten más de 50 días en el agua si esta no posee una adecuada concentración de materia orgánica. Los NO3 por su parte pueden mantenerse en solución en forma casi indefinida, salvo que sean reducidos a NO2, NH4, NH3, o N2, por actividad bacteriana, o por otro medio reductor.

Artificial inducida: Es la que deriva de la sobre-explotación; la más común es la salinización en acuíferos costeros o por ascenso de agua salada de fondo en acuíferos continentales lentiformes, portadores de agua dulce (figura 7).

FIGURA 7

SALINIZACIÓN POR ASCENSO VERTICAL

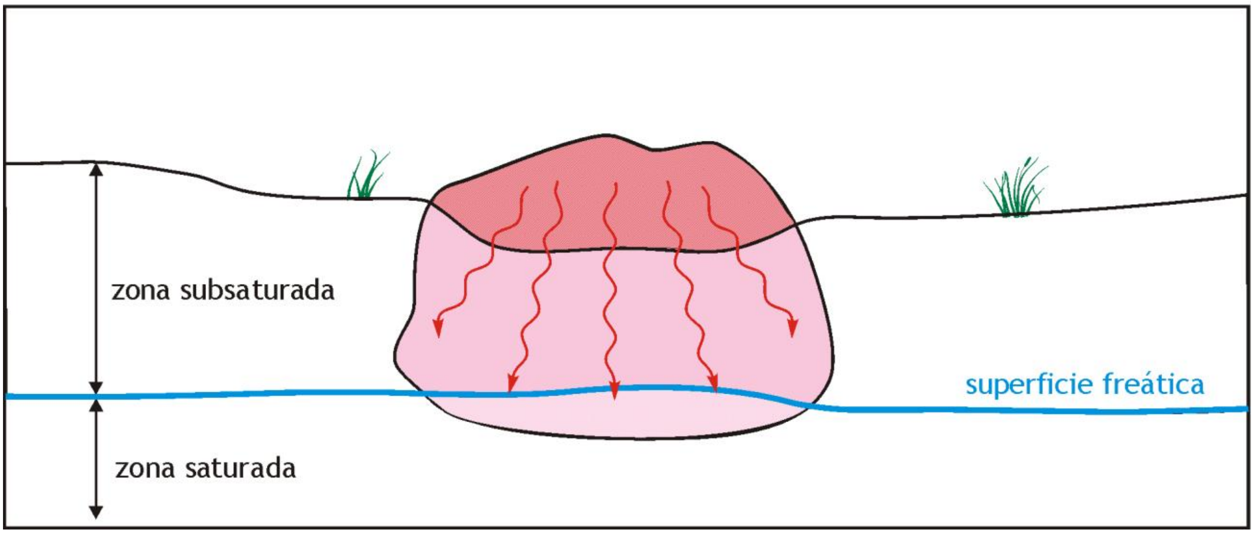


7.1. ZONA SUBSATURADA

Es la sección que se ubica inmediatamente por encima de la superficie freática y en ella coexisten los 3 estados de la materia (sólido, líquido y vapor) (figura 12). La zona subsaturada posee gran trascendencia hidrogeológica, no sólo en el aspecto dinámico sino también geoquímico, pues en ella, particularmente en su franja más superficial (franja edáfica), es donde se produce la mayor incorporación de las sales solubles que caracterizan al agua subterránea de ciclo. Además, la zona **subsaturada o de aireación, o no saturada**, es un efectivo filtro natural frente a los contaminantes, en su recorrido descendente hacia la zona saturada, o del agua subterránea propiamente dicha (figura 8).

FIGURA 8

CONTAMINACIÓN DE LA ZONA SATURADA

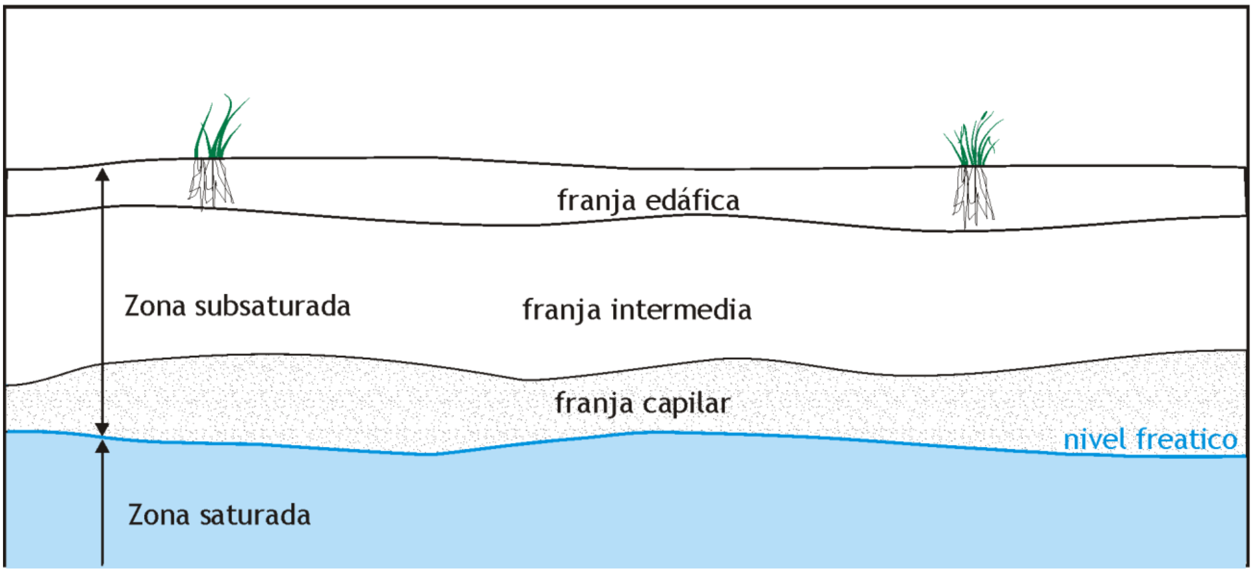


Generalidades. La eficacia de la zona subsaturada para impedir o dificultar el acceso de los contaminantes al agua subterránea deriva de: la capacidad de fijación que poseen los microporos, la interacción del sólido-agua-contaminante-aire, el intercambio iónico, la actividad biológica, la adsorción sobre las partículas finas, la formación de complejos de baja solubilidad, etc.

Dentro de la zona subsaturada, la franja edáfica (hasta donde penetran las raíces) es la más efectiva como filtro natural, debido a su alto contenido en materia orgánica y fuerte actividad biológica (figura 9).

FIGURA 9

COMPONENTES HIDRÁULICOS DEL SUBSUELO



Los contaminantes solubles, persistentes y estables (Cl, NO3) no son retenidos en la zona de aireación si existe excedente en el balance hídrico e infiltración efectiva (zonas húmedas), aún cuando ésta tenga baja permeabilidad y un espesor considerable.

Comportamiento de los contaminantes más comunes

Nitratos

La contaminación con NO3 se ha convertido en una de las causas principales de deterioro del agua subterránea, tanto en los países desarrollados como en los que se están desarrollando.

También se presenta en los ámbitos urbanos, provistos de servicios sanitarios y en aquellos que no los tienen; en pequeñas ciudades o poblados y en las megalópolis como México, Lima, Sao Paulo y Buenos Aires; en las comarcas rurales y en los emplazamientos industriales.

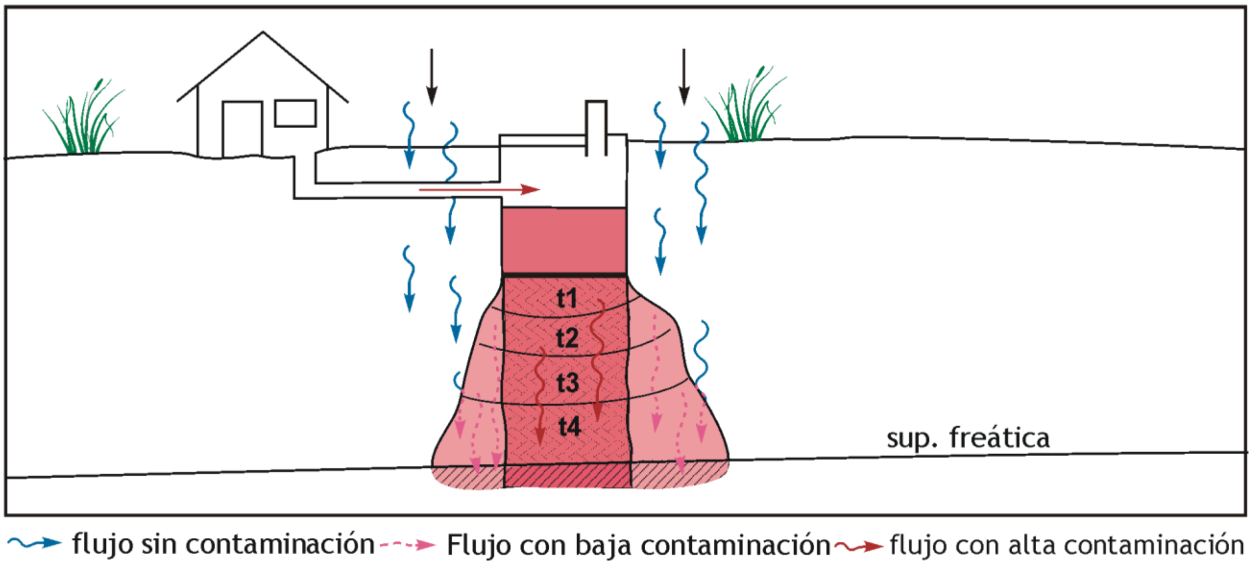
En definitiva, en la actualidad, la contaminación con nitratos aparece como la más difundida mundialmente y vinculada a la mayor parte de las actividades humanas.

En los **centros urbanos carentes de servicios cloacales** los NO3 derivan de la degradación de la materia orgánica, mayormente de origen fecal. Los pozos ciegos o negros, en los que se vierten los desechos fecales, son las fuentes de emisión principales.

El espesor y la permeabilidad de la zona subsaturada condicionan la velocidad y el tiempo de tránsito hasta la saturada, favoreciendo la disminución en la concentración, por dilución, en el caso de producirse infiltración efectiva de agua no contaminada. Sin embargo, la zona de aireación por sí sola, no es hábil para detener a los nitratos cuando existe flujo vertical descendente (figura 10).

FIGURA 10

VERTIDO EN POZO ABSORBENTE

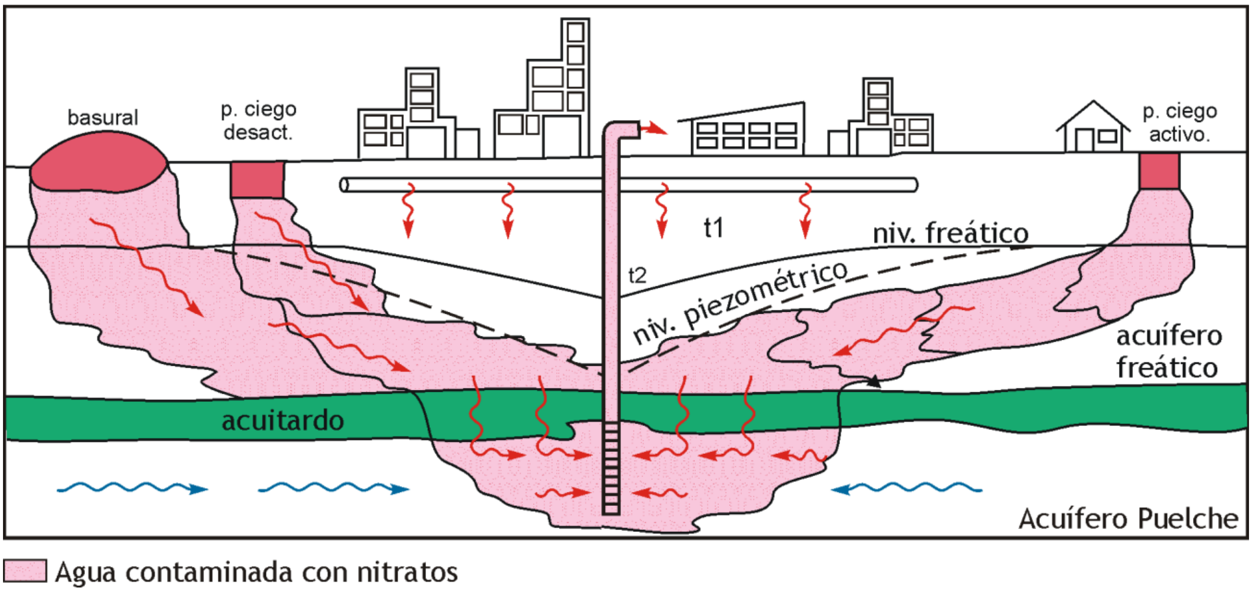


En las **ciudades con servicios cloacales**, los NO3 derivan de pérdidas en las redes, de aportes provenientes de los sectores suburbanos, que carecen o tienen poca cobertura cloacal, de viejos pozos ciegos que estaban situados en los cascos urbanos y fueron reemplazados posteriormente por las redes sanitarias y, en algunos casos, de antiguos repositorios de basura que estuvieron emplazados en la vecindad del ejido poblado y que luego de desactivados, fueron empleados como terrenos para la construcción de viviendas (Auge et al, 2004).

En los ámbitos urbanos es frecuente que la contaminación con NO3 no sólo deteriore la calidad del agua freática, sino también la de acuíferos semiconfinados, como sucede en gran parte del Conurbano de Buenos Aires y en La Plata, donde la contaminación es de tipo areal o regional y llega al acuífero inferior (semiconfinado), luego de atravesar el acuitardo que lo separa de la capa freática, por el proceso de filtración vertical descendente. Este proceso se genera por la disminución de presión hidráulica en la base del acuitardo, derivada de la importante extracción a que está sometido el acuífero semiconfinado, para agua potable y uso industrial (figura 11).

FIGURA 11

CONTAMINACIÓN CON NO3 DEL ACUÍFERO PUELCHE



En la zona subsaturada, la materia orgánica se degrada por actividad biológica, generando aminas las que producen nitrógeno orgánico y éste a su vez pasa a NO2 y a NH4, que son inestables y se oxidan rápidamente para formar NO3, que es la forma más estable y móvil de la materia nitrogenada.

En el **campo**, los NO3 derivan de fertilizantes a base de abonos, sulfato de amonio o urea, en los sitios cultivados y de la bosta y orín existentes en corrales, tambos, criaderos de aves y en la vecindad de bebederos. También es común encontrar tenores altos de NO3, derivados de los pozos ciegos que se utilizan para las descargas fecales de las viviendas (figura 10). En general este tipo de contaminación es puntual o localizada, particularmente la vinculada a corrales y pozos ciegos. En la faja cultivada que rodea a La Plata, también tiene carácter local, pese a que la carga de materia orgánica y nitrogenada que se aplica al suelo para mejorar su productividad es alta (Auge y Nagy, 1996).

La práctica de cría de ganado mediante feed lot, que se está difundiendo rápidamente, consiste en la concentración de una gran cantidad de animales por unidad de superficie, lo que origina una alta carga de desechos orgánicos (bosta y orín) que inevitablemente derivará en una fuerte contaminación biológica y con materia nitrogenada del agua subyacente a los mismos.

La industria que produce alimentos, la que faena, la que embute carnes y la que procesa y fabrica productos lácteos, genera desechos con alta proporción de materia orgánica, que si no son adecuadamente tratados y dispuestos, darán lugar a la formación de NO3, que pueden contaminar al agua subterránea luego de atravesar la zona subsaturada.

Pesticidas o plaguicidas

Se agrupa con estas denominaciones a los herbicidas, insecticidas y fungicidas. Se trata de sustancias químicas de composición muy diversa, en general de carácter orgánico y de alta toxicidad aún en muy bajas concentraciones (µg/L). Los pesticidas se pueden clasificar en: organoclorados, altamente tóxicos, poco móviles, pero muy persistentes en el suelo y los vegetales; organofosforados, altamente tóxicos, con alta movilidad y baja persistencia y los carbamatos, menos tóxicos que los anteriores.

Organoclorados (OCl). Se caracterizan por un importante efecto residual (persistencia) y por su baja solubilidad y movilidad. Justamente el efecto residual y su alta toxicidad, agravada por el efecto acumulativo en el organismo, hizo que algunos fueran prohibidos en los países del Norte, y últimamente en Argentina. Felizmente, los OCl están compuestos por moléculas grandes por lo que son fijados con facilidad en el suelo, especialmente por las partículas arcillosas. Ello inhibe su movilidad y hace muy difícil que puedan atravesar la zona subsaturada y alcanzar al agua subterránea. En sitios donde la zona de aireación es delgada (menos de 2 m) y compuesta por material aluvial mediano y grueso (arena, grava) los organoclorados pueden llegar hasta la sección superior de la capa freática. Los OCl usados con frecuencia como plaguicidas son el DDT, Aldrín, Dieldrín, Heptacloro y Lindano, todos con persistencias en el suelo del orden de años.

Organofosforados (OP). También son altamente tóxicos, mucho más solubles y móviles que los OCl, pero mucho menos persistentes. Los más utilizados son: Malatión, Paratión, Fentión y Dimetoato. Sus vidas medias en el suelo van de semanas a meses.

Carbamatos. Son mucho menos agresivos que los anteriores y con persistencias similares a los OP. Los más empleados son el Carbaryl y Carbofuran.

El efecto producido por los distintos pesticidas en el organismo del hombre y de los animales es poco conocido; sin embargo, la OMS señala que alrededor de 2 millones de personas se intoxican anualmente en el mundo con plaguicidas, de las que unas 200.000 mueren. La EPA (Environmental Protection Agency de EUA) considera que la mayoría son potencialmente cancerígenos o generadores de alteraciones en el sistema nervioso, hepático o renal, y por ello, les fija límites máximos en el agua que van desde unidades de µg/L a décimas de µg/L (anexo II).

Metales pesados

Forman un grupo de compuestos poco solubles y altamente tóxicos, en bajas concentraciones. La mayoría de las normas les asigna límites de potabilidad mayores, que a los pesticidas y las más severas se refieren al Cd y al Hg.

Los metales pesados más comunes son Cd, Mn, Pb, Cu, Cr, Ni y Zn y derivan de contaminación, principalmente de la producida por la industria. Más raro es que tengan origen natural, generalmente relacionados con yacimientos metalíferos. En general no se presentan como iones libres, sino formando complejos aniónicos asociados a compuestos orgánicos, de baja movilidad, aunque esta depende de su grado de oxidación. El Cr^{+3} p.ej. es fácilmente retenido por el terreno, pero como Cr^{-4} es mucho más móvil y en forma de cromato ($CrO_4^{=}$), es mucho más soluble y móvil.

Hidrocarburos

Los HC son compuestos orgánicos que por sus características, conviene tratarlos independientemente. En efecto, se diferencian de los plaguicidas, por su densidad, volatilidad e inmiscibilidad. Si bien existen excepciones, los HC más comunes suelen ser menos densos que el agua, es frecuente que se volatilicen en mayor o menor medida y en general son inmiscibles en agua, por lo que pueden presentarse formando una fase líquida no acuosa (FLNA).

La propagación de un HC en la zona subsaturada depende de las características propias del suelo, o la roca que la forma (porosidad, permeabilidad, composición mineralógica, anisotropía, heterogeneidad, espesor) y del grado de saturación que presente, por un lado y de las propiedades del HC por el otro (densidad, viscosidad, solubilidad).

En términos generales los HC se pueden clasificar en parafínicos, nafténicos, aromáticos volátiles y aromáticos polinucleares, ordenamiento en el que acrecientan su solubilidad.

Para estimar la propagación vertical de un HC liviano, se puede utilizar la siguiente ecuación (Kozlovsky, 1984):

$$\mathbf{p = HCi \;.\; 1000/Ai \;.\; Cs}$$

p: profundidad alcanzada por el HC (m) HCi: cantidad de producto infiltrado (m3) Ai: área en la que se produjo la infiltración (m2) Cs: capacidad de retención del suelo frente al HC (L/m3)

Las magnitudes aproximadas de Cs en función de la granometría de la zona subsaturada son (tabla 4):

TABLA 4

CAPACIDAD DE RETENCIÓN DEL SUELO FRENTE A LOS HC

Litología	L/m3
grava y grava arenosa	5
arena gruesa	8
arena mediana	15-25
arena fina y arena arcillosa	40

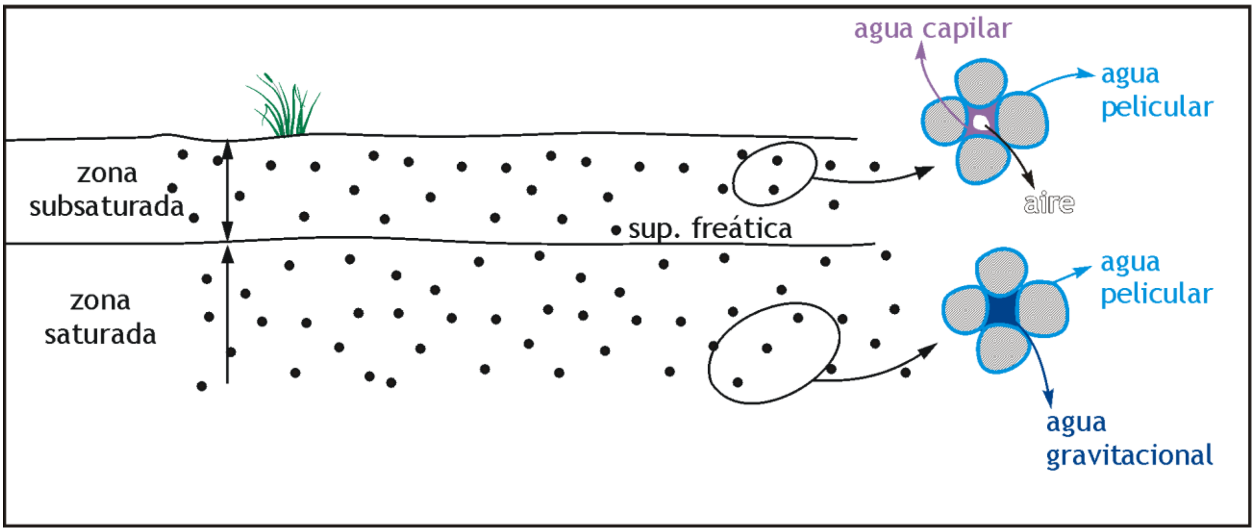
7.2. ZONA SATURADA

En la zona saturada sólo se presentan los estados líquido (agua) y sólido (granos).

El agua contenida en la zona de saturación es de dos tipos. Una prácticamente inmóvil, está adherida a la superficie de los clastos con una fuerza superior a la de la gravedad que, generalizando, se la puede denominar pelicular. La otra, que se dispone recubriendo a la pelicular, es móvil bajo la acción gravitatoria (figura 12), por lo que se llama agua gravitacional y dado que es la que se extrae en las obras de captación, resulta la más peligrosa como medio de transporte de eventuales contaminantes.

FIGURA 12

TIPOS DE AGUA EN EL SUBSUELO



Ya se mencionó que el desplazamiento de un contaminante en el agua está controlado por varios factores: la solubilidad, la reactividad con el agua y con el suelo, el tamaño molecular, la relación disolución - precipitación, la permeabilidad y porosidad del medio, la persistencia, la difusión molecular, la dispersión mecánica, etc.

De cualquier manera, la velocidad de propagación no puede ser mayor que la del agua subterránea y el sentido seguirá al del flujo hidráulico. Algunos compuestos altamente solubles y móviles y que no reaccionan con el componente sólido (Cl, NO3), se mueven prácticamente a la misma velocidad que el agua y por ello se los emplea como trazadores. Los NO3, sin embargo, pueden ser reducidos por bacterias desnitrificantes, que, en el caso de existir, modifican significativamente su concentración.

Dado que al tratar el tema en la zona subsaturada se hizo referencia a los contaminantes generados por diferentes tipos de actividades y a sus características específicas, aquí se tratará sobre el comportamiento particularmente dinámico de los mismos.

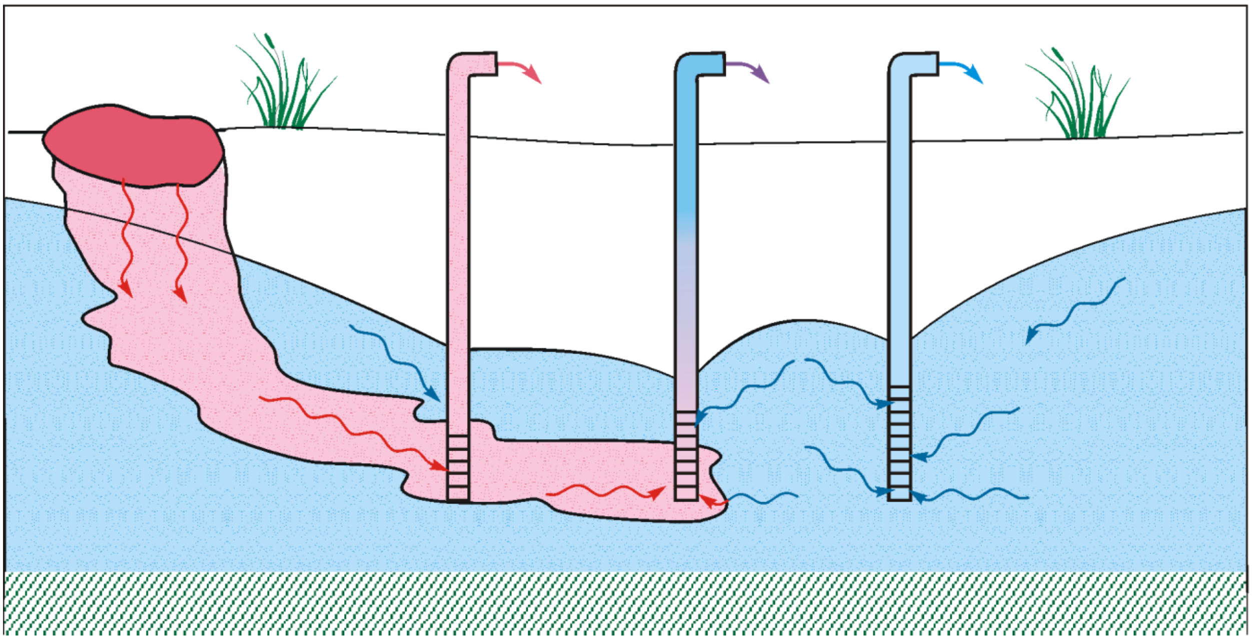
En lo que hace al volumen del recurso deteriorado, se puede clasificar a la contaminación en puntual y difusa.

7.2.1. Contaminación Puntual

Afecta a un volumen reducido del acuífero, extendiéndose sobre una superficie pequeña (Ej. contaminación que afecta a un pozo o a unos pocos pozos) y se caracteriza por presentar elevadas concentraciones, pero que disminuyen rápidamente por dilución, si se elimina la fuente de contaminación (figura 13).

FIGURA 13

CONTAMINACIÓN PUNTUAL



7.2.2. Contaminación Difusa

Afecta a volúmenes significativos del acuífero y en general presenta concentraciones relativamente bajas del o los contaminantes, pero es de más difícil corrección que la puntual. En el ejemplo graficado en la figura 10, la contaminación deteriora al acuífero freático, que es el más expuesto, pero también al semiconfinado subyacente, mediante el flujo descendente a través del acuitardo. Este mecanismo es el responsable del incremento en los tenores de NO3 registrados en el Acuífero Puelche (semiconfinado) en el Conurbano Bonaerense y en La Plata.

La llegada de un contaminante no reactivo (no se separa del agua, ni reacciona, ni es retenido por el terreno) a un pozo, se produce luego de su pasaje a través de las zonas subsaturada y saturada.

A efectos de disponer de órdenes de magnitud respecto al tiempo de tránsito, considerando un medio isótropo y homogéneo, se pueden emplear las siguientes ecuaciones para contaminaciones de tipo puntual (Custodio 1994):

$$ta = H.mr / R \qquad ts = d.m / K.i$$

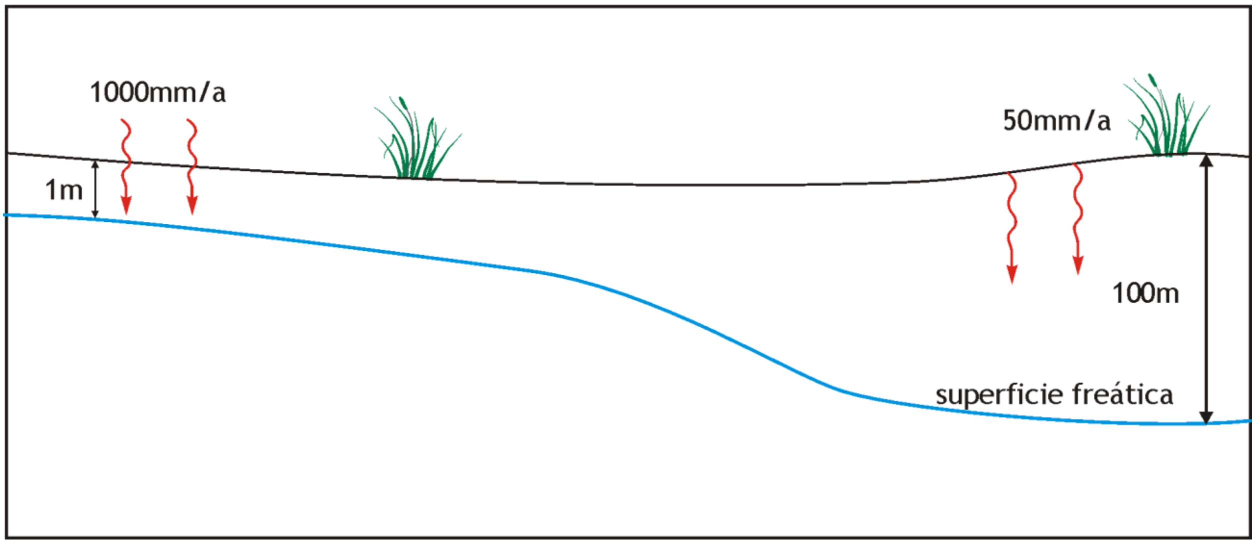
ta: tiempo de tránsito por la zona subsaturada H: espesor de la zona subsaturada mr: humedad relativa del suelo R: recarga local ts: tiempo de tránsito por la zona saturada d: distancia horizontal (foco - captación) m: porosidad K: permeabilidad i: gradiente hidráulico

La ecuación para el medio subsaturado es demasiado simplista, pues no contempla la permeabilidad vertical del mismo.

Considerando una humedad relativa del suelo del 10%, se obtiene un tiempo de tránsito de 1 mes para una recarga alta (1.000 mm/año) y un reducido espesor de la zona de aireación (1 m). Para la mima humedad relativa, pero con baja recarga (50 mm/año) y una profundidad de la superficie freática de 100 m, el tiempo de tránsito es del orden de 200 años (figura 14).

FIGURA 14

TIEMPO DE TRÁNSITO EN LA ZONA SUBSATURADA

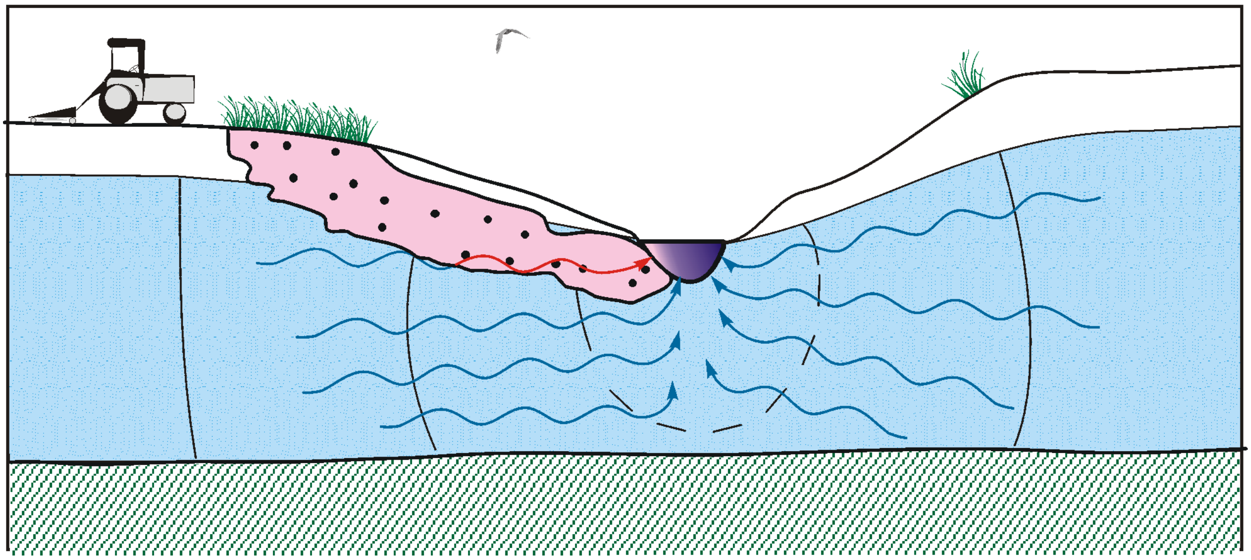


7.3. PROPAGACIÓN

La forma de producirse, de propagarse, de situarse y la intensidad de la contaminación, dependen de las características y ubicación de la fuente de polución, de las propiedades del contaminante (reactivo - no reactivo) de su movilidad, de la recarga y de las características del medio (permeabilidad,

FIGURA 15

RÍO EFLUENTE



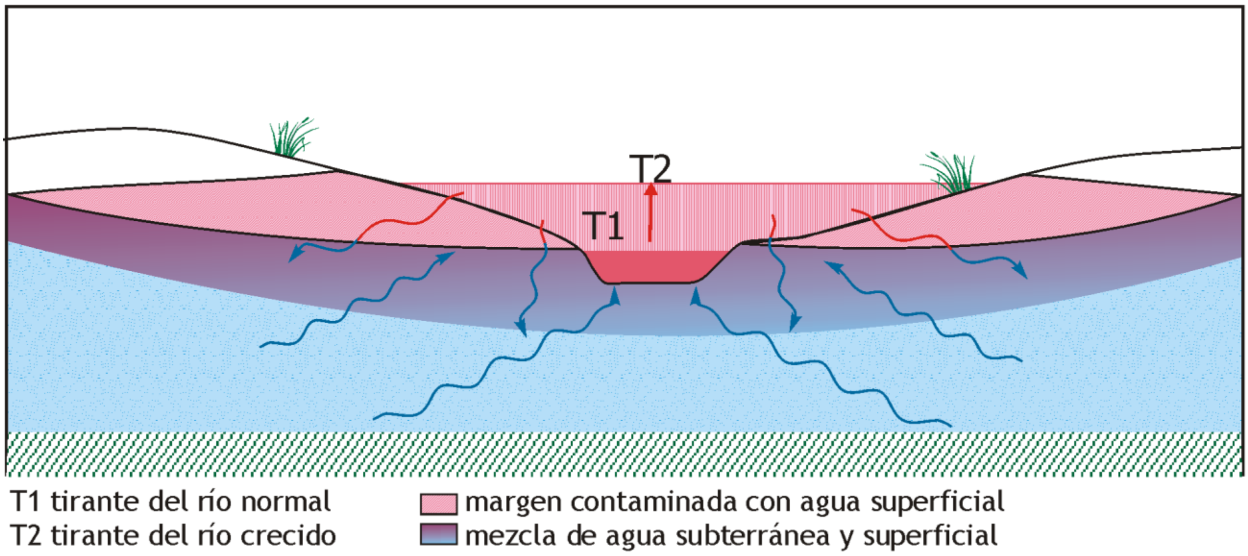
porosidad, anisotropía, heterogeneidad), que inciden en las del agua (gradiente hidráulico, velocidad de flujo). Por ello, existe una variedad muy grande de situaciones, en realidad una para cada caso, lo que hace muy difícil realizar generalizaciones.

La relación de potenciales hidráulicos entre el agua superficial y la subterránea, controla la posibilidad de que se produzca contaminación de una de ellas, a partir de la otra. Así, si el río es efluente (recibe aporte subterráneo), no es posible que exista contaminación difusa del agua subterránea a partir de la superficial, pero sí de esta última como resultado del aporte subterráneo (figura 15).

Solamente puede producirse contaminación localizada en la vecindad de las márgenes, si el tirante del río sube y se invierte la relación de potenciales hidráulicos (figura 16).

FIGURA 16

RÍO EFLUENTE EN CRECIDA

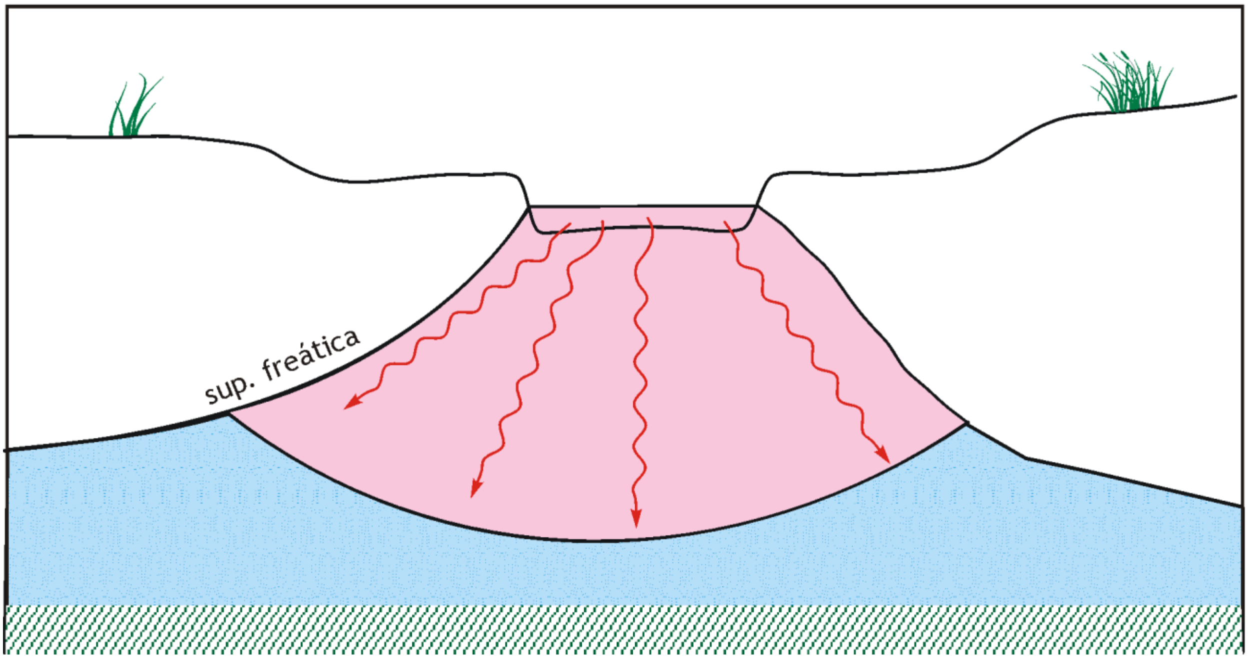


Cuando el río retorna a su tirante normal, la condición hidráulica vuelve a la de la figura 15.

El agua subterránea corre peligro cierto de contaminación a partir del agua superficial, si el río es influente (figura 17).

FIGURA 17

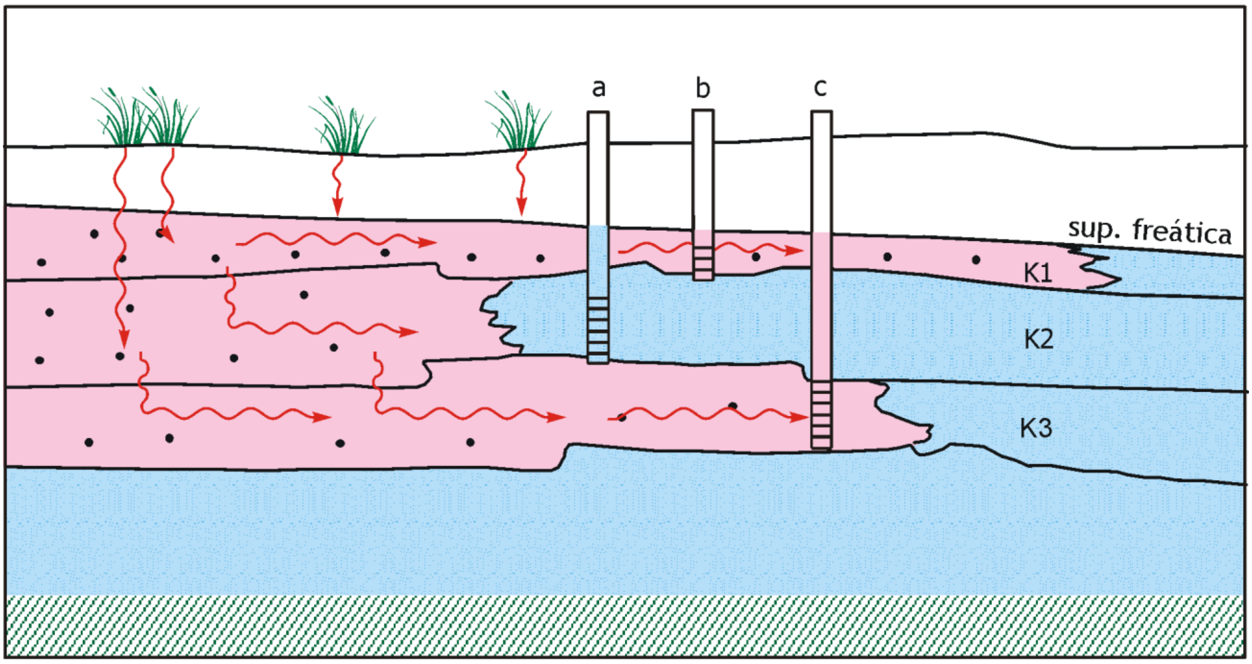
RÍO INFLUENTE



En un acuífero heterogéneo como el de la figura 18, la contaminación difusa desde superficie, se propaga con relativa facilidad a través del medio 1. Parte de ella llega al medio 2, donde la velocidad disminuye notoriamente

FIGURA 18

CONTAMINACIÓN EN UN ACUÍFERO HETEROGÉNEO



K1 ≅ K3 » K2

🟥 Agua contaminada

debido a su baja permeabilidad. En 3, por el aumento de la permeabilidad, vuelve a incrementarse la velocidad de propagación.

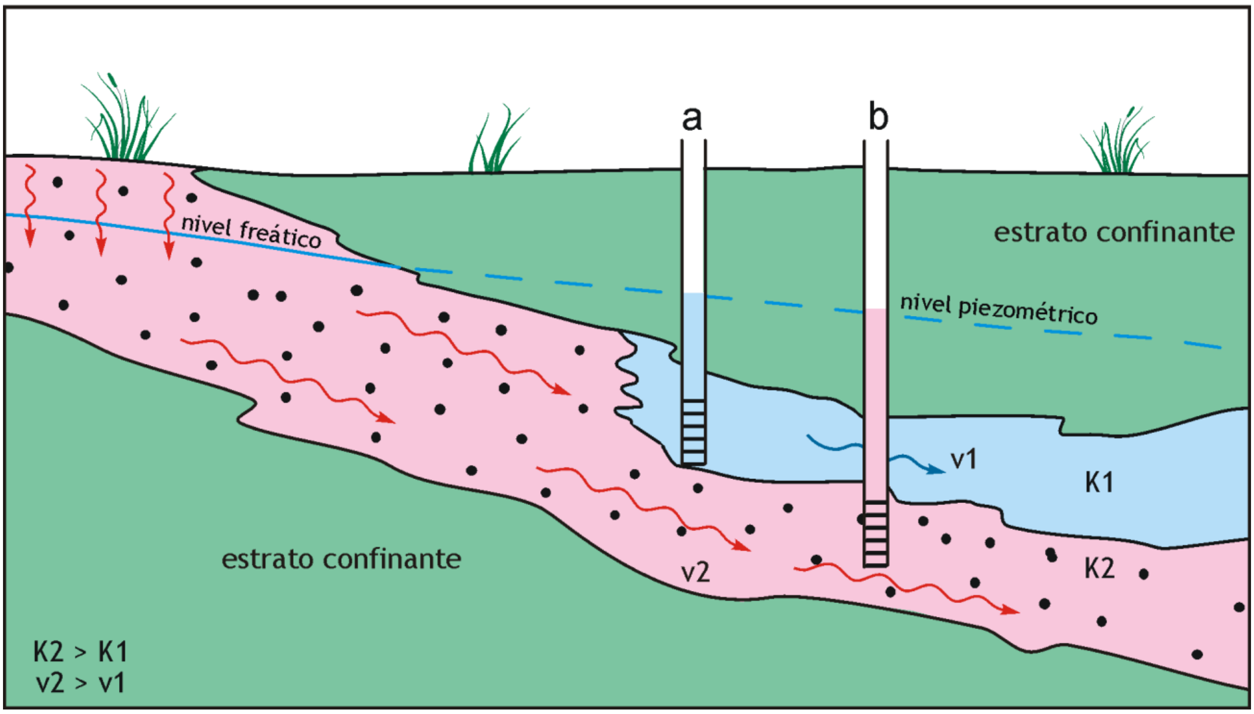
El pozo (b) registra la pluma de contaminación en un tiempo (t1) pero no el (a), más cercano a la fuente de polución, debido a la baja velocidad de propagación en el medio 2. El 3, más profundo, pese a manifestar un retardo respecto al medio 2 frente al flujo vertical, presenta un mayor desplazamiento lateral de la pluma, que es identificada por el sondeo (c), en un tiempo t2, mientras que el sondeo (a), aún no la registra.

En caso de cesar el ingreso de contaminantes al sistema subterráneo, la recarga será mucho más activa en los medios 1 y 3, lo que dará lugar a una disminución relativamente rápida de la contaminación por dilución. El medio 2, debido a su baja dinámica, recibirá menor aporte y por ende el proceso de dilución será bastante más lento, lo que permitirá una mayor persistencia de la contaminación (Auge, 2004).

En un acuífero confinado, la polución puede producirse en el ámbito de recarga, generando contaminación difusa. Como en el caso anterior, si el acuífero es heterogéneo y la unidad geológica presenta estratificación gradada, casi seguramente K2 > K1 y la velocidad de propagación por el medio 2 (v2 > v1), por lo que la pluma avanza más rápidamente en 2 que en 1 y es detectada antes en el pozo b (figura 19).

FIGURA 19

CONTAMINACIÓN EN UN ACUÍFERO CONFINADO



Si finaliza el aporte de contaminantes, en el pozo a se seguirá registrando la contaminación bastante tiempo después de su desaparición en el sondeo b.

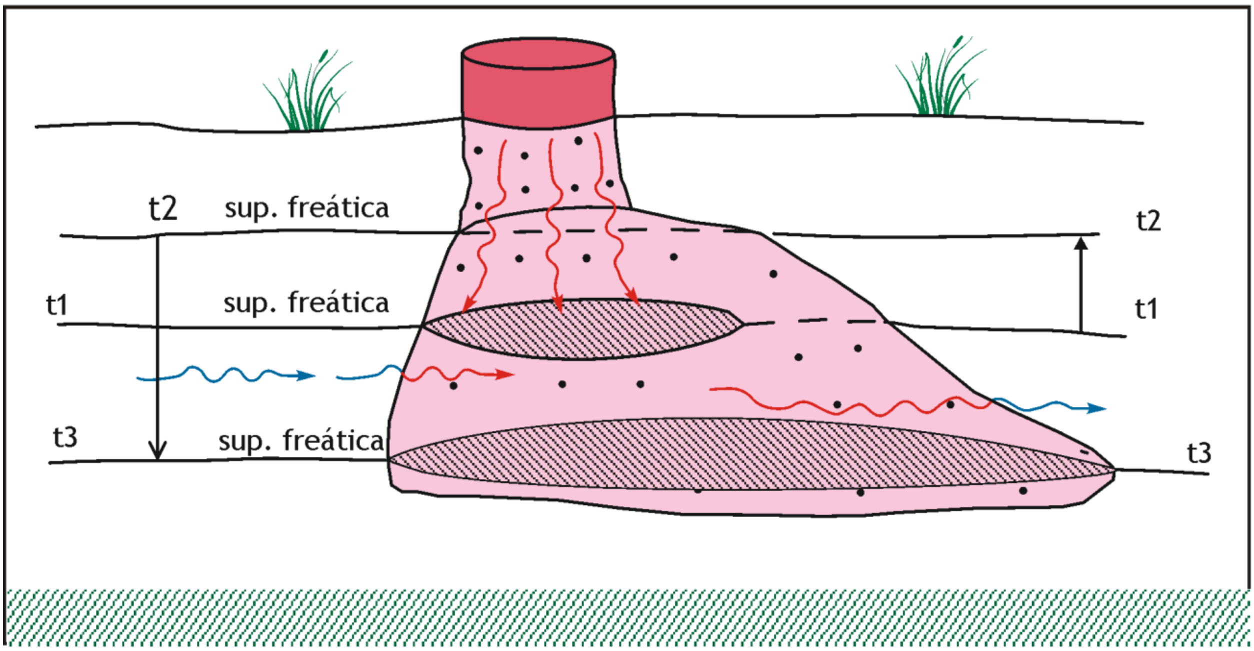
Los ejemplos demuestran claramente la incidencia que ejerce el medio (mayor o menor heterogeneidad) y la dinámica del agua subterránea, en los procesos de contaminación y lo complicado que resulta detectarla y cuantificarla.

Por ello, para lograr un seguimiento adecuado (monitoreo) es necesario conocer las características y el comportamiento hidrogeológico de los acuíferos y de sus unidades asociadas.

Los HC pueden llegar a la zona saturada, luego de atravesar la subsaturada, dejando una mancha en esta última, de hidrocarburos inmóviles (saturación irreductible). La mancha origina la contaminación del agua que se infiltra, debido a que una fracción de los HC es soluble. La oscilación de la superficie freática desplaza verticalmente al HC, dando lugar a una mancha que puede ubicarse por encima o por debajo del nivel freático (figura 20).

FIGURA 20

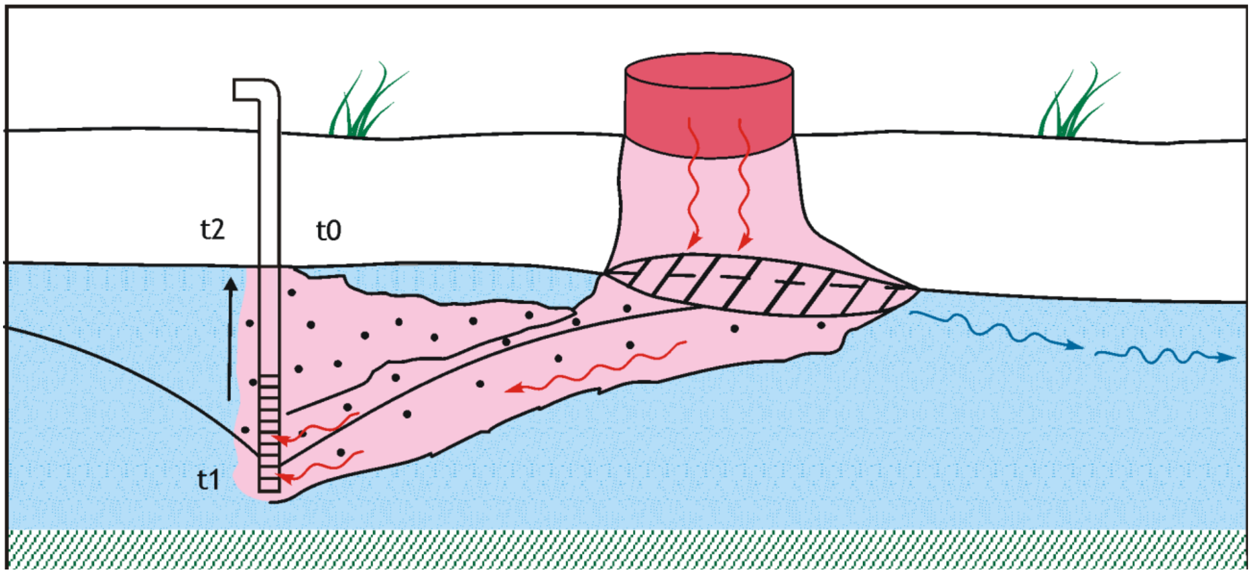
EVOLUCIÓN DE LA MANCHA DE HC



Esta situación se magnifica cuando la superficie hidráulica está influenciada por el bombeo (figura 21). La movilidad de los HC, además de

FIGURA 21

EVOLUCIÓN DE LA MANCHA DE HC POR BOMBEO



las propiedades del medio, es función de su viscosidad y densidad.

La permeabilidad de un medio frente a un HC varía notoriamente respecto del agua. De cualquier manera, un HC puede fluir si su saturación residual llega al 20%, índice bastante similar al que necesita el agua (20 al 22%). En términos generales se pueden asumir las siguientes relaciones entre la permeabilidad y el grado de saturación del medio con HC, expresados en %:

índice de saturación con HC	**80**	**60**	**45**	**20**
permeabilidad relativa	**75**	**45**	**23**	**0**

8. PROTECCIÓN DEL AGUA SUBTERRÁNEA FRENTE A LA CONTAMINACIÓN Y AL AGOTAMIENTO

Las medidas para proteger al agua subterránea de la contaminación, están orientadas a prevenirla, a eliminar sus consecuencias y a preservar su calidad, para asegurar un uso efectivo de la misma.

Dado que la contaminación del agua subterránea está íntimamente relacionada con el estado del agua superficial, la atmósfera, la lluvia y el suelo, su protección debe encararse al mismo tiempo y sobre la base de pautas que apunten a la preservación del ambiente en forma global.

Dentro de las medidas de naturaleza técnica, se pueden citar:

* la creación de sistemas cerrados para la disposición de residuos líquidos industriales y urbanos.
* el empleo de tecnología limpia o que genere pocos residuos.
* el tratamiento de las aguas servidas.
* la verificación y reparación de pérdidas en los sistemas de saneamiento (desagües cloacales).
* el aislamiento de las aguas contaminadas respecto de las aptas.
* la desactivación y reemplazo de los pozos ciegos o fosas sépticas por redes cloacales.
* la eliminación o purificación de emisiones gaseosas o humos.
* la limitación en el empleo de fertilizantes y pesticidas en la actividad agropecuaria.
* la creación de territorios especiales para la preservación del agua y de los otros recursos naturales (suelo, aire, biota).

La experiencia indica que la restauración de la calidad de un acuífero deteriorado por el ingreso de uno o varios contaminantes, constituye una tarea sumamente complicada en el aspecto técnico y generalmente de elevado costo. Además, no sólo resulta impracticable restaurarlo a su condición original, sino que con frecuencia, ni siquiera se logra recomponerlo para las exigencias que requiere el uso.

En este sentido, no debe olvidarse la escasa dinámica que posee el agua subterránea si se la compara con el agua superficial o el aire, por lo que los procesos de contaminación insumen tiempos prolongados para producirse y manifestarse (años, decenios, centenios y hasta milenios), pero también para mejorar su condición frente a la polución. Por ello, en la generalidad, es mucho más sencillo y rápido, restaurar la calidad de un río que la de un acuífero (Auge, 1990).

Otros factores trascendentes en la prevención para evitar el deterioro del agua subterránea son: la educación; la difusión; las normas legales y el control que asegure su cumplimiento.

En lo referente a **educación**, es poco lo que se hace a nivel mundial respecto a la importancia de los recursos naturales y su preservación.

Los habitantes de los países desarrollados y sus dirigentes, han comprendido la trascendencia de este tema y por ello, lo han incluido en los programas de enseñanza primaria, secundaria y en la mayoría de las carreras universitarias. En los países en desarrollo, si bien se le está prestando mayor atención, su enseñanza en los tres niveles todavía resulta escasa.

Con la **difusión**, lo que se pretende es llevar a conocimiento de la población que ya ha dejado los claustros de la enseñanza, la importancia que tienen los recursos naturales y la preservación ambiental. En este sentido, también es poco lo que se hace desde los organismos gubernamentales e incluso desde las organizaciones no gubernamentales. La realización de campañas educativas e instructivas, mediante el aprovechamiento de medios masivos de comunicación como la televisión, la radio, los diarios y revistas y la publicidad impresa, constituyen excelentes vías para lograr el objetivo citado.

Otras herramientas trascendentes en la lucha para evitar el deterioro del agua subterránea, son las **normas legales, regulaciones y leyes,** que traten sobre la utilización, las concentraciones máximas admitidas para diferentes usos y las cargas de contaminantes permitidas en los efluentes industriales, urbanos y agrícolas. Para que tengan éxito, las normativas deben ir acompañadas de un **control adecuado que asegure su cumplimiento (policía del agua)**.

La mayoría de los países en desarrollo dispone de un marco legal adecuado que regula el uso y la preservación de los recursos naturales, pero lamentablemente no sucede lo mismo con los organismos de control y por ello, su aplicación resulta muy dificultosa y generalmente, imposible de concretar.

9. VULNERABILIDAD

Existen numerosas definiciones y las que se menciona a continuación, fueron tomadas de Auge, 2003.

Vrba y Zaporozec (1994) definen a la vulnerabilidad como una propiedad intrínseca del sistema de agua subterránea que depende de la sensibilidad del mismo a los impactos humanos y/o naturales. De la definición se desprende que los autores incluyen en la misma tanto al sistema subterráneo como a los contaminantes y dentro de estos a los artificiales y a los naturales.

Foster e Hirata (1991) dicen que la vulnerabilidad de un acuífero a la contaminación, representa su sensibilidad para ser adversamente afectado por una carga contaminante impuesta. En este caso al citar a una carga contaminante impuesta, los autores parecen referirse solamente a una contaminación de origen artificial.

Custodio (1995) señala: la vulnerabilidad a la polución expresa la incapacidad del sistema para absorber las alteraciones, tanto naturales como artificiales. Vuelven a aparecer aquí procesos naturales y/o artificiales, como potenciales generadores de la alteración.

Carbonell (1993) define la vulnerabilidad a la contaminación, como la tendencia de los contaminantes a localizarse en el sistema de agua subterránea, luego de ser introducidos por encima del acuífero más somero. En este caso el autor considera solamente la acción de los contaminantes.

EPA (1991) hace referencia a la vulnerabilidad subterránea respecto a un plaguicida, como la facilidad con que un contaminante aplicado en la superficie, puede alcanzar al acuífero en función de las prácticas agrícolas empleadas, las características del plaguicida y la susceptibilidad hidrogeológica. Esta definición incorpora, además de las condiciones del medio, las propiedades del contaminante y las prácticas de cultivo (vulnerabilidad específica).

Otro concepto íntimamente asociado a la **vulnerabilidad** es el de **riesgo** a la contaminación, aunque este también genera diferencias en su definición, utilidad y técnicas para el mapeo.

Algunos autores (Foster, 1987) definen al riesgo como el peligro de deterioro en la calidad de un acuífero, por la existencia real o potencial de sustancias contaminantes en su entorno. Otros (Vrba y Zaporozec, 1994) lo asimilan a la vulnerabilidad específica, que se refiere al peligro de contaminación del agua subterránea respecto a un contaminante o familia de contaminantes de características y comportamientos similares (nitratos, hidrocarburos livianos o pesados, plaguicidas, materia orgánica, fenoles, metales, etc.).

En el entendimiento del suscrito la **vulnerabilidad intrínseca** tiene mayor utilidad en los trabajos de planificación de uso del territorio y del agua, particularmente en lo que respecta a la preservación de la calidad del recurso, en los sitios donde no está afectado, ni se realizan prácticas como fertilización, aplicación de plaguicidas, riego, cría concentrada de ganado, ni actividades domésticas, urbanas, o industriales, que por su intensidad pudieren afectarlo.

La **vulnerabilidad específica** incluye parcialmente el concepto de riesgo, toda vez que se refiere al peligro de deterioro en relación a sustancias contaminantes específicas.

Finalmente, (Auge, 2004) considera a la vulnerabilidad como “un concepto cualitativo, que en la generalidad se refiere al grado de protección natural de un acuífero frente a la contaminación. Por ello, también se la conoce como **protección o defensa natural**”.

También existen numerosos métodos para cualificar la vulnerabilidad del agua subterránea a la contaminación; entre los más utilizados pueden citarse, siguiendo a Auge, 2003:

DRASTIC. Fue desarrollado por Aller et al (1987) para EPA, con el objeto de evaluar la vulnerabilidad intrínseca de los acuíferos. Es un método de uso muy difundido, tanto para la cualificación (evaluación cualitativa) como para el mapeo y se basa en la asignación de índices que van de 1 a 10, de acuerdo a las características y el comportamiento de las variables consideradas en el acrónimo **DRASTIC**: **D** (**d**epth - profundidad del agua freática) **R** (**r**echarge - recarga neta) **A** (**a**quifer – litología del acuífero) **S** (**s**oil – tipo de suelo) **T** (**t**opography - topografía) **I** (**i**mpact - litología de la sección subsaturada) **C** (hydraulic **c**onductivity – conductividad hidráulica del acuífero). El índice 1 indica la mínima vulnerabilidad y el 10 la máxima. Además de lo expresado, a cada variable se le asigna un peso o ponderación, de acuerdo a la influencia respecto a la vulnerabilidad. Para el peso ponderado se emplean índices entre 1 y 5, adoptando los autores el mayor (5) para la profundidad del agua (D) y la litología de la sección subsaturada (I) y el menor (1) para la topografía (T). Ambos índices se multiplican y luego se suman los 7 resultados, para obtener un valor final o índice de vulnerabilidad, cuyos extremos son 23 (mínima) y 230 (máxima), aunque en la práctica el índice dominante varía entre 50 y 200.

SINTACS. Es una derivación del DRASTIC, desarrollado por Civita et al (1990) para adecuarlo a las diversificadas características hidrogeológicas de Italia y al requerimiento de un mapeo de mayor detalle. El acrónimo SINTACS comprende: **S** (**s**oggiacenza – profundidad del agua) **I** (**i**nfiltrazione - infiltración) **N** (**n**on saturo - sección subsaturada) **T** (**t**ipologia della copertura – tipo de suelo) **A** (**a**cquifero – características hidrogeológicas del acuífero) **C** (**c**onducibilità – conductividad hidráulica) **S** (**s**uperficie topografica – pendiente topográfica).

Este método presenta una estructura compleja, tanto para la entrada de datos como para la salida, por lo que su operación se realiza mediante un programa cibernético preparado especialmente para el mismo. A las variables mencionadas, que influyen en la vulnerabilidad intrínseca, se les puede añadir la incidencia del agua superficial y el uso de la tierra.

GOD. Este método propuesto por Foster (1987), se basa en la asignación de índices entre 0 y 1 a 3 variables que son las que nominan el acrónimo: **G** (**g**round water occurrence – tipo de acuífero) **O** (**o**verall aquifer class – litología de la cobertura) **D** (**d**epth – profundidad del agua o del acuífero). Los 3 índices que se multiplican entre sí, resultan en uno final (diagrama de salida - output) que puede variar entre 1 (vulnerabilidad máxima) y 0 (mínima).

AVI. Acrónimo de **a**quifer **v**ulnerability **i**ndex, fue desarrollado por Van Stempvoort et al (1992) para el mapeo de la vulnerabilidad del agua subterránea de la provincia de Prairie en Canadá. Se basa en la relación entre el espesor de la zona subsaturada (d) y la permeabilidad vertical de los componentes de la misma (K). Mediante dicha relación los autores definen un parámetro que denominan resistencia hidráulica (c), equivalente a:

$$c = \sum d_i / K_i \quad \text{para un número de capas de 1 a i}$$

De acuerdo a la relación, c se expresa en unidades de tiempo, normalmente en años, para lo cual d suele expresarse en metros y K en m/año. Las magnitudes para la cualificación de la vulnerabilidad son (tabla 5):

TABLA 5

RESISTENCIA HIDRÁULICA - VULNERABILIDAD

Resistencia Hidráulica (años)	Vulnerabilidad
< 10	Muy alta
10 -100	Alta
100 –1.000	Moderada
1.000 – 10.000	Baja
> 10.000	Muy baja

Para reducir los valores temporales, los autores proponen trabajar con los logaritmos decimales de los mismos, con lo que la vulnerabilidad muy alta pasaría a ser < 1 y la muy baja a > 4.

EKv. En relación a los acuíferos libres Auge (2001), desarrolla una clasificación basada en la profundidad de la superficie freática (**E**) y en la permeabilidad vertical de la zona subsaturada (**Kv**), parámetros que también considera el método AVI. A ambas les asigna índices que van de 1 (menos vulnerable) a 5 (más vulnerable), finalizando en el diagrama de la tabla 3 donde **Kv** es la permeabilidad vertical y **E** el espesor de la sección subsaturada. Ambos valores se suman brindando un índice final, con extremos de 2 y 10. Para índices de **E + Kv entre 2 y 4 la vulnerabilidad es baja, entre 5 y 7 media y de 8 a 10 alta**.

TABLA 6

	ESPESOR DE LA ZONA SUBSATURADA (E)				
m	>30	>10 a 30	>5 a 10	>2 a 5	<2
índice	1	2	3	4	5

TABLA 7

	PERMEABILIDAD VERTICAL DE LA ZONA SUBSATURADA (Kv)				
m/día	$<1.10^{-3}$	$>1.10^{-3}$ a 0,01	>0,01 a 1	>1 a 50	>50 a 500
índice	1	2	3	4	5

vulnerab.	**muy baja**	**baja**	**media**	**alta**	**muy alta**

5: con permeabilidades verticales (Kv) de 50 a 500 m/día, está representado por arena mediana y gruesa, grava arenosa y grava.
4: Kv de 1 a 50 m/d, por arena muy fina a limosa, arena fina y arena mediana a gruesa.
3: Kv de 0,01 a 1 m/d, por limo y limo arenoso.
2: Kv de 0,001 a 0,01 m/d, por limo y limo arcilloso.
1: Kv < de 0,001 m/d, por arcilla y arcilla limosa.

TABLA 8

DIAGRAMA DE VULNERABILIDAD - ACUÍFEROS LIBRES

Kv	**1**	6	5	4	3	2
	2	7	6	5	4	3
	3	8	7	6	5	4
	4	9	8	7	6	5
	5	10	9	8	7	6
		5	**4**	**3**	**2**	**1**
	E					

Es muy poco lo que se ha hecho respecto a la vulnerabilidad de acuíferos parcialmente confinados o semiconfinados. Auge et al (2004) desarrollan una metodología preliminar basada en pautas similares al GOD, a la que denominan **GODE**. En esta última se agrega un nivel o escalón **(E)**, que considera el espesor de la zona saturada correspondiente al acuífero libre sobrepuesto y el espesor del acuitardo, como factores de dilución y retardo de la contaminación respectivamente. En el proyecto de La Plata (op cit), el método no brindó buenos resultados.

Otro método para acuíferos semiconfinados es el desarrollado por Auge (2003) y denominado **ΔhT'**, que se basa primariamente en las diferencia de potenciales hidráulicos entre los citados y los acuíferos libres sobrepuestos y, secundariamente, en la transmisividad vertical de los acuitardos (capas de baja permeabilidad que forman el techo de los acuíferos semiconfinados). Esta metodología brindó buenos resultados en el proyecto de La Plata.

Denominando **h1** al potencial hidráulico del acuífero libre y **h2** al del semiconfinado, se tiene que:

h2 > h1	**vulnerabilidad baja**
h2 ≈ h1	**vulnerabilidad media**
h2 < h1	**vulnerabilidad alta**

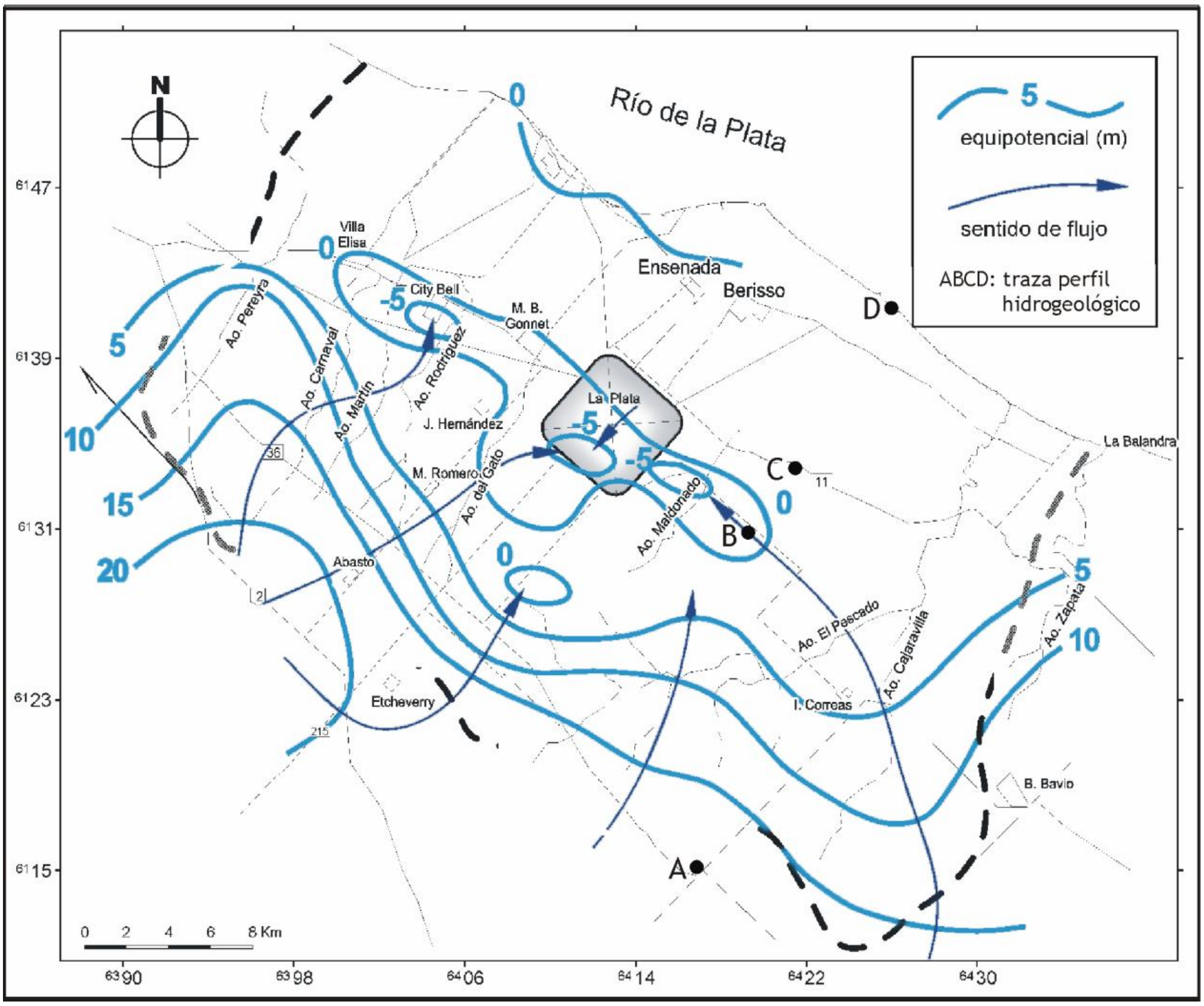
Seguidamente se analiza la hidrodinámica subterránea y la vulnerabilidad a la contaminación por NO3 en La Plata y alrededores (Auge et al, 2004).

En la figura 3 se representa el perfil hidrogeológico tipo de La Plata y alrededores, con los dos acuíferos más importantes de la región (Puelche y Pampeano). Por debajo del primero, a partir de unos 50 – 70 m de profundidad y hasta el basamento hidrogeológico, integrado por rocas gnéisicas y graníticas, a unos 485 m de profundidad, los acuíferos subyacentes (Paraná y Olivos) poseen elevado tenor salino y por ello prácticamente no se los emplea.

En la figura 22 se representa la red de flujo del Acuífero Puelche, elaborada con los niveles piezométricos medidos en junio del 2003.

FIGURA 22

CONO DE DEPRESIÓN DE LA PLATA
ACUÍFERO PUELCHE



En la misma “se aprecia claramente el control que, sobre el flujo del Puelche, ejerce el bombeo de los pozos para agua potable de La Plata y localidades vecinas, como Hernández, Gonnet, City Bell y Villa Elisa. La equipotencial de 0 m tiene forma elongada en dirección NO – SE, con un perímetro de 58 km, y un marcado lóbulo hacia el SO a la altura de La Plata. Su eje mayor es de 24 km, mientras que el menor varía entre 3 y 7 km. En el interior de la de 0 m, se presentan 3 curvas de –5 m, también cerradas, que abarcan pequeñas superficies. Los gradientes hidráulicos, en el sector SO de la región estudiada (zona no alterada), varían entre 1,0 y $2{,}5.10^{-3}$, para incrementarse en la zona explotada hasta $1{,}9.10^{-2}$.

Para calcular el flujo subterráneo que ingresa al cono, a través de la equipotencial de 0 m, se empleó Darcy:

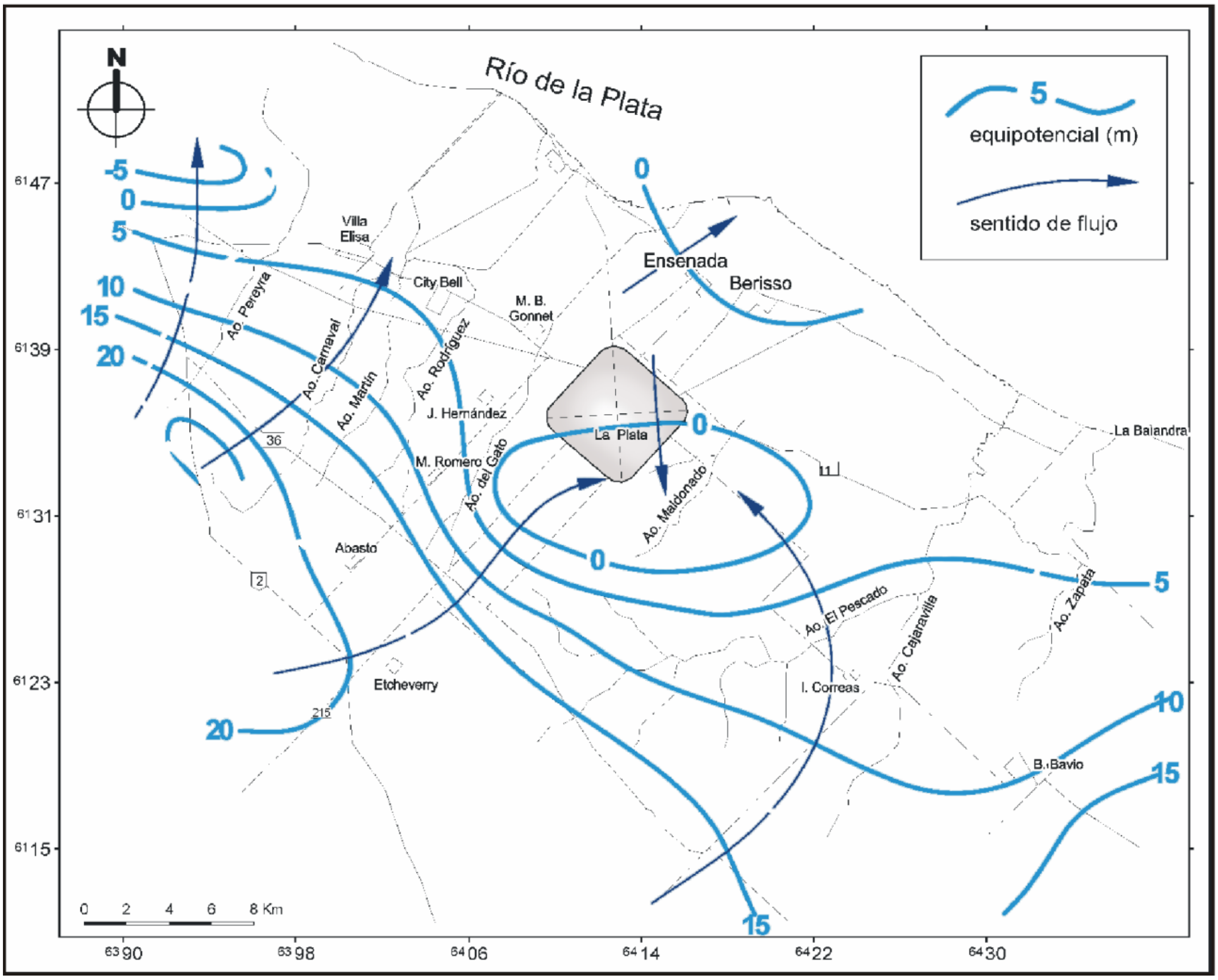
Q = T . i . L   145.000 m3/d ≈ 500 m2/d . 5.10^{-3} . 58.000 m
Q: caudal T: transmisividad i: gradiente hidráulico L: longitud

Los 145.000 m3/d equivalen a 53 hm3/año y, dado que la extracción alcanza a 75 hm3/a, el déficit asciende a unos 22 hm3/a. La estabilidad piezométrica observada en los últimos años, indica que las entradas deben ser similares a las salidas y por lo tanto, el déficit mencionado debe cubrirse con aporte natural y artificial, ambos a partir del Pampeano" (Auge, 2005).

La figura 23, "que reproduce la red de flujo del Acuífero Pampeano, presenta un cono de depresión, limitado por la equipotencial de 0 m, ubicado al S de La Plata. El cono es más suave que el existente en el Acuífero Puelche y tiene forma elongada en dirección E-O. El origen de este cono es el descenso

FIGURA 23

CONO DE DEPRESIÓN DE LA PLATA
ACUÍFERO PAMPEANO

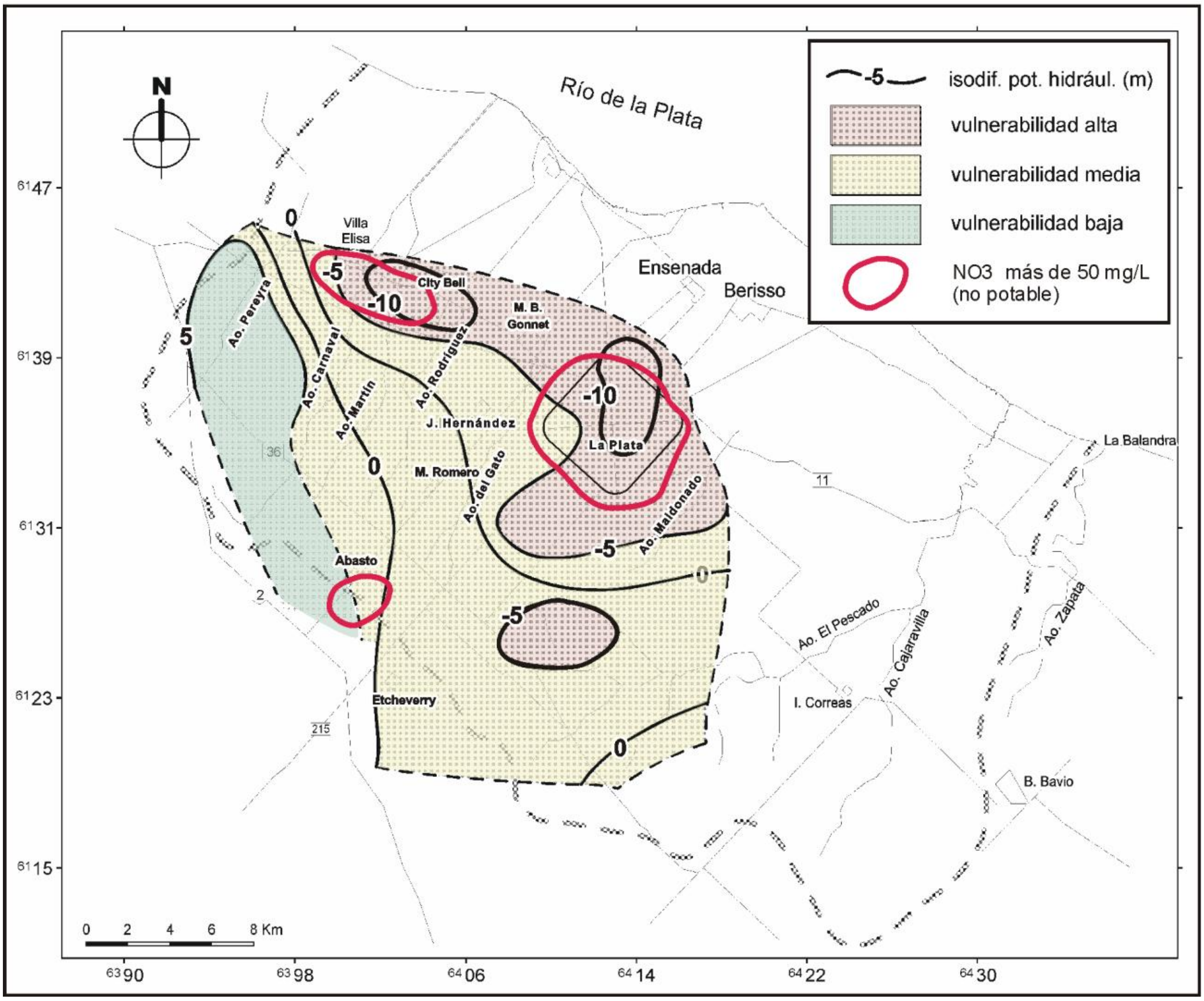


de la superficie freática, como consecuencia de la explotación del acuífero subyacente (Puelche). Otro cono, en el vértice NO del mapa, fuera de la zona estudiada, se insinúa mediante la isolínea de -5 m. Los mayores gradientes hidráulicos del Pampeano ($2,4.10^{-3}$), son similares a los registrados en el Puelche de la zona no disturbada, pero los menores ($3,7.10^{-4}$), son más bajos que sus equivalentes del Puelche. Existe una distorsión bastante menor en la red de flujo del Acuífero Pampeano que en la del Puelche, debido a la menor extracción a que está sometido el primero” (Auge, 2005).

La figura 24 representa la diferencia de potenciales hidráulicos entre ambos acuíferos y en la misma, se aprecian dos depresiones de –10 m en el Acuífero Puelche respecto al Pampeano (La Plata y City Bell). Dichos potenciales, favorables al Pampeano, coinciden con altas concentraciones de nitratos en el Puelche (figura 25), lo que indica la representatividad del método en la región estudiada.

FIGURA 24

DIFERENCIA DE POTENCIALES HIDRÁULICOS
VULNERABILIDAD ACUÍFERO PUELCHE

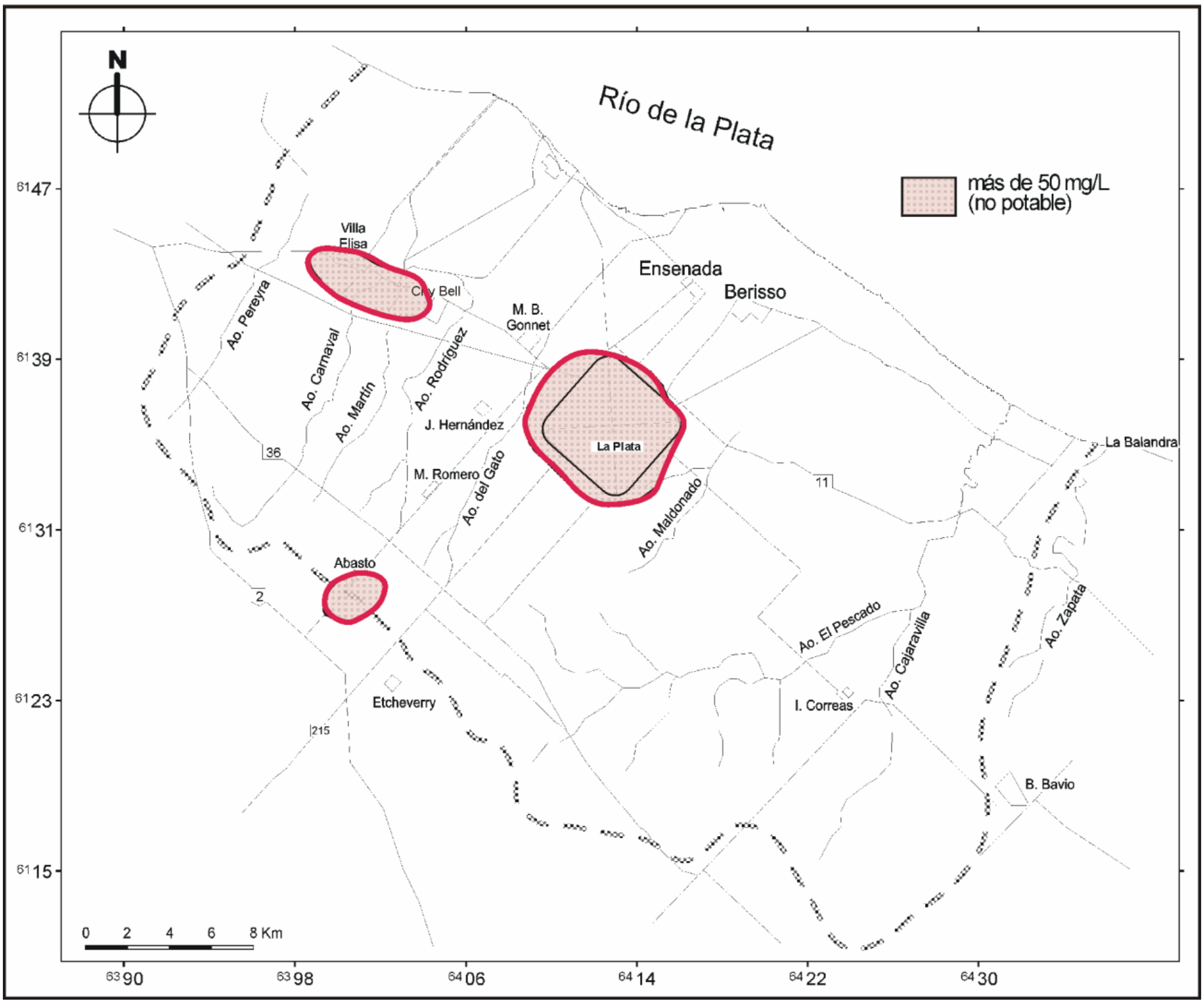


Contrariamente, el espesor del acuitardo no incide en la vulnerabilidad, pues en el ejido urbano de La Plata es donde presenta los mayores valores (6 a

10 m); sin embargo es justamente allí, donde el Acuífero Puelche está más afectado por la contaminación con nitratos. De lo expuesto se desprende que el acuitardo dificulta pero no impide el flujo vertical y no es hábil para detener el transporte de NO3, por lo que la contaminación del Puelche, especialmente en el ejido urbano, es producto de la migración de nitratos desde el Pampeano sobrepuesto, transportados por un flujo vertical descendente, inducido por la mayor carga hidráulica de este último, respecto al Puelche (figura 11).

FIGURA 25

ACUÍFERO PUELCHE
NITRATOS



Respecto a la vulnerabilidad del Acuífero Pampeano, que se comporta dominantemente como libre, la variable a la que más preponderancia le otorgan la mayoría de los métodos (espesor de la zona subsaturada), no muestra correspondencia con los altos contenidos en NO3 de extensión areal significativa. La figura 26, que representa la variación en la profundidad de la superficie freática, muestra que en el sector Sur de La Plata, el espesor de la zona subsaturada supera 12 m y que en el vértice NO del mapa alcanza más de 20 m. Sin embargo la mayor concentración areal de NO3 se sitúa justamente en parte del ejido urbano de La Plata y sus alrededores (figura 27), mientras que los sectores más vulnerables, respecto a la profundidad de la freática, como la Planicie Costera del Río de La Plata y la región ubicada al SO del ámbito estudiado, presentan bajas concentraciones y, eventualmente, algunos pozos con valores elevados pero de extensión areal reducida.

FIGURA 26

VULNERABILIDAD - ACUÍFERO PAMPEANO
PROFUNDIDAD DE LA SUPERFICIE FRÉATICA

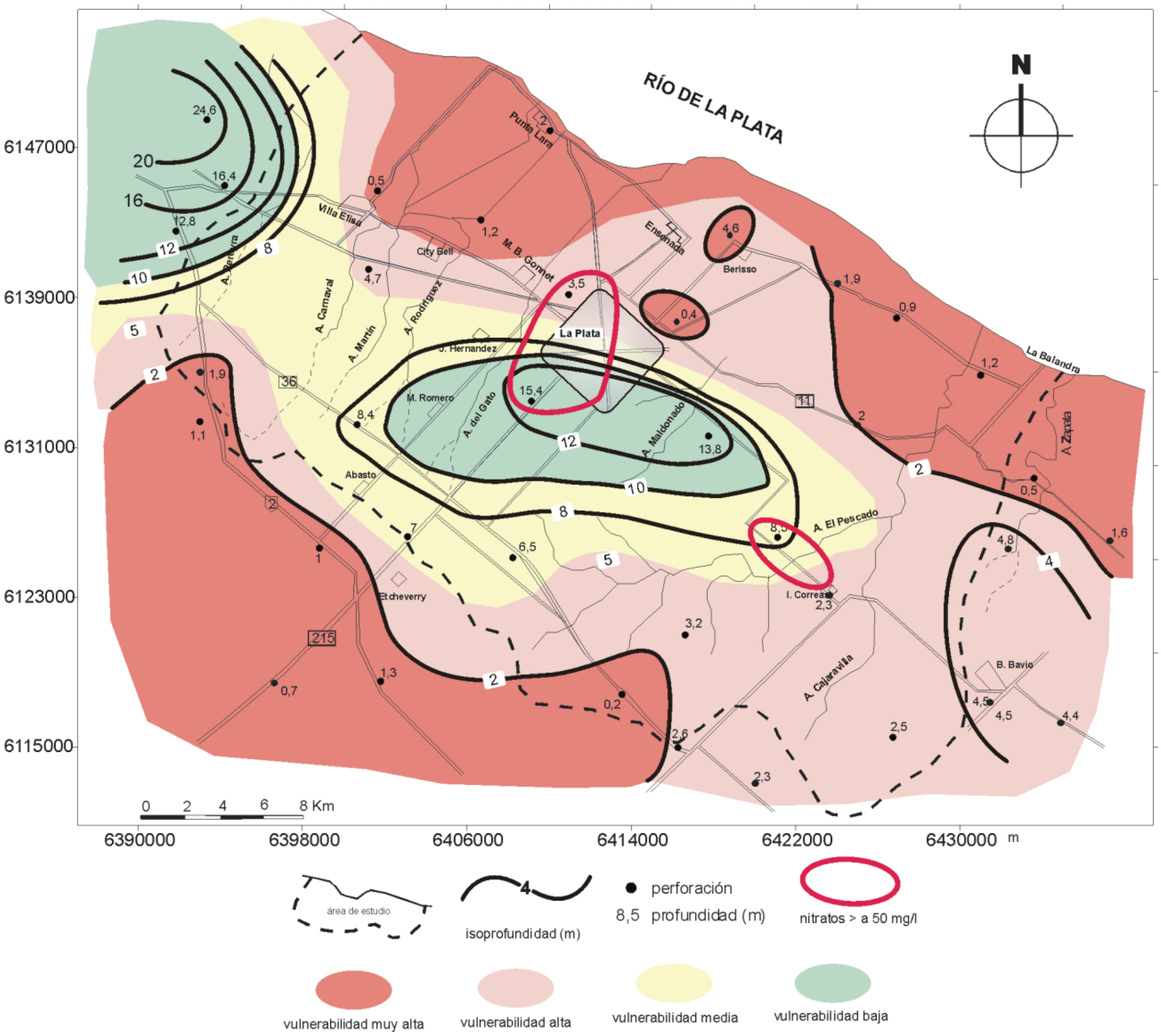
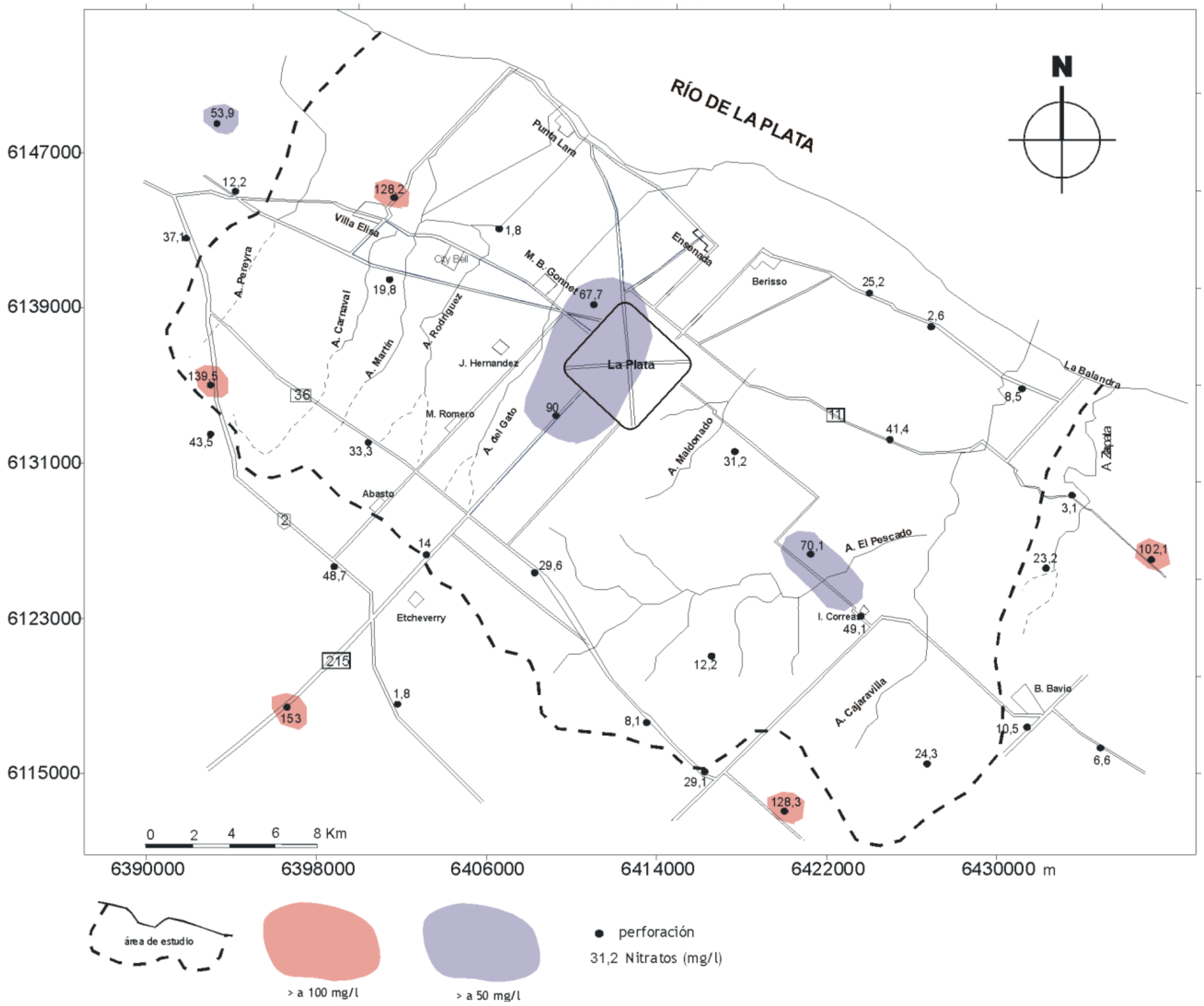


FIGURA 27

ACUÍFERO PAMPEANO
NITRATOS



10. MONITOREO

El primer paso para un adecuado sistema de prevención hidrogeológica, es la instalación de una red para el monitoreo de niveles y calidad del agua subterránea. El término monitoreo implica seguimiento y por lo tanto, se refiere a mediciones y muestreos reiterados (periódicos). La periodicidad del monitoreo, depende de variados factores: régimen de flujo (natural o artificial por extracción); fuentes reconocidas o potenciales de contaminación (ubicación y características), carga, movilidad, persistencia y toxicidad de los contaminantes; tamaño del acuífero; comportamiento hidráulico (libre, semiconfinado o confinado); características y espesor de la zona subsaturada; características y posición de la zona de recarga y profundidad de los acuíferos semi y confinados; relación exceso - déficit y periodicidad de la recarga; etc.

La mayoría de estos factores incide también en la distribución y separación de los pozos para monitoreo, cuya principal virtud es que sean hábiles para brindar valores representativos de los potenciales hidráulicos y para permitir un muestreo que también sea representativo de la calidad del acuífero.

La condición señalada, no sólo debe cumplirse espacialmente, sino también en el tiempo y en este sentido, los pozos que integren la red, deben elegirse teniendo presente el lapso previsto para el monitoreo de forma de disponer de puntos estables, que permitan una fácil medición y muestreo. Además deberán tener libre acceso en los momentos elegidos para los registros.

Los requerimientos mencionados no son fáciles de cumplimentar, especialmente en las redes que se utilizan para monitorear a nivel regional (más de 50.000 hectáreas), dado que para esta tarea, generalmente se emplean pozos existentes, construidos con otra finalidad (agua potable, riego, uso industrial o doméstico, etc).

Pozos exclusivamente para monitoreo, suelen perforarse en acuíferos bajo explotación, o en terrenos industriales, o en la cercanía de basurales, pero cubriendo superficies mucho menores que la citada (hectáreas a cientos de ha).

En estos casos, lógicamente el espaciado es mucho menor y aunque éste depende como ya se dijo, de variados factores, a título ilustrativo se puede señalar que para un monitoreo regional es satisfactorio contar con 1 pozo cada 500 a 2.000 ha, mientras que para otro local, particularmente para monitorear hidrocarburos, es necesario disponer de 2 a 5 pozos por ha (Auge, 2004).

Además del tamaño del ámbito a monitorear, el número y la distribución de los pozos, depende en gran medida de la dinámica del acuífero y más específicamente de la dinámica del agua contaminada.

Es muy conveniente detectar el límite entre el agua contaminada y la que no lo está, para conocer su desplazamiento espacial y temporal. Para ello, se eligen o ubican pozos en secciones caracterizadas por ambos tipos de agua.

Si el acuífero es confinado, o semiconfinado, debe asegurarse la aislación respecto al freático, que normalmente es el más expuesto a la contaminación. En los acuíferos semiconfinados, con filtración vertical descendente, es común la contaminación difusa a través de los acuitardos, que es más dañina debido a que deteriora un volumen mucho mayor que la puntual, producto de la mala aislación o estado de las cañerías.

Otro elemento a tener muy en cuenta, es la técnica para el muestreo y preservación de las muestras. En efecto, algunos contaminantes se presentan en concentraciones muy bajas (millonésimas de gramo por litro) y aún así son altamente tóxicos (plaguicidas, metales pesados, hidrocarburos alifáticos, HC aromáticos, sustancias radiactivas). Por ello, el muestreo debe efectuarse con sumo cuidado, empleando el equipamiento y el instrumental adecuado para cada caso, con el objeto de evitar pérdidas (HC aromáticos volátiles), o la introducción accidental de la misma sustancia que se quiere detectar (bomba o roscas lubricadas con aceite, si se va a determinar HC total).

El personal debe estar bien aseado, con ropa limpia y el manipuleo debe efectuarse con suma precaución.

En los casos de determinaciones analíticas con precisión de µg/L, no es conveniente reiterar el uso del equipo de muestreo; o sea, se utiliza un equipo diferente en cada pozo, para evitar la contaminación cruzada. En estos casos es conveniente establecer el fondo o background ambiental para deducirlo de las concentraciones del contaminante registradas en el agua (Auge, 1996). Esta práctica se emplea corrientemente cuando se muestrea para HC totales o metales pesados, en las refinerías o plantas de almacenamiento de HC. Las muestras para determinar el fondo del contaminante, se llaman "blancos" y en general son de agua destilada.

Las muestras tomadas en los sondeos, deben disponerse en recipientes que se adecuen a sus características p.ej., para preservar HC, el envase debe ser de vidrio color caramelo y además, hay que acidificar con HCl hasta pH 3 y mantenerlas enfriadas a unos 3 ºC, para evitar su degradación.

Para los metales pesados, se emplean los mismos recipientes, también se mantienen enfriados, pero luego de bajar el pH a 2 con HNO3.

Lógicamente que la calidad del laboratorio, particularmente en la precisión que logre en la determinación de contenidos tan bajos, juega un rol preponderante en el éxito de los trabajos.

En relación al monitoreo para establecer el estado hidráulico de un acuífero, lo que se hace es medir periódicamente los niveles de agua en los pozos que integran la red y en el caso de existir, en los sitios donde se concentra de descarga natural p.ej. manantiales.

La variación en la posición de la superficie freática de un acuífero libre, indica variación del volumen de agua almacenada, (si asciende aumenta, si desciende disminuye), mientras que la variación en la posición de la superficie piezométrica de un acuífero confinado, si se produce por encima del techo impermeable del mismo, es producto de diferencias en la presión hidráulica.

En los acuíferos semiconfinados, la modificación en la posición de su superficie hidráulica, puede derivar de variaciones de la presión hidráulica, de cambios en el volumen almacenado, o de ambos procesos.

Las variaciones en la reserva pueden deberse a procesos naturales (relación recarga-descarga) o artificiales (extracción).

En el primer caso, durante los períodos de exceso (recarga superior a descarga) la tendencia general es al ascenso del nivel, en los tres tipos de acuíferos. En los lapsos de déficit, sucede lo contrario. A estos cambios se los denomina estacionales porque se producen en el transcurso del año hidrológico. Otros, de mayor duración (plurianuales), derivan de ciclos climáticos secos o húmedos y normalmente abarcan varios años y aún decenios (Ej. Oeste de la Provincia de Buenos Aires).

En la generalidad, las variaciones de los potenciales hidráulicos producidas artificialmente, superan con amplitud a las que se originan naturalmente.

En sitios sometidos a extracción para consumo humano, riego o uso industrial, la tendencia es declinante y si la disminución de la reserva resulta significativa, el acuífero está sobre-explotado.

En definitiva, el objetivo principal del monitoreo hidráulico, es efectuar un seguimiento de la evolución del agua almacenada. Para ello, los niveles deben medirse en reposo, o sea sin que haya incidencia del bombeo. Lamentablemente, en la mayoría de los centros urbanos que se abastecen con agua subterránea esto resulta prácticamente imposible, debido a que los pozos funcionan en forma continuada y, en el mejor de los casos, sólo se puede sacar temporariamente de servicio a algunos de ellos. En estos lugares, la red de flujo subterráneo presenta una marcada distorsión, con fuertes cambios en los gradientes y en las velocidades y con la aparición de las formas hidráulicas que tipifican a la extracción (conos de depresión o embudos hidráulicos).

Los pozos de observación para el monitoreo deben ubicarse de manera que permitan definir las características de los conos de depresión (extensión lateral y vertical, gradientes hidráulicos), pero también de los ámbitos vecinos no distorsionados por el bombeo.

Esta será la única manera de poder cuantificar, conociendo la magnitud de otro parámetro hidráulico trascendente (transmisividad), el caudal que ingresa al o a los conos de depresión, para comparar dicho caudal con el que se extrae por bombeo, a fin de establecer la relación entre ambos (Auge, 1991).

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Buenos Aires, enero del 2006

ANEXO I

CÓDIGO ALIMENTARIO ARGENTINO (CAA)

CAPÍTULO XII - BEBIDAS HÍDRICAS, AGUA Y AGUA GASIFICADA

AGUA POTABLE

Art 982 - (Res MSyAS n° 494 del 7.07.94) "Con las denominaciones de Agua potable de suministro público y Agua potable de uso domiciliario, se entiende la que es apta para la alimentación y uso doméstico: no deberá contener substancias o cuerpos extraños de origen biológico, orgánico, inorgánico o radiactivo en tenores tales que la hagan peligrosa para la salud. Deberá presentar sabor agradable y ser prácticamente incolora, inodora, límpida y transparente.

El agua potable de uso domiciliario es el agua proveniente de un suministro público, de un pozo o de otra fuente, ubicada en los reservorios o depósitos domiciliarios.

Ambas deberán cumplir con las características físicas, químicas y microbiológicas siguientes:

CARACTERÍSTICAS FÍSICAS		
Turbiedad	máx.	3 *NTU*
Color	máx.	5 *escala Pt-Co*
Olor		sin olores extraños
CARACTERÍSTICAS QUÍMICAS		
pH		6,5 - 8,5
pH sat.		*pH ± 0,2*
Substancias inorgánicas (mg/L)		
Amoníaco (NH_4^+)	máx.	0,20
Aluminio residual Al)	máx.	0,20
Arsénico (As)	máx.	0,05
Cadmio (Cd)	máx.	0,005

Cianuro (CN^-)	máx.	0,10
Cinc (Zn)	máx.	5,0
Cloruro (Cl^-)	máx.	350
Cobre (Cu)	máx.	1,00
Cromo (Cr)	máx.	0,05
Dureza total ($CaCO_3$)	máx.	400
Fluoruro (F^-)	Ver detalle al final de la tabla	
Hierro total (Fe)	máx.	0,30
Manganeso (Mn)	máx.	0,10
Mercurio (Hg)	máx.	0,001
Nitrato (NO_3^-)	máx.	45
Nitrito (NO_2^-)	máx.	0,10
Plata (Ag)	máx.	0,05
Plomo (Pb)	máx.	0,05
Sólidos disueltos totales	máx.	1500
Sulfatos ($SO_4^=$)	máx.	400
Cloro activo residual	mínimo	0,2

Fluoruro (F^-): para los *fluoruros* la calidad máxima se da en función de la temperatura promedio de la zona, teniendo en cuenta el consumo diario del agua de bebida:

Temperatura mediay máxima del año (°C)	Contenido límite recomendado de *Flúor* **(mg/L)**	
	Límite inferior	Límite superior
10,0 - 12,0	0,9	1,7
12,1 - 14,6	0,8	1,5
14,7 - 17,6	0,8	1,3
17,7 - 21,4	0,7	1,2
21,5 - 26,2	0,7	1,0
26,3 - 32,6	0,6	0,8

La autoridad sanitaria competente podrá admitir valores distintos si la composición normal del agua de la zona y la imposibilidad de aplicar tecnologías de corrección lo hicieran necesario.

Características Microbiológicas:

- Bacterias coliformes: NMP a 37° C – 48 hs. (Caldo Mc Conkey o Lauril Sulfato), en 100 ml: igual o menor de 3.
- Escherichia coli: ausencia en 100 ml.
- Pseudomonas aeruginosa: ausencia en 100 ml.

En la evaluación de la potabilidad del agua ubicada en reservorios de almacenamiento domiciliario deberá incluirse entre los parámetros microbiológicos a controlar el recuento de bacterias mesófilas en agar (APC - 24 hs. a 37 °C): en el caso de que el recuento supere las 500 UFC/ml y se cumplan el resto de los parámetros indicados, sólo se deberá exigir la higienización del reservorio y un nuevo recuento.

En las aguas ubicadas en los reservorios domiciliarios no es obligatoria la presencia de cloro activo.

Contaminantes orgánicos (µg/L)		
Aldrin + Dieldrin	máx.	0,03
Clordano	máx.	0,30
DDT (Total + isómeros)	máx.	1,0
Detergentes	máx.	0,50
Heptacloro + Heptacloroepóxido	máx.	0,10
Lindano	máx.	3,0
Metoxicloro	máx.	30
2,4 D	máx.	100
Benceno	máx.	10
Hexacloro benceno	máx.	0,01
Monocloro benceno	máx.	3,0
1,2 Dicloro benceno	máx.	0,5
1,4 Dicloro benceno	máx.	0,4
Pentaclorofenol	máx.	10
2,4,6 Tricloro fenol	máx.	10
Tetracloruro de carbono	máx.	3,0

1,1 Dicloro eteno	máx.	0,30
Tricloro etileno	máx.	30
1,2 Dicloro etano	máx.	10
Cloruro de vinilo	máx.	2,0
Benzopireno	máx.	0,01
Tetra cloro eteno	máx.	10
Metil Paratión	máx.	7
Paratión	máx.	35
Malatión	máx.	35

Los tratamientos de potabilización que sea necesario realizar deberán ser puestos en conocimiento de la autoridad sanitaria competente.

AGUA GASIFICADA

Art 983 (Res 494 del 7.07.94) "Se entiende por agua de bebida envasada o agua potabilizada envasada a un agua de origen subterráneo o proveniente de un abastecimiento público, al agua que se comercialice envasada en botellas, contenedores u otros envases adecuados, provistos de la rotulación reglamentaria y que cumpla con las exigencias del presente artículo. La utilización de un agua proveniente de un suministro público queda condicionada a la aprobación de la autoridad competente, la que se deberá ajustar a las pautas sanitarias existentes. Podrán ser adicionadas de gas carbónico en cuyo caso la presión del gas no podrá ser menor de 1,5 atmósferas medidas a 21°C Tratamientos permitidos:

A fin de conservar o mejorar sus características físicas, químicas, microbiológicas o sensoriales se permiten los siguientes tipos de tratamientos:

1. La decantación y/o filtración al solo efecto de eliminar substancias naturales indeseables tales como arena, limo, arcilla u otras.
2. La separación de elementos inestables tales como compuestos de hierro y/o azufre, mediante la decantación y/o filtración eventualmente precedida de aereación y/u oxigenación.
3. La eliminación de arsénico, vanadio, flúor, manganeso, nitratos u otros elementos o compuestos que se encuentren presentes en concentraciones que excedan los límites permitidos.
4. La cloración, aereación, ozonización, radiación ultravioleta, ósmosis inversa, absorción por carbón, pasaje por resinas de intercambio y filtros de retención microbiana así como otra operación que autorice la autoridad sanitaria competente.

CARACTERÍSTICAS FÍSICAS		
Turbiedad	máx.	3 *NTU*
Color	máx.	5 *escala Pt-Co*
Olor		característico
CARACTERÍSTICAS QUÍMICAS		
pH (a excepción de las aguas carbonatadas)		6,0 a 9,0

Substancias Inorgánicas (mg/L)		
Amoníaco (NH_4^+)	máx.	0,20
Aluminio residual (Al)	máx.	0,20
Arsénico (As)	máx.	0,05
Cadmio (Cd)	máx.	0,01
Cianuro (CN^-)	máx.	0,10
Cinc (Zn)	máx.	5,0
Cloro residual (Cl)	máx.	0,50
Cloruro (Cl^-)	máx.	350
Cobre (Cu)	máx.	2,0
Cromo (Cr)	máx.	0,05
Fluoruro (F^-)	máx.	2,0
Hierro total (Fe)	máx.	2,0
Manganeso (Mn)	máx.	0,10
Mercurio (Hg)	máx.	0,001
Nitrato (NO_3^-)	máx.	45
Nitrito (NO_2^-)	máx.	0,10
Plata (Ag)	máx.	0,05
Plomo (Pb)	máx.	0,05
Sólidos disueltos totales	máx.	1.500
Sulfatos ($SO_4^=$)	máx.	500

La autoridad sanitaria competente podrá admitir valores distintos si la composición normal del agua de la zona y la imposibilidad de aplicar tecnologías de corrección lo hicieran necesario. El agua envasada en esas condiciones deberá consignar en el rotulado la localidad de elaboración y no podrá expenderse fuera de ella.

La autoridad sanitaria competente deberá informar la nómina de los productos así autorizados a las restantes jurisdicciones y a la Autoridad Sanitaria Nacional.

Características Microbiológicas:

- Bacterias coliformes: NMP a 37°C - 48 hs (Caldo de Mc Conkey o Lauril sulfato), en 100 ml: igual o menor de 3.
- Escherichia coli: ausencia en 100 ml.
- Pseudomonas aeruginosa: ausencia en 100 ml.
- Bacterias mesófilas (APC - 37°C 24 hs) máximo: 500 UFC/ml. En el caso de que el recuento supere las 500 UFC/ml, y se cumplan con el resto de los parámetros indicados, solo se deberá exigir la higienización de la planta y realizar un nuevo recuento.

Contaminantes Orgánicos (µg/L)					
THM	máx.	100	1,4 Dicloro benceno	máx.	0,40
Aldrin + Dieldrin	máx.	0,03	Pentaclorofenol	máx.	10
Clordano	máx.	0,30	2,4,6 Tricloro fenol	máx.	10
DDT (Total + isómeros)	máx.	1,0	Tetracloruro de carbono	máx.	3,0
Detergentes	máx.	0,50	1,1 Dicloro eteno	máx.	0,30
Heptacloro + Heptacloroepóxido	máx.	0,10	Tricloro etileno	máx.	30
Lindano	máx.	3,0	1,2 Dicloro etano	máx.	10
Metoxicloro	máx.	30	Cloruro de vinilo	máx.	2,0
2,4 D	máx.	100	Benzopireno	máx.	0,01
Benceno	máx.	10	Tetra cloro eteno	máx.	10
Hexacloro benceno	máx.	0,01	Metil Paratión	máx.	7,0
Monocloro benceno	máx.	3,0	Paratión	máx.	35
1,2 Dicloro benceno	máx.	0,50	Malatión	máx.	35

Las aguas de bebida envasadas deben suministrarse en recipientes destinados directamente al consumidor, y elaborados sólo con los materiales aprobados por el presente Código.

Deberán ser obturados en alguna de las siguientes formas:
1) Con tapones de tierra cocida esmaltada o de porcelana, provistos de anillos de caucho o de corcho de buena calidad, o de cualquier otro material debidamente autorizado, libre de impurezas tóxicas.
2) Con tapas de metal del tipo de las denominadas corona, las cuales deberán ser hechas con niquelados, o con hojalata nueva barnizada y llevar una lámina de estaño técnicamente puro, corcho de buena calidad o plástico adecuado.
3) Con tapas-roscas de aluminio y plásticos adecuados o provistos de discos de cierre de corcho de buena calidad o de plástico adecuado o de metal técnicamente puro autorizado. En todos los casos deberán estar provistos de un sistema de cierre o dispositivo que resulte inviolable y evite toda posibilidad de falsificación y/o contaminación. Los envases cuyo volumen sea superior a los 25 litros deberán ser autorizados por la autoridad sanitaria competente. Aquéllas empresas que utilicen envases de retorno para envasar agua de bebida deben cumplir las exigencias del Anexo I del presente artículo.

En la rotulación de este producto se consignarán los siguientes datos:
a) La denominación de producto mediante las expresiones "Agua de bebida embotellada (o envasada)", "Agua potable embotellada (o envasada)", "Agua tratada embotellada (o envasada)", "Agua de Mesa embotellada (o envasada)", "Soda en botellas".
b) Marca registrada.
c) Nombre o razón social y domicilio de la planta embotelladora.
d) Tratamiento eventual al que pudo haber sido sometida de acuerdo a lo consignado en el inciso 3, mediante expresiones como "desazufrada", "defluorurada", o similares.
e) Optativamente datos referidos a la composición química o el resultado de análisis efectuado por la autoridad sanitaria competente en el momento de autorizar el producto y/o los resultados del análisis microbiológico o mencionar que la calidad microbiológica cumple con las normas oficiales.
f) Número de registro del producto y del establecimiento otorgado por autoridad sanitaria competente.
g) Fecha de duración máxima que se deberá indicar mediante la expresión "Consumir preferentemente antes de...", llenando el espacio en blanco con la fecha correspondiente. Este valor deberá ser establecido por el fabricante.
h) Identificación de la partida o día, mes y año de elaboración lo que podrá efectuarse mediante una clave que se pondrá en conocimiento de la autoridad sanitaria competente.
i) La indicación "Gasificada" cuando se le haya incorporado gas carbónico. Se exceptúa de esta indicación a los productos rotulados "Soda" o "Soda en botellas".

Los nombres de fantasía o marcas no serán de fuentes o localidades donde se obtenga o hubiera obtenido agua mineral natural.

No están autorizados en los rótulos o cualquier forma de publicidad imágenes de fuentes, cascadas u otra forma de representación que puedan sugerir agua mineral. En los envases con el rótulo vitrificado, las exigencias de rotulación del presente artículo sólo serán exigidas en aquellos fabricados a partir de la fecha de vigencia del presente. Conjuntamente con la solicitud de aprobación del producto se deberá presentar ante la autoridad sanitaria competente las siguientes informaciones:

1) Lugar y/o situación de la captación del agua.
2) Descripción de los proyectos referidos a las obras de captación, tanque de almacenamiento, canalizaciones, maquinarias, equipos y materiales empleados.
3) Sistemas y equipos para procesos de decantación, filtración, ozonización, gasificación y toda otra operación facultativa autorizada que se lleve a cabo.

Cuando por razones accidentales resultara indispensable proceder a practicar el saneamiento total o parcial de la planta deberán utilizarse hipocloritos alcalinos u otros desinfectantes autorizados.

En todos los casos las tareas de limpieza y desinfección deberán realizarse manteniendo en receso el proceso de producción. Todas las plantas deberán ajustarse a las exigencias particulares impuestas por el Anexo 1, por el artículo 119 y a las generales de higiene para los establecimientos que elaboran alimentos. Todo establecimiento embotellador de los productos consignado en el presente artículo deben contar con un Asesor Técnico que por la naturaleza de sus estudios, a juicio de la autoridad sanitaria competente esté capacitado para supervisar las operaciones de producción y verificar la calidad de los productos elaborados, tarea que podrá ser realizada sin desempeñarse en relación de dependencia ni con dedicación exclusiva".

ANEXO I DEL ART. 983 (Res MSyAS 494 del 7.07.94) " - CONDICIONES Y EXIGENCIAS MINIMAS PARA ESTABLECIMIENTOS:

Objeto: En este anexo se establecen las exigencias y condiciones particulares mínimas que deberán ser observadas en los establecimientos elaboradores de aguas de bebida envasadas.

Definiciones:

Captación: Conjunto de operaciones requeridas para la obtención de agua.

Canalizaciones: Las tuberías, filtros y bombas extractoras usadas para la extracción de agua.

Carbonatación: Incorporación de dióxido de carbono previa a la etapa de envasado.

Contaminación: La presencia de toda substancia objetable en el producto.

Desinfección: reducción del número de microorganismos mediante agentes químicos y/u otros métodos físicos previamente aprobados por la autoridad sanitaria competente.

Envase: Todo recipiente elaborado con material aprobado por la autoridad sanitaria competente, destinado a contener el producto para su conservación y venta al consumidor. Establecimiento: Todo edificio y la zona que lo rodea donde se elabore y envase el producto. En esta definición se incluyen los vestuarios, comedores, oficinas y demás dependencias. Se designa también como PLANTA.

Filtración: Operación destinada a retener partículas mediante el uso de material apropiado.

Reservorios: Depósitos de acumulación y/o reserva del producto a envasar.

Tratamiento: Operación destinada a eliminar elementos indeseables que deben ser autorizadas por la autoridad sanitaria competente.

Requisitos para los Establecimientos:

El establecimiento deberá estar ubicado en zonas libres de olores desagradables, humos, polvos, o cualquier otro tipo de contaminantes.

La construcción de los edificios deben ser sólida, de mampostería u otros materiales que permitan su limpieza. El establecimiento deberá contar como mínimo con un sector para el lavado mecánico de los envases, sala de llenado y tapado y sector de rotulado y encajonado.

Las captaciones y canalizaciones deben ser de materiales inatacables, que no cedan substancias objetables al agua en cantidades superiores a las permitidas.

Los reservorios deben ser cerrados, con materiales resistentes al agua, de fácil limpieza y con filtros en los sistemas de ventilación.

Todas las máquinas deben estar ubicadas dejando un espacio con la pared para permitir la limpieza.

Los suministros se deben almacenar a una distancia de las paredes que permitan la limpieza.

La sala de envasado debe estar cerrada en todo su contorno (paredes, cielo raso y puertas), contar con cierra-puertas automático y preferiblemente ser presurizada. Las aberturas para las cintas transportadoras que ingresan los envases vacíos y limpios y las de las cintas transportadoras que retiran los envases llenos, no deben exceder el tamaño requerido para el paso de los envases.

La planta debe ser adecuadamente ventilada para minimizar olores y prevenir la condensación de agua en las áreas de lavado y envasado.

Los artefactos de iluminación deben ser de seguridad para prevenir rotura y posibilidad de caída de vidrios. Todos los equipos, conductos, cañerías y partes salientes deben estar ubicados de tal forma que eviten el goteo por condensación o pérdidas de las cañerías que pudieran caer en el producto envasado.

Las cocinas, baños y otros locales no afectados al proceso de producción deben estar ubicados sin acceso directo a las áreas de procesamiento.

Las puertas de los baños deben tener cierra-puertas. El aire comprimido debe estar libre de aceite, polvo, agua y otros contaminantes.

Toda la basura y desechos deben ser guardados fuera de los locales de elaboración, limpieza y envasado. Todos los recipientes para este fin deben tener tapa. Las superficies de los equipos que deban estar en contacto con el agua que se va envasar deben ser de materiales inalterables, resistentes al agua, no absorbentes, que no cedan substancias objetables en cantidades superiores a las permitidas y que puedan resistir repetidas operaciones de limpieza.

El agua a envasar y la de limpieza de planta no deben mezclarse. Las máquinas llenadoras y tapadoras deben tener un sistema de seguridad que evite contaminaciones si se rompe algún envase de vidrio.
Las tolvas donde se colocan las tapas a usar deben permanecer cubiertas.

Requisitos de Higiene:

Todos los locales y anexos, vinculados con la toma de agua, su tratamiento, almacenamiento, envasado y cualquier etapa de la industrialización deben mantenerse en óptimo estado de pulcritud y lavado.

Los reservorios del agua, las tuberías, equipos de tratamiento y de llenado deben ser sometidos a limpieza periódica y en el momento que se detecte alguna anormalidad. El lavado y sanitización de los envases vacíos se debe realizar en un recinto adecuado para prevenir contaminaciones. Los envases retornables deben ser lavados, sanitizados e inspeccionados antes de ser llenados. Debe realizarse en equipos adecuados para asegurar su eficaz limpieza. Preferentemente se emplearán soluciones de hidróxido de sodio a temperaturas no menores de 60°C o procedimientos previamente aprobados por la autoridad sanitaria competente. Deben ser enjuagados con agua potable y verificar la ausencia de trazas de hidróxido de sodio mediante un indicador ácido-base como la fenolftaleína.

Los envases llenos deben ser inspeccionados. El personal debe estar vestido con prendas limpias y con gorros para retener el pelo. No se debe permitir trabajar en el proceso total de la planta a personas con enfermedades y/o heridas expuestas que puedan contaminar al agua.

Controles:

Las plantas deben llevar un registro de los controles analíticos (físicos, químicos y microbiológicos) que realicen en su laboratorio o en laboratorio de terceros autorizados por la autoridad sanitaria competente, con la indicación de la fecha de toma de muestra y el código del lote.

Art 984 - Queda expresamente prohibido expender con la denominación de polvos o granulados para agua carbónica o similares, las mezclas de distintos componentes que al disolverse en el agua liberen gas carbónico.

AGUAS MINERALES

Art 985 - (Res MSyAS n° 209 del 7.03.94):

1) "Definición: Se entiende por Agua mineral natural un agua apta para la bebida, de origen subterráneo, procedente de un yacimiento o estrato acuífero no sujeto a influencia de aguas superficiales y proveniente de una fuente explotada mediante una o varias captaciones en los puntos de surgencia naturales o producidas por perforación.

2) Características: El agua mineral natural debe diferenciarse claramente del agua potabilizada o agua común para beber en razón de:

   a) su naturaleza caracterizada por su tenor en minerales y sus respectivas proporciones relativas, oligo-elementos y/u otros constituyentes;

   b) su pureza microbiológica original;

   c) la constancia de su composición y temperatura en la captación las que deberán permanecer establecer estables en el marco de las fluctuaciones naturales, en particular ante eventuales variaciones de caudal, aceptándose una variación de sus componentes mayoritarios de hasta el 20% respecto de los valores registrados en su aprobación, en tanto no superen los valores máximos admitidos;

3) Operaciones facultativas: Se admiten las siguiente operaciones:

   a) la decantación y/o filtración al solo efecto de eliminar sustancias naturales inestables que se encuentren en suspensión, tales como arena, limo, arcilla u otras;

   b) la separación de elementos inestables, tales como los compuestos de hierro y/o azufre, mediante filtración o decantación eventualmente precedida de aereación u oxigenación, siempre que dicho tratamiento no tenga por efecto modificar la composición del agua en los constituyentes esenciales que le confieren sus propiedades particulares;

   c) la eliminación total o parcial del gas carbónico libre, mediante procedimientos físicos exclusivamente;

   d) la incorporación de gas carbónico procedente o no de la fuente;

   e) el tratamiento con radiación ultravioleta u ozonización en tanto no altere sustancialmente la composición química del agua y/o el pasaje a través de filtros de retención microbiana.

4) Operaciones prohibidas: una agua mineral natural no puede ser objeto de tratamiento o agregado alguno que no sean los indicados en el inciso 3) del presente artículo.

5) Composición y factores de calidad:

   a) Caracteres sensoriales:

      Color: hasta 5 u (unidades de la escala Pt-Co),
      Olor: característico, sin olores extraños
      Sabor: característico, sin sabores extraños
      Turbidez: hasta tres UT (unidades Jackson o nefelométricas);

b) Caracteres químicos y físico-químicos:

Residuo seco soluble (180°C)	no menor de 50 mg/l	ni mayor de 2000 mg/l
pH	entre	4 y 9 mg/l
Arsénico	máximo	0,2 mg/l
Bario	máximo	1,0 mg/l
Boro (como H_3BO_3)	máximo	30,0 mg/l
Bromo	máximo	6,0 mg/l
Cadmio	máximo	0,01 mg/l
Carbonatos (como $CaCO_3$)	máximo	600 mg/l
Cloruro (como *ion*)	máximo	900 mg/l
Cobre	máximo	1,0 mg/l
Flúor	máximo	2,0 mg/l
Hierro	máximo	5,0 mg/l
Iodo	máximo	8,5 mg/l
Manganeso	máximo	2,0 mg/l
Nitratos (como *ion nitrato*)	máximo	45,0 mg/l
Selenio	máximo	0,01 mg/l
Sulfato (como *ion*)	máximo	600 mg/l
Sulfuro (como *ion*)	máximo	0,05 mg/l
Zinc	máximo	5,0 mg/l
Materia orgánica (oxígeno consumido por $KMnO_4$, medio ácido)	máximo	3,0 mg/l

c) Contaminantes

Cromo (VI)	máximo	0,05 mg/l
Mercurio	máximo	0,01 mg/l
Plomo	máximo	0,05 mg/l

Cianuro (como *ion*)	máximo	0,01 mg/l
Nitrito (como *ion*)	máximo	0,1 mg/l
Nitrógeno amoniacal (como *ion* amonio)	máximo	0,2 mg/l
Residuo de pesticidas		ausencia
Hidrocarburos, aceites, grasas		ausencia
Agentes tensioactivos		ausencia
Compuestos fenólicos		ausencia
Productos indicadores de contaminación		ausencia
Cloro residual		ausencia

d) Calidad microbiológica: en la captación y durante su comercialización el agua mineral natural deberá estar exenta de:
i) Parásitos en 250 cc
ii) Escherichia coli, en 250 cc
iii) Estreptococos fecales, en 250 cc
iv) Anaerobios esporulados sulfito reductores, en 50 cc
v) Pseudomonas aeruginosa, en 250 cc

Art 986 - (Res MSyAS n° 209 del 7.03.94) "Clasificación: las aguas minerales naturales se clasificarán de la siguiente manera:

1. De acuerdo al grado de mineralización determinado por el residuo seco soluble a 180°C:
   a) Oligominerales: residuo entre 50 y 100 mg/l
   b) De mineralización débil: residuo entre 101 y 500 mg/l
   c) De mineralización media: residuo entre 501 y 1500 mg/l
   d) De mineralización fuerte: residuo entre 1501 y 2000 mg/l
2. De acuerdo a su composición:
   - Alcalina o bicarbonatada: contiene más de 600 mg/l de ion bicarbonato
   - Acidulada o carbogaseosa: contiene más de 250 mg/l de dióxido de carbono libre
   - Salina o clorurada: contiene más de 500 mg/l de cloruro de sodio
   - Cálcica: contiene más de 150 mg/l de calcio
   - Magnésica: contiene más de 50 mg/l de magnesio
   - Fluorada: contiene más de 1 mg/l de flúor
   - Ferruginosa: contiene más de 2 mg/l de hierro
   - Iodadas: contiene más de 1 mg/l de iodo

- Sulfatadas: contiene más de 200 mg/l ion sulfato

3. De acuerdo a la temperatura del agua en la surgencia o extracción:

   Atermales: 0° a 20°C
   Hipotermales: 21° a 30°C
   Mesotermales: 31° a 40°C
   Hipertermales: más de 40°C

4. De acuerdo al contenido gaseoso:

a) Naturalmente gaseosa: agua mineral natural cuyo tenor en gas carbónico proveniente de la fuente, luego de una eventual decantación y del embotellado, resulte igual al que se presentaba en la captación. Es permitida la reincorporación de gas proveniente de la misma fuente, en cantidad equivalente a la del gas liberado en esas operaciones con las tolerancias técnicas habituales.

b) Gasificada o con gas: agua mineral natural que ha sido carbonatada en el lugar de origen con gas carbónico procedente o no de la fuente y que después de embotellada contiene una presión de gas no menor de 1,5 atmósferas a 21°C. En el caso de que el gas carbónico no provenga de la fuente deberá ser de grado alimentario.

c) No gasificada: agua mineral natura que no contiene gas carbónico".

Art 987 - (Res MSyAS n° 209 del 7.03.94) " Envases: Las aguas minerales naturales deberán ser envasadas en el lugar de origen salvo que el agua se transporte desde la fuente y/o captaciones hasta la planta de envasado mediante canalizaciones adecuadas que eviten su contaminación microbiológica y no alteren su composición química.

Serán envasadas en los recipientes destinado directamente al consumidor.

Los recipientes de materiales poliméricos y los compuestos para su fabricación en las plantas deberán ser bromatológicamente aptos y estar previamente aprobados por la autoridad sanitaria competente.

Todo envase utilizado para el acondicionamiento de las aguas minerales naturales debe estar provisto de un dispositivo de cierre hermético inviolable destinado a evitar toda posibilidad de falsificación y/o contaminación.

El volumen de los envases no podrá ser superior a dos (2) litros y queda prohibido el transporte y comercialización de agua mineral natural en todo envase que no sea el autorizado para el consumidor final".

Art 988 - (Res MSyAS n° 209 del 7.03.94) "Rotulación: En la rotulación de las aguas minerales se consignarán, los siguientes datos:

1. Indicaciones obligatorias:

a) Denominación del producto mediante las expresiones:

"Agua mineral natural de manantial de mesa" o
"Agua mineral natural de manantial" o
"Agua mineral natural de mesa" o
"Agua mineral natural"

con caracteres de igual tamaño, realce y visibilidad, reservándose las dos primeras designaciones para aquellas aguas provenientes de fuentes surgentes naturales;
b) Marca registrada
c) Nombre o razón social y domicilio de la planta productora
d) Contenido neto
e) Clasificación correspondiente de acuerdo al grado de mineralización, a la composición y al contenido gaseoso de acuerdo a lo establecido en el Art 986, inc. 1, 2 y 4, con caracteres y en lugar bien visibles
f) Tratamiento eventual al que pudo haber sido sometida el agua de acuerdo a las disposiciones del Art 985, inc. 3), apartado b). Se consignará mediante expresiones tales como "deazufrada", y/o "deferrinizada"
g) Lugar del emplazamiento de la fuente mediante indicaciones que no puedan suscitar engaño y confusión.
h) Datos referidos a la composición o el resultado del análisis practicado por la autoridad sanitaria competente en el momento de autorizar el producto. Optativamente podrán mencionarse resultados del análisis microbiológicos
i) Números de registro del producto y del establecimiento otorgados por la autoridad sanitaria competente
j) Fecha de vencimiento que también podrá indicarse con la expresión "Consumir preferentemente antes de ...", llenando el espacio en blanco con la fecha correspondiente.
k) Identificación de la partida o del día de elaboración, la que podrá efectuares mediante una clave que se pondrá en conocimiento de la autoridad sanitaria competente.
2. Indicaciones optativas:
a) Nombre de la fuente
b) Termalidad y/o radioactividad mediante las menciones "Temperatura (o radioactividad) en el punto de captación" o expresiones similares que no den lugar a confusión o engaño con respecto a que tales propiedades correspondan al agua en el momento de su captación y no al producto envasado".

Art 989 - (Res MSyAS n° 209 del 7.03.94) "Restricciones y prohibiciones:
1. La denominación de agua mineral queda exclusivamente reservada a las aguas minerales naturales
2. Queda prohibido comercializar bajo una misma marca aguas minerales naturales procedentes de diferentes localidades de origen. Queda prohibido tanto en los envases y en la rotulación cuanto en cualquier forma de publicidad, la utilización de indicaciones, denominaciones, marcas de fábrica o comerciales, imágenes, símbolos u otros signos figurativos o no que:
a) sugieran o atribuyan a un agua mineral natural propiedades de prevención, tratamiento o cura de cualquier tipo de enfermedad,
b) con respecto a un agua mineral natural sugieran o indiquen una característica que la misma no posea con respecto al origen, autorización de

explotación, resultado de análisis, calificaciones o toda otra referencia análoga a las garantías de autenticidad
c) con respecto a un agua potable envasada o a aguas mineralizadas artificialmente sean susceptibles de crear confusión con un agua natural".

Art 990 - (Res MSyAS n° 209 del 7.03.94) "El nombre de una localidad, pueblo, municipio o lugar podrá integrar el texto de una designación comercial o marca, siempre que se refiera a un agua mineral natural cuya fuente de explotación se encuentre en el lugar indicado por dicha designación comercial o marca. Los nuevos productos a registrar como agua mineral natural deberán adoptar como marca una denominación que no induzca a confusión ni visual ni fonética con las anteriormente registradas".

Art 991 - (Res MSyAS n° 209 del 7.03.94)
"1) Toda agua mineral natural, antes de ser librada al consumo, así como la fuente que le da origen, tendrán que se previamente aprobadas por la autoridad sanitaria competente, la que deberá apreciarlas en los siguientes aspectos:
a) Geológicos e hidrogeológico
b) Físico, químico y fisicoquímico
c) Microbiológico
2) La autoridad sanitaria efectuará los análisis correspondientes del agua en estudio a fin de establecer su composición química, caracteres fisico-químicos y calidad microbiológica: Estos exámenes deberán ser repetidos íntegramente tres veces en un año, con periodicidad semestral, para poder considerar completado en estos aspectos, el estudio previo a la evaluación. La metodología de análisis se consignará en el presente Código y será de carácter obligatorio a partir de la fecha de su publicación;
3) La empresa que explotará la fuente deberá presentar, conjuntamente con la solicitud de aprobación del producto y de la planta, las siguientes informaciones:
1. Temperatura del agua en el momento de su captación
2. Radio-actinología del agua en el momento de su captación en el caso de fuente radioactiva
3. Caudal de la fuente
4. Situaciones exactas de las captaciones determinadas por su altitud y, en el plano topográfico, por un mapa en escala de 1:1000 como máximo.
5. Informe geológico detallado sobre el origen y la naturaleza de los terrenos
6. Estratigrafía del yacimiento hidrogeológico
7. Area de restricción proyectada en un perímetro alrededor de la fuente u otras medidas de protección contra las contaminaciones
8. Descripción de los proyectos referidos a las obras de captación, tanques de almacenamiento, canalizaciones, maquinaria, equipos, materiales empleados
9. Sistemas y equipos para procesos de decantación, filtración, gasificación y toda otra operación facultativa autorizada.

4) La autorización definitiva de explotación de una fuente, luego de ser aprobada el agua mineral natural que de ella proviene, quedará condicionada a la aprobación de las instalaciones de la planta y a que las operaciones se realicen con los debidos recaudos de higiene".

Art 992 - (Res MSyAS n° 209 del 7.03.94) "Cuando por razones accidentales resultara indispensable proceder a practicar el saneamiento parcial o total de la fuente, perforaciones y/o instalaciones, deberá utilizarse hipocloritos alcalinos u otros desinfectantes autorizados.

En todo caso las tareas de limpieza y/o desinfección deberán realizarse manteniendo en receso el proceso de captación y envasado que sólo podrá reiniciarse cuando el tenor en cloro activo o de cualquier otro desinfectante empleado en un examen de prueba del agua sea cero.

Los controles y ensayos a que dieran lugar los supuestos casos enunciados, así como toda otra evaluación al respecto no expresamente indicada, serán llevados a cabo en el laboratorio de la empresa cuya existencia determinan las disposiciones del Anexo I". (Ver el Anexo I a continuación del Art 118)

Art 992bis - (Res MSyAS n° 209 del 7.03.94) " Cualquier modificación en las condiciones de las eventuales operaciones facultativas autorizadas deben ser puestas en conocimiento de la autoridad sanitaria competente. Asimismo deberá serle comunicada toda variación permanente que se haya constatado en las características químicas del agua que supere las tolerancias admitidas, a fin de que pueda autorizar -si correspondiere- la continuación de la explotación".

Art 993 - (Res MSyAS n° 209 del 7.03.94) "Todas las plantas de explotación de una fuente de agua mineral natural deberán ajustarse a las disposiciones y exigencias impuestas por el Anexo I (Ver el Anexo I a continuación del Art 118) y complementariamente a las generales de higiene para los establecimientos que elaboran alimentos".

Art 994 - (Res MSyAS n° 209 del 7.03.94) "Las aguas minerales naturales podrán ser utilizadas en la elaboración de bebidas sin alcohol u otros productos alimenticios únicamente en el lugar de explotación de la fuente.

Los productos elaborados con agua mineral podrá hacer mención en el rótulo de esta circunstancia, pero no podrán mencionar ninguna propiedad particular vinculada con la composición del agua mineral".

Art 994bis - (Res MSyAS n° 209 del 7.03.94) "Se entiende por Agua mineral aromatizada o saborizada el producto elaborado con agua mineral natural que cumpla con las exigencias del presente Código, adicionada de sustancias aromatizantes naturales de uso permitido.

Deberá cumplir con los requisitos microbiológicos y químicos consignados en el Art 985, con la única excepción del contenido de materia orgánica.

El envase deberá responder a las exigencias del Art 987. Este producto deberá ser elaborado exclusivamente en el lugar de explotación de la fuente.

El producto se rotulará en el cuerpo del envase "Agua Mineral Aromatizada (o Saborizada)", seguido de la leyenda "con sabor natural de..." o "con aroma natural de..." llenando el espacio en blanco con el sabor o aroma que lo caracteriza, con caracteres de buenas visibilidad y altura no mayor de 2/3 de la denominación del producto.

El producto carbonatado en el lugar de origen con dióxido de carbono, deberá consignar la indicación gasificado.

Deberá además consignar las indicaciones que correspondan establecidas en el Art 986 y cumplir con las restricciones señaladas en los Art 988, inc. 2), párrafo b); 989, inc. 2, párrafo a) y 990".

Art 995 - (Res MSyAS n° 209 del 7.03.94) "Con la denominación de "Agua mineralizada artificialmente" se entiende al producto elaborado con agua potable adicionada de minerales de uso permitido, gasificada o no, envasada en recipientes bromatológicamente aptos, de no más de dos (2) litros de capacidad, de cierre hermético e inviolable.

Deberá cumplimentar las siguientes exigencias:

a) Cumplir los requisitos microbiológicos y de compuestos químicos y contaminantes establecidos para el agua mineral, según lo prescripto en el Art 985 de este Código

b) La presión de dióxido de carbono (cuando corresponda) no será menor de 1,5 atmósferas a 21°C

c) Los nombres de fantasía o marcas no serán de fuentes o localidades donde se obtengan o hubieren obtenido aguas minerales naturales.

Este producto se rotulará: Agua Mineralizada artificialmente con caracteres de buen tamaño, realce y visibilidad. En el rótulo deberá figurar además, con iguales caracteres y en lugar bien visible la clasificación que le hubiere correspondido en razón de las sales añadidas según lo indicado en el Art 986, inc. 2, así como la expresión Gasificada o No Gasificada, según corresponda. Deberá consignarse nombre o razón social y domicilio del elaborador.

Podrán consignarse en la rotulación datos analíticos de resultados de análisis químicos y bacteriológicos realizados en laboratorios oficiales".

ANEXO II

AGENCIA DE PROTECCIÓN AMBIENTAL de EUA (EPA)

Agua Subterránea & Agua Potable

ESTÁNDARES DEL REGLAMENTO NACIONAL PRIMARIO DE AGUA POTABLE

ontaminante	**MNMC[1] (mg/l) [4]**	**NMC[2] o TT[3](mg/l)[4]**	**Posibles efectos sobre la salud por exposición que supere el NMC**	**Fuentes de contaminación comunes en agua potable**
Químicos Inorgánicos				
Antimonio	0.006	0.006	Aumento de colesterol en sangre; descenso de azúcar en sangre (aumento de colesterolhemia; hipoglucemia).	Efluentes de refinerías de petróleo; retardadores de fuego; cerámicas; productos electrónicos; soldaduras.
Arsénico	ninguno[5]	0.05	Lesiones en la piel; trastornos circulatorios; alto riesgo de cáncer.	Erosión de depósitos naturales; agua de escorrentía de huertos; aguas con residuos de fabricación de vidrio y productos electrónicos.
Asbestos (fibras >10 micrómetros)	7 millones de fibras por litro (MFL)	7 MFL	Alto riesgo de desarrollar pólipos intestinales benignos.	Deterioro de cemento amiantado (fibrocemento) en cañerías principales de agua; erosión de depósitos naturales.
Bario	2	2	Aumento de presión arterial.	Aguas con residuos de perforaciones; efluentes de refinerías de metales; erosión de depósitos naturales.
Berilio	0.004	0.004	Lesiones intestinales.	Efluentes de refinerías de metales y fábricas que emplean carbón; efluentes de industrias eléctricas, aeroespaciales y de defensa.
Cadmio	0.005	0.005	Lesiones renales.	Corrosión de tubos galvanizados; erosión de

				depósitos naturales; efluentes de refinerías de metales; líquidos de escorrentía de baterías usadas y de pinturas.
Cromo (total)	0.1	0.1	Dermatitis alérgica.	Efluentes de fábricas de acero y papel; erosión de depósitos naturales.
Cobre	1.3	Nivel de acción=1.3; TT[6]	Exposición a corto plazo: molestias gastrointestinales. Exposición a largo plazo: lesiones hepáticas o renales. Aquellos con enfermedad de Wilson deben consultar a su médico si la cantidad de cobre en el agua superara el nivel de acción.	Corrosión de cañerías en el hogar; erosión de depósitos naturales; percolado de conservantes de madera.
Cianuro (como cianuro libre)	0.2	0.2	Lesiones en sistema nervioso o problemas de tiroides	Efluentes de fábricas de acero y metales; efluentes de fábricas de plásticos y fertilizantes
Flúor	4.0	4.0	Enfermedades óseas (dolor y fragilidad ósea) Los niños podrían sufrir de dientes manchados	Aditivo para agua para tener dientes fuertes; erosión de depósitos naturales; efluentes de fábricas de fertilizantes y de aluminio.
Plomo	cero	Nivel de acción=0.015; TT[6]	Bebés y niños: retardo en desarrollo físico o mental; los niños podrían sufrir leve déficit de atención y de capacidad de aprendizaje. Adultos: trastornos renales; hipertensión	Corrosión de cañerías en el hogar; erosión de depósitos naturales.
Mercurio (Inorgánico)	0.002	0.002	Lesiones renales	Erosión de depósitos naturales; efluentes de refinerías y fábricas; lixiviados de vertederos y tierras de cultivo.
Nitrato (medido como nitrógeno)	10	10	Los bebés de menos de seis meses que tomen agua que contenga mayor concentración de nitratos que el NMC, podrían enfermarse gravemente; si no se los tratara, podrían morir. Entre los síntomas se incluye dificultad respiratoria y síndrome de bebé cianótico (azul).	Aguas contaminadas por el uso de fertilizantes; percolado de tanques sépticos y de redes de alcantarillado; erosión de depósitos naturales.

Nitrito (medido como nitrógeno)	1	1	Los bebés de menos de seis meses que tomen agua que contenga mayor concentración de nitritos que el NMC, podrían enfermarse gravemente; si no se los tratara, podrían morir. Entre los síntomas se incluye dificultad respiratoria y síndrome de bebé cianótico (azul).	Aguas contaminadas por el uso de fertilizantes; percolado de tanques sépticos y de redes de alcantarillado; erosión de depósitos naturales.
Selenio	0.05	0.05	Caída del cabello o de las uñas; adormecimiento de dedos de manos y pies; problemas circulatorios.	Efluentes de refinerías de petróleo; erosión de depósitos naturales; efluentes de minas.
Talio	0.0005	0.002	Caída del cabello; alteración de la sangre; trastornos renales, intestinales o hepáticos.	Percolado de plantas procesadoras de minerales; efluentes de fábricas de vidrio, productos
Químicos Orgánicos				
Acrilamida	cero	TT[7]	Trastornos sanguíneos o del sistema nervioso; alto riesgo de cáncer.	Se agrega al agua durante el tratamiento de efluentes y de agua de alcantarillado.
Alaclor	cero	0.002	Trastornos oculares, hepáticos, renales o esplénicos; anemia; alto riesgo de cáncer.	Aguas contaminadas por la aplicación de herbicidas para cultivos.
Atrazina	0.003	0.003	Trastornos cardiovasculares o del sistema reproductor.	Aguas contaminadas por la aplicación de herbicidas para cultivos.
Benceno	cero	0.005	Anemia; trombocitopenia; alto riesgo de cáncer.	Efluentes de fábricas; percolado de tanques de almacenamiento de combustible y de vertederos para residuos.
Benzo(a)pireno	cero	0.0002	Dificultades para la reproducción; alto riesgo de cáncer.	Percolado de revestimiento de tanques de almacenamiento de agua y líneas de distribución.
Carbofurano	0.04	0.04	Trastornos sanguíneos, del sistema nervioso o del sistema reproductor.	Percolado de productos fumigados en cultivos de arroz y alfalfa.
Tetracloruro de	cero	0.005	Trastornos hepáticos; alto	Efluentes de plantas

carbono			riesgo de cáncer.	químicas y de otras actividades industriales.
Clordano	cero	0.002	Trastornos hepáticos o del sistema nervioso; alto riesgo de cáncer.	Residuos de termiticidas prohibidos.
Clorobenceno	0.1	0.1	Trastornos hepáticos o renales.	Efluentes de plantas químicas y de plantas de fabricación de agroquímicos.
2,4-D	0.07	0.07	Trastornos renales, hepáticos o de la glándula adrenal.	Aguas contaminadas por la aplicación de herbicidas para cultivos.
Dalapon	0.2	0.2	Pequeños cambios renales.	Aguas contaminadas por la aplicación de herbicidas utilizados en servidumbres de paso.
1,2-Dibromo-3-cloropropano (DBCP)	cero	0.0002	Dificultades para la reproducción; alto riesgo de cáncer.	Aguas contaminadas/percolado de productos fumigados en huertos y en campos de cultivo de soja, algodón y piña (ananá).
o-Diclorobenceno	0.6	0.6	Trastornos hepáticos, renales o circulatorios.	Efluentes de fábricas de productos químicos de uso industrial.
p-Diclorobenceno	0.075	0.075	Anemia; lesiones hepáticas, renales o esplénicas; alteración de la sangre.	Efluentes de fábricas de productos químicos de uso industrial.
1,2-Dicloroetano	cero	0.005	Alto riesgo de cáncer.	Efluentes de fábricas de productos químicos de uso industrial.
1-1-Dicloroetileno	0.007	0.007	Trastornos hepáticos.	Efluentes de fábricas de productos químicos de uso industrial.
cis-1, 2-Dicloroetileno	0.07	0.07	Trastornos hepáticos.	Efluentes de fábricas de productos químicos de uso industrial.
trans-1,2-Dicloroetileno	0.1	0.1	Trastornos hepáticos.	Efluentes de fábricas de productos químicos de uso industrial.
Diclorometano	cero	0.005	Trastornos hepáticos; alto riesgo de cáncer.	Efluentes de plantas químicas y farmacéuticas.
1-2-Dicloropropano	cero	0.005	Alto riesgo de cáncer.	Efluentes de fábricas de productos químicos de uso industrial.

Adipato de di-(2-etilhexilo)	0.4	0.4	Efectos tóxicos generales o dificultades para la reproducción	Efluentes de plantas químicas.
Ftalato de di-(2-etilhexilo)	cero	0.006	Dificultades para la reproducción; trastornos hepáticos; alto riesgo de cáncer	Efluentes de plantas químicas y de fabricación de goma.
Dinoseb	0.007	0.007	Dificultades para la reproducción	Aguas contaminadas por la aplicación de herbicidas utilizados en soja y vegetales.
Dioxina (2,3,7,8-TCDD)	cero	0.00000003	Dificultades para la reproducción; alto riesgo de cáncer	
Diquat	0.02	0.02	Cataratas	Aguas contaminadas por la aplicación de herbicidas.
Endotal	0.1	0.1	Trastornos estomacales e intestinales.	Aguas contaminadas por la aplicación de herbicidas.
Endrina	0.002	0.002	Trastornos hepáticos.	Residuo de insecticidas prohibidos.
Epiclorohidrina	cero	TT[7]	Alto riesgo de cáncer y a largo plazo, trastornos estomacales.	Efluentes de fábricas de productos químicos de uso industrial; impurezas de algunos productos químicos usados en el tratamiento de aguas.
Etilbenceno	0.7	0.7	Trastornos hepáticos o renales.	Efluentes de refinerías de petróleo.
Dibromuro de etileno	cero	0.00005	Trastornos hepáticos, estomacales, renales o del sistema reproductor; alto riesgo de cáncer.	Efluentes de refinerías de petróleo.
Glifosato	0.7	0.7	Trastornos renales; dificultades para la reproducción.	Aguas contaminadas por la aplicación de herbicidas.
Heptacloro	cero	0.0004	Lesiones hepáticas; alto riesgo de cáncer	Residuos de termiticidas prohibidos.
Heptaclorepóxido	cero	0.0002	Lesiones hepáticas; alto riesgo de cáncer	Descomposición de heptacloro.
Hexaclorobenceno	cero	0.001	Trastornos hepáticos o renales; dificultades para la	Efluentes de refinerías de metales y plantas de

			reproducción; alto riesgo de cáncer.	agroquímicos.
Hexacloro-ciclopentadieno	0.05	0.05	Trastornos renales o estomacales.	Efluentes de plantas químicas.
Lindano	0.0002	0.0002	Trastornos hepáticos o renales.	Aguas contaminadas/percolado de insecticidas usados en ganado, madera, jardines.
Metoxicloro	0.04	0.04	Dificultades para la reproducción.	Aguas contaminadas/percolado de insecticidas usados en frutas, vegetales, alfalfa, ganado.
Oxamil (Vidato)	0.2	0.2	Efectos leves sobre el sistema nervioso.	Aguas contaminadas/percolado de insecticidas usados en manzanas, papas y tomates.
Bifenilos policlorados (PCB)	cero	0.0005	Cambios en la piel; problemas de la glándula timo; inmunodeficiencia;dificultades para la reproducción o problemas en el sistema nervioso; alto riesgo de cáncer.	Agua de escorrentía de vertederos; aguas con residuos químicos.
Pentaclorofenol	cero	0.001	Trastornos hepáticos o renales; alto riesgo de cáncer.	Efluentes de plantas de conservantes para madera.
Picloram	0.5	0.5	Trastornos hepáticos.	Aguas contaminadas por la aplicación de herbicidas.
Simazina	0.004	0.004	Problemas sanguíneos.	Aguas contaminadas por la aplicación de herbicidas.
Estireno	0.1	0.1	Trastornos hepáticos, renales o circulatorios.	Efluentes de fábricas de goma y plástico; lixiviados de vertederos.
Tetracloroetileno	cero	0.005	Trastornos hepáticos; alto riesgo de cáncer.	Efluentes de fábricas y empresas de limpieza en seco.
Tolueno	1	1	Trastornos renales, hepáticos o del sistema nervioso.	Efluentes de refinerías de petróleo.
Trihalometanos	ninguno	0.10	Trastornos renales, hepáticos	Subproducto de la

totales (TTHM)			o del sistema nervioso central; alto riesgo de cáncer.	desinfección de agua potable.
Toxafeno	cero	0.003	Problemas renales, hepáticos o de tiroides; alto riesgo de cáncer.	Aguas contaminadas/percolado de insecticidas usados en algodón y ganado.
2,4,5-TP (Silvex)	0.05	0.05	Trastornos hepáticos.	Residuos de herbicidas prohibidos.
1,2,4-Triclorobenceno	0.07	0.07	Cambios en glándulas adrenales.	Efluentes de fábricas de textiles.
1,1,1-Tricloroetano	0.20	0.2	Problemas circulatorios, hepáticos o del sistema nervioso.	Efluentes de plantas para desgrasar metales y de otros tipos de plantas.
1,1,2-Tricloroetano	3	5	Problemas hepáticos, renales o del sistema inmunológico.	Efluentes de fábricas de productos químicos de uso industrial.
Tricloroetileno	cero	5	Trastornos hepáticos; alto riesgo de cáncer.	Efluentes de plantas para desgrasar metales y de otros tipos de plantas.
Cloruro de vinilo	cero	2	Alto riesgo de cáncer.	Percolado de tuberías de PVC; efluentes de fábricas de plásticos.
Xilenos (total)	10	10	Lesiones del sistema nervioso.	Efluentes de refinerías de petróleo; efluentes de plantas químicas.
Radionucleidos				
Emisores de partículas beta y de fotones.	ninguno[5]	4 milirems por año (mrem/año)	Alto riesgo de cáncer.	Desintegración radiactiva de depósitos naturales y artificiales de ciertos minerales que son radiactivos y pueden emitir radiación conocida como fotones y radiación beta.
Actividad bruta de partículas alfa	ninguno[5]	15 picocurios por litro (pCi/l)	Alto riesgo de cáncer.	Erosión de depósitos naturales de ciertos minerales que son radiactivos y pueden emitir radiación conocida como radiación alfa.
Radio 226 y Radio 228 (combinados)	ninguno[5]	5 pCi/l	Alto riesgo de cáncer.	Erosión de depósitos naturales.

Microorganismos				
Giardia lamblia	cero	TT[8]	Trastornos gastrointestinales (diarrea, vómitos, retortijones).	Desechos fecales humanos y de animales.
Conteo de placas de bacterias heterotróficas(HPC)	N/A	TT[8]	El HPC no tiene efecto sobre la salud; es sólo un método analítico usado para medir la variedad de bacterias comúnmente encontradas en el agua. Cuanto menor sea la concentración de bacterias en el agua potable, mejor mantenido estará el sistema.	Con el HPC se determinan las diversas bacterias que hay en forma natural en el medio ambiente.
Legionella	cero	TT[8]	Enfermedad de los legionarios, un tipo de neumonía[9].	Presente naturalmente en el agua; se multiplica en los sistemas de calefacción.
Coliformes totales (incluye coliformes fecales y *E. coli*)	cero	5.0%[10]	Por sí mismos, los coliformes no constituyen una amenaza para la salud; su determinación se usa para indicar si pudiera haber presentes otras bacterias posiblemente nocivas[11].	Los coliformes se presentan naturalmente en el medio ambiente; los coliformes fecales y la *E. coli*provienen de heces fecales de humanos y de animales.
Turbidez	N/A	TT[8]	La turbidez es una medida del enturbiamiento del agua. Se utiliza para indicar la calidad del agua y la eficacia de la filtración (por ejemplo, para determinar si hay presentes organismos que provocan enfermedades). Una alta turbidez suele asociarse a altos niveles de microorganismos causantes de enfermedades, como por ejemplo, virus, parásitos y algunas bacterias. Estos organismos pueden provocar síntomas tales como náuseas, retortijones, diarrea y dolores de cabeza asociadas.	Agua de escorrentía por el terreno.
Virus (entéricos)	cero	TT[8]	Trastornos gastrointestinales (diarrea, vómitos, retortijones).	Heces fecales de humanos y de animales.

Notas

1. Meta del Nivel Máximo del Contaminante (MNMC) Es el nivel de un contaminante en el agua potable por debajo del cual no se conocen o no se esperan riesgos para la salud. Los MNMC permiten contar con un margen de seguridad y no son objetivos de salud pública obligatorios.
2. Nivel Máximo del Contaminante (NMC) - Es el máximo nivel permitido de un contaminante en agua potable. Los NMC se establecen tan próximos a los MNMC como sea posible, usando para ello la mejor tecnología de tratamiento disponible y teniendo en cuenta también los costos. Los NMC son normas obligatorias.
3. Técnica de Tratamiento (TT) Proceso obligatorio, cuya finalidad es reducir el nivel de un contaminante dado en el agua potable.
4. Las unidades se expresan en miligramos por litro (mg/l) a menos que se indique otra cosa.
5. Los MNMC se establecieron luego de la Enmienda de 1986 a la Ley de Agua Potable Segura. El estándar para este contaminante se fijó antes de 1986. Por lo tanto, no hay MNMC para este contaminante.
6. El plomo y el cobre se regulan mediante una Técnica de Tratamiento que exige la implementación de sistemas que controlen el poder corrosivo del agua. El nivel de acción sirve como un aviso para que los sistemas de agua públicos tomen medidas adicionales de tratamiento si los niveles de las muestras de agua superan en más del 10 % los valores permitidos. Para el cobre, el nivel de acción es 1.3 mg/l y para el plomo es 0.015mg/l.
7. Todos y cada uno de los sistemas de agua deben declarar al estado, por escrito, que si se usa acrilamida y/o epiclorhidrina para tratar agua, la combinación (o producto) de dosis y cantidad de monómero no supera los niveles especificados, a saber: acrilamida = 0.05% dosificada a razón de 1 mg/l (o su equivalente); epiclorohidrina = 0.01% dosificada a razón de 20 mg/l (o su equivalente).
8. La Regla de Tratamiento de Agua de Superficie requiere que los sistemas que usan agua de superficie o subterránea bajo influencia directa de agua de superficie, (1) desinfecten el agua y (2) filtren el agua o realicen el mismo nivel de tratamiento que aquellos que filtran el agua. El tratamiento debe reducir los niveles de *Giardia lamblia* (parásito) en un 99.9% y los virus en un 99.99%. La *Legionella* (bacteria) no tiene límite, pero la EPA considera que si se inactivan la *Giardia* y los virus, la *Legionella* también estará controlada. En ningún momento la turbidez (enturbiamiento del agua) puede superar las 5 unidades nefelométricas de turbidez ("NTU") [los sistemas filtrantes deben asegurar que la turbidez no supera 1 NTU (0.5 NTU para filtración convencional o directa) en al menos el 95% de las muestras diarias de cualquier mes]; HPC- no más de 500 colonias por mililitro.

9. La Enfermedad de los Legionarios se produce cuando las personas susceptibles inhalan un aerosol que contiene *Legionella*, no cuando se bebe agua que contiene *Legionella*. (Las duchas, grifos de agua caliente, jacuzzis y equipos de enfriamiento, tales como torres de enfriamiento y acondicionadores de aire, producen aerosoles). Algunos tipos de *Legionella* pueden provocar un tipo de neumonía llamada Enfermedad de los Legionarios. La *Legionella* también puede provocar una enfermedad mucho menos grave llamada fiebre Pontiac. Los síntomas la fiebre Pontiac pueden incluir: dolores musculares, cefaleas, tos, náuseas, mareos y otros síntomas.
10. En un mes dado, no pueden detectarse más de 5.0% de muestras con coliformes totales positivas. (Para sistemas de agua en los que se recogen menos de 40 muestras de rutina por mes, no puede detectarse más de una muestra con coliformes totales positiva). Toda muestra que presente coliformes totales debe analizarse para saber si presenta *E. coli*o coliformes fecales, a fin de determinar si hubo contacto con heces fecales humanas o de animales (coliformes fecales y *E. coli*son parte del grupo de coliformes totales).
11. Coliformes fecales y *E. coli* son bacterias cuya presencia indica que el agua podría estar contaminada con heces fecales humanas o de animales. Los microbios que provocan enfermedades (patógenos) y que están presentes en las heces, causan diarrea, retortijones, náuseas, cefaleas u otros síntomas. Estos patógenos podrían representar un riesgo de salud muy importante para bebés, niños pequeños y personas con sistemas inmunológicos gravemente comprometidos.

ANEXO III

LEY 24.051 Decreto Reglamentario 831/93

POTABILIDAD

Régimen de desechos peligrosos, niveles guia de calidad para fuentes de agua de bebida humana con tratamiento convencional.

Constituyente Peligroso	C A S	Nivel Guía (µg/l)	Referencias	
ACIDO NITRICO - TRIACETICO	137-13-9	50	B	
ACROLEINA	107-02-8	542	D	2
ALDICARB	116-06-3	3	D	1
ALDRIN	309-00-2	0.03	A	
ALUMINIO (TOTAL)	7429-90-5	200	A	
AMONIO (ug/ l NH4)	7664-41-7	50	C	1
ANTIMONIO (TOTAL)	7440-36-0	10	C	2
ARSENICO (TOTAL)	7440-38-2	50	A	
ATRAZINA	1912-24-9	3	D	1
BARIO (TOTAL)	7440-39-3	1000	B	
BENCENO	71-43-2	10	A	
BENCIDINA	92-87-5	0.0015	D	2
BENDIOCARB	22781-23-3	40	B	
BENZO(A) PIRENO	50-32-8	0.01	A	
BERILIO (TOTAL)	7440-41-7	0.039	D	2
BHC-ALFA	319-84-6	0.131	D	2
BHC-BETA	319-85-7	0.232	D	2
BHC-GAMA (LINDANO)	58-89-9	3	A	
BIS (2-CLOROETIL) ETER	111-44-4	3.85	D	2
BIS (CLOROMETIL) ETER	542-88-1	0.000038	D	2
BIS (2-CLOROISOPROPIL) ETER	108-60-1	5	D	2
BIS (ETILHEXIL) FTALATO	117-81-7	21400	D	2
BORO (TOTAL)	7440-42-8	1000	C	1
BROMOMETANO	74-83-9	2	D	2
BROMOXIMIL	1689-84-5	5	B	
CADMIO (TOTAL)	7440-43-9	5	A	
CARBARIL	63-25-2	90	B	

CARBOFURANO	1563-66-2	40	D	1
CIANAZINA	21725-46-2	10	B	1
CIANURO (TOTAL)	57-12-5	100	A	
CINC (TOTAL)	7440-66-6	5000	B	
CLORDANO	57-74-9	0.3	A	
CLOROBENCENO	108-90-7	100	D	1
CLOROFENOL (2-)	95-57-8	0.1	D	2
CLOROFORMO	67-66-3	30	A	
CLOROMETANO	74-87-3	1.9	D	2
CLORPIRIFOS	2991-88-2	90	B	
CLORURO DE VINILO	75-01-4	20	D	2
COBRE (TOTAL)	7440-50-8	1000	B	
CROMO (TOTAL)	7440-47-3	50	A	
CROMO (+6)	18540-29-9	50	D	2
D (2,4-)	94-75-7	100	A	
DDT	50-29-3	1	A	
DIAZINON	333-41-5	20	B	
DIBROMOCLOROPROPANO (DBCP)	96-12-8	0.2	D	1
DIBROMOETILENO	106-93-4	0.05	D	1
DICAMBA	1918-00-9	120	B	2
DICLOFOP-METIL	51338-27-3	9	B	1
DICLOROBENCENO (1,2-)	95-50-1	200	B	
DICLOROBENCENO (1,4-)	106-46-7	5	B	
DICLOROETANO (1,2-)	107-06-2	10	A	1
DICLOROETILENO (1,1-)	75-35-4	0.3	A	2
DICLOROETILENO (1,2-sis)	540-59-0	70	D	1
DICLOROETILENO (1,2-trans)	156-60-5	100	D	1
DICLOROFENOL (2,4-)	120-83-2	0.3	D	2
DICLOROMETANO	75-09-2	50	B	
DICLOROPROPANO (1,2-)	78-87-5	5	D	1
DICLOROPROPILENO (1,2-)	563-54-2	87	D	2
DIELDRIN	60-57-1	0.03	A	
DIMETILFENOL (2,4-)	105-67-9	400	D	2
DIMETOATO	60-51-5	20	B	1
DINITROFENOL (2,4-)	51-28-5	70	D	2
DINITROTOLUENO (2,4-)	121-14-2	1.1	D	2
DIQUAT	85-00-7	70	B	2
DIURON	330-54-1	150	B	2
ENDOSULFAN	108-60-1	138	D	2
ENDRIN	72-20-8	0.2	B	2

ESTIRENO	100-42-5	100	D	1
ETILBENCENO	100-41-4	700	D	1
FENOL	108-95-2	2	B	
FLUORANTENO	206-44-0	190	D	2
FLUORURO (TOTAL)	16984-48-8	1500	A	
FORATO	298-02-2	2	B	1
GLIFOSATO	1071-83-6	280	B	1
HEPTACLORO	76-44-8	0.1	A	
HEPTACLORO EPOXIDO	1024-57-3	0.1	A	
HEXACLOROBENCENO	118-74-1	0.01	A	
HEXACLOROBUTADIENO	87-68-3	4.5	D	2
HEXACLOROCICLOPENTADIENO	77-47-4	1	D	2
HEXACLOROETANO	67-72-1	24	D	2
HIDROCARB. AR. POLINUCLEARES	74-87-3	0.03	D	2
HIERRO (TOTAL)	7439-89-6	300	A	
ISOFORONE	78-59-1	5	D	2
MALATION	121-75-5	190	B	
MANGANESO (TOTAL)	7439-96-5	100	A	
MERCURIO (TOTAL)	7439-97-6	1	A	2
METIL-PARATION	298-00-0	7	B	
METIL-AZINFOS (GUTION)	86-50-0	20	B	
METOLACLOR	51218-45-2	50	B	1
METOXICLORO	72--43-5	30	A	1
METRIBUZINA	21087-64-9	80	B	1
NIQUEL (TOTAL)	7440-02-0	25	E	1
NITRATO	1918-00-9	10000	A	2
NITRITO	51338-27-3	50	B	1
NITROBENCENO	98-95-3	30	D	2
ORGANOCLORADOS TOTALES	106-46-7	10	F	
ORGANOCLORADOS (NO PLAG.)	107-06-2	1	C	1
PARAQUAT	1910-42-5	10	B	1
PARATION	56-38-2	50	B	1
PCB (TOTAL)	1336-36-3	0.00079	D	2
PCB-1016 (AROCHLOR 1016)	12674-11-2	2	D	1
PCB-1221 (AROCHLOR 1221)	11104-28-2	2	D	1
PCB-1232 (AROCHLOR 1232)	11141-16-5	2	D	1
PCB-1242 (AROCHLOR 1242)	53469-21-9	2	D	1
PCB-1248 (AROCHLOR 1248)	12672-29-6	2	D	1
PCB-1254 (AROCHLOR 1254)	11097-69-1	2	D	1
PCB 1260 (AROCHLOR 1260)	11096-82-5	2	D	1

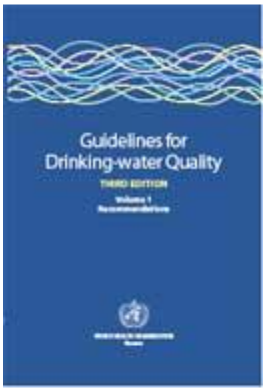
PENTACLOROBENCENO	608-93-5	572	D	2
PENTACLOROFENOL	87-86-5	10	A	2
PLAGUICIDAS TOTALES	85-00-7	100	B	2
PLATA (TOTAL)	7440-22-4	50	B	2
PLOMO (TOTAL)	7439-92-1	50	A	2
SELENIO (TOTAL)	7782-49-2	10	A	2
SIMAZINE	122-34-9	10	B	1
T (2,4,5-)	93-76-5	280	B	1
TALIO (TOTAL)	7440-28-0	18	D	2
TEMEFOS	3383-96-8	280	B	1
TERBUFOS	13071-79-9	1	B	1
TETRACLOROETANO (1,1,2,2-)	79-34-5	1.7	D	2
TETRACLOROETILENO	127-18-4	10	A	
TETRACLOROFENOL (2,3,4,6-)	58-90-2	1	D	1
TETRACLORURO DE CARBONO	56-23-5	3	A	
TOLUENO	108-88-3	1000	D	1
TOXAFENO	8001-35-2	5	B	2
TP (2,4,5-)	93-72-1	10	B	2
TRIALATO	2303-17-5	230	B	2
TRIBROMOMETANO	75-25-2	2	D	2
TRICLOROETANO (1,1,1-)	71-55-6	200	G	
TRICLOROETANO (1,1,2-)	79-00-5	6	D	2
TRICLOROETILENO	79-01-6	30	A	
TRICLOROFENOL (2,3,4-)	15950-66-0	10	H	
TRICLOROFENOL (2,4,6-)	88-06-2	10	A	2
TRICLOROFLUORMETANO	75-69-4	2	D	2
TRIHALOMETANOS	86-50-0	100	G	
URANIO TOTAL	51218-45-2	100	B	1
XILENOS (TOTALES)	1330-20-7	10000	D	1

ANEXO IV

GUIDELINES FOR DRINKING-WATER QUALITY (OMS)

THIRD EDITION

Volume 1 – Recommendations



The first and second editions of the WHO Guidelines for Drinking-water Quality were used by developing and developed countries worldwide as the basis for regulation and standard setting to ensure the safety of drinking-water. They recognized the priority that should be given to ensuring microbial safety and provided guideline values for a large number of chemical hazards.

This third edition of the Guidelines has been comprehensively updated to take account of developments in risk assessment and risk management. It describes a “Framework for Drinking-water Safety” and discusses the roles and responsibilities of different stakeholders, including the complementary roles of national regulators, suppliers, communities and independent “surveillance” agencies.

Developments in this edition of the Guidelines include significantly expanded guidance on ensuring the microbial safety of drinking-water — in particular through comprehensive system-specific “water safety plans”. Information on many chemicals has been revised to account for new scientific information and information on chemicals not previously considered has been included. For the first time, reviews of many waterborne pathogens are provided.

Recognizing the need for different tools and approaches in supporting large and community supplies, this edition continues to describe the principal characteristics of the approaches to each. New sections deal with the application of the Guidelines to specific circumstances, such as emergencies and disasters, large buildings, packaged/bottled water, travellers, desalination systems, food production and processing and water safety on ships and in aviation.

Microbial aspects

The greatest risk from microbes in water is associated with consumption of drinking-water that is contaminated with human and animal excreta, although other sources and routes of exposure may also be significant.

This chapter focuses on organisms for which there is evidence, from outbreak studies or from prospective studies in non-outbreak situations, of disease being caused by ingestion of drinking-water, inhalation of droplets or contact with drinking-water; and their control.

7.1 Microbial hazards associated with drinking-water

Infectious diseases caused by pathogenic bacteria, viruses and parasites (e.g., proto-zoa and helminths) are the most common and widespread health risk associated with drinking-water. The public health burden is determined by the severity of the illness (es) associated with pathogens, their infectivity and the population exposed.

Breakdown in water supply safety may lead to large-scale contamination and potentially to detectable disease outbreaks. Other breakdowns and low-level, potentially repeated contamination may lead to significant sporadic disease, but is unlikely to be associated with the drinking-water source by public health surveillance.

Quantified risk assessment can assist in understanding and managing risks, especially those associated with sporadic disease.

7.1.1 Waterborne infections

The pathogens that may be transmitted through contaminated drinking-water are diverse. Table 7.1 and Figure 7.1 provide general information on pathogens that are of relevance for drinking-water supply management. The spectrum changes in response to variables such as increases in human and animal populations, escalating use of wastewater, changes in lifestyles and medical interventions, population movement and travel and selective pressures for new pathogens and mutants or recombinations of existing pathogens. The immunity of individuals also varies considerably, whether acquired by contact with a pathogen or influenced by such factors as age, sex, state of health and living conditions.

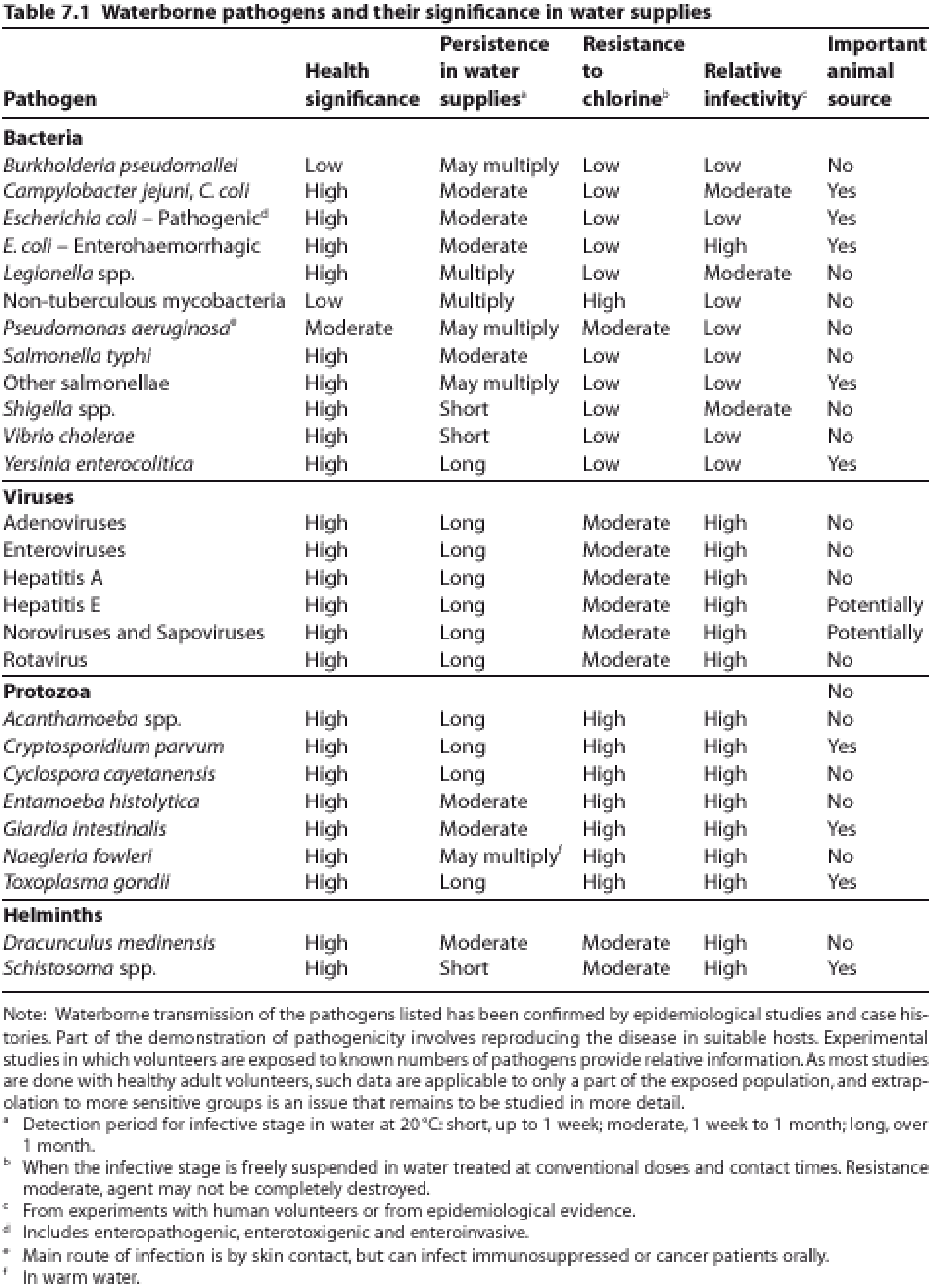


Table 7.1 Waterborne pathogens and their significance in water supplies

Pathogen	Health significance	Persistence in water supplies[a]	Resistance to chlorine[b]	Relative infectivity[c]	Important animal source
Bacteria					
Burkholderia pseudomallei	Low	May multiply	Low	Low	No
Campylobacter jejuni, C. coli	High	Moderate	Low	Moderate	Yes
Escherichia coli – Pathogenic[d]	High	Moderate	Low	Low	Yes
E. coli – Enterohaemorrhagic	High	Moderate	Low	High	Yes
Legionella spp.	High	Multiply	Low	Moderate	No
Non-tuberculous mycobacteria	Low	Multiply	High	Low	No
Pseudomonas aeruginosa[e]	Moderate	May multiply	Moderate	Low	No
Salmonella typhi	High	Moderate	Low	Low	No
Other salmonellae	High	May multiply	Low	Low	Yes
Shigella spp.	High	Short	Low	Moderate	No
Vibrio cholerae	High	Short	Low	Low	No
Yersinia enterocolitica	High	Long	Low	Low	Yes
Viruses					
Adenoviruses	High	Long	Moderate	High	No
Enteroviruses	High	Long	Moderate	High	No
Hepatitis A	High	Long	Moderate	High	No
Hepatitis E	High	Long	Moderate	High	Potentially
Noroviruses and Sapoviruses	High	Long	Moderate	High	Potentially
Rotavirus	High	Long	Moderate	High	No
Protozoa					No
Acanthamoeba spp.	High	Long	High	High	No
Cryptosporidium parvum	High	Long	High	High	Yes
Cyclospora cayetanensis	High	Long	High	High	No
Entamoeba histolytica	High	Moderate	High	High	No
Giardia intestinalis	High	Moderate	High	High	Yes
Naegleria fowleri	High	May multiply[f]	High	High	No
Toxoplasma gondii	High	Long	High	High	Yes
Helminths					
Dracunculus medinensis	High	Moderate	Moderate	High	No
Schistosoma spp.	High	Short	Moderate	High	Yes

Note: Waterborne transmission of the pathogens listed has been confirmed by epidemiological studies and case histories. Part of the demonstration of pathogenicity involves reproducing the disease in suitable hosts. Experimental studies in which volunteers are exposed to known numbers of pathogens provide relative information. As most studies are done with healthy adult volunteers, such data are applicable to only a part of the exposed population, and extrapolation to more sensitive groups is an issue that remains to be studied in more detail.

[a] Detection period for infective stage in water at 20°C: short, up to 1 week; moderate, 1 week to 1 month; long, over 1 month.

[b] When the infective stage is freely suspended in water treated at conventional doses and contact times. Resistance moderate, agent may not be completely destroyed.

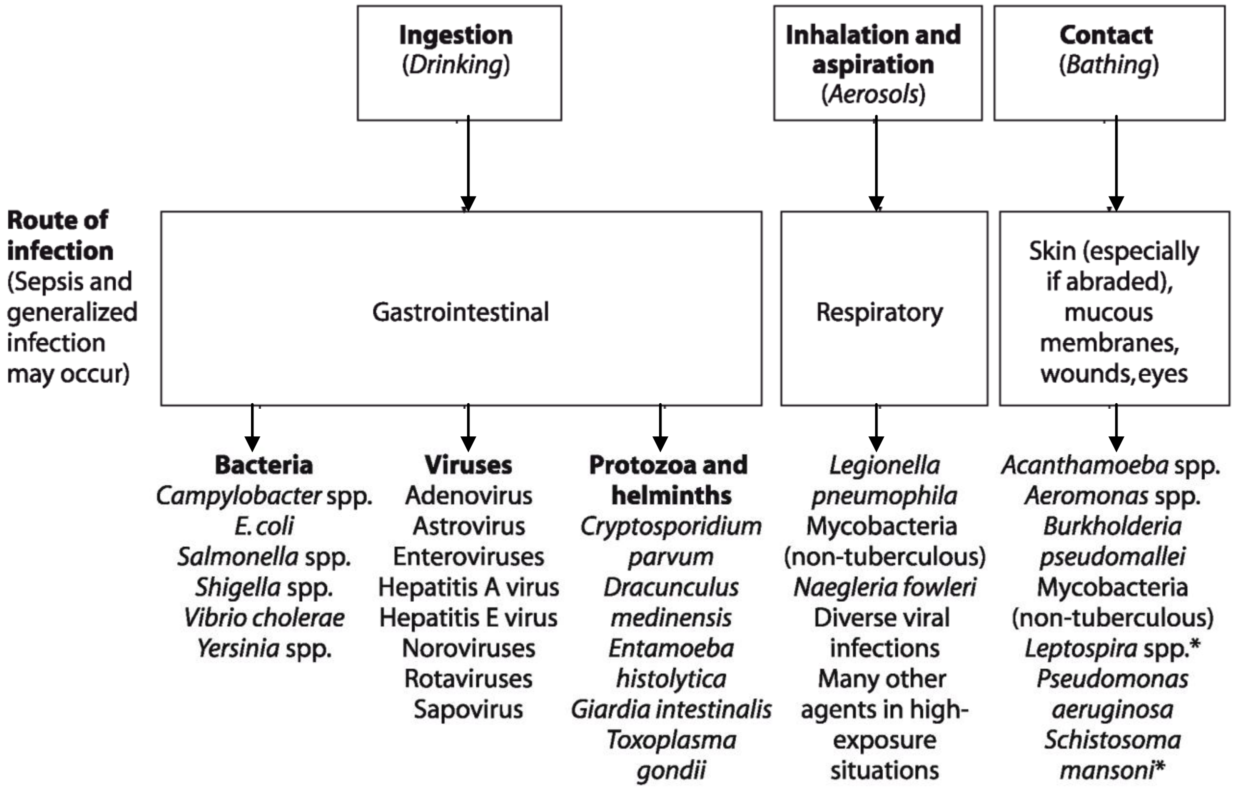
[c] From experiments with human volunteers or from epidemiological evidence.

[d] Includes enteropathogenic, enterotoxigenic and enteroinvasive.

[e] Main route of infection is by skin contact, but can infect immunosuppressed or cancer patients orally.

[f] In warm water.

For pathogens transmitted by the faecal –oral route, drinking-water is only one vehicle of transmission. Contamination of food, hands, utensils and clothing can also play a role, particularly when domestic sanitation and hygiene are poor. Improvements in the quality and availability of water, in excreta disposal and in general hygiene are all important in reducing faecal –oral disease transmission.



* Primarily from contact with highly contaminated surface waters.

Figure 7.1 Transmission pathways for and examples of water-related pathogens

Drinking-water safety is not related only to faecal contamination. Some organisms grow in piped water distribution systems (e.g., *Legionella*), whereas others occur in source waters (guinea worm *Dracunculus medinensis*) and may cause outbreaks and individual cases. Some other microbes (e.g., toxic cyanobacteria) require specific management approaches, which are covered elsewhere in these Guidelines (see section 11.5).

Infectious diseases caused by pathogenic bacteria, viruses, protozoa and helminths are the most common and widespread health risk associated with drinking-water.

Certain serious illnesses result from inhalation of water droplets (aerosols) in which the causative organisms have multiplied because of warm temperatures and the presence of nutrients. These include legionellosis and Legionnaires' disease, caused by *Legionella* spp., and those caused by the amoebae *Naegleria fowleri* (primary amoebic meningoencephalitis [PAM]) and *Acanthamoeba* spp. (amoebic meningitis, pulmonary infections).

Schistosomiasis (bilharziasis) is a major parasitic disease of tropical and subtropical regions that is transmitted when the larval stage (cercariae), which is released by infected aquatic snails, penetrates the skin. It is primarily spread by contact with water. Ready availability of safe drinking-water contributes to disease prevention by reducing the need for contact with contaminated water resources – for example, when collecting water to carry to the home or when using water for bathing or laundry.

It is conceivable that unsafe drinking-water contaminated with soil or faeces could act as a carrier of other parasitic infections, such as balantidiasis (*Balantidium coli*) and certain helminths (species of *Fasciola*, *Fasciolopsis*, *Echinococcus*, *Spirometra*, *Ascaris*, *Trichuris*, *Toxocara*, *Necato*, *Ancylostoma*, *Strongyloides* and *Taenia solium*). However, in most of these, the normal mode of transmission is ingestion of the eggs in food contaminated with faeces or faecally contaminated soil (in the case of *Taenia solium*, ingestion of the larval cysticercus stage in uncooked pork) rather than ingestion of contaminated drinking-water.

Other pathogens that may be naturally present in the environment may be able to cause disease in people with impaired local or general immune defence mechanisms, such as the elderly or the very young, patients with burns or extensive wounds, those undergoing immunosuppressive therapy or those with acquired immunodeficiency syndrome (AIDS). If water used by such persons for drinking or bathing contains sufcient numbers of these organisms, they can produce various infections of the skin and the mucous membranes of the eye, ear, nose and throat. Examples of such agents are *Pseudomonas aeruginosa* and species of *Flavobacterium*, *Acinetobacter*, *Klebsiella*, *Serratia*, *Aeromonas* and certain "slow-growing" (non-tuberculous) mycobacteria (see the supporting document *Pathogenic Mycobacteria in Water*; section 1.3).

Most of the human pathogens listed in Table 7.1 (which are described in more detail in chapter 11) are distributed worldwide; some, however, such as those causing outbreaks of cholera or guinea worm disease, are regional. Eradication of *D.medinensis* is a recognized target of the World Health Assembly (1991).

It is likely that there are pathogens not shown in Table 7.1 that are also transmitted by water. This is because the number of known pathogens for which water is a transmission route continues to increase as new or previously unrecognized pathogens continue to be discovered (see WHO, 2003a).

7.1.2 Persistence and growth in water

While typical waterborne pathogens are able to persist in drinking-water, most do not grow or proliferate in water. Microorganisms like *E.coli* and *Campylobacter* can accumulate in sediments and are mobilized when water flow increases.

After leaving the body of their host, most pathogens gradually lose viability and the ability to infect. The rate of decay is usually exponential, and a pathogen will become undetectable after a certain period. Pathogens with low persistence must rapidly find new hosts and are more likely to be spread by person-to-person contact or poor personal hygiene than by drinking-water. Persistence is affected by several factors, of which temperature is the most important. Decay is usually faster at higher temperatures and may be mediated by the lethal effects of UV radiation in sunlight acting near the water surface.

The most common waterborne pathogens and parasites are those that have high infectivity and either can proliferate in water or possess high resistance to decay outside the body.

Viruses and the resting stages of parasites (cysts, oocysts, ova) are unable to multiply in water. Conversely, relatively high amounts of biodegradable organic carbon, together with warm temperatures and low residual concentrations of chlorine, can permit growth of *Legionella*, *V.cholerae, eNaegleria fowleri*, *Acanthamoeba* and nuisance organisms in some surface waters and during water distribution (see also the supporting document *Heterotrophic Plate Counts and Drinking-water Safety*; section 1.3).

Microbial water quality may vary rapidly and widely. Short-term peaks in pathogen concentration may increase disease risks considerably and may also trigger outbreaks of waterborne disease. Results of water quality testing for microbes are not normally available in time to inform management action and prevent the supply of unsafe water.

7.1.3 Public health aspects

Outbreaks of waterborne disease may affect large numbers of persons, and the first priority in developing and applying controls on drinking-water quality should be the control of such outbreaks. Available evidence also suggests that drinking-water can contribute to background rates of disease in non-outbreak situations, and control of drinking-water quality should therefore also address waterborne disease in the general community.

Experience has shown that systems for the detection of waterborne disease outbreaks are typically inefficient in countries at all levels of socioeconomic development, and failure to detect outbreaks is not a guarantee that they do not occur; nor does it suggest that drinking-water should necessarily be considered safe.

Some of the pathogens that are known to be transmitted through contaminated drinking-water lead to severe and sometimes life-threatening disease. Examples include typhoid, cholera, infectious hepatitis (caused by hepatitis A virus [HAV] or HEV) and disease caused by *Shigella* spp. and *E.coli* O157. Others are typically associated with less severe outcomes, such as self-limiting diarrhoeal disease (e.g., Norovirus, *Cryptosporidium*).

The effects of exposure to pathogens are not the same for all individuals or, as a consequence, for all populations. Repeated exposure to a pathogen may be associated with a lower probability or severity of illness because of the effects of acquired immunity. For some pathogens (e.g., HAV), immunity is lifelong, whereas for others (e.g., *Campylobacter*), the protective effects may be restricted to a few months to years. On the other hand, sensitive subgroups (e.g., the young, the elderly, pregnant women and the immunocompromised) in the population may have a greater probability of illness or the illness may be more severe, including mortality. Not all pathogens have greater effects in all sensitive subgroups.

Not all infected individuals will develop symptomatic disease. The proportion of the infected population that is asymptomatic (including carriers) differs between pathogens and also depends on population characteristics, such as prevalence of immunity. Carriers and those with asymptomatic infections as well as individuals developing symptoms may all contribute to secondary spread of pathogens.

7.2 Health-based target setting

7.2.1 Health-based targets applied to microbial hazards

General approaches to health-based target setting are described in section 2.1.1 and chapter 3.

Sources of information on health risks may be from both epidemiology and risk assessment, and typically both are employed as complementary sources.

Health-based targets may also be set using a health outcome approach, where the waterborne disease burden is believed to be sufficiently high to allow measurement of the impact of interventions – i.e., to measure reductions in disease that can be attributed to drinking-water.

Risk assessment is especially valuable where the fraction of disease that can be attributed to drinking-water is low or difficult to measure directly through public health surveillance or analytical epidemiological studies.

Data – from both epidemiology and risk assessment – with which to develop health-based targets for many pathogens are limited, but are increasingly being produced. Locally generated data will always be of great value in setting national targets.

For the control of microbial hazards, the most frequent form of health-based target applied is performance targets (see section 3.2.2), which are anchored to a tolerable burden of disease. WQTs (see section 3.2.3) are typically not developed for pathogens, because monitoring finished water for pathogens is not considered a feasible or costeffective option.

7.2.2 Risk assessment approach

In many circumstances, estimating the effects of improved drinking-water quality on health risks in the population is possible through constructing and applying risk assessment models.

QMRA is a rapidly evolving field that systematically combines available information on exposure and dose – response to produce estimates of the disease burden associated with exposure to pathogens. Mathematical modelling is used to estimate the effects of low doses of pathogens in drinking-water on populations and subpopulations.

Interpreting and applying information from analytical epidemiological studies to derive health-based targets for application at a national or local level require consideration of a number of factors, including the following:

- Are specific estimates of disease reduction or indicative ranges of expected reductions to be provided?
- How representative of the target population was the study sample in order to ensure confidence in the reliability of the results across a wider group?

- To what extent will minor differences in demographic or socioeconomic conditions affect expected outcomes?

Risk assessment commences with problem formulation to identify all possible hazards and their pathways from source(s) to recipient(s). Human exposure to the pathogens (environmental concentrations and volumes ingested) and dose – responses of these selected organisms are then combined to characterize the risks. With the use of additional information (social, cultural, political, economic, environmental, etc.), management options can be prioritized. To encourage stakeholder support and participation, a transparent procedure and active risk communication at each stage of the process are important. An example of a risk assessment approach is described in Table7.2 and outlined below.

Problem formulation and hazard identification

All potential hazards, sources and events that can lead to the presence of these hazards (i.e., what can happen and how) should be identified and documented for each component of the drinking-water system, regardless of whether or not the component is under the direct control of the drinking-water supplier. This includes point sources of pollution (e.g., human and industrial waste discharge) as well as diffuse sources (e.g., those arising from agricultural and animal husbandry activities). Continuous, intermittent or seasonal pollution patterns should also be considered, as well as extreme and infrequent events, such as droughts and floods.

The broader sense of hazards focuses on hazardous scenarios, which are events that may lead to exposure of consumers to specific pathogenic microorganisms. In this, the hazardous event (e.g., peak contamination of source water with domestic waste-water) may be referred to as the hazard.

Representative organisms are selected that, if controlled, would ensure control of all pathogens of concern. Typically, this implies inclusion of at least one bacterial pathogen, virus and protozoan.

Table 7.2 Risk assessment paradigm for pathogen health risks

Step	Aim
1. Problem formulation and hazard identification	To identify all possible hazards associated with drinking-water that would have an adverse public health consequence, as well as their pathways from source(s) to consumer(s)
2. Exposure assessment	To determine the size and nature of the population exposed and the route, amount and duration of the exposure
3. Dose–response assessment	To characterize the relationship between exposure and the incidence of the health effect
4. Risk characterization	To integrate the information from exposure, dose–response and health interventions in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty

Source: Adapted from Haas *et al.* (1999).

Exposure assessment

Exposure assessment involves estimation of the number of pathogenic microbes to which an individual is exposed, principally through ingestion. Exposure assessment is a predictive activity that often involves subjective judgement. It inevitably contains uncertainty and must account for variability of factors such as concentrations of microorganisms over time, volumes ingested, etc.

Exposure can be considered as a single dose of pathogens that a consumer ingests at a certain point of time or the total amount over several exposures (e.g., over a year). Exposure is determined by the concentration of microbes in drinking-water and the volume of water consumed.

It is rarely possible or appropriate to directly measure pathogens in drinking-water on a regular basis. More often, concentrations in source waters are assumed or measured, and estimated reductions – for example, through treatment – are applied to estimate the concentration in the water consumed. Pathogen measurement, when performed, is generally best carried out at the location where the pathogens are at highest concentration (generally source waters). Estimation of their removal by sequential control measures is generally achieved by the use of surrogates (such as *E.coli* for enteric bacterial pathogens).

The other component of exposure assessment, which is common to all pathogens, is the volume of unboiled water consumed by the population, including person-to-person variation in consumption behaviour and especially consumption behaviour of at-risk groups. For microbial hazards, it is important that the unboiled volume of drinking-water, both consumed directly and used in food preparation, is used in the risk assessment, as heating will rapidly inactivate pathogens. This amount is lower than that used for deriving chemical guideline values and WQTs.

The daily exposure of a consumer can be assessed by multiplying the concentration of pathogens in drinking-water by the volume of drinking-water consumed. For the purposes of the Guidelines, unboiled drinking-water consumption is assumed to be 1 litre of water per day.

Dose –response assessment

The probability of an adverse health effect following exposure to one or more pathogenic organisms is derived from a dose–response model. Available dose–response data have been obtained mainly from studies using healthy adult volunteers. Several subgroups in the population, such as children, the elderly and immunocompromised persons, are more sensitive to infectious disease; currently, however, adequate data are lacking to account for this.

The conceptual basis for the infection model is the observation that exposure to the described dose leads to the probability of infection as a conditional event. For infection to occur, one or more viable pathogens must have been ingested. Furthermore, one or more of these ingested pathogens must have survived in the host's body. An important concept is the single-hit principle (i.e., that even a single organism may be able to cause infection and disease, possibly with a low probability). This concept supersedes the concept of (minimum) infectious dose that is frequently used in older literature (see the supporting document *Hazard Characterization for Pathogens in Food and Water*; section 1.3).

In general, well dispersed pathogens in water are considered to be Poisson distributed. When the individual probability of any organism to survive and start infection is the same, the dose–response relation simplifies to an exponential function. If, however, there is heterogeneity in this individual probability, this leads to the beta-Poisson dose–response relation, where the "beta" stands for the distribution of theindividual probabilities among pathogens (and hosts). At low exposures, such as would typically occur in drinking-water, the dose–response model is approximately linear and can be represented simply as the probability of infection resulting from exposure to a single organism (see the supporting document *Hazard Characterization for Pathogens in Food and Water*; section 1.3).

Risk characterization

Risk characterization brings together the data collected on pathogen exposure, dose–response, severity and disease burden.

The probability of infection can be estimated as the product of the exposure by drinking-water and the probability that exposure to one organism would result in infection. The probability of infection per day is multiplied by 365 to calculate the probability of infection per year. In doing so, it is assumed that different exposure events are independent, in that no protective immunity is built up. This simplification is justified for low risks only.

Not all infected individuals will develop clinical illness; asymptomatic infection is common for most pathogens. The percentage of infected persons that will develop clinical illness depends on the pathogen, but also on other factors, such as the immune status of the host. Risk of illness per year is obtained by multiplying the probability of infection by the probability of illness given infection.

The low numbers in Table 7.3 can be interpreted to represent the probability that a single individual will develop illness in a given year. For example, a risk of illness for *Campylobacter* of 2.5 ¥10 - 4 per year indicates that, on average, 1 out of 4000 consumers would contract campylobacteriosis from drinking-water.

To translate the risk of developing a specific illness to disease burden per case, the metric DALYs is used. This should reflect not only the effects of acute end-points (e.g., diarrhoeal illness) but also mortality and the effects of more serious end-points (e.g., Guillain-Barré syndrome associated with *Campylobacter*). Disease burden per case varies widely. For example, the disease burden per 1000 cases of rotavirus diarrhoea is 480 DALYs in low-income regions, where child mortality frequently occurs. However, it is only 14 DALYs per 1000 cases in high-income regions, where hospital facilities are accessible to the great majority of the population (see the supporting document *Quantifying Public Health Risk in the WHO Guidelines for Drinking-water*

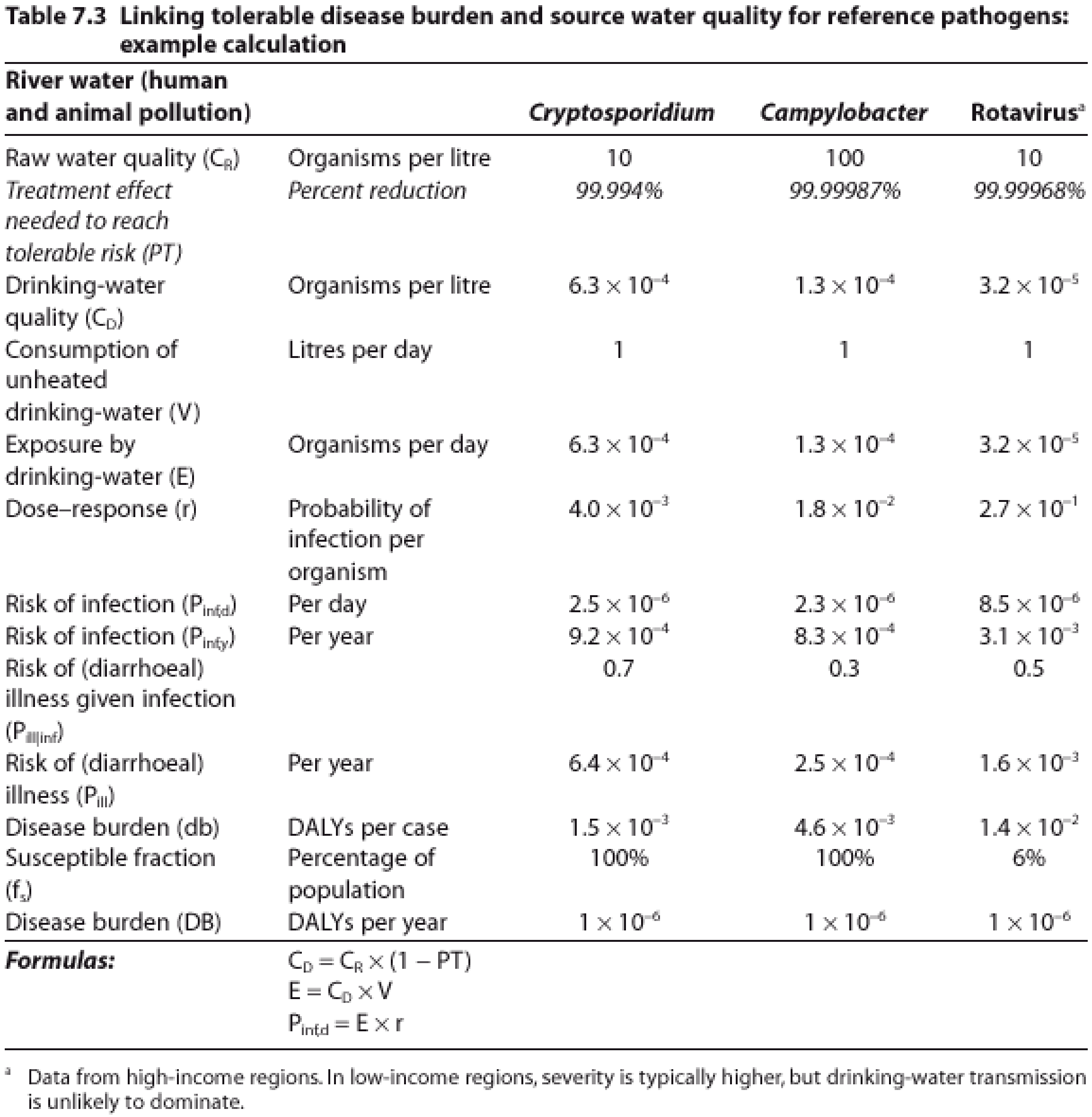


Table 7.3 Linking tolerable disease burden and source water quality for reference pathogens: example calculation

River water (human and animal pollution)		***Cryptosporidium***	***Campylobacter***	**Rotavirus**[a]
Raw water quality (C_R)	Organisms per litre	10	100	10
Treatment effect needed to reach tolerable risk (PT)	*Percent reduction*	*99.994%*	*99.99987%*	*99.99968%*
Drinking-water quality (C_D)	Organisms per litre	6.3×10^{-4}	1.3×10^{-4}	3.2×10^{-5}
Consumption of unheated drinking-water (V)	Litres per day	1	1	1
Exposure by drinking-water (E)	Organisms per day	6.3×10^{-4}	1.3×10^{-4}	3.2×10^{-5}
Dose–response (r)	Probability of infection per organism	4.0×10^{-3}	1.8×10^{-2}	2.7×10^{-1}
Risk of infection ($P_{inf,d}$)	Per day	2.5×10^{-6}	2.3×10^{-6}	8.5×10^{-6}
Risk of infection ($P_{inf,y}$)	Per year	9.2×10^{-4}	8.3×10^{-4}	3.1×10^{-3}
Risk of (diarrhoeal) illness given infection ($P_{ill\|inf}$)		0.7	0.3	0.5
Risk of (diarrhoeal) illness (P_{ill})	Per year	6.4×10^{-4}	2.5×10^{-4}	1.6×10^{-3}
Disease burden (db)	DALYs per case	1.5×10^{-3}	4.6×10^{-3}	1.4×10^{-2}
Susceptible fraction (f_s)	Percentage of population	100%	100%	6%
Disease burden (DB)	DALYs per year	1×10^{-6}	1×10^{-6}	1×10^{-6}
Formulas:	$C_D = C_R \times (1 - PT)$ $E = C_D \times V$ $P_{inf,d} = E \times r$			

[a] Data from high-income regions. In low-income regions, severity is typically higher, but drinking-water transmission is unlikely to dominate.

Quality; section 1.3). This considerable difference in disease burden results in far stricter treatment requirements in low-income regions for the same source water quality in order to obtain the same risk (expressed as DALYs per year). deally, the default disease burden estimates in Table 7.3 should be adapted to specific national situations. In Table 7.3, no accounting is made for effects on immunocompromised persons (e.g., cryptosporidiosis in HIV/AIDS patients), which is significant in some countries. Section 3.3.3 gives more information on the DALY metric and how it is applied to derive a reference level of risk.

Only a proportion of the population may be susceptible to some pathogens, because immunity developed after an initial episode of infection or illness may provide lifelong protection. Examples include HAV and rotaviruses. It is estimated that in developing countries, all children above the age of 5 years are immune to rotaviruses because of repeated exposure in the first years of life. This translates to an average of 17%of the population being susceptible to rotavirus illness. In developed countries, rotavirus infection is also common in the first years of life, and the illness is diagnosed mainly in young children, but the percentage of young children as part of the total population is lower. This translates to an average of 6%of the population in developed countries being susceptible.

The uncertainty of the risk estimate is the result of the uncertainty and variability of the data collected in the various steps of the risk assessment. Risk assessment models should ideally account for this variability and uncertainty, although here we present only point estimates (see below).

It is important to choose the most appropriate point estimate for each of the variables. Theoretical considerations show that risks are directly proportional to the arithmetic mean of the ingested dose. Hence, arithmetic means of variables such as concentration in raw water, removal by treatment and consumption of drinking-water are recommended. This recommendation is different from the usual practice among microbiologists and engineers of converting concentrations and treatment effects to log-values and making calculations or specifications on the log-scale. Such calculations result in estimates of the geometric mean rather than the arithmetic mean, and these may significantly underestimate risk. Analysing site-specific data may therefore require going back to the raw data rather than relying on reported log-transformed values.

7.2.3 Risk-based performance target setting

The process outlined above enables estimation of risk on a population level, taking account of source water quality and impact of control. This can be compared with the reference level of risk (see section 3.3.2) or a locally developed tolerable risk. The calculations enable quantification of the degree of source protection or treatment that is needed to achieve a specified level of acceptable risk and analysis of the estimated impact of changes in control measures.

Performance targets are most frequently applied to treatment performance – i.e., to determine the microbial reduction necessary to ensure water safety. A performance target may be applied to a specific system (i.e., allow account to be taken of specific source water characteristics) or generalized (e.g., impose source water quality assumptions on all systems of a certain type or abstracting water from a certain type of source).

Figure 7.2 illustrates the targets for treatment performance for a range of pathogens occurring in the raw water. For example, 10 microorganisms per litre of source water will lead to a performance target of 4.2 logs (or 99.994%) for *Cryptosporidium* or of 5.5 logs (99.99968%) for rotavirus in high-income regions (see also Table 7.4 below).

The difference in performance targets for rotavirus in high-and low-income countries (5.5 and 7.6 logs; Figure 7.2) is related to the difference in disease severity by this organism. In low-income countries, the child case fatality rate is relatively high, and, as a consequence, the disease burden is higher. Also, a larger proportion of the population in low-income coutries is under the age of 5 and at risk for rotavirus infection.

Figure 7.2 Performance targets for selected bacterial, viral and protozoan pathogens in relation to raw water quality (to achieve 10^{-6} DALYs per person per year)

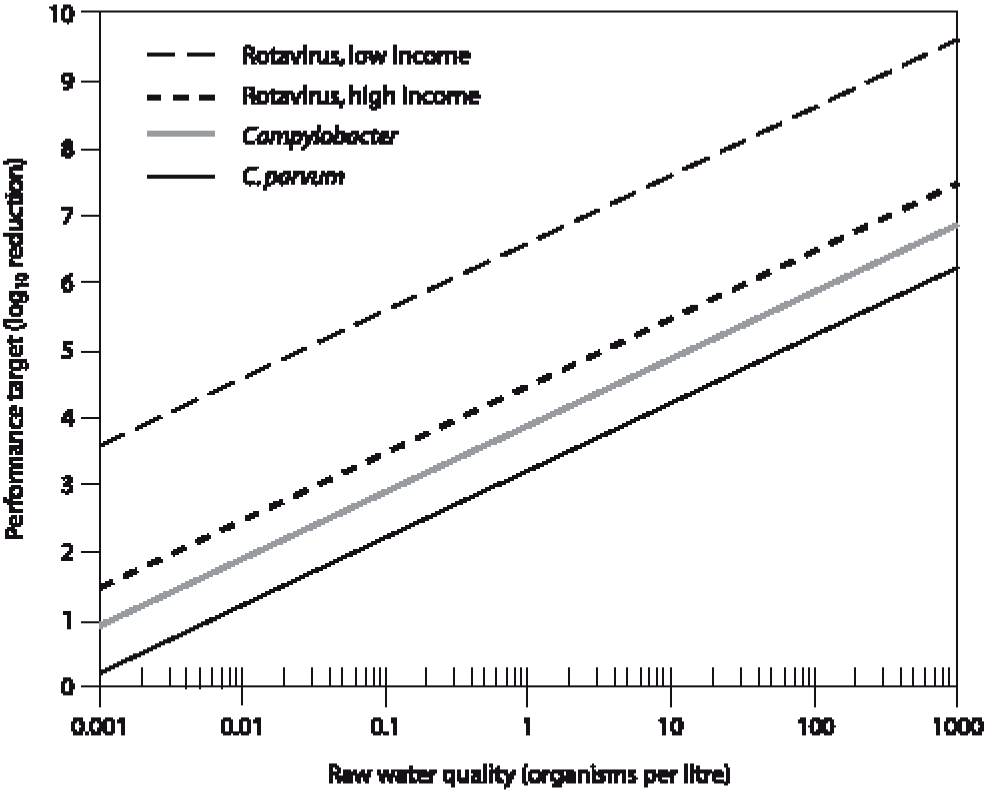


Table 7.4 Health-based targets derived from example calculation in Table 7.3

	Cryptosporidium	Campylobacter	Rotavirus[a]
Organisms per litre in source water	10	100	10
Health outcome target	10^{-6} DALYs per person per year	10^{-6} DALYs per person per year	10^{-6} DALYs per person per year
Risk of diarrhoeal illness[b]	1 per 1600 per year	1 per 4000 per year	1 per 11 000 per year
Drinking-water quality	1 per 1600 litres	1 per 8000 litres	1 per 32 000 litres
Performance target[c]	4.2 $\log_{10}$ units	5.9 $\log_{10}$ units	5.5 $\log_{10}$ units

[a] Data from high-income regions. In low-income regions, severity is typically higher, but drinking-water transmission is unlikely to dominate.

[b] For the susceptible population.

[c] Performance target is a measure of log reduction of pathogens based on source water quality.

The derivation of these performance targets is described in Table 7.4, which provides an example of the data and calculations that would normally be used to construct a risk assessment model for waterborne pathogens. The table presents data for representatives of the three major groups of pathogens (bacteria, viruses and protozoa) from a range of sources. These example calculations aim at achieving the reference level of risk of 10^{-6} DALYs per person per year, as described in section 3.3.3.The average of 17%of the population being susceptible to rotavirus illness. In developed countries, rotavirus infection is also common in the first years of life, and the illness is diagnosed mainly in young children, but the percentage of young children as part of the total population is lower. This translates to an average of 6%of the population in developed countries being susceptible.

The uncertainty of the risk estimate is the result of the uncertainty and variability of the data collected in the various steps of the risk assessment. Risk assessment models should ideally account for this variability and uncertainty, although here we present only point estimates (see below).

It is important to choose the most appropriate point estimate for each of the variables. Theoretical considerations show that risks are directly proportional to the arithmetic mean of the ingested dose. Hence, arithmetic means of variables such as concentration in raw water, removal by treatment and consumption of drinking-water are recommended. This recommendation is different from the usual practice among microbiologists and engineers of converting concentrations and treatment effects to log-values and making calculations or specifications on the log-scale. Such calculations result in estimates of the geometric mean rather than the arithmetic mean, and these may significantly underestimate risk. Analysing site-specific data may therefore require going back to the raw data rather than relying on reported log-transformed values.

7.2.4 Presenting the outcome of performance target development

Table 7.4 presents some data from Table 7.3 in a format that is more meaningful to risk managers. The average concentration of pathogens in drinking-water is included for information. It is not a WQT, nor is it intended to encourage pathogen monitoring in finished water. As an example, a concentration of 6.3×10^{-4} *Cryptosporidium* per litre (see Table 7.3) corresponds to 1 oocyst per 1600 litres (see Table 7.4). The performance target (in the row “Treatment effect” in Table 7.3), expressed as a percent reduction, is the most important management information in the risk assessment table. It can also be expressed as a log-reduction value. For example, 99.99968% reduction for rotavirus corresponds to 5.5 $\log_{10}$ units.

7.2.5 Issues in adapting risk-based performance target setting to national/local circumstances

The choice of pathogens in Table 7.4 was based mainly on availability of data on resistance to water treatment, infectivity and disease burden. The pathogens illustrated may not be priority pathogens in all regions of the world, although amending pathogen selection would normally have a small impact on the overall conclusions derived from applying the model.

Wherever possible, country-or site-specific information should be used in assessments of this type. If no specific data are available, an approximate risk estimate can be based on default values (see Table 7.5 below).

Table 7.4 accounts only for changes in water quality derived from treatment and not source protection measures, which are often important contributors to overall safety, impacting on pathogen concentration and/or variability. The risk estimates presented in Table 7.3 also assume that there is no degradation of water quality in the distribution network. These may not be realistic assumptions under all circumstances, and it is advisable to take these factors into account wherever possible.

Table 7.4 presents point estimates only and does not account for variability and uncertainty. Full risk assessment models would incorporate such factors by representing the input variables by statistical distributions rather than by point estimates.

However, such models are currently beyond the means of many countries, and data to define such distributions are scarce. Producing such data may involve considerable efforts in terms of time and resources, but will lead to much improved insight into the actual source water quality and treatment performance.

The necessary degree of treatment also depends on the values assumed for variables (e.g., drinking-water consumption, fraction of the population that is susceptible) that can be taken into account in the risk assessment model. Figure 7.3 shows the effect of variation in the consumption of unboiled drinking-water on the performance targets for *Cryptosporidium parvum*. For example, if the raw water concentration is 1 oocyst per litre, the performance target varies between 2.6 and 3.5 log10 units if consumption values vary between 0.25 and 2 litres per day. Some outbreak data suggest that in developed countries, a significant proportion of the population above 5 years of age may not be immune to rotavirus illness. Figure 7.4 shows the effect of variation in the susceptible fraction of the population. For example, if the raw water concentration is 10 virus particles per litre, the performance target increases from 5.5 to 6.7 if the susceptible fraction increases from 6 to 100%.

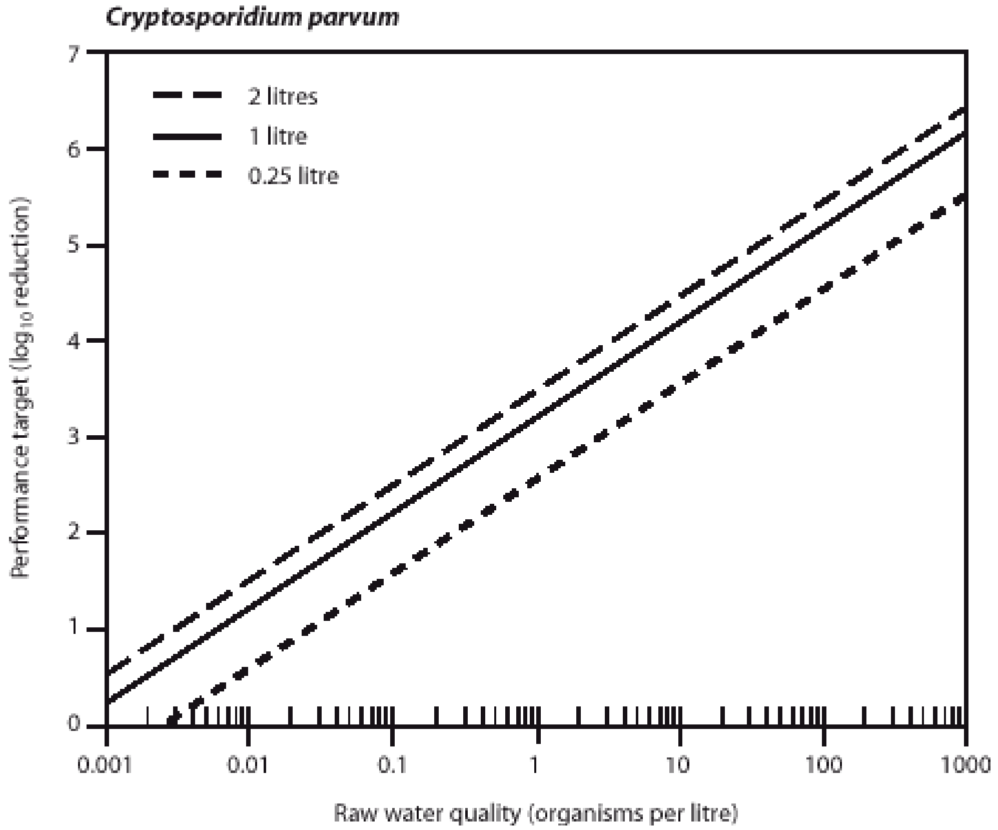


Figure 7.3 Performance targets for *Cryptosporidium parvum* in relation to the daily consumption of unboiled drinking-water (to achieve 10^{-6} DALYs per person per year)

7.2.6 Health outcome targets

Health outcome targets that identify disease reductions in a community may be applied to the WSPs developed for specified water quality interventions at community and household levels. These targets would identify expected disease reductions in communities receiving the interventions.

The prioritization of water quality interventions should focus on those aspects that are estimated to contribute more than e.g.5% of the burden of a given disease (e.g., 5% of total diarrhoea). In many parts of the world, the implementation of a water quality intervention that results in an estimated health gain of more than 5%would be considered extremely worthwhile. Directly demonstrating the health gains arising from improving water quality – as assessed, for example, by reduced *E.coli* counts at the point of consumption – may be possible where disease burden is high and effective interventions are applied and can be a powerful tool to demonstrate a first stepin incremental water safety improvement.

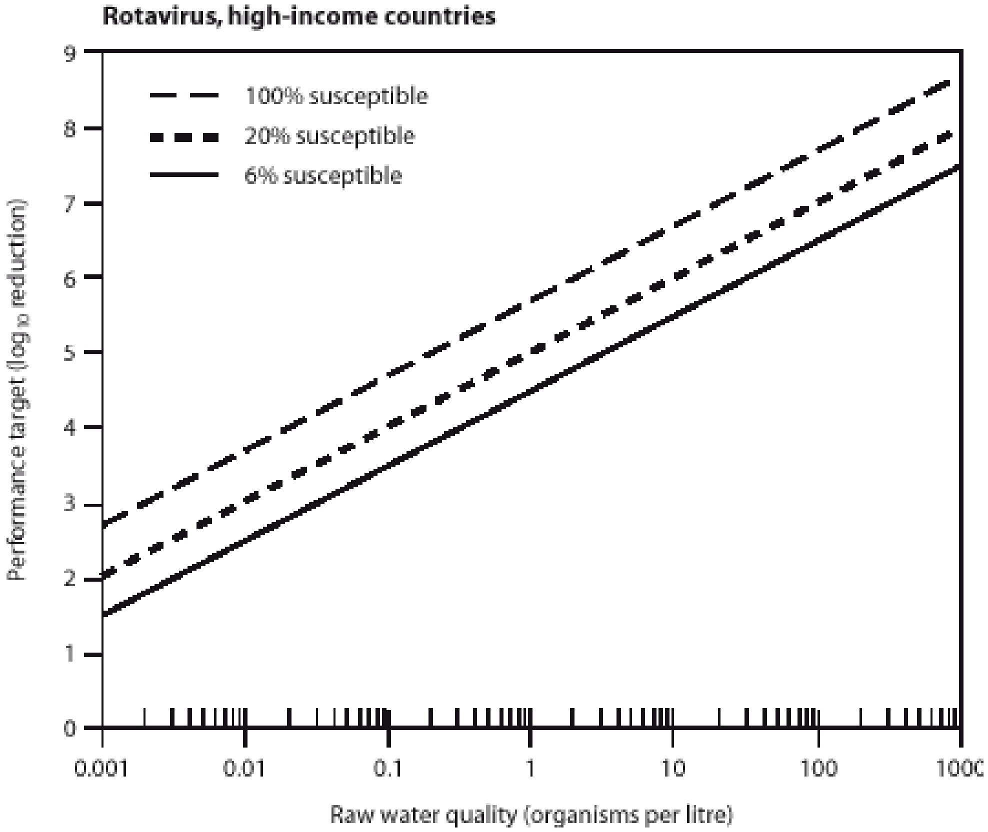


Figure 7.4 Performance targets for rotavirus in relation to the fraction of the population that is susceptible to illness (to achieve 10^{-6} DALYs per person per year)

Where a specified quantified disease reduction is identified as a health outcome target, it may be advisable to undertake ongoing proactive public health surveillance among representative communities rather than through passive surveillance.

7.3 Occurrence and treatment of pathogens

As discussed in section 4.1, system assessment involves determining whether the drinking-water supply chain as a whole can deliver drinking-water quality that meets identified targets. This requires an understanding of the quality of source water and the efficacy of control measures.

An understanding of pathogen occurrence in source waters is essential, because it facilitates selection of the highest-quality source for drinking-water supply, determines pathogen loads and concentrations in source waters and provides a basis for establishing treatment requirements to meet health-based targets within a WSP.

Understanding the efficacy of control measures includes validation (see sections 2.1.2 and 4.1.7). Validation is important both in ensuring that treatment will achieve the desired goals (performance targets) and in assessing areas in which efficacy may be improved (e.g., by comparing performance achieved with that shown to be achievable through well run processes).

7.3.1 Occurrence

The occurrence of pathogens and indicator organisms in groundwater and surface water sources depends on a number of factors, including intrinsic physical and chemical characteristics of the catchment area and the magnitude and range of human activities and animal sources that release pathogens to the environment.

In surface waters, potential pathogen sources include point sources, such as municipal sewerage and urban stormwater overflows, as well as non-point sources, such as contaminated runoff from agricultural areas and areas with sanitation through on site septic systems and latrines. Other sources are wildlife and direct access of live stock to surface water bodies. Many pathogens in surface water bodies will reduce in concentration due to dilution, settling and die-off due to environmental effects (thermal, sunlight, predation, etc.).

Groundwater is often less vulnerable to the immediate influence of contamination sources due to the barrier effects provided by the overlying soil and its unsaturated zone. Groundwater contamination is more frequent where these protective barriers are breached, allowing direct contamination. This may occur through contaminated or abandoned wells or underground pollution sources, such as latrines and sewer lines. However, a number of studies have demonstrated pathogens and indicator organisms in groundwater, even at depth in the absence of such hazardous circumstances, especially where surface contamination is intense, as with land application of manures or other faecal impacts from intensive animal husbandry (e.g., feedlots). Impacts of these contamination sources can be greatly reduced by, for example, aquifer protection measures and proper well design and construction.

For more detailed discussion on both pathogen sources and key factors determining their fate, refer to the supporting documents *Protecting Surface Waters for Health* and *Protecting Groundwaters for Health* (section 1.3).

Table 7.5 presents estimates of high concentrations of enteric pathogens and microbial indicators in different types of surface waters and groundwaters, derived primarily from a review of published data. High values have been presented because they represent higher-risk situations and, therefore, greater degrees of vulnerability. The table includes two categories of data for rivers and streams: one for impacted sources and one for less impacted sources. More detailed information about these data is published in a variety of references, including several papers cited in Dangendorf et al. (2003).

The data in Table 7.5 provide a useful guide to the concentrations of enteric pathogens and indicator microorganisms in a variety of sources. However, there are a number of limitations and sources of uncertainty in these data, including:

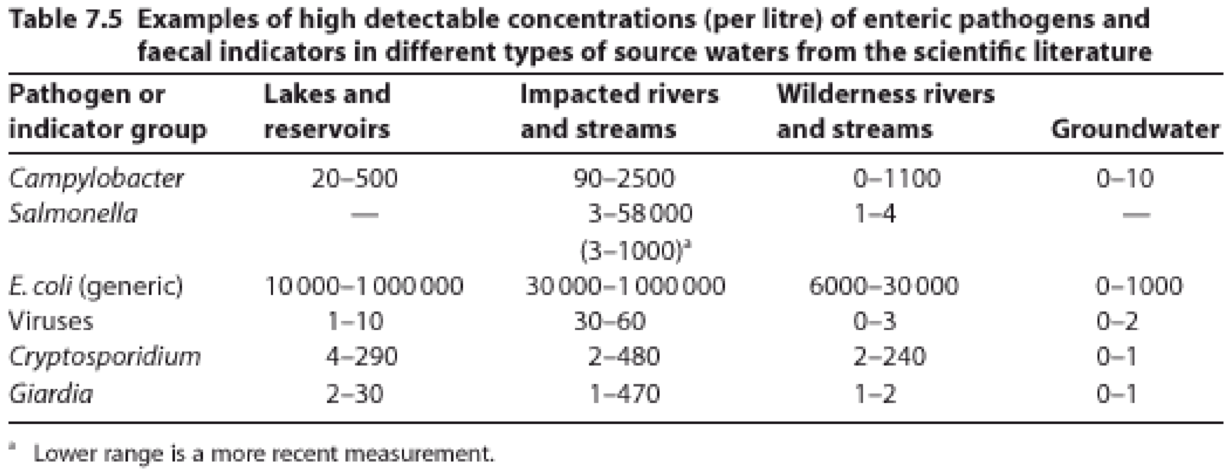


Table 7.5 Examples of high detectable concentrations (per litre) of enteric pathogens and faecal indicators in different types of source waters from the scientific literature

Pathogen or indicator group	Lakes and reservoirs	Impacted rivers and streams	Wilderness rivers and streams	Groundwater
Campylobacter	20–500	90–2500	0–1100	0–10
Salmonella	—	3–58 000 (3–1000)[a]	1–4	—
E. coli (generic)	10 000–1 000 000	30 000–1 000 000	6000–30 000	0–1000
Viruses	1–10	30–60	0–3	0–2
Cryptosporidium	4–290	2–480	2–240	0–1
Giardia	2–30	1–470	1–2	0–1

[a] Lower range is a more recent measurement.

— the lack of knowledge on sampling locations in relation to pollution sources;
— concerns about the sensitivity of analytical techniques, particularly for viruses and protozoa; and
— the lack of knowledge about the viability and human infectivity of *Cryptosporidium* oocysts, *Giardia* cysts and viruses detected in the different studies, because the various methods used are based upon non-culture methods (e.g., microscopy or molecular/nucleic acid analysis).

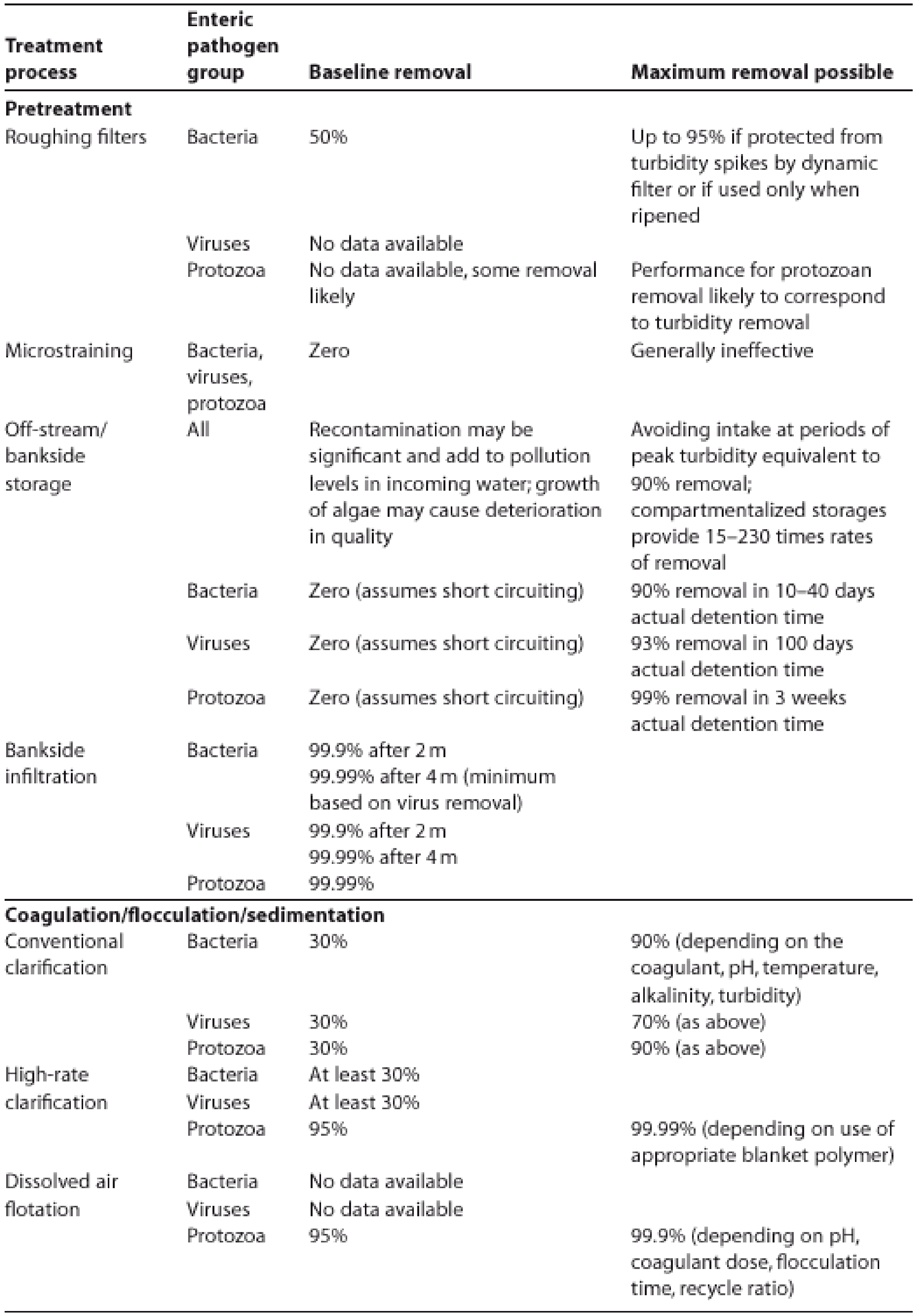
While the table provides an indication of concentrations that might be present inwater sources, by far the most accurate way of determining pathogen loads and concentrations in specific catchments and other water sources is by analysing water quality over a period of time, taking care to include consideration of seasonal variation and peak events such as storms. Direct measurement of pathogens and indicators in the specific source waters for which a WSP and its target pathogens are being established is recommended wherever possible, because this provides the best estimates of microbial concentrations and loads.

7.3.2 Treatment

Waters of very high quality – for example, groundwater from confined aquifers – may rely on source water and distribution system protection as the principal control measures for provision of safe water. More typically, water treatment is required to remove or destroy pathogenic microorganisms. In many cases (e.g., poor-quality surface water), multiple treatment stages are required, including, for example, coagulation, flocculation, sedimentation, filtration and disinfection. Table 7.6 provides a summary of treatment processes that are commonly used individually or in combination to achieve microbial reductions.

The microbial reductions presented in Table 7.6 are for broad groups or categories of microbes: bacteria, viruses and protozoa. This is because it is generally the case that treatment efficacy for microbial reduction differs among these microbial groups due to the inherently different properties of the microbes (e.g., size, nature of protective outer layers, physicochemical surface properties, etc.). Within these microbial groups,

Table 7.6 Reductions of bacteria, viruses and protozoa achieved by typical and enhanced water treatment processes



Treatment process	Enteric pathogen group	Baseline removal	Maximum removal possible
Pretreatment			
Roughing filters	Bacteria	50%	Up to 95% if protected from turbidity spikes by dynamic filter or if used only when ripened
	Viruses	No data available	
	Protozoa	No data available, some removal likely	Performance for protozoan removal likely to correspond to turbidity removal
Microstraining	Bacteria, viruses, protozoa	Zero	Generally ineffective
Off-stream/ bankside storage	All	Recontamination may be significant and add to pollution levels in incoming water; growth of algae may cause deterioration in quality	Avoiding intake at periods of peak turbidity equivalent to 90% removal; compartmentalized storages provide 15–230 times rates of removal
	Bacteria	Zero (assumes short circuiting)	90% removal in 10–40 days actual detention time
	Viruses	Zero (assumes short circuiting)	93% removal in 100 days actual detention time
	Protozoa	Zero (assumes short circuiting)	99% removal in 3 weeks actual detention time
Bankside infiltration	Bacteria	99.9% after 2 m 99.99% after 4 m (minimum based on virus removal)	
	Viruses	99.9% after 2 m 99.99% after 4 m	
	Protozoa	99.99%	
Coagulation/flocculation/sedimentation			
Conventional clarification	Bacteria	30%	90% (depending on the coagulant, pH, temperature, alkalinity, turbidity)
	Viruses	30%	70% (as above)
	Protozoa	30%	90% (as above)
High-rate clarification	Bacteria	At least 30%	
	Viruses	At least 30%	
	Protozoa	95%	99.99% (depending on use of appropriate blanket polymer)
Dissolved air flotation	Bacteria	No data available	
	Viruses	No data available	
	Protozoa	95%	99.9% (depending on pH, coagulant dose, flocculation time, recycle ratio)

Table 7.6 ***Continued***

Treatment process	Enteric pathogen group	Baseline removal	Maximum removal possible
Lime softening	Bacteria	20% at pH 9.5 for 6 h at 2–8 °C	99% at pH 11.5 for 6 h at 2–8 °C
	Viruses	90% at pH < 11 for 6 h	99.99% at pH > 11, depending on the virus and on settling time
	Protozoa	Low inactivation	99% through precipitative sedimentation and inactivation at pH 11.5
Ion exchange			
	Bacteria	Zero	
	Viruses	Zero	
	Protozoa	Zero	
Filtration			
Granular high-rate filtration	Bacteria	No data available	99% under optimum coagulation conditions
	Viruses	No data available	99.9% under optimum coagulation conditions
	Protozoa	70%	99.9% under optimum coagulation conditions
Slow sand filtration	Bacteria	50%	99.5% under optimum ripening, cleaning and refilling and in the absence of short circuiting
	Viruses	20%	99.99% under optimum ripening, cleaning and refilling and in the absence of short circuiting
	Protozoa	50%	99% under optimum ripening, cleaning and refilling and in the absence of short circuiting
Precoat filtration, diatomaceous earth and perlite	Bacteria	30–50%	96–99.9% using chemical pretreatment with coagulants polymers
	Viruses	90%	98% using chemical pretreatment with coagulants or polymers
	Protozoa	99.9%	99.99%, depending on media grade and filtration rate
Membrane filtration – microfiltration	Bacteria	99.9–99.99%, providing adequate pretreatment and membrane integrity conserved	
	Viruses	<90%	
	Protozoa	99.9–99.99%, providing adequate pretreatment and membrane integrity conserved	
Membrane filtration – ultrafiltration,	Bacteria	Complete removal, providing adequate pretreatment and membrane integrity conserved	

continued

Table 7.6 *Continued*

Treatment process	**Enteric pathogen group**	**Baseline removal**	**Maximum removal possible**
nanofiltration and reverse osmosis	Viruses	Complete removal with nanofilters, with reverse osmosis and at lower pore sizes of ultrafilters, providing adequate pretreatment and membrane integrity conserved	
	Protozoa	Complete removal, providing adequate pretreatment and membrane integrity conserved	
Disinfection			
Chlorine	Bacteria	Ct_{99}: 0.08 mg·min/litre at 1–2 °C, pH 7; 3.3 mg·min/litre at 1–2 °C, pH 8.5	
	Viruses	Ct_{99}: 12 mg·min/litre at 0–5 °C; 8 mg·min/litre at 10 °C; both at pH 7–7.5	
	Protozoa	*Giardia* Ct_{99}: 230 mg·min/litre at 0.5 °C; 100 mg·min/litre at 10 °C; 41 mg·min/litre at 25 °C; all at pH 7–7.5 *Cryptosporidium* not killed	
Monochloramine	Bacteria	Ct_{99}: 94 mg·min/litre at 1–2 °C, pH 7; 278 mg·min/litre at 1–2 °C, pH 8.5	
	Viruses	Ct_{99}: 1240 mg·min/litre at 1 °C; 430 mg·min/litre at 15 °C; both at pH 6–9	
	Protozoa	*Giardia* Ct_{99}: 2550 mg·min/litre at 1 °C; 1000 mg·min/litre at 15 °C; both at pH 6–9 *Cryptosporidium* not inactivated	
Chlorine dioxide	Bacteria	Ct_{99}: 0.13 mg·min/litre at 1–2 °C, pH 7; 0.19 mg·min/litre at 1–2 °C, pH 8.5	
	Viruses	Ct_{99}: 8.4 mg·min/litre at 1 °C; 2.8 mg·min/litre at 15 °C; both at pH 6–9	
	Protozoa	*Giardia* Ct_{99}: 42 mg·min/litre at 1 °C; 15 mg·min/litre at 10 °C; 7.3 mg·min/litre at 25 °C; all at pH 6–9 *Cryptosporidium* Ct_{99}: 40 mg·min/litre at 22 °C, pH 8	

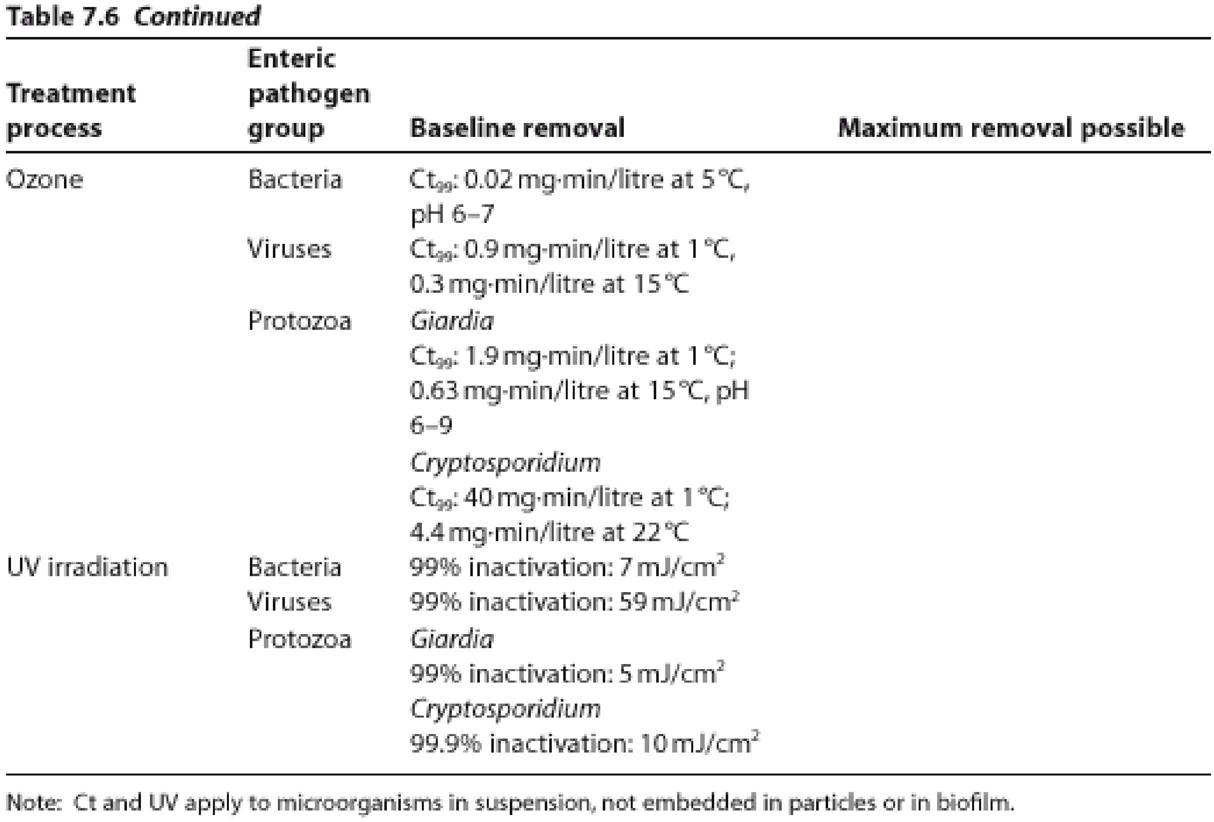


Table 7.6 ***Continued***

Treatment process	Enteric pathogen group	Baseline removal	Maximum removal possible
Ozone	Bacteria	Ct$_{99}$: 0.02 mg·min/litre at 5 °C, pH 6–7	
	Viruses	Ct$_{99}$: 0.9 mg·min/litre at 1 °C, 0.3 mg·min/litre at 15 °C	
	Protozoa	*Giardia* Ct$_{99}$: 1.9 mg·min/litre at 1 °C; 0.63 mg·min/litre at 15 °C, pH 6–9 *Cryptosporidium* Ct$_{99}$: 40 mg·min/litre at 1 °C; 4.4 mg·min/litre at 22 °C	
UV irradiation	Bacteria	99% inactivation: 7 mJ/cm^2	
	Viruses	99% inactivation: 59 mJ/cm^2	
	Protozoa	*Giardia* 99% inactivation: 5 mJ/cm^2 *Cryptosporidium* 99.9% inactivation: 10 mJ/cm^2	

Note: Ct and UV apply to microorganisms in suspension, not embedded in particles or in biofilm.

differences in treatment process efficiencies are smaller among the specific species, types or strains of microbes. Such differences do occur, however, and the table presents conservative estimates of microbial reductions based on the more resistant or persistent pathogenic members of that microbial group. Where differences in removal by treatment between specific members of a microbial group are great, the results for the individual microbes are presented separately in the table.

Non-piped water supplies such as roof catchments (rainwater harvesting) and water collected from wells or springs may often be contaminated with pathogens. Such sources often require treatment and protected storage to achieve safe water. Many of the processes used for water treatment in households are the same as those used for community-managed and other piped water supplies (Table 7.6). The performance of these treatment processes at the household level is likely to be similar to that for baseline removal of microbes, as shown in Table 7.6. However, there are additional water treatment technologies recommended for use in non-piped water supplies at the household level that typically are not used for piped supplies.

Further information about these water treatment processes, their operations and their performance for pathogen reduction is provided in more detail in supporting documents (for piped water supplies: *Water Treatment and Pathogen Control*; for non-piped [primarily household] water supplies: *Managing Water in the Home*; see section 1.3).

7.4 Verification of microbial safety and quality

Pathogenic agents have several properties that distinguish them from other drinking-water contaminants:

- Pathogens are discrete and not in solution.
- Pathogens are often clumped or adherent to suspended solids in water.
- The likelihood of a successful challenge by a pathogen, resulting in infection, depends upon the invasiveness and virulence of the pathogen, as well as upon the immunity of the individual.
- If infection is established, pathogens multiply in their host. Certain pathogenic bacteria are also able to multiply in food or beverages, thereby perpetuating or even increasing the chances of infection.
- Unlike many chemical agents, the dose–response of pathogens is not cumulative.

Faecal indicator bacteria, including *E.coli*, are important parameters for verification of microbial quality (see also section 2.2.1). Such water quality verification complements operational monitoring and assessments of contamination risks – for instance, through auditing of treatment works, evaluation of process control and sanitary inspection.

Faecal indicator bacteria should fulfil certain criteria to give meaningful results. They should be universally present in high numbers in the faeces of humans and other warm-blooded animals, should be readily detectable by simple methods and should not grow in natural water.

The indicator organism of choice for faecal pollution is *E.coli*. Thermotolerant coliforms can be used as an alternative to the test for *E.coli* in many circumstances.

Water intended for human consumption should contain no indicator organisms.

In the majority of cases, monitoring for indicator bacteria provides a high degree of safety because of their large numbers in polluted waters.

Pathogens more resistant to conventional environmental conditions or treatment technologies may be present in treated drinking-water in the absence of *E.coli*. Retrospective studies of waterborne disease outbreaks and advances in the understanding of the behaviour of pathogens in water have shown that continued reliance on assumptions surrounding the absence or presence of *E.coli* does not ensure that optimal decisions are made regarding water safety.

Protozoa and some enteroviruses are more resistant to many disinfectants, including chlorine, and may remain viable (and pathogenic)in drinking-water following disinfection. Other organisms may be more appropriate indicators of persistent microbial hazards, and their selection as additional indicators should be evaluated in relation to local circumstances and scientific understanding. Therefore, verification may require analysis of a range of organisms, such as intestinal enterococci, (spores of) *Clostridium perfringens* and bacteriophages.

Table 7.7 presents guideline values for verification of microbial quality of drinking-water. Individual values should not be used directly from the tables. The guidelines values should be used and interpreted in conjunction with the information contained in these Guidelines and other supporting documentation.

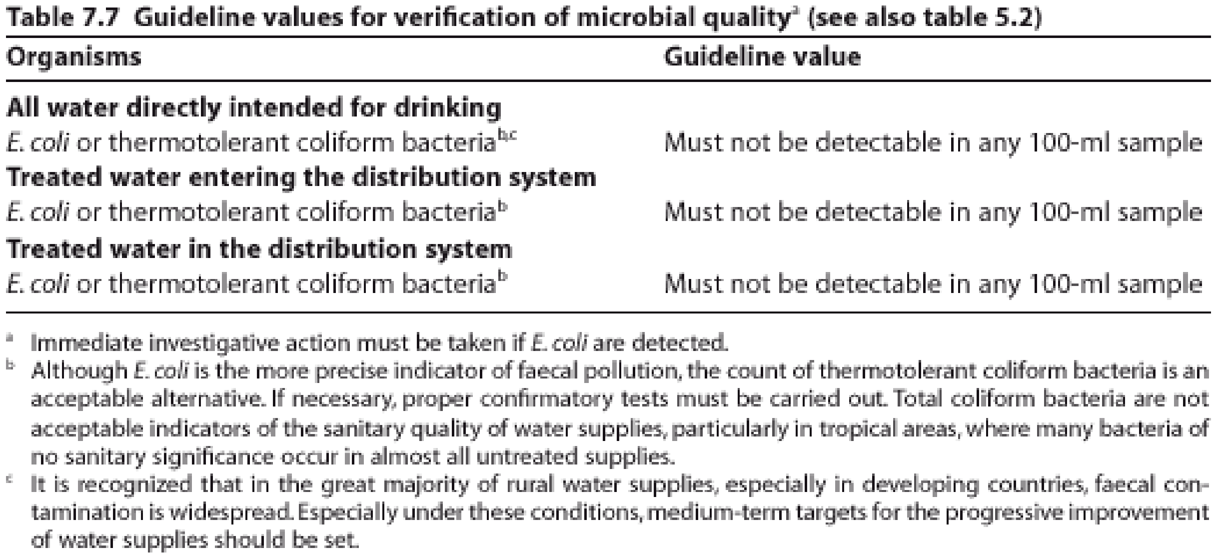


Table 7.7 Guideline values for verification of microbial quality[a] (see also table 5.2)

Organisms	Guideline value
All water directly intended for drinking	
E. coli or thermotolerant coliform bacteria[b,c]	Must not be detectable in any 100-ml sample
Treated water entering the distribution system	
E. coli or thermotolerant coliform bacteria[b]	Must not be detectable in any 100-ml sample
Treated water in the distribution system	
E. coli or thermotolerant coliform bacteria[b]	Must not be detectable in any 100-ml sample

[a] Immediate investigative action must be taken if *E. coli* are detected.

[b] Although *E. coli* is the more precise indicator of faecal pollution, the count of thermotolerant coliform bacteria is an acceptable alternative. If necessary, proper confirmatory tests must be carried out. Total coliform bacteria are not acceptable indicators of the sanitary quality of water supplies, particularly in tropical areas, where many bacteria of no sanitary significance occur in almost all untreated supplies.

[c] It is recognized that in the great majority of rural water supplies, especially in developing countries, faecal contamination is widespread. Especially under these conditions, medium-term targets for the progressive improvement of water supplies should be set.

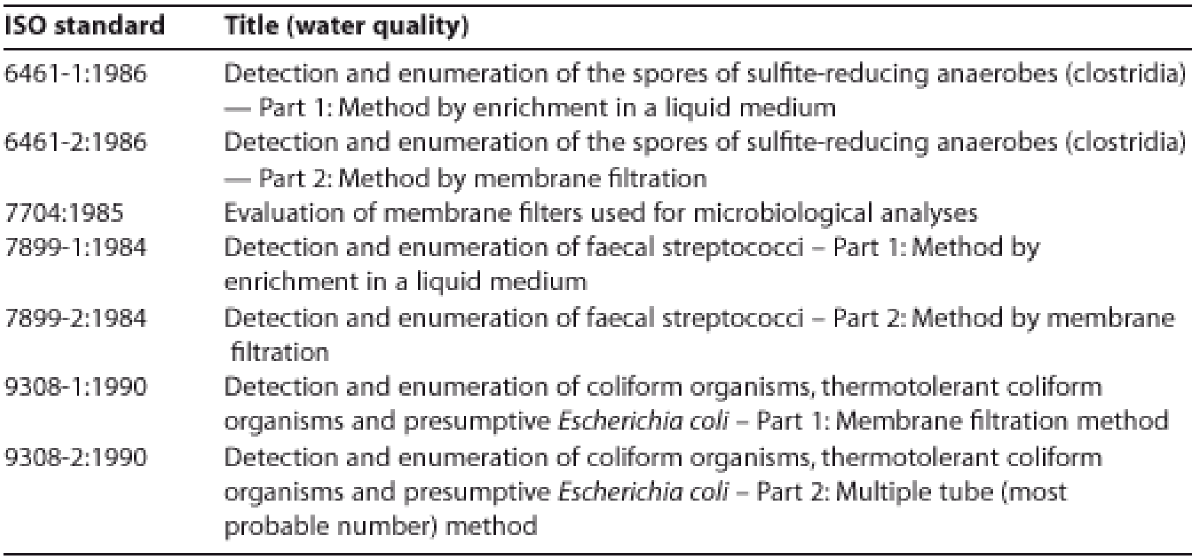
A consequence of variable susceptibility to pathogens is that exposure to drinking-water of a particular quality may lead to different health effects in different populations. For guideline derivation, it is necessary to define reference populations or, in some cases, to focus on specific sensitive subgroups. National or local authorities may wish to apply specific characteristics of their populations in deriving national standards.

7.5 Methods of detection of faecal indicator bacteria

Analysis for faecal indicator bacteria provides a sensitive, although not the most rapid, indication of pollution of drinking-water supplies. Because the growth medium and the conditions of incubation, as well as the nature and age of the water sample, can influence the species isolated and the count, microbiological examinations may have variable accuracy. This means that the standardization of methods and of laboratory procedures is of great importance if criteria for the microbial quality of water are to be uniform in different laboratories and internationally.

International standard methods should be evaluated under local circumstances before being adopted. Established standard methods are available, such as those of the ISO (Table 7.8) or methods of equivalent efficacy and reliability. It is desirable that established standard methods be used for routine examinations. Whatever method is chosen for detection of *E.coli* or thermotolerant coliforms, the importance of “resuscitating” or recovering environmentally damaged or disinfectant-damaged strains must be considered.

Table 7.8 International Organization for Standardization (ISO) standards for detection and enumeration of faecal indicator bacteria in water



ISO standard	Title (water quality)
6461-1:1986	Detection and enumeration of the spores of sulfite-reducing anaerobes (clostridia) — Part 1: Method by enrichment in a liquid medium
6461-2:1986	Detection and enumeration of the spores of sulfite-reducing anaerobes (clostridia) — Part 2: Method by membrane filtration
7704:1985	Evaluation of membrane filters used for microbiological analyses
7899-1:1984	Detection and enumeration of faecal streptococci – Part 1: Method by enrichment in a liquid medium
7899-2:1984	Detection and enumeration of faecal streptococci – Part 2: Method by membrane filtration
9308-1:1990	Detection and enumeration of coliform organisms, thermotolerant coliform organisms and presumptive *Escherichia coli* – Part 1: Membrane filtration method
9308-2:1990	Detection and enumeration of coliform organisms, thermotolerant coliform organisms and presumptive *Escherichia coli* – Part 2: Multiple tube (most probable number) method

Chemical aspects

Most chemicals arising in drinking-water are of health concern only after extended exposure of years, rather than months. The principal exception is nitrate. Typically, changes in water quality occur progressively, except for those substances that are discharged or leach intermittently to flowing surface waters or groundwater supplies from, for example, contaminated landfill sites.

In some cases, there are groups of chemicals that arise from related sources – for example, the DBPs – and it may not be necessary to set standards for all of the substances for which there are guideline values. If chlorination is practised, the THMs, of which chloroform is the major component, are likely to be the main DBPs, together with the chlorinated acetic acids in some instances. In some cases, control of chloroform levels and, where appropriate, trichloroacetic acid levels will also provide an adequate measure of control over other chlorination by-products.

Several of the inorganic elements for which guideline values have been recommended are recognized to be essential elements in human nutrition. No attempt has been made here at this time to define a minimum desirable concentration of such substances in drinking-water.

Fact sheets for individual chemical contaminants are provided in chapter 12. For those contaminants for which a guideline value has been established, the fact sheets include a brief toxicological overview of the chemical, the basis for guideline derivation, treatment achievability and analytical limit of detection. More detailed chemical reviews are available (http://www.who.int/water_sanitation_health/dwq/guidelines/en/).

8.1 Chemical hazards in drinking-water

A number of chemical contaminants have been shown to cause adverse health effects in humans as a consequence of prolonged exposure through drinking-water. However, this is only a very small proportion of the chemicals that may reach drinking-water from various sources. The substances considered here have been assessed for possible health effects, and guideline values have been proposed only on the basis of health concerns. Additional consideration of the potential effects of chemical contaminants on the acceptability of drinking-water to consumers is included in chapter 10. Some substances of health concern have effects on the acceptability of drinking-water that would normally lead to rejection of the water at concentrations significantly lower than those of health concern. For such substances, health-based guideline values are needed, for instance, for use in interpreting data collected in response to consumer complaints.

The lists of chemicals addressed in these Guidelines do not imply that all of these chemicals will always be present or that other chemicals not addressed will be absent.

In section 2.3.2, it is indicated that "In developing national drinking-water standards based on these Guidelines, it will be necessary to take account of a variety of environmental, social, cultural, economic, dietary and other conditions affecting potential exposure. This may lead to national standards that differ appreciably from these Guidelines." This is particularly applicable to chemical contaminants, for which there is a long list, and setting standards for, or including, all of them in monitoring programmes is neither feasible nor desirable.

It is important that chemical contaminants be prioritized so that the most important are considered for inclusion in national standards and monitoring programmes.

The probability that any particular chemical may occur in significant concentrations in any particular setting must be assessed on a case-by-case basis. The presence of certain chemicals may already be known within a particular country, but others may be more difficult to assess.

In most countries, whether developing or industrialized, water sector professionals are likely to be aware of a number of chemicals that are present in significant concentrations in drinking-water supplies. A body of local knowledge that has been built up by practical experience over a period of time is invaluable. Hence, the presence of a limited number of chemical contaminants in drinking-water is usually already known in many countries and in many local systems. Significant problems, even crises, can occur, however, when chemicals posing high health risk are widespread but their presence is unknown because their long-term health effect is caused by chronic exposure as opposed to acute exposure. Such has been the case of arsenic in groundwater in Bangladesh and West Bengal, for example.

For some contaminants, there will be exposure from sources other than drinkingwater, and this may need to be taken into account when setting standards and considering the need for standards. It may also be important when considering the need for monitoring. In some cases, drinking-water will be a minor source of exposure, and controlling levels in water will have little impact on overall exposure. In other cases, controlling a contaminant in water may be the most cost-effective way of reducing exposure. Drinking-water monitoring strategies, therefore, should not be considered in isolation from other potential routes of exposure to chemicals in the environment.

Table 8.1 Categorization of source of chemical constituents

Source of chemical constituents	Examples of sources
Naturally occurring	Rocks, soils and the effects of the geological setting and climate
Industrial sources and human dwellings	Mining (extractive industries) and manufacturing and processing industries, sewage, solid wastes, urban runoff, fuel leakages
Agricultural activities	Manures, fertilizers, intensive animal practices and pesticides
Water treatment or materials in contact with drinking-water	Coagulants, DBPs, piping materials
Pesticides used in water for public health	Larvicides used in the control of insect vectors of disease
Cyanobacteria	Eutrophic lakes

The scientific basis for each of the guideline values is summarized in chapter 12. This information is important in helping to modify guideline values to suit national requirements or in assessing the significance for health of concentrations of a contaminant that are greater than the guideline value.

Chemical contaminants in drinking-water may be categorized in various ways; however, the most appropriate is to consider the primary source of the contaminant – i. e., to group chemicals according to where control may be effectively exercised. This aids in the development of approaches that are designed to prevent or minimize contamination, rather than those that rely primarily on the measurement of contaminant levels in final waters.

In general, approaches to the management of chemical hazards in drinking-water vary between those where the source water is a significant contributor (with control effected, for example, through source water selection, pollution control, treatment or blending) and those from materials and chemicals used in the production and distribution of drinking-water (controlled by process optimization or product specification). In these Guidelines, chemicals are therefore divided into six major source groups, as shown in Table 8.1.

Categories may not always be clear-cut. The group of naturally occurring contaminants, for example, includes many inorganic chemicals that are found in drinking-water as a consequence of release from rocks and soils by rainfall, some of which may become problematical where there is environmental disturbance, such as in mining areas.

8.2 Derivation of chemical guideline values

The criteria used to decide whether a guideline value is established for a particular chemical constituent are as follows:

- there is credible evidence of occurrence of the chemical in drinking-water, combined with evidence of actual or potential toxicity; or
- the chemical is of significant international concern; or
- the chemical is being considered for inclusion or is included in the WHO Pesticide Evaluation Scheme (WHOPES) programme (approval programme for direct application of pesticides to drinking-water for control of insect vectors of disease).

Guideline values are derived for many chemical constituents of drinking-water. A guideline value normally represents the concentration of a constituent that does not result in any significant risk to health over a lifetime of consumption. A number of provisional guideline values have been established at concentrations that are reasonably achievable through practical treatment approaches or in analytical laboratories; in these cases, the guideline value is above the concentration that would normally represent the calculated health-based value. Guideline values are also designated as provisional when there is a high degree of uncertainty in the toxicology and health data (see also section 8.2.6).

There are two principal sources of information on health effects resulting from exposure to chemicals that can be used in deriving guideline values. The first and preferred source is studies on human populations. However, the value of such studies for many substances is limited, owing to lack of quantitative information on the concentration to which people have been exposed or on simultaneous exposure to other agents. However, for some substances, such studies are the primary basis on which guideline values are developed. The second and most frequently used source of information is toxicity studies using laboratory animals. The limitations of toxicology studies include the relatively small number of animals used and the relatively high doses administered, which create uncertainty as to the relevance of particular findings to human health. This is because there is a need to extrapolate the results from animals to humans and to the low doses to which human populations are usually exposed. In most cases, the study used to derive the guideline value is supported by a range of other studies, including human data, and these are also considered in carrying out a health risk assessment.

In order to derive a guideline value to protect human health, it is necessary to select the most suitable study or studies. Data from well conducted studies, where a clear dose–response relationship has been demonstrated, are preferred. Expert judgement was exercised in the selection of the most appropriate study from the range of information available.

8.2.1 Approaches taken

Two approaches to the derivation of guideline values are used: one for "threshold chemicals" and the other for "non-threshold chemicals" (mostly genotoxic carcinogens).

It is generally considered that the initiating event in the process of genotoxic chemical carcinogens is the induction of a mutation in the genetic material (DNA) of somatic cells (i.e., cells other than ova or sperm) and that there is a theoretical risk at any level of exposure (i.e., no threshold). On the other hand, there are carcinogens that are capable of producing tumours in animals or humans without exerting a genotoxic activity, but acting through an indirect mechanism. It is generally believed that a demonstrable threshold dose exists for non-genotoxic carcinogens.

In deriving guideline values for carcinogens, consideration was given to the potential mechanism (s) by which the substance may cause cancer, in order to decide whether a threshold or non-threshold approach should be used (see sections 8.2.2 and 8.2.4).

The evaluation of the potential carcinogenicity of chemical substances is usually based on long-term animal studies. Sometimes data are available on carcinogenicity in humans, mostly from occupational exposure.

On the basis of the available evidence, the International Agency for Research on Cancer (IARC) categorizes chemical substances with respect to their potential carcinogenic risk into the following groups:

Group 1: the agent is carcinogenic to humans
Group 2A: the agent is probably carcinogenic to humans
Group 2B: the agent is possibly carcinogenic to humans
Group 3: the agent is not classifiable as to its carcinogenicity to humans
Group 4: the agent is probably not carcinogenic to humans

According to IARC, these classifications represent a first step in carcinogenic risk assessment, which leads to a second step of quantitative risk assessment where possible. In establishing guideline values for drinking-water, the IARC evaluation of carcinogenic compounds, where available, is taken into consideration.

8.2.2 Threshold chemicals

For most kinds of toxicity, it is believed that there is a dose below which no adverse effect will occur. For chemicals that give rise to such toxic effects, a tolerable daily intake (TDI) should be derived as follows, using the most sensitive end-point in the most relevant study, preferably involving administration in drinking-water:

$$TDI = (NOAEL \text{ or } LOAEL) / UF$$

where:

- NOAEL =no-observed-adverse-effect level
- LOAEL =lowest-observed-adverse-effect level
- UF =uncertainty factor

The guideline value (GV) is then derived from the TDI as follows:

$$GV = (TDI \times bw \times P\ C) / C$$

where:

- bw = body weight (see Annex 3)
- P = fraction of the TDI allocated to drinking-water
- C = daily drinking-water consumption (see Annex 3)

Tolerable daily intake

The TDI is an estimate of the amount of a substance in food and drinking-water, expressed on a body weight basis (mg/kg or µg/kg of body weight), that can be ingested over a lifetime without appreciable health risk.

Acceptable daily intakes (ADIs) are established for food additives and pesticide residues that occur in food for necessary technological purposes or plant protection reasons. For chemical contaminants, which usually have no intended function in drinking-water, the term "tolerable daily intake" is more appropriate than "acceptable daily intake," as it signifies permissibility rather than acceptability.

Over many years, JECFA and JMPR have developed certain principles in the derivation of ADIs. These principles have been adopted where appropriate in the derivation of TDIs used in developing guideline values for drinking-water quality.

As TDIs are regarded as representing a tolerable intake for a lifetime, they are not so precise that they cannot be exceeded for short periods of time. Short-term exposure to levels exceeding the TDI is not a cause for concern, provided the individual's intake averaged over longer periods of time does not appreciably exceed the level set. The large uncertainty factors generally involved in establishing a TDI (see below) serve to provide assurance that exposure exceeding the TDI for short periods is unlikely to have any deleterious effects upon health. However, consideration should be given to any potential acute effects that may occur if the TDI is substantially exceeded for short periods of time.

No-observed-adverse-effect level and lowest-observed-adverse-effect level

The NOAEL is defined as the highest dose or concentration of a chemical in a single study, found by experiment or observation, that causes no detectable adverse health effect. Wherever possible, the NOAEL is based on long-term studies, preferably of ingestion in drinking-water. However, NOAELs obtained from short-term studies and studies using other sources of exposure (e.g., food, air) may also be used.

If a NOAEL is not available, a LOAEL may be used, which is the lowest observed dose or concentration of a substance at which there is a detectable adverse health effect. When a LOAEL is used instead of a NOAEL, an additional uncertainty factor is normally applied (see below).

Uncertainty factors

The application of uncertainty (or safety) factors has been widely used in the derivation of ADIs and TDIs for food additives, pesticides and environmental contaminants.

The derivation of these factors requires expert judgement and careful consideration of the available scientific evidence.

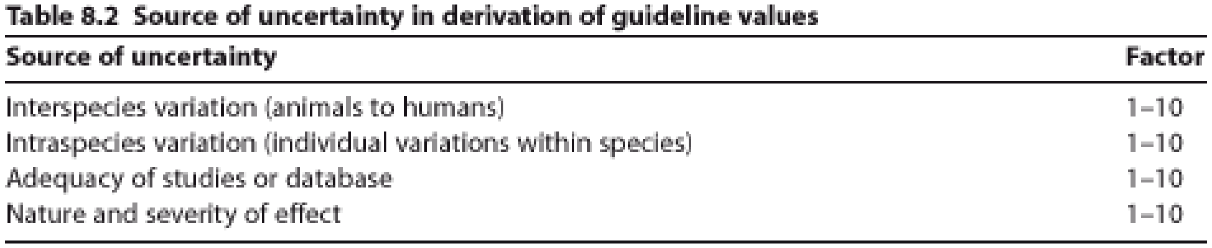


Table 8.2 Source of uncertainty in derivation of guideline values

Source of uncertainty	Factor
Interspecies variation (animals to humans)	1–10
Intraspecies variation (individual variations within species)	1–10
Adequacy of studies or database	1–10
Nature and severity of effect	1–10

In the derivation of guideline values, uncertainty factors are applied to the NOAEL or LOAEL for the response considered to be the most biologically significant.

In relation to exposure of the general population, the NOAEL for the critical effect in animals is normally divided by an uncertainty factor of 100. This comprises two 10-fold factors, one for interspecies differences and one for interindividual variability in humans (see Table 8.2). Extra uncertainty factors may be incorporated to allow for database deficiencies and for the severity and irreversibility of effects.

Factors lower than 10 were used, for example, for interspecies variation when humans are known to be less sensitive than the animal species studied. Inadequate studies or databases include those where a LOAEL was used instead of a NOAEL and studies considered to be shorter in duration than desirable. Situations in which the nature or severity of effect might warrant an additional uncertainty factor include studies in which the end-point was malformation of a fetus or in which the end-point determining the NOAEL was directly related to possible carcinogenicity. In the latter case, an additional uncertainty factor was usually applied for carcinogenic compounds for which the guideline value was derived using a TDI approach rather than a theoretical risk extrapolation approach.

For substances for which the uncertainty factors were greater than 1000, guideline values are designated as provisional in order to emphasize the higher level of uncertainty inherent in these values. A high uncertainty factor indicates that the guideline value may be considerably lower than the concentration at which health effects would actually occur in a real human population. Guideline values with high uncertainty are more likely to be modified as new information becomes available.

The selection and application of uncertainty factors are important in the derivation of guideline values for chemicals, as they can make a considerable difference in the values set. For contaminants for which there is sufficient confidence in the database, the guideline value was derived using a smaller uncertainty factor. For most contaminants, however, there is greater scientific uncertainty, and a relatively large uncertainty factor was used. The use of uncertainty factors enables the particular attributes of the chemical and the data available to be considered in the derivation of guideline values.

Allocation of intake

Drinking-water is not usually the sole source of human exposure to the substances for which guideline values have been set. In many cases, the intake of chemical contaminants from drinking-water is small in comparison with that from other sources, such as food and air. Guideline values derived using the TDI approach take into account exposures from all sources by apportioning a percentage of the TDI to drinking-water. This approach ensures that total daily intake from all sources (including drinking-water containing concentrations of the substance at or near the guideline value) does not exceed the TDI.

Wherever possible, data concerning the proportion of total intake normally ingested in drinking-water (based on mean levels in food, air and drinking-water) or intakes estimated on the basis of consideration of physical and chemical properties were used in the derivation of the guideline values. Where such information was not available, an arbitrary (default) value of 10% for drinking-water was used. This default value is, in most cases, sufficient to account for additional routes of intake (i.e., inhalation and dermal absorption) of contaminants in water. In some cases, a specific discussion is made of the potential for exposure from intake through inhalation and dermal uptake in bathing and showering where there is evidence that this is likely to be significant, usually in circumstances where the allocation of the TDI to drinking-water is greater than 10%.

It is recognized that exposure from various media may vary with local circumstances. It should be emphasized, therefore, that the derived guideline values apply to a typical exposure scenario or are based on default values that may or may not be applicable for all areas. In those areas where relevant exposure data are available, authorities are encouraged to develop context-specific guideline values that are tailored to local circumstances and conditions. For example, in areas where the intake of a particular contaminant in drinking-water is known to be much greater than that from other sources (i.e., air and food), it may be appropriate to allocate a greater proportion of the TDI to drinking-water to derive a guideline value more suited to the local conditions. In addition, in cases in which guideline values are exceeded, efforts should be made to assess the contribution of other sources to total intake in order to interpret the health significance of the exceedance and to orient remedial measures to sources of exposure that are most relevant.

Significant figures

The calculated TDI is used to derive the guideline value, which is then rounded to one significant figure. In some instances, ADI values with only one significant figure set by JECFA or JMPR were used to calculate the guideline value. The guideline value was generally rounded to one significant figure to refiect the uncertainty in animal toxicity data and exposure assumptions made.

8.2.3 Alternative approaches

Alternative approaches being considered in the derivation of TDIs for threshold effects include the benchmark dose (BMD) (IPCS, 1994), categorical regression (IPCS, 1994) and chemical-specific adjustment factors (CSAF) (IPCS, 2001).

Benchmark dose[1]

The benchmark dose (BMD) is the lower confidence limit of the dose that produces a small increase in the level of adverse effects (e.g., 5% or 10%; Crump, 1984) to which uncertainty factors can be applied to develop a tolerable intake.

The BMD has a number of advantages over the NOAEL:

- It is derived on the basis of data from the entire dose –response curve for the critical effect rather than from the single dose group at the NOAEL (i.e., one of the few preselected dose levels).
- Use of the BMD facilitates the use and comparison of studies on the same agent or the potencies of different agents.
- The BMD can be calculated from data sets in which a NOAEL was not determined, eliminating the need for an additional uncertainty factor to be applied to the LOAEL.
- Definition of the BMD as a lower confidence limit accounts for the statistical power and quality of the data. That is, the cofidence intervals around the dose –response curve for studies with small numbers of animals and, therefore, lower statistical power would be wide; similarly, confidence intervals in studies of poor quality with highly variable responses would also be wide. In either case, the wider confidence interval would lead to a lower BMD, reflecting the greater uncertainty of the database. On the other hand, narrow confidence limits (reflecting better studies) would result in higher BMDs.

Categorical regression[2]

The theory and application of categorical regression have been addressed by Hertzberg &Miller (1985), Hertzberg (1989), Guth et al. (1991) (inhalation exposure to methylisocyanate) and Farland & Dourson (1992) (oral exposure to arsenic). Data on toxicity are classified into one of several categories, such as no-observed-effect level (NOEL) or NOAEL, or others, as appropriate. These categories are then regressed on the basis of dose and, if required, duration of exposure. The result is a graph of probability of a given category of effect with dose or concentration, which is useful in the analysis of potential risks above the tolerable intake, especially for comparisons among chemicals.

Depending on the extent of the available data on toxicity, additional estimations regarding the percentage of individuals with specific adverse effects are possible. Such estimations require, however, an understanding of the mechanisms of toxicity of the critical effect, knowledge of the extrapolation between the experimental animal and humans and/ or knowledge of the incidence of specific effects in humans.

Similar to the BMD, categorical regression utilizes information from the entire dose –response curve, resulting in more precise estimates of risk when compared with the current approach (NOAEL-based tolerable intakes). However, categorical regression requires more information than the current tolerable intake method, and the interpretation of the probability scale can be problematic.

Chemical-specific adjustment factors

Approaches to the derivation of TDIs are increasingly being based on understanding of a chemical's mode of action in order to reduce reliance on empirical mathematical modelling and to eliminate the need to determine whether a threshold or nonthreshold approach is more appropriate. This approach provides a departure from the use of default uncertainty factors and relies on the use of quantitative toxicokinetic and toxicodynamic data and "chemical-specific adjustment factors" (CSAFs) (IPCS, 2001) to assess interspecies and interindividual extrapolations in dose / concentration – response assessment. Previously, CSAFs were called "data-derived uncertainty factors" (Renwick, 1993; IPCS, 1994). The part of the CSAF approach that is at present best developed is the use of physiologically based pharmacokinetic models to replace the default values for extrapolation between species and between routes of exposure.

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[1] This section has been taken from IPCS (1994).

[2] This section has been taken from IPCS (1994).

8.2.4 Non-threshold chemicals

In the case of compounds considered to be genotoxic carcinogens, guideline values were normally determined using a mathematical model. Although several models exist, the linearized multistage model was generally adopted. Other models were considered more appropriate in a few cases. Guideline values presented are the concentrations in drinking-water associated with an estimated upper-bound excess lifetime cancer risk of 10^{-5} (or one additional cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years).

The guideline values for carcinogenic substances have been computed from hypothetical mathematical models that cannot be verified experimentally. These models do not usually take into account a number of biologically important considerations, such as pharmacokinetics, DNA repair or protection by the immune system. They also assume the validity of a linear extrapolation of very high dose exposures in test animals to very low dose exposures in humans. As a consequence, the models used are conservative (i.e., err on the side of caution). The guideline values derived using these models should be interpreted differently from TDI-based values because of the lack of precision of the models. At best, these values must be regarded as rough estimates of cancer risk. Moderate short-term exposure to levels exceeding the guideline value for carcinogens does not significantly affect the risk.

8.2.5 Data quality

The following factors were taken into account in assessing the quality and reliability of available information:

- Oral studies are preferred (in particular, drinking-water studies), using the pure substance with appropriate dosing regime and a good-quality pathology.
- The database should be sufficiently broad that all potential toxicological end-points of concern have been identified.
- The quality of the studies is such that they are considered reliable; for example, there has been adequate consideration of confounding factors in epidemiological studies.
- There is reasonable consistency between studies; the end-point and study used to derive a guideline value do not contradict the overall weight of evidence.
- For inorganic substances, there is some consideration of speciation in drinking-water.
- There is appropriate consideration of multimedia exposure in the case of epidemiological studies.

In the development of guideline values, existing international approaches were carefully considered. In particular, previous risk assessments developed by the International Programme on Chemical Safety (IPCS) in EHC monographs and CICADs, IARC, JMPR and JECFA were reviewed. These assessments were relied upon except where new information justified a reassessment, but the quality of new data was critically evaluated before it was used in any risk assessment. Where international reviews were not available, other sources of data were used in the derivation of guideline values, including published reports from peer-reviewed open literature, national reviews recognized to be of high quality, information submitted by governments and other interested parties and, to a limited extent, unpublished proprietary data (primarily for the evaluation of pesticides). Future revisions and assessments of pesticides will take place primarily through WHO/IPCS/JMPR/JECFA processes.

8.2.6 Provisional guideline values

The use and designation of provisional guideline values are outlined in Table 8.3. For non-threshold substances, in cases in which the concentration associated with an upper-bound excess lifetime cancer risk of 10^{-5} is not feasible as a result of inadequate analytical or treatment technology, a provisional guideline value (designated A or T, respectively) is recommended at a practicable level.

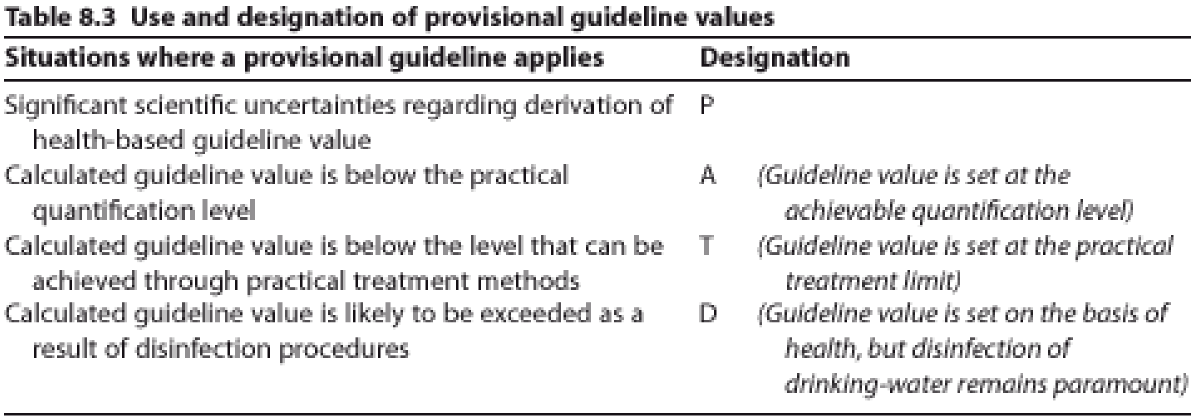


Table 8.3 Use and designation of provisional guideline values

Situations where a provisional guideline applies	Designation	
Significant scientific uncertainties regarding derivation of health-based guideline value	P	
Calculated guideline value is below the practical quantification level	A	*(Guideline value is set at the achievable quantification level)*
Calculated guideline value is below the level that can be achieved through practical treatment methods	T	*(Guideline value is set at the practical treatment limit)*
Calculated guideline value is likely to be exceeded as a result of disinfection procedures	D	*(Guideline value is set on the basis of health, but disinfection of drinking-water remains paramount)*

8.2.7 Chemicals with effects on acceptability

Some substances of health concern have effects on the taste, odour or appearance of drinking-water that would normally lead to rejection of water at concentrations significantly lower than those of concern for health. Such substances are not normally appropriate for routine monitoring. Nevertheless, health-based guideline values may be needed – for instance, for use in interpreting data collected in response to consumer complaints. In these circumstances, a health-based summary statement and guideline value are presented in the usual way. In the summary statement, the relationship between concentrations relevant to health and those relevant to the acceptability of the drinking-water is explained. In tables of guideline values, the health-based guideline values are designated with a “C.”

8.2.8 Non-guideline chemicals

Additional information on many chemicals not included in these Guidelines is available from several credible sources, including WHO EHCs and CICADs (www.who.int/pcs/index), chemical risk assessment reports from JMPR, JECFA and IARC, and published documents from a number of national sources, such as the USEPA. Although these information sources may not have been reviewed for these Guidelines, they have been peer reviewed and provide readily accessible information on the toxicology of many additional chemicals. They can help drinking-water suppliers and health officials decide upon the significance (if any) of a detected chemical and on the response that might be appropriate.

8.2.9 Mixtures

Chemical contaminants of drinking-water supplies are present with numerous other inorganic and/or organic constituents. The guideline values are calculated separately for individual substances, without specific consideration of the potential for interaction of each substance with other compounds present. The large margin of uncertainty incorporated in the majority of the guideline values is considered to be sufficient to account for potential interactions. In addition, the majority of contaminants will not be continuously present at concentrations at or near their guideline value.

For many chemical contaminants, mechanisms of toxicity are different; consequently, there is no reason to assume that there are interactions. There may, however, be occasions when a number of contaminants with similar toxicological mechanisms are present at levels near their respective guideline values. In such cases, decisions concerning appropriate action should be made, taking into consideration local circumstances. Unless there is evidence to the contrary, it is appropriate to assume that the toxic effects of these compounds are additive.

8.3 Analytical aspects

As noted above, guideline values are not set at concentrations of substances that cannot reasonably be measured. In such circumstances, provisional guideline values are set at the reasonable analytical limits.

Guidance provided in this section is intended to assist readers to select appropriate analytical methods for specific circumstances.

8.3.1 Analytical achievability

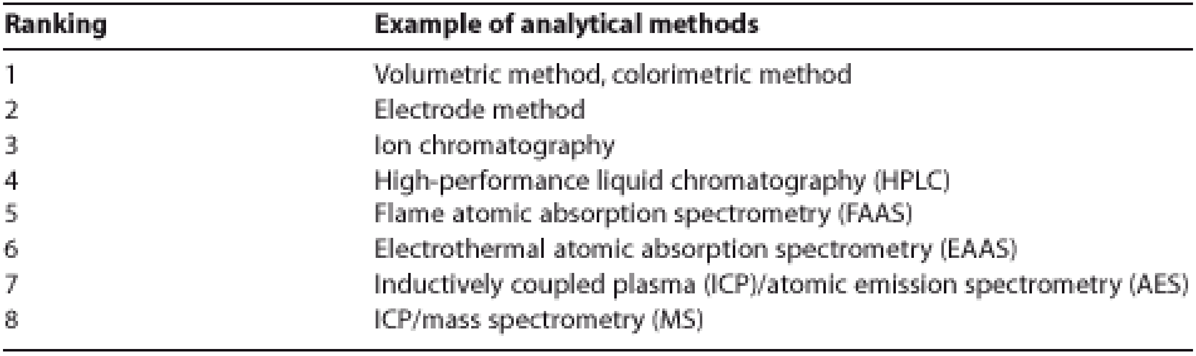
Various collections of “standard” or “recommended” methods for water analysis are published by a number of national and international agencies. It is often thought that adequate analytical accuracy can be achieved provided that all laboratories use the same standard method. Experience shows that this is not always the case, as a variety of factors may affect the accuracy of the results. Examples include reagent purity, apparatus type and performance, degree of modification of the method in a particular laboratory and the skill and care of the analyst. These factors are likely to vary both between the laboratories and over time in an individual laboratory. Moreover, the precision and accuracy that can be achieved with a particular method frequently depend upon the adequacy of sampling and nature of the sample (“matrix”). While it is not essential to use standard methods, it is important that the methods used are properly validated and precision and accuracy determined before significant decisions are made based on the results. In the case of “non-specific” variables such as taste and odour, colour and turbidity, the result is method specific, and this needs to be considered when using the data to make comparisons.

A number of considerations are important in selecting methods:

- The overriding consideration is that the method chosen is demonstrated to have the required accuracy. Other factors, such as speed and convenience, should be considered only in selecting among methods that meet this primary criterion.
- There are a number of markedly different procedures for measuring and reporting the errors to which all methods are subject. This complicates and prejudices the effectiveness of method selection, and suggestions for standardizing such procedures have been made. It is therefore desirable that details of all analytical methods are published together with performance characteristics that can be interpreted unambiguously.
- If the analytical results from one laboratory are to be compared with those from others and/ or with a numerical standard, it is obviously preferable for them not to have any associated systematic error. In practice, this is not possible, but each laboratory should select methods whose systematic errors have been thoroughly evaluated and shown to be acceptably small.

A qualitative ranking of analytical methods based on their degree of technical complexity is given in Table 8.4 for inorganic chemicals and in Table 8.5 for organic chemicals. These groups of chemicals are separated, as the analytical methods used differ greatly. The higher the ranking, the more complex the process in terms of equipment and / or operation. In general, higher rankings are also associated with higher total costs. Analytical achievabilities of the chemical guideline values based on detection limits are given in Tables 8.6 –8.10.

Table 8.4 Ranking of complexity of analytical methods for inorganic chemicals



Ranking	Example of analytical methods
1	Volumetric method, colorimetric method
2	Electrode method
3	Ion chromatography
4	High-performance liquid chromatography (HPLC)
5	Flame atomic absorption spectrometry (FAAS)
6	Electrothermal atomic absorption spectrometry (EAAS)
7	Inductively coupled plasma (ICP)/atomic emission spectrometry (AES)
8	ICP/mass spectrometry (MS)

There are many kinds of field test kits that are used for compliance examinations as well as operational monitoring of drinking-water quality. Although the field test kits are generally available at relatively low prices, their analytical accuracy is generally less than that of the methods shown in Tables 8.4 and 8.5.It is therefore necessary to check the validity of the field test kit before applying it.

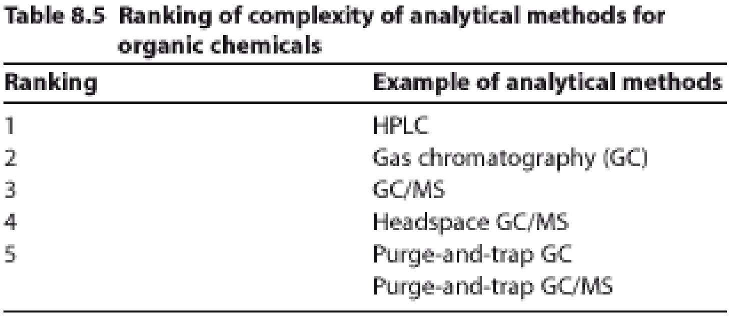


Table 8.5 Ranking of complexity of analytical methods for organic chemicals

Ranking	Example of analytical methods
1	HPLC
2	Gas chromatography (GC)
3	GC/MS
4	Headspace GC/MS
5	Purge-and-trap GC Purge-and-trap GC/MS

8.3.2 Analytical methods

In *volumetric titration*, chemicals are analysed by titration with a standardized titrant. The titration end-point is identified by the development of colour resulting from the reaction with an indicator, by the change of electrical potential or by the change of pH value.

Colorimetric methods are based on measuring the intensity of colour of a coloured target chemical or reaction product. The optical absorbance is measured using light of a suitable wavelength. The concentration is determined by means of a calibration curve obtained using known concentrations of the determinant. The UV method is similar to this method except that UV light is used.

For ionic materials, the ion concentration can be measured using an *ion-selective electrode*. The measured potential is proportional to the logarithm of the ion concentration.

Some organic compounds absorb UV light (wavelength 190 – 380 nm) in proportion to their concentration. *UV absorption* is useful for qualitative estimation of organic substances, because a strong correlation may exist between UV absorption and organic carbon content.

Atomic absorption spectrometry (AAS) is used for determination of metals. It is based on the phenomenon that the atom in the ground state absorbs the light of wave-lengths that are characteristic to each element when light is passed through the atoms in the vapour state. Because this absorption of light depends on the concentration of atoms in the vapour, the concentration of the target element in the water sample is determined from the measured absorbance. The Beer-Lambert law describes the relationship between concentration and absorbance.

In fl*ame atomic absorption spectrometry (FAAS)*, a sample is aspirated into a flame and atomized. A light beam from a hollow cathode lamp of the same element as the target metal is radiated through the flame, and the amount of absorbed light is meas-ured by the detector. This method is much more sensitive than other methods and free from spectral or radiation interference by co-existing elements. Pretreatment is either unnecessary or straightforward. However, it is not suitable for simultaneous analysis of many elements, because the light source is different for each target element.

Table 8.6 Analytical achievability for inorganic chemicals for which guideline values have been established, by source category[a]

	Field methods		Laboratory methods				
	Col	Absor	IC	FAAS	EAAS	ICP	ICP/MS
Naturally occurring chemicals							
Arsenic		#		+(H)	++□+++(H)	++(H)	+++
Barium				+	+++	+++	+++
Boron		++				++	+++
Chromium		#		+	+++	+++	+++
Fluoride	#	+	++				
Manganese	+	++		++	+++	+++	+++
Molybdenum					+	+++	+++
Selenium		#		#	+++(H)	++(H)	+
Uranium						+	+++
Chemicals from industrial sources and human dwellings							
Cadmium		#			++	++	+++
Cyanide	#	+	+				
Mercury					+		
Chemicals from agricultural activities							
Nitrate/nitrite	+++	+++	#				
Chemicals used in water treatment or materials in contact with drinking-water							
Antimony				#	++(H)	++(H)	+++
Copper	#	+++		+++	+++	+++	+++
Lead		#			+	+	++
Nickel		+		#	+	+++	++

[a] For definitions and notes to Table 8.6, see below Table 8.10.

Table 8.7 Analytical achievability for organic chemicals from industrial sources and human dwellings for which guideline values have been established[a]

	Col	GC	GC/PD	GC/EC	GC/ FID	GC/ FPD	GC/ TID	GC/ MS	PT- GC/MS	HPLC	HPLC/FD	HPLC/ UVPAD	EAAS	IC/FD
Benzene				++	+				+++					
Carbon tetrachloride				+					+					
Di(2-ethylhexyl)phthalate								++						
1,2-Dichlorobenzene			+++	+++					+++					
1,4-Dichlorobenzene			+++	+++					+++					
1,2-Dichloroethane				+++					++					
1,1-Dichloroethene				+++	+				+++					
1,2-Dichloroethene				++	++				+++					
Dichloromethane				#	+				+++					
Edetic acid (EDTA)								+++						
Ethylbenzene				+++	+++				+++					
Hexachlorobutadiene									+					
Nitrilotriacetic acid (NTA)		+++												
Pentachlorophenol				++					+++	+++				
Styrene				++	+				+++					
Tetrachloroethene				+++	+				+++					
Toluene					+++				+++					
Trichloroethene				+++	+				+++					+
Xylenes					+++				+++					

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[a] For definitions and notes to Table 8.7, see below Table 8.10.

Table 8.8 Analytical achievability for organic chemicals from agricultural activities for which guideline values have been established[a]

	Col	GC	GC/PD	GC/EC	GC/ FID	GC/ FPD	GC/ TID	GC/ MS	PT- GC/MS	HPLC	HPLC/FD	HPLC/ UVPAD	EAAS	IC/FD
Alachlor				☐				+++						
Aldicarb												+		
Aldrin and dieldrin				+										
Atrazine								+++☐						
Carbofuran							++				++			
Chlordane				+										
Chlorotoluron				☐										
Cyanazine								++				+		
2,4-D				++				+++						
2,4-DB				++				++						
1,2-Dibromo-3-chloropropane				☐				+++	++					
1,2-Dibromoethane								+	+					
1,2-Dichloropropane				+++					+++					
1,3-Dichloropropene				+++					+++					
Dichlorprop (2,4-DP)								+++						
Dimethoate								+++						
Endrin				+				#						
Fenoprop				+										
Isoproturon				+								+++		
Lindane				+										
MCPA				+++				+++				+++		
Mecoprop				++				++						
Methoxychlor		+++												
Metolachlor				+++										
Molinate								+++						
Pendimethalin				+++			++	+++						
Simazine					+		+	+++						
2,4,5-T			+	+++										
Terbuthylazine (TBA)								+++				++		
Trifluralin		+++						+++				+		

[a] For definitions and notes to Table 8.8, see below Table 8.10.

Table 8.9 Analytical achievability for chemicals used in water treatment or from materials in contact with water for which guideline values have been established[a]

	Col	GC	GC/PD	GC/EC	GC/FID	GC/FPD	GC/TID	GC/MS	PT-GC/MS	HPLC	HPLC/FD	HPLC/UVPAD	EAAS	IC
Disinfectants														
Monochloramine	+++													
Chlorine	+++									+++				+++
Disinfection by-products														
Bromate														+
Bromodichloromethane				+++					+++					
Bromoform				+++					+++					
Chloral hydrate (trichloroacetaldehyde)				+				+						
Chlorate														☐
Chlorite	☐													☐
Chloroform				+++					+++					
Cyanogen chloride														☐
Dibromoacetonitrile				☐				☐						
Dibromochloromethane				+++					+++					
Dichloroacetate				☐				☐						
Dichloroacetonitrile				+++				+						
Formaldehyde				☐				☐						
Monochloroacetate		++						++						
Trichloroacetate				☐				☐						
2,4,6-Trichlorophenol				+++				+++						
Trihalomethanes[b]				+++					+++					
Organic contaminants from treatment chemicals														
Acrylamide		+					+				+			
Epichlorohydrin				+	+				+					
Organic contaminants from pipes and fittings														
Benzo[*a*]pyrene								++			++			
Vinyl chloride				+					+					

[a] For definitions and notes to Table 8.9, see below Table 8.10.
[b] See also individual THMs.

Table 8.10 Analytical achievability for pesticides used in water for public health purposes for which guideline values have been established[a]

	Col	GC	GC/PD	GC/EC	GC/ FID	GC/ FPD	GC/ TID	GC/MS	PT- GC/MS	HPLC	HPLC/FD	HPLC/ UVPAD	EAAS	IC/FD
Chlorpyrifos				+++	+++	+	+++	+++						
DDT (and metabolites)				+++				+						
Pyriproxyfen								+++						

[a] For definitions and notes to Table 8.10, see below.

Definitions to Tables 8.6–8.10

Col	Colorimetry
Absor	Absorptiometry
GC	Gas chromatography
GC/PD	Gas chromatography photoionization detector
GC/EC	Gas chromatography electron capture
GC/FID	Gas chromatography flame ionization detector
GC/FPD	Gas chromatography flame photodiode detector
GC/TID	Gas chromatography thermal ionization detector
GC/MS	Gas chromatography mass spectrometry
PT-GC/MS	Purge-and-trap gas chromatography mass spectrometry
HPLC	High-performance liquid chromatography
HPLC/FD	High-performance liquid chromatography fluorescence detector
HPLC/ UVPAD	High-performance liquid chromatography ultraviolet photodiode array detector
EAAS	Electrothermal atomic absorption spectrometry
IC	Ion chromatography
ICP	Inductively coupled plasma
ICP/MS	Inductively coupled plasma mass spectrometry
FAAS	Flame atomic absorption spectrometry
IC/FAAS	Ion chromatography flame atomic absorption spectrometry
IC/FD	Ion chromatography fluorescence detector

Notes to Tables 8.6–8.10

+	The detection limit is between the guideline value and 1/10 of its value.
++	The detection limit is between 1/10 and 1/50 of the guideline value.
+++	The detection limit is under 1/100 of the guideline value.
#	The analytical method is available for detection of the concentration of the guideline value, but it is difficult to detect the concentration of 1/10 of the guideline value.
☐	The detection method(s) is/are available for the item.
(H)	This method is applicable to the determination by conversion to their hydrides by hydride generator.

Electrothermal atomic absorption spectrometry (EAAS) is based on the same principle as FAAS, but an electrically heated atomizer or graphite furnace replaces the standard burner head for determination of metals. In comparison with FAAS, EAAS gives higher sensitivities and lower detection limits, and a smaller sample volume is required. EAAS suffers from more interference through light scattering by co-existing elements and requires a longer analysis time than FAAS.

The principle of *inductively coupled plasma/atomic emission spectrometry (*ICP/AES*)* for determination of metals is as follows. An ICP source consists of a flowing stream of argon gas ionized by an applied radio frequency. A sample aerosol is generated in a nebulizer and spray chamber and then carried into the plasma through an injector tube. A sample is heated and excited in the high-temperature plasma. The high temperature of the plasma causes the atoms to become excited. On returning to the ground state, the excited atoms produce ionic emission spectra. A monochromator is used to separate specific wavelengths corresponding to different elements, and a detector measures the intensity of radiation of each wavelength. A significant reduction in chemical interference is achieved. In the case of water with low pollution, simultaneous or sequential analysis is possible without special pretreatment to achieve low detection limits for many elements. This, coupled with the extended dynamic range from three digits to five digits, means that multi-element determination of metals can be achieved. ICP/AES has similar sensitivity to FAAS or EAAS.

In *inductively coupled plasma/mass spectrometry (ICP/MS)*, elements are atomized and excited as in ICP/AES, then passed to a mass spectrometer. Once inside the mass spectrometer, the ions are accelerated by high voltage and passed through a series of ion optics, an electrostatic analyser and, finally, a magnet. By varying the strength of the magnet, ions are separated according to mass/charge ratio and passed through a slit into the detector, which records only a very small atomic mass range at a given time. By varying the magnet and electrostatic analyser settings, the entire mass range can be scanned within a relatively short period of time. In the case of water with low pollution, simultaneous or sequential analysis is possible without special pretreatment to achieve low detection limits for many elements. This, coupled with the extended dynamic range from three digits to five digits, means that multi-element determination of metals can be achieved.

Chromatography is a separation method based on the affinity difference between two phases, the stationary and mobile phases. A sample is injected into a column, either packed or coated with the stationary phase, and separated by the mobile phase based on the difference in interaction (distribution or adsorption) between compounds and the stationary phase. Compounds with a low affinity for the stationary phase move more quickly through the column and elute earlier. The compounds that elute from the end of the column are determined by a suitable detector.

In *ion chromatography*, an ion exchanger is used as the stationary phase, and the eluant for determination of anions is typically a dilute solution of sodium hydrogen carbonate and sodium carbonate. Colorimetric, electrometric or titrimetric detectors can be used for determining individual anions. In suppressed ion chromatography, anions are converted to their highly conductive acid forms; in the carbonate – bicarbonate eluant, anions are converted to weakly conductive carbonic acid. The separated acid forms are measured by conductivity and identified on the basis of retention time as compared with their standards.

High-performance liquid chromatography (HPLC) is an analytical technique using a liquid mobile phase and a column containing a liquid stationary phase. Detection of the separated compounds is achieved through the use of absorbance detectors for organic compounds and through conductivity or electrochemical detectors for metallic and inorganic compounds.

Gas chromatography (GC) permits the identification and quantification of trace organic compounds. In GC, gas is used as the mobile phase, and the stationary phase is a liquid that is coated either on an inert granular solid or on the walls of a capillary column. When the sample is injected into the column, the organic compounds are vaporized and moved through the column by the carrier gas at different rates depending on differences in partition coefficients between the mobile and stationary phases. The gas exiting the column is passed to a suitable detector. A variety of detectors can be used, including flame ionization (FID), electron capture (ECD) and nitrogen –phosphorus. Since separation ability is good in this method, mixtures of substances with similar structure are systematically separated, identified and determined quantitatively in a single operation.

The *gas chromatography/mass spectrometry (GC/MS)* method is based on the same principle as the GC method, using a mass spectrometer as the detector. As the gas emerges from the end of the GC column opening, it flows through a capillary column interface into the MS. The sample then enters the ionization chamber, where a collimated beam of electrons impacts the sample molecules, causing ionization and fragmentation. The next component is a mass analyser, which uses a magnetic field to separate the positively charged particles according to their mass. Several types of separating techniques exist; the most common are quadrupoles and ion traps. After the ions are separated according to their masses, they enter a detector.

The *purge-and-trap packed-column GC/MS method* or *purge-and-trap packed-column GC* method is applicable to the determination of various purgeable organic compounds that are transferred from the aqueous to the vapour phase by bubbling purge gas through a water sample at ambient temperature. The vapour is trapped with a cooled trap. The trap is heated and back fiushed with the same purge gas to desorb the compounds onto a GC column. The principles of GC or GC/MS are as referred to above.

The principle of *enzyme-linked immunosorbent assay (ELISA)* is as follows. The protein (antibody) against the chemical of interest (antigen) is coated onto the solid material. The target chemical in the water sample binds to the antibody, and a second antibody with an enzyme attached is also added that will attach to the chemical of interest. After washing to remove any of the free reagents, a chromogen is added that will give a colour reaction due to cleavage by the enzyme that is proportional to the quantity of the chemical of interest. The ELISA method can be used to determine microcystin and synthetic surfactants.

8.4 Treatment

As noted above, where a health-based guideline value cannot be achieved by reasonably practicable treatment, then the guideline value is designated as provisional and set at the concentration that can be reasonably achieved through treatment.

8.4.1 Treatment achievability

The ability to achieve a guideline value within a drinking-water supply depends on a number of factors, including:

- the concentration of the chemical in the raw water;
- control measures employed throughout the drinking-water system;
- nature of the raw water (groundwater or surface water, presence of natural back-ground and other components); and
- treatment processes already installed.

If a guideline value cannot be met with the existing system, then additional treatment may need to be considered, or water should be obtained from alternative sources.

The cost of achieving a guideline value will depend on the complexity of any additional treatment or other control measures required. It is not possible to provide general quantitative information on the cost of achieving individual guideline values. Treatment costs (capital and operating) will depend not only on the factors identified above, but also on issues such as plant throughput; local costs for labour, civil and mechanical works, chemicals and electricity; life expectancy of the plant; and so on.

A qualitative ranking of treatment processes based on their degree of technical complexity is given in Table 8.11. The higher the ranking, the more complex the process in terms of plant and/or operation. In general, higher rankings are also associated with higher costs.

Table 8.11 Ranking of technical complexity and cost of water treatment processes

Ranking	Examples of treatment processes
1	Simple chlorination Plain filtration (rapid sand, slow sand)
2	Pre-chlorination plus filtration Aeration
3	Chemical coagulation Process optimization for control of DBPs
4	Granular activated carbon (GAC) treatment Ion exchange
5	Ozonation
6	Advanced oxidation processes Membrane treatment

Table 8.12 Treatment achievability for naturally occurring chemicals for which guideline values have been established[a,b]

	Chlorination	Coagulation	Ion exchange	Precipitation softening	Activated alumina	Activated carbon	Ozonation	Membranes
Arsenic		+++ <0.005	+++ <0.005	+++ <0.005	+++ <0.005			+++ <0.005
Fluoride		++			+++ <1			+++ <1
Manganese	+++ <0.05	++					+++ <0.05	+++ <0.05
Selenium		++	+++ <0.01		+++ <0.01			+++ <0.01
Uranium		++	+++ <0.001	++	+++ <0.001			

[a] Symbols are as follows:
++ 50% or more removal
+++ 80% or more removal

[b] The table includes only those chemicals for which some treatment data are available. A blank entry in the table indicates either that the process is completely ineffective or that there are no data on the effectiveness of the process. For the most effective process(es), the table indicates the concentration of the chemical, in mg/litre, that should be achievable.

Tables 8.12 –8.16 summarize the treatment processes that are capable of removing chemical contaminants of health significance. The tables include only those chemicals for which some treatment data are available.

These tables are provided to help inform decisions regarding the ability of existing treatment to meet guidelines and what additional treatment might need to be installed. They have been compiled on the basis of published literature, which includes mainly laboratory experiments, some pilot plant investigations and relatively few fullscale studies of water treatment processes. Consequently:

- Many of the treatments outlined are designed for larger treatment plants and may not necessarily be appropriate for smaller treatment plants or individual type treat-ment. In these cases, the choice of technology must be made on a case-by-case basis.

- The information is probably “best case,” since the data would have been obtained under laboratory conditions or with a carefully controlled plant for the purposes of experimentation.
- Actual process performance will depend on the concentration of the chemical in the raw water and on general raw water quality. For example, chlorination and removal of organic chemicals and pesticides using activated carbon or ozonation will be impaired there is a high concentration of natural organic matter.
- For many contaminants, potentially several different processes could be appropriate, and the choice between processes should be made on the basis of technical complexity and cost, taking into account local circumstances. For example, membrane processes can remove a broad spectrum of chemicals, but simpler and cheaper alternatives are effective for the removal of most chemicals.
- It is normal practice to use a series of unit processes to achieve desired water quality objectives (e.g., coagulation, sedimentation, filtration, GAC, chlorination). Each of these may contribute to the removal of chemicals. It may be technically and 8. CHEMICAL economically advantageous to use a combination of processes (e.g., ozonation plus GAC) to remove particular chemicals.
- The effectiveness of potential processes should be assessed using laboratory or pilot plant tests on the actual raw water concerned. These tests should be of sufficient duration to identify potential seasonal or other temporal variations in contaminant concentrations and process performance.

Table 8.13 Treatment achievability for chemicals from industrial sources and human dwellings for which guideline values have been established[a,b]

	Air stripping	Coagulation	Ion exchange	Precipitation softening	Activated carbon	Ozonation	Advanced oxidation	Membranes
Cadmium		+++ <0.002	+++ <0.002	+++ <0.002				+++ <0.002
Mercury		+++ <0.0001		+++ <0.0001	+++ <0.0001			+++ <0.0001
Benzene	+++ <0.01				+++ <0.01	+++ <0.01		
Carbon tetrachloride	+++ <0.001	+			+++ <0.001			+++ <0.001
1,2-Dichlorobenzene	+++ <0.01				+++ <0.01	+++ <0.01		
1,4-Dichlorobenzene	+++ <0.01				+++ <0.01	+++ <0.01		
1,2-Dichloroethane	+				+++ <0.01	+	++	
1,2-Dichloroethene	+++ <0.01				+++ <0.01	+++ <0.01		
1,4-Dioxane						+++ no data		
Edetic acid (EDTA)					+++ <0.01			
Ethylbenzene	+++ <0.001	+			+++ <0.001	+++ <0.001		
Hexachlorobutadiene					+++ <0.001			
Nitrilotriacetic acid (NTA)					+++ no data			
Pentachlorophenol					+++ <0.0004			
Styrene	+++ <0.02				+++ <0.002			
Tetrachloroethene	+++ <0.001				+++ <0.001			
Toluene	+++ <0.001				+++ <0.001	+++ <0.001	+++ <0.001	
Trichloroethene	+++ <0.02				+++ <0.02	+++ <0.02	+++ <0.02	
Xylenes	+++ <0.005				+++ <0.005		+++ <0.005	

[a] Symbols are as follows:
+ Limited removal
++ 50% or more removal
+++ 80% or more removal

[b] The table includes only those chemicals for which some treatment data are available. A blank entry in the table indicates either that the process is completely ineffective or that there are no data on the effectiveness of the process. For the most effective process(es), the table indicates the concentration of the chemical, in mg/litre, that should be achievable.

Table 8.14 Treatment achievability for chemicals from agricultural activities for which guideline values have been established[a,b]

	Chlorination	Air stripping	Coagulation	Ion exchange	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment
Nitrate				+++ <5				+++ <5	+++ <5
Nitrite	+++ <0.1					+++ <0.1	+++ <0.1		
Alachlor					+++ <0.001	++	+++ <0.001	+++ <0.001	
Aldicarb	+++ <0.001				+++ <0.001	+++ <0.001		+++ <0.001	
Aldrin/dieldrin			++		+++ <0.00002	+++ <0.00002		+++ <0.00002	
Atrazine			+		+++ <0.0001	++	+++ <0.0001	+++ <0.0001	
Carbofuran	+				+++ <0.001			+++ <0.001	
Chlordane					+++ <0.0001	+++ <0.0001			
Chlorotoluron					+++ <0.0001	+++ <0.0001			
Cyanazine					+++ <0.0001	+		+++ <0.0001	
2,4-Dichlorophenoxyacetic acid (2,4-D)			+		+++ <0.001	+++ <0.001			
1,2-Dibromo-3-chloropropane		++ <0.001			+++ <0.0001				
1,2-Dibromoethane		+++ <0.0001			+++ <0.0001				
1,2-Dichloropropane (1,2-DCP)					+++ <0.001	+		+++ <0.001	
Dimethoate	+++ <0.001				++	++			
Endrin			+		+++ <0.0002				
Isoproturon	++				+++ <0.0001	+++ <0.0001	+++ <0.0001	+++ <0.0001	
Lindane					+++ <0.0001	++			
MCPA					+++ <0.0001	+++ <0.0001			
Mecoprop					+++ <0.0001	+++ <0.0001			
Methoxychlor			++		+++ <0.0001	+++ <0.0001			
Metalochlor					+++ <0.0001	++			

continued

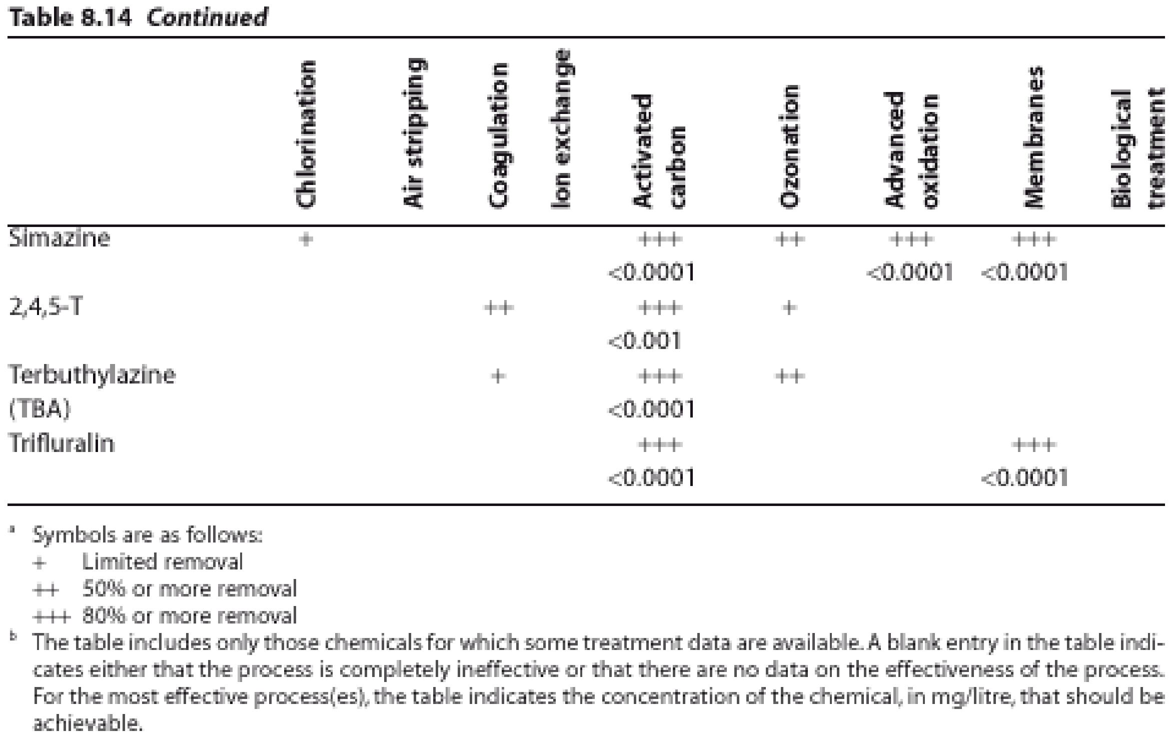


Table 8.14 ***Continued***

	Chlorination	Air stripping	Coagulation	Ion exchange	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment
Simazine	+				+++ <0.0001	++	+++ <0.0001	+++ <0.0001	
2,4,5-T			++		+++ <0.001	+			
Terbuthylazine (TBA)			+		+++ <0.0001	++			
Trifluralin					+++ <0.0001			+++ <0.0001	

[a] Symbols are as follows:
+ Limited removal
++ 50% or more removal
+++ 80% or more removal

[b] The table includes only those chemicals for which some treatment data are available. A blank entry in the table indicates either that the process is completely ineffective or that there are no data on the effectiveness of the process. For the most effective process(es), the table indicates the concentration of the chemical, in mg/litre, that should be achievable.

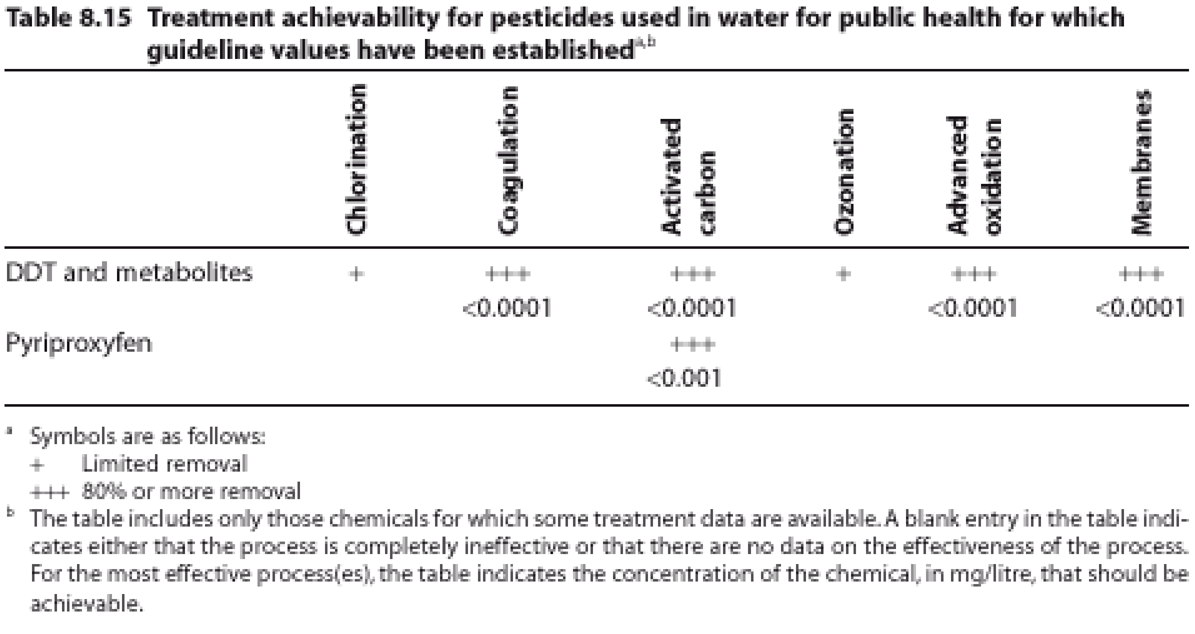


Table 8.15 Treatment achievability for pesticides used in water for public health for which guideline values have been established[a,b]

	Chlorination	Coagulation	Activated carbon	Ozonation	Advanced oxidation	Membranes
DDT and metabolites	+	+++ <0.0001	+++ <0.0001	+	+++ <0.0001	+++ <0.0001
Pyriproxyfen			+++ <0.001			

[a] Symbols are as follows:
+ Limited removal
+++ 80% or more removal

[b] The table includes only those chemicals for which some treatment data are available. A blank entry in the table indicates either that the process is completely ineffective or that there are no data on the effectiveness of the process. For the most effective process(es), the table indicates the concentration of the chemical, in mg/litre, that should be achievable.

8.4.2 Chlorination

Chlorination can be achieved by using liquefied chlorine gas, sodium hypochlorite solution or calcium hypochlorite granules and on-site chlorine generators. Liquefied chlorine gas is supplied in pressurized containers. The gas is withdrawn from the cylinder and is dosed into water by a chlorinator, which both controls and measures the gas flow rate. Sodium hypochlorite solution is dosed using a positive-displacement electric dosing pump or gravity feed system. Calcium hypochlorite has to be dissolved in water, then mixed with the main supply. Chlorine, whether in the form of chlorine gas from a cylinder, sodium hypochlorite or calcium hypochlorite, dissolves in water to form hypochlorous acid (HOCl) and hypochlorite ion (OCl^-).

Different techniques of chlorination can be used, including breakpoint chlorination, marginal chlorination and superchlorination/dechlorination. Breakpoint chlorination is a method in which the chlorine dose is sufficient to rapidly oxidize all the ammonia nitrogen in the water and to leave a suitable free residual chlorine available to protect the water against reinfection from the point of chlorination to the point of use. Superchlorination/dechlorination is the addition of a large dose of chlorine to effect rapid disinfection and chemical reaction, followed by reduction of excess free chlorine residual. Removing excess chlorine is important to prevent taste problems.

It is used mainly when the bacterial load is variable or the detention time in a tank is not enough. Marginal chlorination is used where water supplies are of high quality and is the simple dosing of chlorine to produce a desired level of free residual chlorine. The chlorine demand in these supplies is very low, and a breakpoint might not even occur.

Chlorination is employed primarily for microbial disinfection. However, chlorine also acts as an oxidant and can remove or assist in the removal of some chemicals – for example, decomposition of easily oxidized pesticides such as aldicarb; oxidation of dissolved species (e.g., manganese(II)) to form insoluble products that can be removed by subsequent filtration; and oxidation of dissolved species to more easily removable forms (e.g., arsenite to arsenate).

A disadvantage of chlorine is its ability to react with natural organic matter to produce THMs and other halogenated DBPs. However, by-product formation may be controlled by optimization of the treatment system.

8.4.3 Ozonation

Ozone is a powerful oxidant and has many uses in water treatment, including oxidation of organic chemicals. Ozone can be used as a primary disinfectant. Ozone gas (O3) is formed by passing dry air or oxygen through a high-voltage electric field. The resultant ozone-enriched air is dosed directly into the water by means of porous diffusers at the base of baffied contactor tanks. The contactor tanks, typically about 5 m deep, provide 10 –20 min of contact time. Dissolution of at least 80% of the applied ozone should be possible, with the remainder contained in the off-gas, which is passed through an ozone destructor and vented to the atmosphere.

The performance of ozonation relies on achieving the desired concentration after a given contact period. For oxidation of organic chemicals, such as a few oxidizable pesticides, a residual of about 0.5 mg/litre after a contact time of up to 20 min is typically used. The doses required to achieve this vary with the type of water but are typically in the range 2 –5 mg/litre. Higher doses are needed for untreated waters, because of the ozone demand of the natural background organics.

Ozone reacts with natural organics to increase their biodegradability, measured as assimilable organic carbon. To avoid undesirable bacterial growth in distribution, ozonation is normally used with subsequent treatment, such as filtration or GAC, to remove biodegradable organics, followed by a chlorine residual, since it does not provide a disinfectant residual. Ozone is effective for the degradation of a wide range of pesticides and other organic chemicals.

8.4.4 Other disinfection processes

Other disinfection methods include chloramination, the use of chlorine dioxide, UV radiation and advanced oxidation processes.

Chloramines (monochloramine, dichloramine and “trichloramine,” or nitrogen trichloride) are produced by the reaction of aqueous chlorine with ammonia. Mono-chloramine is the only useful chloramine disinfectant, and conditions employed for chloramination are designed to produce only monochloramine. Monochloramine is a less effective disinfectant than free chlorine, but it is persistent, and it is therefore an attractive secondary disinfectant for the maintenance of a stable distribution system residual.

Although historically chlorine dioxide was not widely used for drinking-water disinfection, it has been used in recent years because of concerns about THM production associated with chlorine disinfection. Typically, chlorine dioxide is generated immediately prior to application by the addition of chlorine gas or an aqueous chlorine solution to aqueous sodium chlorite. Chlorine dioxide decomposes in water to form chlorite and chlorate. As chlorine dioxide does not oxidize bromide (in the absence of sunlight), water treatment with chlorine dioxide will not form bromoform or bromate.

Use of UV radiation in potable water treatment has typically been restricted to small facilities. UV radiation, emitted by a low-pressure mercury arc lamp, is biocidal between wavelengths of 180 and 320 nm. It can be used to inactivate protozoa, bacteria, bacteriophage, yeast, viruses, fungi and algae. Turbidity can inhibit UV disinfection. UV radiation can act as a strong catalyst in oxidation reactions when used in conjunction with ozone.

Processes aimed at generating hydroxyl radicals are known collectively as advanced oxidation processes and can be effective for the destruction of chemicals that are difficult to treat using other methods, such as ozone alone. Chemicals can react either directly with molecular ozone or with the hydroxyl radical ($HO\cdot$), which is a product of the decomposition of ozone in water and is an exceedingly powerful indiscriminate oxidant that reacts readily with a wide range of organic chemicals. The formation of hydroxyl radicals can be encouraged by using ozone at high pH. One advanced oxidation process using ozone plus hydrogen peroxide involves dosing hydrogen peroxide simultaneously with ozone at a rate of approximately 0.4 mg of hydrogen peroxide per litre per mg of ozone dosed per litre (the theoretical optimum ratio for hydroxyl radical production)and bicarbonate.

8.4.5 Filtration

Particulate matter can be removed from raw waters by rapid gravity, horizontal, pressure or slow sand filters. Slow sand filtration is essentially a biological process, whereas the others are physical treatment processes.

Rapid gravity, horizontal and pressure filters can be used for direct filtration of raw water, without pretreatment. Rapid gravity and pressure filters are commonly used to filter water that has been pretreated by coagulation and sedimentation. An alternative process is direct filtration, in which coagulation is added to the water, which then passes directly onto the filter where the precipitated floc (with contaminants) is removed; the application of direct filtration is limited by the available storage within the filter to accommodate solids.

Rapid gravity filters

Rapid gravity sand filters usually consist of open rectangular tanks (usually <100 m^2) containing silica sand (size range 0.5 –1.0 mm) to a depth of between 0.6 and 2.0 m. The water flows downwards, and solids become concentrated in the upper layers of the bed. The flow rate is generally in the range 4 –20 $m^3/m^2 \cdot h$. Treated water is collected via nozzles in the floor of the filter. The accumulated solids are removed periodically by backwashing with treated water, sometimes preceded by scouring of the sand with air. A dilute sludge that requires disposal is produced.

In addition to single-medium sand filters, dual-media or multimedia filters are used. Such filters incorporate different materials, such that the structure is from coarse to fine as the water passes through the filter. Materials of suitable density are used in order to maintain the segregation of the different layers following backwashing. A common example of a dual-media filter is the anthracite –sand filter, which typically consists of a 0.2-m-deep layer of 1.5-mm anthracite over a 0.6-m-deep layer of silica sand. Anthracite, sand and garnet can be used in multimedia filters. The advantage of dualand multimedia filters is that there is more efficient use of the whole bed depth for particle retention – the rate of headloss development can be half that of single-medium filters, which can allow higher flow rates without increasing headloss development.

Rapid gravity filters are most commonly used to remove floc from coagulated waters (see section 8.4.7). They may also be used to reduce turbidity (including adsorbed chemicals) and oxidized iron and manganese from raw waters.

Roughing filters

Roughing filters can be applied as pre-filters prior to other processes such as slow sand filters. Roughing filters with coarse gravel or crushed stones as the filter medium can successfully treat water of high turbidity (>50 NTU). The main advantage of roughing filtration is that as the water passes through the filter, particles are removed by both filtration and gravity settling.

Horizontal filters can be up to 10 m long and are operated at filtration rates of 0.3 –1.0 $m^3/m^2 \cdot h$.

Pressure filters

Pressure filters are sometimes used where it is necessary to maintain head in order to eliminate the need for pumping into supply. The filter bed is enclosed in a cylindrical shell .Small pressure filters, capable of treating up to about 15 m_3/h, can be manufactured in glass-reinforced plastics. Larger pressure filters, up to 4 m in diameter, are manufactured in specially coated steel. Operation and performance are generally as described for the rapid gravity filter, and similar facilities are required for backwashing and disposal of the dilute sludge.

Slow sand filters

Slow sand filters usually consist of tanks containing sand (effective size range 0.15 – 0.3 mm) to a depth of between 0.5 and 1.5 m. The raw water flows downwards, and turbidity and microorganisms are removed primarily in the top few centimetres of the sand. A biological layer, known as the “schmutzdecke,” develops on the surface of the filter and can be effective in removing microorganisms. Treated water is collected in underdrains or pipework at the bottom of the filter. The top few centimetres of sand containing the accumulated solids are removed and replaced periodically. Slow sand filters are operated at a water flow rate of between 0.1 and 0.3 $m^3/m^2 \cdot h$.

Slow sand filters are suitable only for low-turbidity water or water that has been pre-filtered. They are used to remove algae and microorganisms, including protozoa, and, if preceded by microstraining or coarse filtration, to reduce turbidity (including adsorbed chemicals). Slow sand filtration is effective for the removal of organics, including certain pesticides and ammonia.

8.4.6 Aeration

Aeration processes are designed to achieve removal of gases and volatile compounds by air stripping. Oxygen transfer can usually be achieved using a simple cascade or diffusion of air into water, without the need for elaborate equipment. Stripping of gases or volatile compounds, however, may require a specialized plant that provides a high degree of mass transfer from the liquid phase to the gas phase.

For oxygen transfer, cascade or step aerators are designed so that water flows in a thin film to achieve efficient mass transfer. Cascade aeration may introduce a significant headloss; design requirements are between 1 and 3 m to provide a loading of 10 –30 $m^3/^2 \cdot h$. Alternatively, compressed air can be diffused through a system of submerged perforated pipes. These types of aerator are used for oxidation and precipitation of iron and manganese.

Air stripping can be used for removal of volatile organics (e.g., solvents), some taste-and odour-causing compounds and radon. Aeration processes to achieve air stripping need to be much more elaborate to provide the necessary contact between the air and water. The most common technique is cascade aeration, usually in packed towers in which water is allowed to flow in thin films over plastic media with air blown counter-current. The required tower height and diameter are functions of the volatilety and concentration of the compounds to be removed and the flow rate.

8.4.7 Chemical coagulation

Chemical coagulation-based treatment is the most common approach for treatment of surface waters and is almost always based on the following unit processes.

Chemical coagulants, usually salts of aluminium or iron, are dosed to the raw water under controlled conditions to form a solid flocculent metal hydroxide. Typical coagulant doses are 2 –5 mg/litre as aluminium or 4 –10 mg/litre as iron. The precipitated floc removes suspended and dissolved contaminants by mechanisms of charge neutralization, adsorption and entrapment. The efficiency of the coagulation process depends on raw water quality, the coagulant or coagulant aids used and operational factors, including mixing conditions, coagulation dose and pH. The floc is removed from the treated water by subsequent solid–liquid separation processes such as sedimentation or flotation and / or rapid or pressure gravity filtration.

Effective operation of the coagulation process depends on selection of the optimum coagulant dose and also the pH value. The required dose and pH can be determined by using small-scale batch coagulation tests, often termed “jar tests.” Increasing doses of coagulant are applied to raw water samples that are stirred, then allowed to settle. The optimum dose is selected as that which achieves adequate removal of colour and turbidity; the optimum pH can be selected in a similar manner. These tests have to be conducted at a sufficient frequency to keep pace with changes in raw water quality and hence coagulant demand.

Powdered activated carbon (PAC) may be dosed during coagulation to adsorb organic chemicals such as some hydrophobic pesticides. The PAC will be removed as an integral fraction of the floc and disposed of with the waterworks sludge.

The floc may be removed by sedimentation to reduce the solids loading to the subsequent rapid gravity filters. Sedimentation is most commonly achieved in horizontal flow or floc blanket clarifiers. Alternatively, floc may be removed by dissolved air flotation, in which solids are contacted with fine bubbles of air that attach to the floc, causing them to float to the surface of the tank, where they are removed periodically as a layer of sludge. The treated water from either process is passed to rapid gravity filters (see section 8.4.5), where remaining solids are removed. Filtered water may be passed to a further stage of treatment, such as additional oxidation and filtration (for removal of manganese), ozonation and/or GAC adsorption (for removal of pesticides and other trace organics), prior to final disinfection before the treated water enters supply.

Coagulation is suitable for removal of certain heavy metals and low-solubility organic chemicals, such as certain organochlorine pesticides. For other organic chemicals, coagulation is generally ineffective, except where the chemical is bound to humic material or adsorbed onto particulates.

8.4.8 Activated carbon adsorption

Activated carbon is produced by the controlled thermalization of carbonaceous material, normally wood, coal, coconut shells or peat. This activation produces a porous material with a large surface area (500 –1500 m^2/g) and a high affinity for organic compounds. It is normally used either in powdered (PAC) or in granular (GAC) form. When the adsorption capacity of the carbon is exhausted, it can be reactivated by burning off the organics in a controlled manner. However, PAC (and some GAC) is normally used only once before disposal. Different types of activated carbon have different affinities for types of contaminants.

The choice between PAC and GAC will depend upon the frequency and dose required. PAC would generally be preferred in the case of seasonal or intermittent contamination or where low dosage rates are required.

PAC is dosed as a slurry into the water and is removed by subsequent treatment processes together with the waterworks sludge. Its use is therefore restricted to surface water treatment works with existing filters. GAC in fixed-bed adsorbers is used much more efficiently than PAC dosed into the water, and the effective carbon use per water volume treated would be much lower than the dose of PAC required to achieve the same removal.

GAC is used for taste and odour control. It is normally used in fixed beds, either in purpose-built adsorbers for chemicals or in existing filter shells by replacement of sand with GAC of a similar particle size. Although at most treatment works it would be cheaper to convert existing filters rather than build separate adsorbers, use of existing filters usually allows only short contact times. It is therefore common practice to install additional GAC adsorbers (in some cases preceded by ozonation) between the rapid gravity filters and final disinfection. Most groundwater sources do not have existing filters, and separate adsorbers would need to be installed.

The service life of a GAC bed is dependent on the capacity of the carbon used and the contact time between the water and the carbon, the empty bed contact time (EBCT), controlled by the flow rate of the water. EBCTs are usually in the range 5 –30 min. GACs vary considerably in their capacity for specific organic compounds, which can have a considerable effect upon their service life. A guide to capacity can be obtained from published isotherm data. Carbon capacity is strongly dependent on the water source and is greatly reduced by the presence of background organic compounds. The properties of a chemical that influence its adsorption onto activated carbon include the water solubility and octanol/water partition coefficient
(log K ow). As a general rule, chemicals with low solubility and high log K ow are well adsorbed.

Activated carbon is used for the removal of pesticides and other organic chemicals, taste and odour compounds, cyanobacterial toxins and total organic carbon.

8.4.9 Ion exchange

Ion exchange is a process in which ions of like charge are exchanged between the water phase and the solid resin phase. Water softening is achieved by cation exchange. Water is passed through a bed of cationic resin, and the calcium ions and magnesium ions in the water are replaced by sodium ions. When the ion exchange resin is exhausted (i.e., the sodium ions are depleted), it is regenerated using a solution of sodium chloride. The process of “dealkalization” can also soften water. Water is passed through a bed of weakly acidic resin,and the calcium and magnesium ions are replaced by hydrogen ions. The hydrogen ions react with the carbonate and bicarbonate ions to produce carbon dioxide. The hardness of the water is thus reduced without any increase in sodium levels. Anion exchange can be used to remove contaminants such as nitrate, which is exchanged for chloride. Nitrate-specific resins are available for this purpose.

An ion exchange plant normally consists of two or more resin beds contained in pressure shells with appropriate pumps, pipework and ancillary equipment for regeneration. The pressure shells are typically up to 4 m in diameter, containing 0.6 –1.5 m depth of resin.

Cation exchange can be used for removal of certain heavy metals.Potential applications of anionic resins, in addition to nitrate removal, are for removal of arsenic and selenium species.

8.4.10 Membrane processes

The membrane processes of most significance in water treatment are reverse osmosis, ultra filtration, micro filtration and nano filtration. These processes have traditionally been applied to the production of water for industrial or pharmaceutical applications but are now being applied to the treatment of drinking-water.

High-pressure processes

If two solutions are separated by a semi-permeable membrane (i.e., a membrane that allows the passage of the solvent but not of the solute), the solvent will naturally pass from the lower-concentration solution to the higher-concentration solution. This process is known as osmosis. It is possible, however, to force the flow of solvent in the opposite direction, from the higher to the lower concentration, by increasing the pressure on the higher-concentration solution. The required pressure differential is known as the osmotic pressure, and the process is known as reverse osmosis.

Reverse osmosis results in the production of a treated water stream and a relatively concentrated waste stream. Typical operating pressures are in the range 15 –50 bar, depending on the application. Reverse osmosis rejects monovalent ions and organics of molecular weight greater than about 50 (membrane pore sizes are less than 0.002 m m). The most common application of reverse osmosis is desalination of brackish water and seawater.

Nano filtration uses a membrane with properties between those of reverse osmosis and ultra filtration membranes; pore sizes are typically 0.001 – 0.01 m m. Nano filtration membranes allow monovalent ions such as sodium or potassium to pass but reject a high proportion of divalent ions such as calcium and magnesium and organic molecules of molecular weight greater than 200. Operating pressures are typically about 5 bar. Nano filtration may be effective for the removal of colour and organic compounds.

Lower-pressure processes

Ultra filtration is similar in principle to reverse osmosis, but the membranes have much larger pore sizes (typically 0.002 –0.03 m m) and operate at lower pressures. Ultra filtration membranes reject organic molecules of molecular weight above about 800 and usually operate at pressures less than 5 bar.

Micro filtration is a direct extension of conventional filtration into the sub-micrometre range. Micro filtration membranes have pore sizes typically in the range 0.01 –12 m m and do not separate molecules but reject colloidal and suspended material at operating pressures of 1 –2 bar. Micro filtration is capable of sieving out particles greater than 0.05 m m.It has been used for water treatment in combination with coagulation or PAC to remove dissolved organic carbon and to improve permeate flux.

8.4.11 Other treatment processes

Other treatment processes that can be used in certain applications include: —precipitation softening (addition of lime, lime plus sodium carbonate or sodium hydroxide to precipitate hardness at high pH);

— biological denitrification for removal of nitrate from surface waters;
— biological nitrification for removal of ammonia from surface waters; and
— activated alumina (or other adsorbents) for specialized applications, such as removal of fluoride and arsenic.

8.4.12 Disinfection by-products – process control measures

All chemical disinfectants produce inorganic and/or organic DBPs that may be of concern.

In attempting to control DBP concentrations, it is of paramount importance that the efficiency of disinfection is not compromised and that a suitable residual level of disinfectant is maintained throughout the distribution system.

The principal DBPs formed during chlorination are THMs, chlorinated acetic acids, chlorinated ketones and haloacetonitriles, as a result of chlorina tion of naturally occurring organic pre cursors such as humic substances. Monochloramine produces lower THM concentrations than chlorine but produces other DBPs, including cyanogen chloride.

Ozone oxidizes bromide to produce hypohalous acids, which react with precursors to form brominated THMs. A range of other DBPs, including aldehydes and carboxylic acids, may also be formed. Of particular concern is bromate, formed by oxidation of bromide. Bromate may also be present in some sources of hypochlorite, ut usually at concentrations that will give rise to levels in final water that are below the guideline value.

The main by-products from the use of chlorine dioxide are chlorite ion, which is an inevitable decomposition product, and chlorate ion. Chlorate is also produced in hypochlorate as it ages.

The basic strategies that can be adopted for reducing the concentrations of DBPs are:

- changing process conditions (including removal of precursor compounds prior to application);
- using a different chemical disinfectant with a lower propensity to produce by products with the source water;
- using non-chemical disinfection; and/or
- removing DBPs prior to distribution.

Changes to process conditions

The formation of THMs during chlorination can be reduced by removing precursors prior to contact with chlorine – for example, by installing or enhancing coagulation (this may involve using higher coagulant doses and/or lower coagulation pH than are applied conventionally). DBP formation can also be reduced by lowering the applied chlorine dose; if this is done, it must be ensured that disinfection is still effective.

The pH value during chlorination affects the distribution of chlorinated by products. Reducing the pH lowers the THM concentration, but at the expense of increased formation of haloacetic acids. Conversely, increasing the pH reduces haloacetic acid production but leads to increased THM formation.

The formation of bromate during ozonation depends on several factors, including concentrations of bromide and ozone and the pH. It is not practicable to remove bromide from raw water, and it is difficult to remove bromate once formed, although GAC filtration has been reported to be effective under certain circumstances. Bromate formation can be minimized by using lower ozone dose, shorter contact time and a lower residual ozone concentration. Operating at lower pH (e.g., pH 6.5) followed by raising the pH after ozonation also reduces bromate formation, and addition of ammonia can also be effective. Addition of hydrogen peroxide can increase or decrease bromate formation.

Changing disinfectants

It may be feasible to change disinfectant in order to achieve guideline values for DBPs. The extent to which this is possible will be dependent on raw water quality and installed treatment (e.g., for precursor removal).

It may be effective to change from chlorine to monochloramine, at least to provide a residual disinfectant within distribution, in order to reduce THM formation and subsequent development within the distribution system. While monochloramine provides a more stable residual within distribution, it is a less powerful disinfectant and should not be used as a primary disinfectant.

Chlorine dioxide can be considered as a potential alternative to both chlorine and ozone disinfection, although it does not provide a residual effect. The main concerns with chlorine dioxide are with the residual concentrations of chlorine dioxide and the by-products chlorite and chlorate. These can be addressed by controlling the dose of chlorine dioxide at the treatment plant. Non-chemical disinfection UV irradiation or membrane processes can be considered as alternatives to chemical disinfection. Neither of these provides any residual disinfection, and it may be considered appropriate to add a small dose of a persistent disinfectant such as chlorine or monochloramine to act as a preservative during distribution.

8.4.13 Treatment for corrosion control

General

Corrosion is the partial dissolution of the materials constituting the treatment and supply systems, tanks, pipes, valves and pumps. It may lead to structural failure, leaks, loss of capacity and deterioration of chemical and microbial water quality. The internal corrosion of pipes and fittings can have a direct impact on the concentration of some water constituents, including lead and copper. Corrosion control is therefore animportant aspect of the management of a drinking-water system for safety.

Corrosion control involves many parameters, including the concentrations of calcium, bicarbonate, carbonate and dissolved oxygen, as well as pH. The detailed requirements differ depending on water quality and the materials used in the distribution system. The pH controls the solubility and rate of reaction of most of the metal species involved in corrosion reactions. It is particularly important in relation to the formation of a protective film at the metal surface. For some metals, alkalinity (carbonate and bicarbonate) and calcium (hardness) also affect corrosion rates.

Iron

Iron is frequently used in water distribution systems, and its corrosion is of concern. While structural failure as a result of iron corrosion is rare, water quality problems (e.g., “red water”) can arise as a result of excessive corrosion of iron pipes. The corrosion of iron is a complex process that involves the oxidation of the metal, normally by dissolved oxygen, ultimately to form a precipitate of iron (III). This leads to the formation of tubercules on the pipe surface. The major water quality factors that determine whether the precipitate forms a protective scale are pH and alkalinity. The concentrations of calcium, chloride and sulfate also influence iron corrosion. Successful control of iron corrosion has been achieved by adjusting the pH to the range 6.8 –7.3, hardness and alkalinity to at least 40 mg/litre (as calcium carbonate), over saturation with calcium carbonate of 4 –10 mg/litre and a ratio of alkalinity to $Cl-+SO_4^2$ - of at least 5 (when both are expressed as calcium carbonate).

Silicates and polyphosphates are often described as “corrosion inhibitors,” but there is no guarantee that they will inhibit corrosion in water distribution systems. However, they can complex dissolved iron (in the iron (II) state) and prevent its precipitation as visibly obvious red “rust.” These compounds may act by masking the effects of corrosion rather than by preventing it. Orthophosphate is a possible corrosion inhibitor and, ike polyphosphates, is used to prevent “red water.”

Lead

Lead corrosion (plumbosolvency) is of particular concern. Lead piping is still common in old houses in some countries, and lead solders have been used widely for jointing copper tube. The solubility of lead is governed by the formation of lead carbonates as pipe deposits. Wherever practicable, lead pipework should be replaced.

The solubility of lead increases markedly as the pH is reduced below 8 because of the substantial decrease in the equilibrium carbonate concentration. Thus, plumbo-solvency tends to be at a maximum in waters with a low pH and low alkalinity, and a useful interim control procedure pending pipe replacement is to increase the pH to 8.0 –8.5 after chlorination, and possibly to dose orthophosphate.

Lead can corrode more rapidly when it is coupled to copper. The rate of such galvanic corrosion is faster than that of simple oxidative corrosion, and lead concentrations are not limited by the solubility of the corrosion products. The rate of galvanic corrosion is affected principally by chloride concentration. Galvanic corrosion is less easily controlled but can be reduced by dosing zinc in conjunction with orthophosphate and by adjustment of pH.

Treatment to reduce plumbo-solvency usually involves pH adjustment. When the water is very soft (less than 50 mg of calcium carbonate per litre), the optimum pH is about 8.0 –8.5. Alternatively, dosing with orthophosphoric acid or sodium orthophosphate might be more effective, particularly when plumbosolvency occurs in non-acidic waters.

Copper

The corrosion of copper pipework and hot water cylinders can cause blue water, blue or green staining of bathroom fittings and, occasionally, taste problems. Copper tubing may be subject to general corrosion, impingement attack and pitting corrosion.

General corrosion is most often associated with soft, acidic waters; waters with pH below 6.5 and hardness of less than 60 mg of calcium carbonate per litre are very aggressive to copper. Copper, like lead, can enter water by dissolution of the corrosion product, basic copper carbonate. The solubility is mainly a function of pH and total inorganic carbon. Solubility decreases with increase in pH, but increases with increase in concentrations of carbonate species. Raising the pH to between 8 and 8.5 is the usual procedure to overcome these difficulties.

Impingement attack is the result of excessive flow velocities and is aggravated in soft water at high temperature and low pH.

The pitting of copper is commonly associated with hard groundwaters having a carbon dioxide concentration above 5 mg/litre and high dissolved oxygen. Surface waters with organic colour may also be associated with pitting corrosion. Copper pipes can fail by pitting corrosion, which involves highly localized attacks leading to perforations with negligible loss of metal. Two main types of attack are recognized. Type I pitting affects cold water systems (below 40 °C) and is associated, particularly, with hard borehole waters and the presence of a carbon .lm in the bore of the pipe, derived from the manufacturing process. Tubes that have had the carbon removed by cleaning are immune from Type I pitting. Type II pitting occurs in hot water systems (above 60 °C) and is associated with soft waters. A high proportion of general and pitting corrosion problems are associated with new pipe in which a protective oxide layer has not yet formed.

Brass

The main corrosion problem with brasses is dezincification, which is the selective dissolution of zinc from duplex brass, leaving behind copper as a porous mass of low mechanical strength. Meringue dezincification, in which a voluminous corrosion product of basic zinc carbonate forms on the brass surface, largely depends on the ratio of chloride to alkalinity. Meringue dezincification can be controlled by maintaining a low zinc to copper ratio (1:3 or lower) and by keeping pH below 8.3.

General dissolution of brass can also occur, releasing metals, including lead, into the water. Impingement attack can occur under conditions of high water velocity with waters that form poorly protective corrosion product layers and that contain large amounts of dissolved or entrained air.

Zinc

The solubility of zinc in water is a function of pH and total inorganic carbon concentrations; the solubility of basic zinc carbonate decreases with increase in pH and concentrations of carbonate species. For low-alkalinity waters, an increase of pH to 8.5 should be sufficient to control the dissolution of zinc.

With galvanized iron, the zinc layer initially protects the steel by corroding preferentially. In the long term, a protective deposit of basic zinc carbonate forms. Protective deposits do not form in soft waters where the alkalinity is less than 50 mg/litre as calcium carbonate or waters containing high carbon dioxide concentrations (>25 mg/litre as carbon dioxide),and galvanized steel is unsuitable for these waters. The corrosion of galvanized steel increases when it is coupled with copper tubing.

Nickel

Nickel may arise due to the leaching of nickel from new nickel/ chromium - plated taps. Low concentrations may also arise from stainless steel pipes and fittings. Nickel leaching falls off over time. An increase of pH to control corrosion of other materials should also reduce leaching of nickel.

Concrete and cement

Concrete is a composite material consisting of a cement binder in which an inert aggregate is embedded. Cement is primarily a mixture of calcium silicates and aluminates together with some free lime. Cement mortar, in which the aggregate is fine sand, is used as a protective lining in iron and steel water pipes. In asbestos – cement pipe, the aggregate is asbestos fibres. Cement is subject to deterioration on prolonged exposure to aggressive water, due either to the dissolution of lime and other soluble compounds or to chemical attack by aggressive ions such as chloride or sulfate, and this may result in structural failure. Cement contains a variety of metals that can be leached into the water. Aggressiveness to cement is related to the “aggressivity index,” which has been used specifically to assess the potential for the dissolution of concrete. A pH of 8.5 or higher may be necessary to control cement corrosion.

Characterizing corrosivity

Most of the indices that have been developed to characterize the corrosion potential of waters are based on the assumption that water with a tendency to deposit a calcium carbonate scale on metal surfaces will be less corrosive. The Langelier Index (LI)is the difference between the actual pH of a water and its “saturation pH,” this being the pH at which a water of the same alkalinity and calcium hardness would be at equilibrium with solid calcium carbonate. Waters with positive LI are capable of depositing calcium carbonate scale from solution.

There is no corrosion index that applies to all materials, and corrosion indices, particularly those related to calcium carbonate saturation, have given mixed results. The parameters related to calcium carbonate saturation status are, strictly speaking, indicators of the tendency to deposit or dissolve calcium carbonate (calcite) scale, not indicators of the “corrosivity” of a water. For example, there are many waters with negative LI that are non-corrosive and many with positive LI that are corrosive. Nevertheless, there are many documented instances of the use of saturation indices for corrosion control based on the concept of laying down a protective “eggshell” scale of calcite in iron pipes. In general, waters with high pH, calcium and alkalinity are less corrosive, and this tends to be correlated with a positive LI.

The ratio of the chloride and sulfate concentrations to the bicarbonate concentration (Larson ratio) has been shown to be helpful in assessing the corrosiveness of water to cast iron and steel. A similar approach has been used in studying zinc dissolution from brass fittings – the Turner diagram..

Water treatment for corrosion control

To control corrosion in water distribution networks, the methods most commonly applied are adjusting pH, increasing the alkalinity and/or hardness or adding corrosion inhibitors, such as polyphosphates, silicates and orthophosphates. The quality and maximum dose to be used should be in line with specifications for such water treatment chemicals. Although pH adjustment is an important approach, its possible impact on other aspects of water supply technology, including disinfection, must always be taken into account.

It is not always possible to achieve the desired values for all parameters. For example, the pH of hard waters cannot be increased too much, or softening will occur. The application of lime and carbon dioxide to soft waters can be used to increase both the calcium concentration and the alkalinity to at least 40 mg/litre as calcium carbonate.

8.5 Guideline values for individual chemicals, by source category

8.5.1 Naturally occurring chemicals

There are a number of sources of naturally occurring chemicals in drinking-water. All natural water contains a range of inorganic and organic chemicals. The former derive from the rocks and soil through which water percolates or over which it flows. The latter derive from the breakdown of plant material or from algae and other microorganisms that grow in the water or on sediments. Most of the naturally occurring chemicals for which guideline values have been derived or that have been considered for guideline value derivation are inorganic. Only one, microcystin-LR, a toxin produced by cyanobacteria or blue-green algae, is organic; it is discussed in section 8.5.6.

The approach to dealing with naturally occurring chemicals will vary according to the nature of the chemical and the source. For inorganic contaminants that arise from rocks and sediments, it is important to screen possible water sources to determine whether the source is suitable for use or whether it will be necessary to treat the water to remove the contaminants of concern along with microbial contaminants. In some cases, where a number of sources may be available, dilution or blending of the water containing high levels of a contaminant with a water containing much lower levels may achieve the desired result.

A number of the most important chemical contaminants (i.e., those that have been shown to cause adverse health effects as a consequence of exposure through drinking-water) fall into the category of naturally occurring chemicals. Some naturally occurring chemicals have other primary sources and are therefore discussed in other sections of this chapter.

Guideline values have not been established for the chemicals listed in Table 8.17 for the reasons indicated in the table. Summary statements are included in chapter 12.

Guideline values have been established for the chemicals listed in Table 8.18, which meet the criteria for inclusion. Summary statements are included for each in chapter 12.

8.5.2 Chemicals from industrial sources and human dwellings

Chemicals from industrial sources can reach drinking-water directly from discharges or indirectly from diffuse sources arising from the use and disposal of materials and products containing the chemical. In some cases, inappropriate handling and disposal may lead to contamination, e.g., degreasing agents that are allowed to reach ground- water. Some of these chemicals, particularly inorganic substances, may also be encountered as a consequence of natural contamination, but this may also be a by-product of industrial activity, such as mining, that changes drainage patterns. Many of these chemicals are used in small industrial units within human settlements, and, particularly where such units are found in groups of similar enterprises, they may be a significant source of pollution. Petroleum oils are widely used in human settlements, and improper handling or disposal can lead to significant pollution of surface water and groundwater. Where plastic pipes are used, the smaller aromatic molecules in petroleum oils can sometimes penetrate the pipes where they are surrounded by earth soaked in the oil, with subsequent pollution of the local water supply.

Table 8.17 Naturally occurring chemicals for which guideline values have not been established

Chemical	Reason for not establishing a guideline value	Remarks
Chloride	Occurs in drinking-water at concentrations well below those at which toxic effects may occur	May affect acceptability of drinking-water (see chapter 10)
Hardness	Occurs in drinking-water at concentrations well below those at which toxic effects may occur	May affect acceptability of drinking-water (see chapter 10)
Hydrogen sulfide	Occurs in drinking-water at concentrations well belowthose at which toxic effects may occur	May affect acceptability of drinking-water (see chapter 10)
pH	Values in drinking-water are well below those at which toxic effects may occur	An important operational water quality parameter
Sodium	Occurs in drinking-water at concentrations well below those at which toxic effects may occur	May affect acceptability of drinking-water (see chapter 10)
Sulfate	Occurs in drinking-water at concentrations well below those at which toxic effects may occur	May affect acceptability of drinking-water (see chapter 10)
Total dissolved solids (TDS)	Occurs in drinking-water at concentrations well below those at which toxic effects may occur	May affect acceptability of drinking-water (see chapter 10)

Table 8.18 Guideline values for naturally occurring chemicals that are of health significance in drinking-water

Chemical	Guideline value[a] (mg/litre)	Remarks
Arsenic	0.01 (P)	
Barium	0.7	
Boron	0.5 (T)	
Chromium	0.05 (P)	For total chromium
Fluoride	1.5	Volume of water consumed and intake from other sources should be considered when setting national standards
Manganese	0.4 (C)	
Molybdenum	0.07	
Selenium	0.01	
Uranium	0.015 (P,T)	Only chemical aspects of uranium addressed

[a] P = provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited; T = provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.; C = concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, resulting in consumer complaints.

A number of chemicals can reach water as a consequence of disposal of general household chemicals; in particular, a number of heavy metals may be found in domestic wastewater. Where wastewater is treated, these will usually partition out into the sludge. Some chemicals that are widely used both in industry and in materials used in a domestic setting are found widely in the environment, e.g., di (2-ethylhexyl) phthalate, and these may be found in water sources, although usually at low concentrations.

Some chemicals that reach drinking-water from industrial sources or human settlements have other primary sources and are therefore discussed in other sections of this chapter. Where latrines and septic tanks are poorly sited, these can lead to contamination of drinking-water sources with nitrat e (see section 8.5.3).

Identification of the potential for contamination by chemicals from industrial activities and human dwellings requires assessment of activities in the catchment and of the risk that particular contaminants may reach water sources. The primary approach to addressing these contaminants is prevention of contamination by encouraging good practices. However, if contamination has occurred, then it may be necessary to consider the introduction of treatment. The chemical listed in Table 8.19 has been excluded from guideline value derivation, as a review of the literature on occurrence and/or credibility of occurrence in drinking-water has shown evidence that it does not occur in drinking-water.

Guideline values have not been established for the chemicals listed in Table 8.20 for the reasons indicated in the table. Summary statements for each are included in chapter 12.

Guideline values have been established for the chemicals listed in Table 8.21, which meet all of the criteria for inclusion. Summary statements are included in chapter 12.

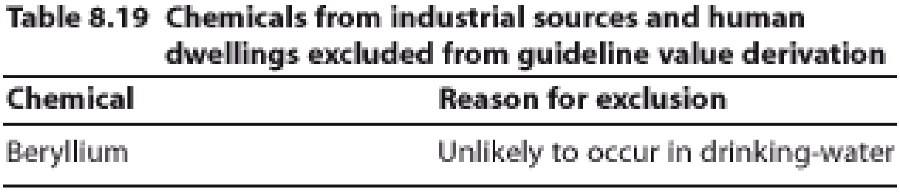


Table 8.19 Chemicals from industrial sources and human dwellings excluded from guideline value derivation

Chemical	Reason for exclusion
Beryllium	Unlikely to occur in drinking-water

8.5.3 Chemicals from agricultural activities

Chemicals are used in agriculture on crops and in animal husbandry. Nitrate may be present as a consequence of tillage when there is no growth to take up nitrate released from decomposing plants, from the application of excess inorganic or organic fertilizer and in slurry from animal production. Most chemicals that may arise from agriculture are pesticides, although their presence will depend on many factors, and not all pesticides are used in all circumstances or climates. Contamination can result from application and subsequent movement following rainfall or from inappropriate disposal methods.

Some pesticides are also used in non-agricultural circumstances, such as the control of weeds on roads and railway lines. These pesticides are also included in this section.

Table 8.20 Chemicals from industrial sources and human dwellings for which guideline values have not been established

Chemical	Reason for not establishing a guideline value
Dichlorobenzene, 1,3-	Toxicological data are insufficient to permit derivation of health-based guideline value
Dichloroethane, 1,1-	Very limited database on toxicity and carcinogenicity
Di(2-ethylhexyl)adipate	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Hexachlorobenzene	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Monochlorobenzene	Occurs in drinking-water at concentrations well below those at which toxic effects may occur, and health-based value would far exceed lowest reported taste and odour threshold
Trichlorobenzenes (total)	Occur in drinking-water at concentrations well below those at which toxic effects may occur, and health-based value would exceed lowest reported odour threshold
Trichloroethane, 1,1,1-	Occurs in drinking-water at concentrations well below those at which toxic effects may occur

Table 8.21 Guideline values for chemicals from industrial sources and human dwellings that are of health significance in drinking-water

Inorganics	Guideline value (mg/litre)	Remarks
Cadmium	0.003	
Cyanide	0.07	
Mercury	0.001	For total mercury (inorganic plus organic)

Organics	Guideline value[a] (µg/litre)	Remarks
Benzene	10[b]	
Carbon tetrachloride	4	
Di(2-ethylhexyl)phthalate	8	
Dichlorobenzene, 1,2-	1000 (C)	
Dichlorobenzene, 1,4-	300 (C)	
Dichloroethane, 1,2-	30[b]	
Dichloroethene, 1,1-	30	
Dichloroethene, 1,2-	50	
Dichloromethane	20	
Edetic acid (EDTA)	600	Applies to the free acid
Ethylbenzene	300 (C)	
Hexachlorobutadiene	0.6	
Nitrilotriacetic acid (NTA)	200	
Pentachlorophenol	9[b] (P)	
Styrene	20 (C)	
Tetrachloroethene	40	
Toluene	700 (C)	
Trichloroethene	70 (P)	
Xylenes	500 (C)	

[a] P = provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited; C = concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

[b] For non-threshold substances, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with estimated upper-bound excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

Guideline values have not been established for the chemicals listed in Table 8.22, as a review of the literature on occurrence and/or credibility of occurrence in drinking-water has shown evidence that the chemicals do not occur in drinking-water.

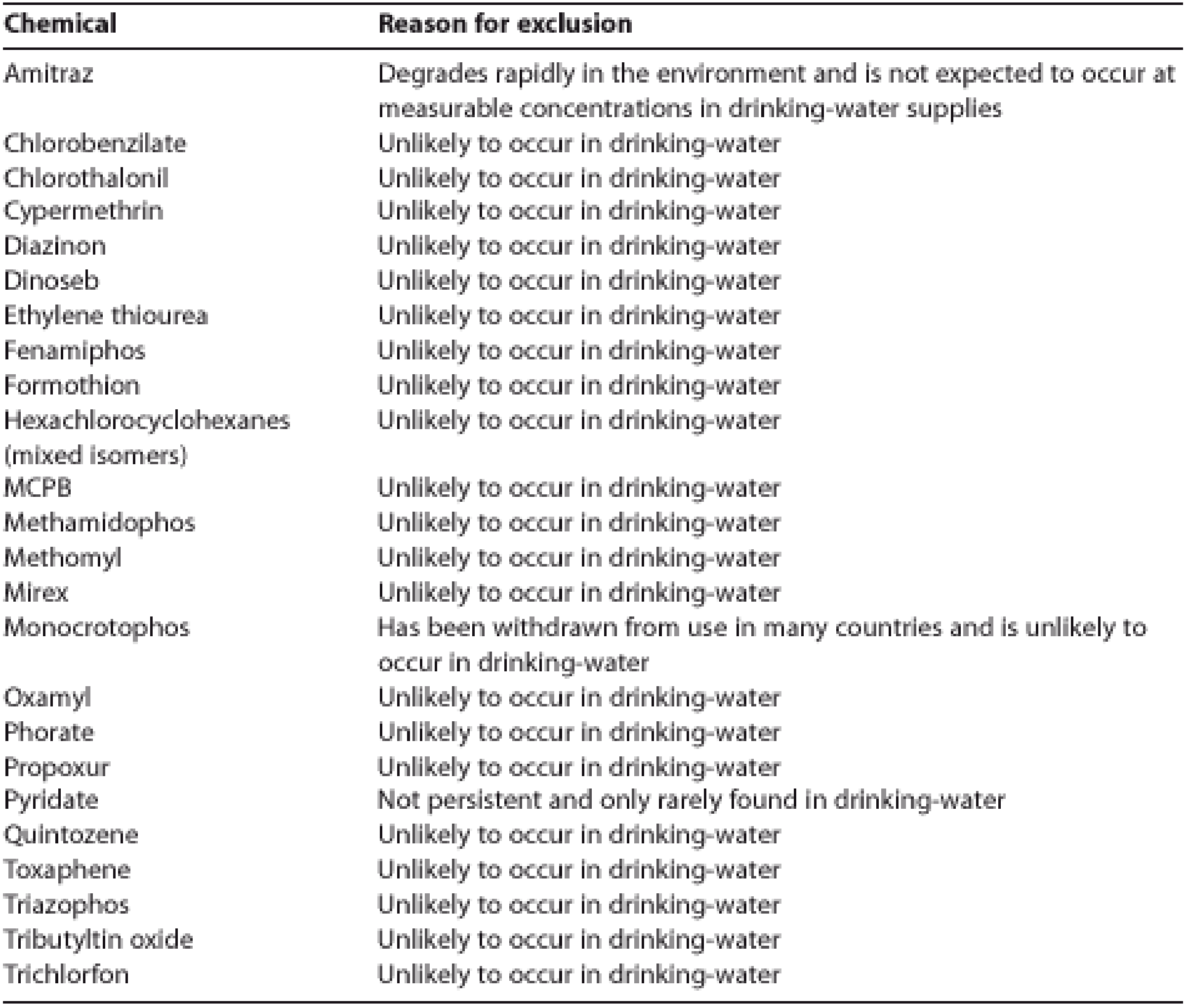
Guideline values have not been established for the chemicals listed in Table 8.23 for the reasons indicated in the table. Summary statements are included in chapter 12.

Guideline values have been established for the chemicals listed in Table 8.24, which meet the criteria for inclusion. Summary statements are included in chapter 12.

8.5.4 Chemicals used in water treatment or from materials in contact with drinking-water

Chemicals are used in water treatment and may give rise to residuals in the final water. In some cases, such as monochloramine and chlorine, this is intentional, and their presence confers a direct benefit to the consumer.

Table 8.22 Chemicals from agricultural activities excluded from guideline value derivation



Chemical	Reason for exclusion
Amitraz	Degrades rapidly in the environment and is not expected to occur at measurable concentrations in drinking-water supplies
Chlorobenzilate	Unlikely to occur in drinking-water
Chlorothalonil	Unlikely to occur in drinking-water
Cypermethrin	Unlikely to occur in drinking-water
Diazinon	Unlikely to occur in drinking-water
Dinoseb	Unlikely to occur in drinking-water
Ethylene thiourea	Unlikely to occur in drinking-water
Fenamiphos	Unlikely to occur in drinking-water
Formothion	Unlikely to occur in drinking-water
Hexachlorocyclohexanes (mixed isomers)	Unlikely to occur in drinking-water
MCPB	Unlikely to occur in drinking-water
Methamidophos	Unlikely to occur in drinking-water
Methomyl	Unlikely to occur in drinking-water
Mirex	Unlikely to occur in drinking-water
Monocrotophos	Has been withdrawn from use in many countries and is unlikely to occur in drinking-water
Oxamyl	Unlikely to occur in drinking-water
Phorate	Unlikely to occur in drinking-water
Propoxur	Unlikely to occur in drinking-water
Pyridate	Not persistent and only rarely found in drinking-water
Quintozene	Unlikely to occur in drinking-water
Toxaphene	Unlikely to occur in drinking-water
Triazophos	Unlikely to occur in drinking-water
Tributyltin oxide	Unlikely to occur in drinking-water
Trichlorfon	Unlikely to occur in drinking-water

Some arise as unwanted by-products of the disinfection process (see Table 8.25) and some as residuals from other parts of the treatment process, such as coagulation. Some may arise as contaminants sin treatment chemicals, and others may arise as contaminants in, or as corrosion products from, materials used as pipes or in other parts of the drinking-water system. Some chemicals used in water treatment (e.g., fluoride) or in materials in contact with drinking-water (e.g., styrene) have other primary sources and are therefore discussed in detail in other sections of this chapter.

The approach to monitoring and management is preferably through control of the material or chemical, and this is covered in more detail in section 4.2. It is also important to optimize treatment processes and to ensure that such processes remain optimized in order to control residuals of chemicals used in treatment and to control the formation of DBPs.

Guideline values have not been established for the chemicals listed in Table 8.26 for the reasons indicated in the table. Summary statements are included in chapter 12.

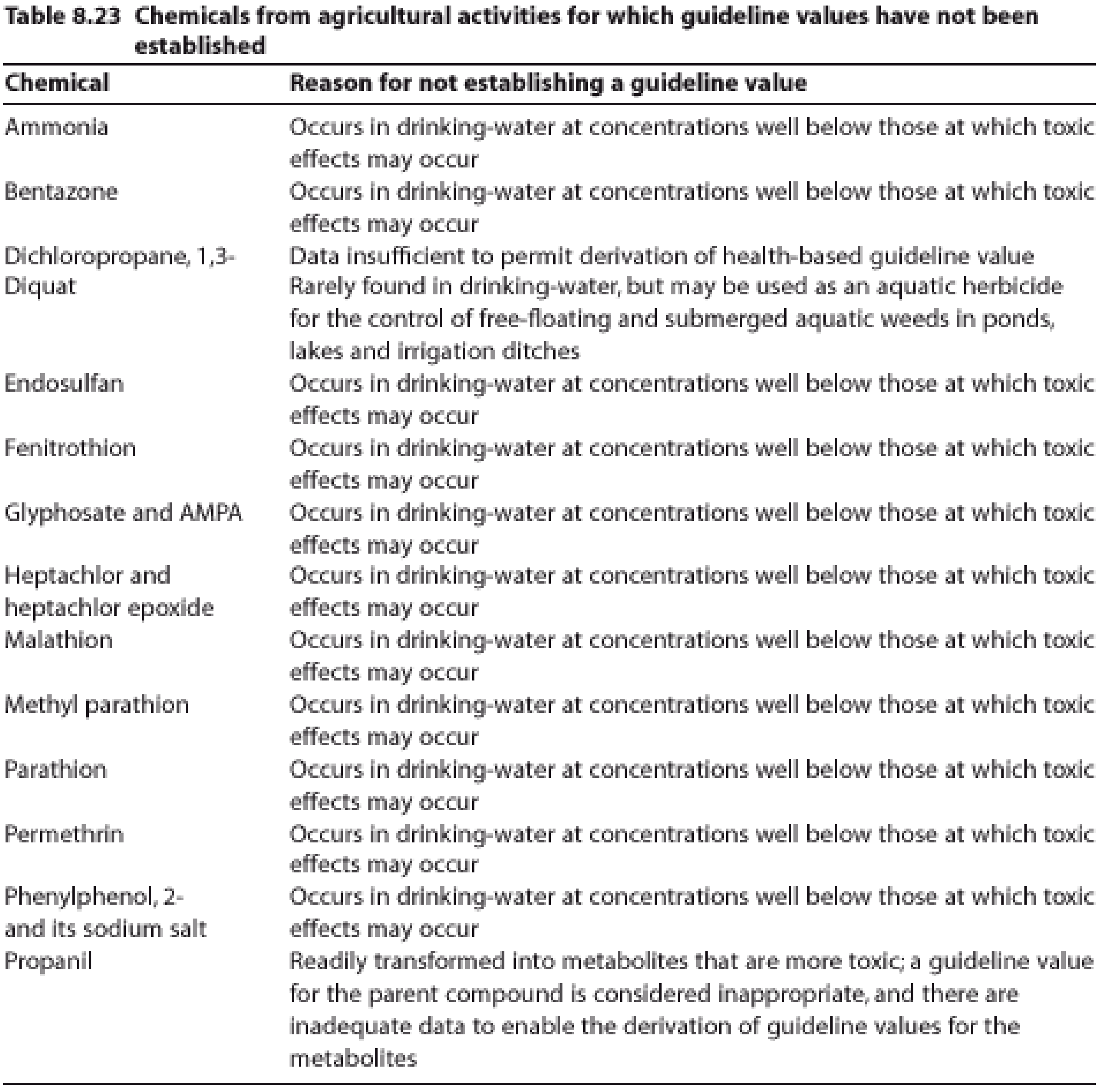


Table 8.23 Chemicals from agricultural activities for which guideline values have not been established

Chemical	Reason for not establishing a guideline value
Ammonia	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Bentazone	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Dichloropropane, 1,3-	Data insufficient to permit derivation of health-based guideline value
Diquat	Rarely found in drinking-water, but may be used as an aquatic herbicide for the control of free-floating and submerged aquatic weeds in ponds, lakes and irrigation ditches
Endosulfan	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Fenitrothion	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Glyphosate and AMPA	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Heptachlor and heptachlor epoxide	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Malathion	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Methyl parathion	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Parathion	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Permethrin	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Phenylphenol, 2- and its sodium salt	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Propanil	Readily transformed into metabolites that are more toxic; a guideline value for the parent compound is considered inappropriate, and there are inadequate data to enable the derivation of guideline values for the metabolites

Guideline values have been established for the chemicals listed in Table 8.27, which meet the criteria for inclusion. Summary statements are included in chapter 12.

8.5.5 Pesticides used in water for public health purposes

Some pesticides are used for public health purposes, including the addition to water to control the aquatic larval stages of insects of public health significance (e.g., mosquitos for the control of malaria and typhus). There are currently four insecticidecompounds and a bacterial larvicide recommended by

WHO (under WHOPES) for addition to drinking-water as larvicides: temephos, methoprene, pyriproxyfen, permethrin and *Bacillus thuringiensis israelensis*. Of these, only pyriproxyfen has been reviewed to date. Other insecticides that are not recommended for addition to water for public health purposes by WHOPES but may be used in some countries as aquatic larvicides, or have been used as such in the past, include chlorpyrifos and DDT.

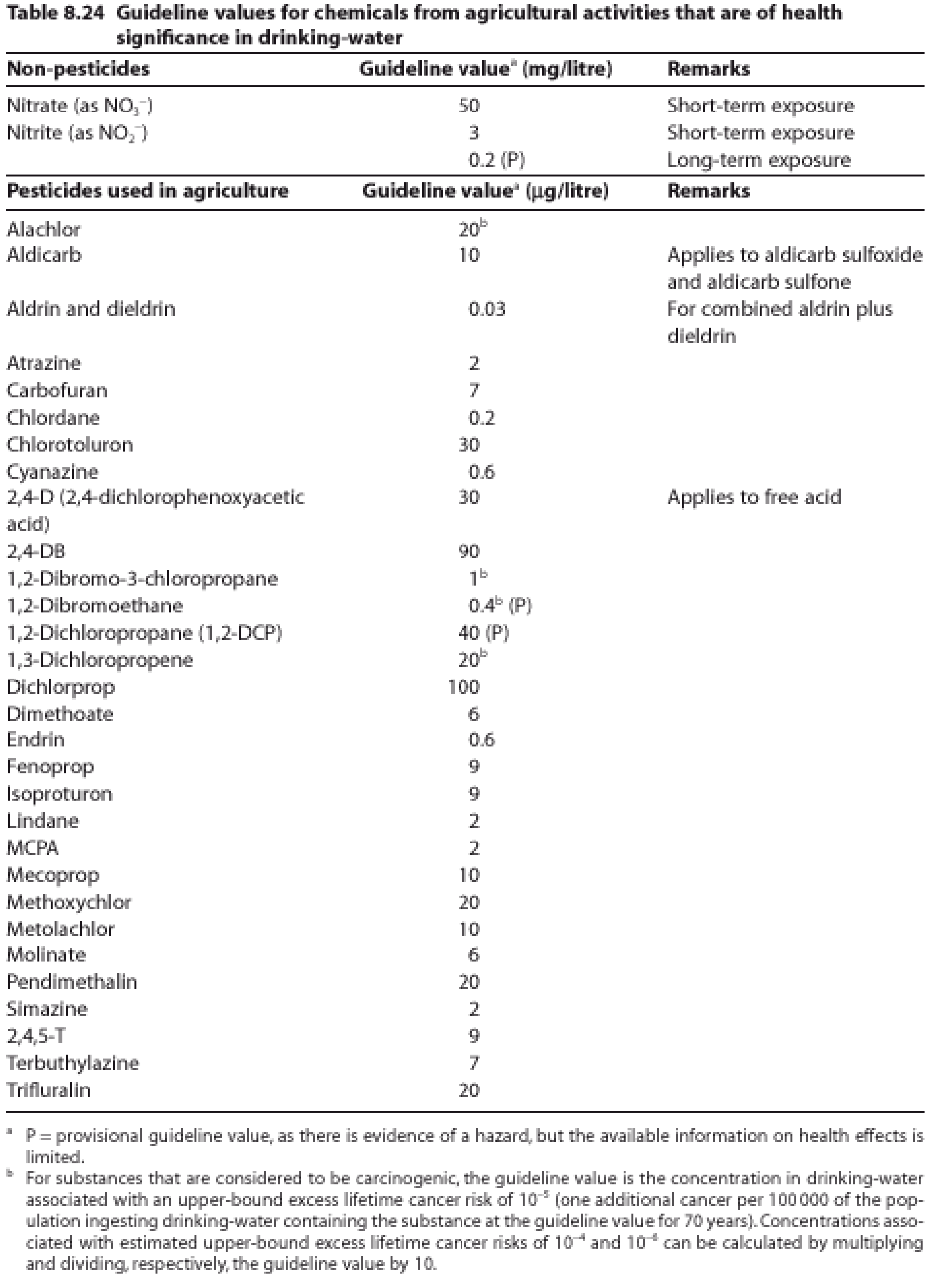


Table 8.24 Guideline values for chemicals from agricultural activities that are of health significance in drinking-water

Non-pesticides	**Guideline value[a] (mg/litre)**	**Remarks**
Nitrate (as NO_3^-)	50	Short-term exposure
Nitrite (as NO_2^-)	3	Short-term exposure
	0.2 (P)	Long-term exposure
Pesticides used in agriculture	**Guideline value[a] (µg/litre)**	**Remarks**
Alachlor	20[b]	
Aldicarb	10	Applies to aldicarb sulfoxide and aldicarb sulfone
Aldrin and dieldrin	0.03	For combined aldrin plus dieldrin
Atrazine	2	
Carbofuran	7	
Chlordane	0.2	
Chlorotoluron	30	
Cyanazine	0.6	
2,4-D (2,4-dichlorophenoxyacetic acid)	30	Applies to free acid
2,4-DB	90	
1,2-Dibromo-3-chloropropane	1[b]	
1,2-Dibromoethane	0.4[b] (P)	
1,2-Dichloropropane (1,2-DCP)	40 (P)	
1,3-Dichloropropene	20[b]	
Dichlorprop	100	
Dimethoate	6	
Endrin	0.6	
Fenoprop	9	
Isoproturon	9	
Lindane	2	
MCPA	2	
Mecoprop	10	
Methoxychlor	20	
Metolachlor	10	
Molinate	6	
Pendimethalin	20	
Simazine	2	
2,4,5-T	9	
Terbuthylazine	7	
Trifluralin	20	

[a] P = provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

[b] For substances that are considered to be carcinogenic, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with estimated upper-bound excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

In considering those pesticides that may be added to water used for drinking-water for purposes of protection of public health, every effort should be made not to develop guidelines that are unnecessarily stringent as to impede their use. This approach enables a suitable balance to be achieved between the protection of drinking-water quality and the control of insects of public health significance. However, it is stressed that every effort should be made to keep overall exposure and the concentration of any larvicide as low as possible.

As for the other groups of chemicals discussed in this chapter, this category is not clear-cut. It includes pesticides that are extensively used for purposes other than public health protection – for example, agricultural purposes, in the case of chlorpyrifos.

Guideline values that have been derived for these larvicides are provided in Table 8.28. Summary statements are included in chapter 12.

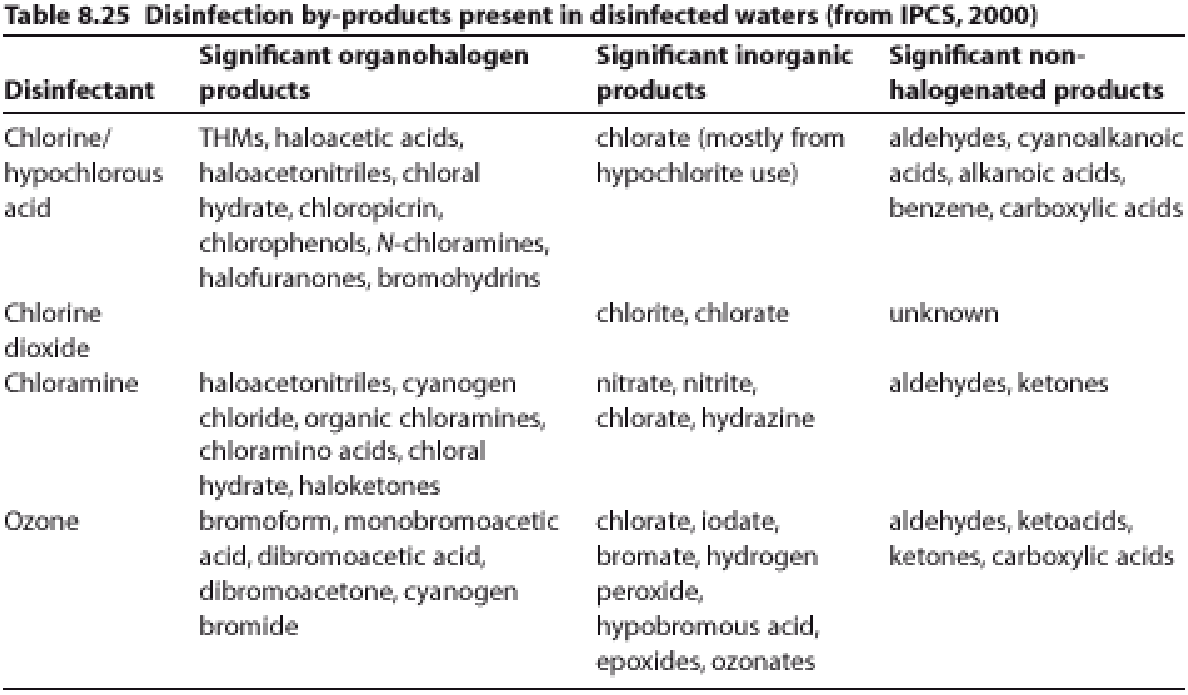


Table 8.25 Disinfection by-products present in disinfected waters (from IPCS, 2000)

Disinfectant	Significant organohalogen products	Significant inorganic products	Significant non-halogenated products
Chlorine/ hypochlorous acid	THMs, haloacetic acids, haloacetonitriles, chloral hydrate, chloropicrin, chlorophenols, *N*-chloramines, halofuranones, bromohydrins	chlorate (mostly from hypochlorite use)	aldehydes, cyanoalkanoic acids, alkanoic acids, benzene, carboxylic acids
Chlorine dioxide		chlorite, chlorate	unknown
Chloramine	haloacetonitriles, cyanogen chloride, organic chloramines, chloramino acids, chloral hydrate, haloketones	nitrate, nitrite, chlorate, hydrazine	aldehydes, ketones
Ozone	bromoform, monobromoacetic acid, dibromoacetic acid, dibromoacetone, cyanogen bromide	chlorate, iodate, bromate, hydrogen peroxide, hypobromous acid, epoxides, ozonates	aldehydes, ketoacids, ketones, carboxylic acids

8.5.6 Cyanobacterial toxins

Cyanobacteria (see also section 11.5) occur widely in lakes, reservoirs, ponds and slow-flowing rivers. Many species are known to produce toxins, i.e., “cyanotoxins,” a number of which are of concern for health. Cyanotoxins vary in structure and may be found within cells or released into water. There is wide variation in the toxicity of recognized cyanotoxins (including different structural variants within a group, e.g., microcystins), and it is likely that further toxins remain unrecognized.

The toxins are classified, according to their mode of action, as hepatotoxins (microcystins and cylindrospermopsins), neurotoxins (anatoxin-a, saxitoxins and anatoxin-a (S)) and irritants or inflammatory agents (lipopolysaccharides). The hepatotoxins are produced by various species within the genera *Microcystis*, *Planktothrix*, *Anabaena*, *Aphanizomenon*, *Nodularia*, *Nostoc*, *Cylindrospermopsis* and *Umezakia*. The cyanotoxins occurring most frequently in elevated concentrations (i.e., >1 m g/litre) seem to be microcystins (oligopeptides) and cylindrospermopsin (an alkaloid) whereas the cyanobacterial neurotoxins appear to occur in high concentrations only occasionally.

Cyanotoxins can reach concentrations potentially hazardous to human health primarily in situations of high cell density through excessive growth, sometimes termed "bloom" events. These occur in response to elevated concentrations of nutrients (phosphorus and sometimes nitrogen) and may be triggered by conditions such as water body stratification and sufficiently high temperature. Blooms tend to recur in the same water bodies. Cells of some cyanobacterial species may accumulate at the surface as scums or at the theromocline of thermally stratified reservoirs. Such accumulations may develop rapidly, and they may be of short duration. In many circumstances, blooms and accumulations are seasonal.

A variety of resource protection and source management actions are available to decrease the probability of bloom occurrence, and some treatment methods, including filtration and chlorination, are available for removal of cyanobacteria and cyanotoxins. Filtration can effectively remove cyanobacterial cells and, with that, often a high share of the toxins. Oxidation through ozone or chlorine at sufficient concentrations and contact times can effectively remove most cyanotoxins dissolved in water.

Chemical analysis of cyanotoxins is not the preferred focus of routine monitoring. The preferred approach is monitoring of source water for evidence of blooms, or bloom-forming potential, and increased vigilance where such events occur. Analysis of cyanotoxins requires time, equipment and expertise, and quantitative analysis of some cyanotoxins is hampered by the lack of analytical standards. However, rapid methods, such as ELISA and enzyme assays, are becoming available for a small number, e.g., microcystins.

Chemical analysis of cyanotoxins is useful for assessing the ef .cacy of treatment and preventive strategies, i.e., as validation of control measures in a WSP (see chapter 4). While guideline values are derived where sufficient data exist, they are primarily intended to inform setting targets for control measures.

A provisional guideline value has been established for microcystin-LR, which meets the criteria for inclusion (see Table 8.29). Microcystin-LR is one of the most toxic of more than 70 structural variants of microcystin. Although, on a global scale, it appears to be one of the most widespread microcystins, in many regions it is not the most commonly occurring variant, and others may well be less toxic. If the provisional guideline value for microcystin-LR is used as a surrogate for their assessment and for setting targets, this serves as a worst-case estimate. A more detailed discussion of using "concentration equivalents" or "toxicity equivalents" for relating microcystins to microcystin-LR is given in Chorus &Bartram (1999).

Table 8.26 Chemicals used in water treatment or materials in contact with drinking-water for which guideline values have not been established

Chemical	Reason for not establishing a guideline value
Disinfectants	
Chlorine dioxide	Rapid breakdown of chlorine dioxide; also, the chlorite provisional guideline value is protective for potential toxicity from chlorine dioxide
Dichloramine	Available data inadequate to permit derivation of health-based guideline value
Iodine	Available data inadequate to permit derivation of health-based guideline value, and lifetime exposure to iodine through water disinfection is unlikely
Silver	Available data inadequate to permit derivation of health-based guideline value
Trichloramine	Available data inadequate to permit derivation of health-based guideline value
Disinfection by-products	
Bromochloroacetate	Available data inadequate to permit derivation of health-based guideline value
Bromochloroacetonitrile	Available data inadequate to permit derivation of health-based guideline value
Chloroacetones	Available data inadequate to permit derivation of health-based guideline values for any of the chloroacetones
Chlorophenol, 2-	Available data inadequate to permit derivation of health-based guideline value
Chloropicrin	Available data inadequate to permit derivation of health-based guideline value
Dibromoacetate	Available data inadequate to permit derivation of health-based guideline value
Dichlorophenol, 2,4-	Available data inadequate to permit derivation of health-based guideline value
Monobromoacetate	Available data inadequate to permit derivation of health-based guideline value
MX	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Trichloroacetonitrile	Available data inadequate to permit derivation of health-based guideline value
Contaminants from treatment chemicals	
Aluminium	Owing to limitations in the animal data as a model for humans and the uncertainty surrounding the human data, a health-based guideline value cannot be derived; however, practicable levels based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants are derived: 0.1 mg/litre or less in large water treatment facilities, and 0.2 mg/litre or less in small facilities
Iron	Not of health concern at concentrations normally observed in drinking-water, and taste and appearance of water are affected at concentrations below the health-based value
Contaminants from pipes and fittings	
Asbestos	No consistent evidence that ingested asbestos is hazardous to health
Dialkyltins	Available data inadequate to permit derivation of health-based guideline values for any of the dialkyltins
Fluoranthene	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Inorganic tin	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Zinc	Not of health concern at concentrations normally observed in drinking-water, but may affect the acceptability of water

Table 8.27 Guideline values for chemicals used in water treatment or materials in contact with drinking-water that are of health significance in drinking-water

Disinfectants	**Guideline value[a] (mg/litre)**	**Remarks**
Chlorine	5 (C)	For effective disinfection, there should be a residual concentration of free chlorine of ≥0.5 mg/litre after at least 30 min contact time at pH <8.0
Monochloramine	3	
Disinfection by-products	**Guideline value[a] (µg/litre)**	**Remarks**
Bromate	10[b] (A, T)	
Bromodichloromethane	60[b]	
Bromoform	100	
Chloral hydrate (trichloroacetaldehyde)	10 (P)	
Chlorate	700 (D)	
Chlorite	700 (D)	
Chloroform	200	
Cyanogen chloride	70	For cyanide as total cyanogenic compounds
Dibromoacetonitrile	70	
Dibromochloromethane	100	
Dichloroacetate	50 (T, D)	
Dichloroacetonitrile	20 (P)	
Formaldehyde	900	
Monochloroacetate	20	
Trichloroacetate	200	
Trichlorophenol, 2,4,6-	200[b] (C)	
Trihalomethanes		The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1
Contaminants from treatment chemicals	**Guideline value[a] (µg/litre)**	**Remarks**
Acrylamide	0.5[b]	
Epichlorohydrin	0.4 (P)	
Contaminants from pipes and fittings	**Guideline value[a] (µg/litre)**	**Remarks**
Antimony	20	
Benzo[*a*]pyrene	0.7[b]	
Copper	2000	Staining of laundry and sanitary ware may occur below guideline value
Lead	10	
Nickel	20 (P)	
Vinyl chloride	0.3[b]	

[a] P = provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited; A = provisional guideline value because calculated guideline value is below the practical quantification level; T = provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source control, etc.; D = provisional guideline value because disinfection is likely to result in the guideline value being exceeded; C = concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, causing consumer complaints.

[b] For substances that are considered to be carcinogenic, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with estimated upper-bound excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

Table 8.28 Guideline values for pesticides used in water for public health purposes that are of health significance in drinking-water

Pesticides used in water for public health purposes[a]	Guideline value (µg/litre)
Chlorpyrifos	30
DDT and metabolites	1
Pyriproxyfen	300

[a] Only pyriproxyfen is recommended by WHOPES for addition to water for public health purposes.

Table 8.29. Guideline values for cyanotoxins that are of health significance in drinking-water

	Guideline value[a] (µg/litre)	Remarks
Microcystin-LR	1 (P)	For total microcystin-LR (free plus cell-bound)

[a] P = provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

Radiological aspects

The objective of this chapter is to provide criteria with which to assess the safety of drinking-water with respect to its radionuclide content. The Guidelines do not differentiate between naturally occurring and artificial or human-made radionuclides.

The guidance values for radioactivity in drinking-water recommended in the first edition of the Guidelines were based on the risks of exposure to radiation sources and the health consequences of exposure to radiation. The second edition of the Guidelines incorporated the 1990 recommendations of the International Commission on Radiological Protection (ICRP, 1991). The third edition incorporates recent developments, including the ICRP publications on prolonged exposures and on dose coefficients.

Radiological hazards may derive from ionizing radiation emitted by a number of radioactive substances (chemicals) in drinking-water. Such hazards from drinking-water are rarely of public health significance, and radiation exposure from drinking-water must be assessed alongside exposure from other sources.

The approach taken in the Guidelines for controlling radiological hazards has two stages:

— initial screening for gross alpha and/or beta activity to determine whether the activity concentrations (in Bq/litre) are below levels at which no further action is required; and

— if these screening levels are exceeded, investigation of the concentrations of individual radionuclides and comparison with specific guidance levels.

The risk due to radon in drinking-water derived from groundwater is typically low compared with that due to total inhaled radon but is distinct, as exposure occurs through both consumption of dissolved gas and inhalation of released radon and its daughter radionuclides. Greatest exposure is general ambient inhalation and inhalation from terrestrial sources, where the gas is in filtrating into dwellings, especially into basements. Radon of groundwater origin would usually be a small increment of the total, but may indicate deposits in the region that are emitting into basements.

The screening and guidance levels apply to routine ("normal") operational conditions of existing or new drinking-water supplies. They do not apply to a water supply contaminated during an emergency involving the release of radionuclides into the environment. Guidance and generic action levels covering emergency situations are available elsewhere (IAEA, 1996, 1997, 1999, 2002).

The current Guidelines are based on:

— a recommended reference dose level (RDL)of the committed effective dose, equal to 0.1 mSv from 1 year's consumption of drinking-water (from the possible total radioactive contamination of the annual drinking-water consumption). This comprises 10% of the intervention exemption level recommended by the ICRP for dominant commodities (e.g., food and drinking-water)for prolonged exposure situations, which is most relevant to long-term consumption of drinking-water by the public (ICRP, 2000). The RDL of 0.1 mSv is also equal to 10% of the dose limit for members of the population, recommended by both the ICRP (1991) and the International Basic Safety Standards (IAEA, 1996). These are accepted by most WHO Member States, the European Commission, FAO and WHO.

— dose coefficients for adults, provided by the ICRP.

The additional risk to health from exposure to an annual dose of 0.1 mSv associated with the intake of radionuclides from drinking-water is considered to be low for the following reasons:

- The nominal probability coefficient for radiation-induced stochastic health effects, which include fatal cancer, non-fatal cancer and severe hereditary effects for the whole population, is $7.3X10^{-2}$/Sv (ICRP, 1991). Multiplying this by an RDL equal to 0.1 mSv annual exposure via drinking-water gives an estimated lifetime risk of stochastic health effects of 10-^{5} , which can be considered small in comparison with other health risks. This risk level is comparable to the reference level of risk used elsewhere in these Guidelines.
- Background radiation exposures vary widely across the Earth, but the average is about 2.4 mSv/year, with the highest local levels being up to 10 times higher without any apparent health consequences; 0.1 mSv therefore represents a small addition to background levels.
- Despite the uncertainties in the determination of risk from radiation exposure at low levels, radiation risks are probably well below those due to microbes and some chemicals in drinking-water.

9.1 Sources and health effects of radiation exposure

Environmental radiation originates from a number of naturally occurring and human-made sources. Radioactive materials occur naturally everywhere in the environment (e.g., uranium, thorium and potassium-40). By far the largest proportion of human exposure to radiation comes from natural sources – from external sources of radiation, including cosmic and terrestrial radiation, and from inhalation or ingestion of radioactive materials (Figure 9.1). The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000)has estimated that the global average annual human exposure from natural sources is 2.4 mSv/year (Table 9.1). Some sources (e.g., uranium) can be concentrated during extraction by mining and other industrial activities.

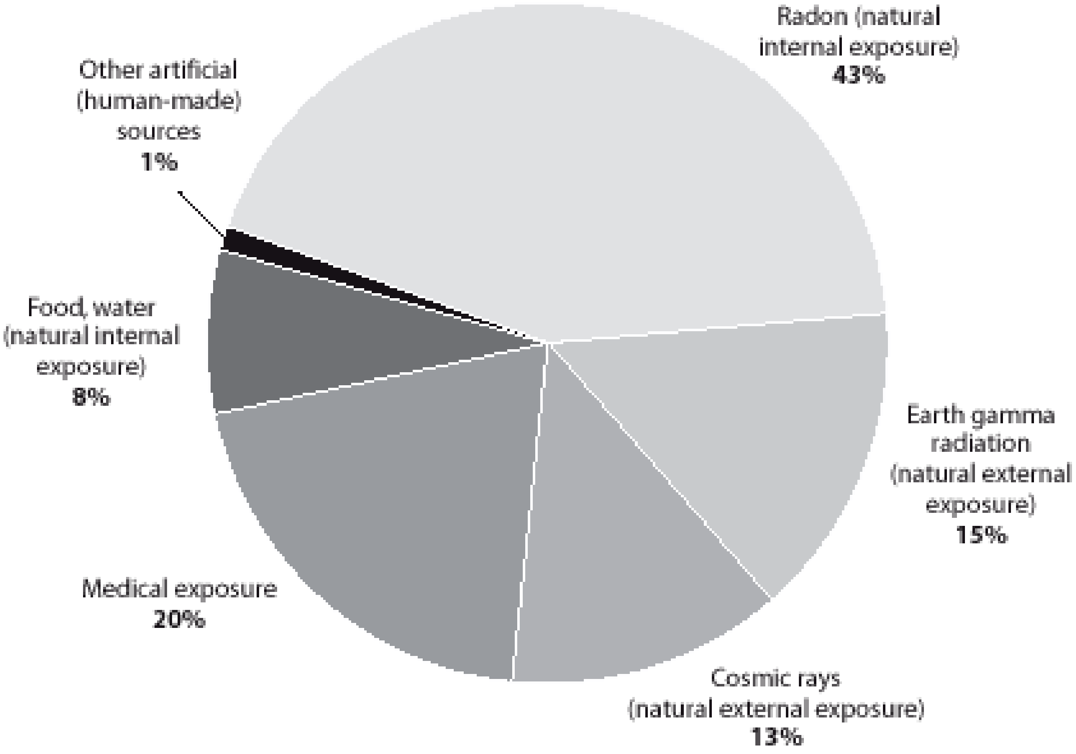


Figure 9.1 Sources and distribution of average radiation exposure for the world population

There are large local variations in human exposure to radiation, depending on a number of factors, such as height above sea level, the amount and type of radio-nuclides in the soil (terrestrial exposure), the composition of radionuclides in the air, food and drinking-water and the amount taken into the body via inhalation or ingestion. There are certain areas of the world, such as parts of the Kerala state in India and the Pocos del Caldas plateau in Brazil, where levels of background radiation are relatively high. Levels of exposure for the general population in such areas may be up to 10 times higher than the average background level of 2.4 mSv given in Table 9.1. No deleterious health effects associated with this elevated radiation exposure have been detected.

Several radioactive compounds may be released into the environment, and hence into drinking-water supplies, from human activities and human-made sources (e.g., from medical or industrial use of radioactive sources). The worldwide per capita effective dose from diagnostic medical examination in 2000 was 0.4 mSv/year (typical range is 0.04 –1.0 mSv/year, depending on level of health care). There is only a very small worldwide contribution from nuclear power production and nuclear weapons testing. The worldwide annual per capita effective dose from nuclear weapons testing in 2000 was estimated at 0.005 mSv; from the Chernobyl accident, 0.002 mSv; and from nuclear power production, 0.0002 mSv (UNSCEAR, 2000).

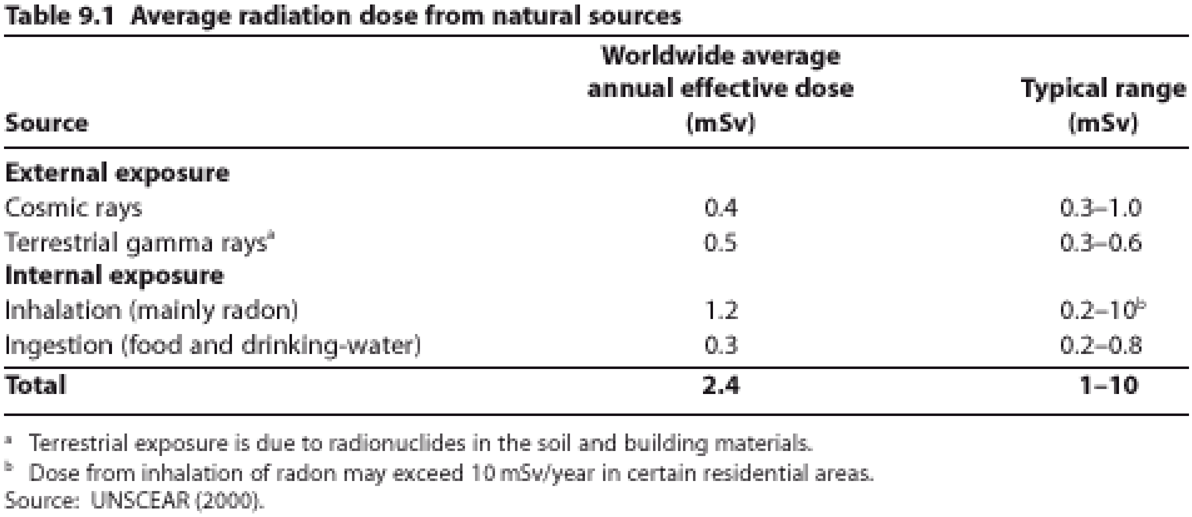


Table 9.1 Average radiation dose from natural sources

Source	Worldwide average annual effective dose (mSv)	Typical range (mSv)
External exposure		
Cosmic rays	0.4	0.3–1.0
Terrestrial gamma rays[a]	0.5	0.3–0.6
Internal exposure		
Inhalation (mainly radon)	1.2	0.2–10[b]
Ingestion (food and drinking-water)	0.3	0.2–0.8
Total	**2.4**	**1–10**

[a] Terrestrial exposure is due to radionuclides in the soil and building materials.

[b] Dose from inhalation of radon may exceed 10 mSv/year in certain residential areas.

Source: UNSCEAR (2000).

9.1.1 Radiation exposure through drinking-water

Radioactive constituents of drinking-water can result from:

— naturally occurring radioactive species (e.g., radionuclides of the thorium and uranium decay series in drinking-water sources), in particular radium 226/228 and a few others;

— technological processes involving naturally occurring radioactive materials (e.g., the mining and processing of mineral sands or phosphate fertilizer production);

— radionuclides discharged from nuclear fuel cycle facilities;

— manufactured radionuclides (produced and used in unsealed form), which might enter drinking-water supplies as a result of regular discharges and, in particular, in case of improper medical or industrial use and disposal of radioactive materials; such incidents are different from emergencies, which are outside the scope of these Guidelines; and

— past releases of radionuclides into the environment, including water sources.

The contribution of drinking-water to total exposure is typically very small and is due largely to naturally occurring radionuclides in the uranium and thorium decay series. Radionuclides from the nuclear fuel cycle and from medical and other uses of radio-active materials may, however, enter drinking-water supplies. The contributions from these sources are normally limited by regulatory control of the source or practice, and it is normally through this regulatory mechanism that remedial action should be taken in the event that such sources cause concern by contaminating drinking-water.

9.1.2 Radiation-induced health effects through drinking-water

There is evidence from both human and animal studies that radiation exposure at low to moderate doses may increase the long-term incidence of cancer. Animal studies in particular suggest that the rate of genetic malformations may be increased by radiation exposure.

No deleterious radiological health effects are expected from consumption of drinking-water if the concentrations of radionuclides are below the guidance levels (equivalent to a committed effective dose below 0.1 mSv/year).

Acute health effects of radiation, leading to reduced blood cell counts and, in very severe cases, death, occur at very high doses of exposure of the whole body or large part of the body (IAEA, 1998). Due to the low levels of radionuclides typically found in drinking-water supplies, acute health effects of radiation are not a concern for drinking-water supplies.

9.2 Units of radioactivity and radiation dose

The SI unit of radioactivity is the becquerel (Bq), where 1 Bq =1 disintegration per second. Guidance levels for drinking-water are given as the activity of the radio-nuclide per litre, called the activity concentration (Bq/litre). The radiation dose resulting from ingestion of a radionuclide depends on a number of chemical and biological factors. These include the fraction of the intake that is absorbed from the gut, the organs or tissues to which the radionuclide is transported and the time during which the radionuclide remains in the organ or tissue before excretion. The nature of the radiation emitted on decay and the sensitivity of the irradiated organs or tissues to radiation must also be considered.

The absorbed dose refers to how much energy is deposited in material by the radiation. The SI unit for absorbed dose is the gray (Gy), where 1 Gy =1 J/kg (joule per kilogram).

The equivalent dose is the product of the absorbed dose and a factor related to the particular type of radiation (depending on the ionizing capacity and density).

The effective dose of radiation received by a person is, in simple terms, the sum of the equivalent doses received by all tissues or organs, weighted for “tissue weighting factors.” These reflect different sensitivities to radiation of different organs and tissues in the human body. The SI unit for the equivalent and effective dose is the sievert (Sv), where 1 Sv =1 J/kg.

To reflect the persistence of radionuclides in the body once ingested, the committed effective dose is a measure of the total effective dose received over a lifetime (70 years) following intake of a radionuclide (internal exposure). The term “dose” may be used as a general term to mean either absorbed dose (Gy) or effective dose (Sv), depending on the situation. For monitoring purposes, doses are determined from the activity concentration of the radionuclide in a given material. In the case of water, activity concentration is given in becquerels per litre (Bq/litre). This value can be related to an effective dose per year (mSv/year) using a dose coefficient (mSv/Bq) and the average annual consumption of water (litres/year). The effective dose arising from the ingestion of a radioisotope in a particular chemical form can be estimated using a dose coefficient. Data for age-related dose coefficients for ingestion of radionuclides have been published by the ICRP and the International Atomic Energy Agency (IAEA). Table 9.2 shows the dose coefficients for naturally occurring radionuclides or those arising from human activities that might be found in drinking-water supplies (IAEA, 1996; ICRP, 1996).

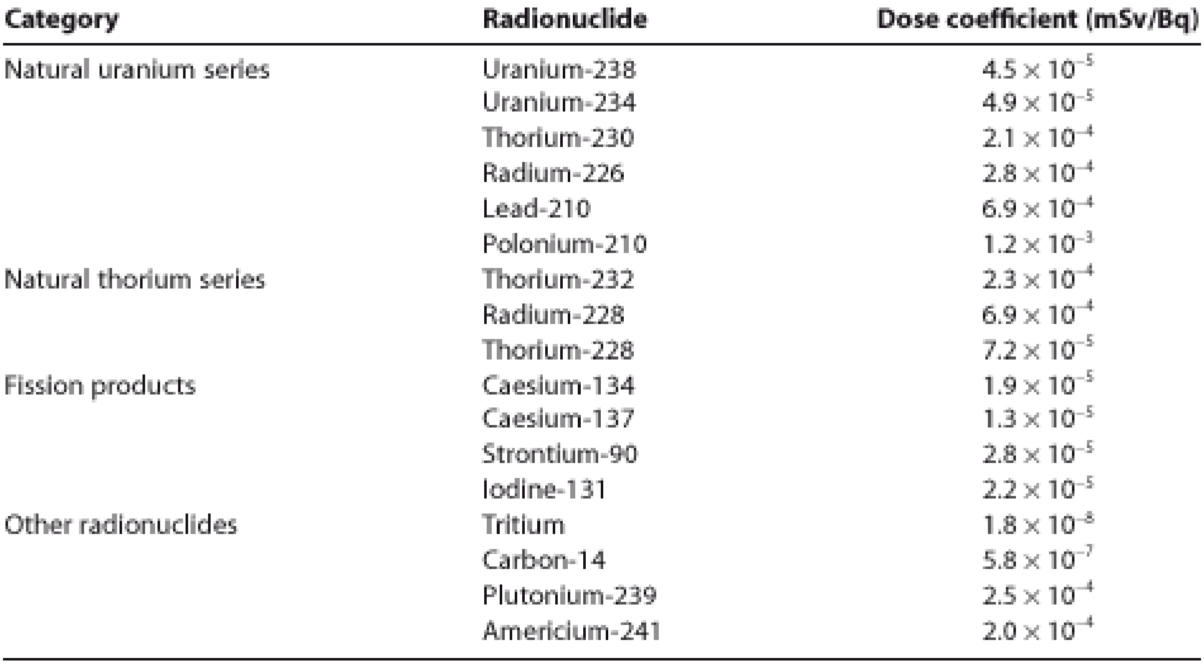


Table 9.2 Dose coefficients for ingestion of radionuclides by adult members of the public

Category	Radionuclide	Dose coefficient (mSv/Bq)
Natural uranium series	Uranium-238	4.5×10^{-5}
	Uranium-234	4.9×10^{-5}
	Thorium-230	2.1×10^{-4}
	Radium-226	2.8×10^{-4}
	Lead-210	6.9×10^{-4}
	Polonium-210	1.2×10^{-3}
Natural thorium series	Thorium-232	2.3×10^{-4}
	Radium-228	6.9×10^{-4}
	Thorium-228	7.2×10^{-5}
Fission products	Caesium-134	1.9×10^{-5}
	Caesium-137	1.3×10^{-5}
	Strontium-90	2.8×10^{-5}
	Iodine-131	2.2×10^{-5}
Other radionuclides	Tritium	1.8×10^{-8}
	Carbon-14	5.8×10^{-7}
	Plutonium-239	2.5×10^{-4}
	Americium-241	2.0×10^{-4}

9.3 Guidance levels for radionuclides in drinking-water

The guidance levels for radionuclides in drinking-water are presented in Table 9.3 for radionuclides originating from natural sources or discharged into the environment as the result of current or past activities. These levels also apply to radionuclides released due to nuclear accidents that occurred more than 1 year previously. The activity concentration values in Table 9.3 correspond to an RDL of 0.1 mSv/ year from each radionuclide listed if their concentration in the drinking-water consumed during the year does not exceed these values. The associated risk estimate was given at the begin-ning of this chapter. However, for the first year immediately after an accident, generic action levels for foodstuffs apply as described in the International Basic Safety

Standards (IAEA, 1996) and other relevant WHO and IAEA publications (WHO, 1988; IAEA, 1997, 1999).

The guidance levels for radionuclides in drinking-water were calculated by the following equation:

$$GL = IDC/(h_{ing} \cdot q)$$

where:
GL = guidance level of radionuclide in drinking-water (Bq/litre),
IDC = individual dose criterion, equal to 0.1 mSv/year for this calculation,
hing = dose coefficient for ingestion by adults (mSv/Bq),
q =annual ingested volume of drinking-water, assumed to be 730 litres/year.

The higher age-dependent dose coefficients calculated for children (accounting for the higher uptake and/or metabolic rates) do not lead to significantly higher doses due to the lower mean volume of drinking-water consumed by infants and children. Consequently, the recommended RDL of committed effective dose of 0.1 mSv/year from 1 year 's consumption of drinking-water applies independently of age.

Table 9.3 Guidance levels for radionuclides in drinking-water

Radionuclides	Guidance level (Bq/litre)[a]	Radionuclides	Guidance level (Bq/litre)[a]	Radionuclides	Guidance level (Bq/litre)[a]
^{3}H	10 000	^{93}Mo	100	^{140}La	100
^{7}Be	10 000	^{99}Mo	100	^{139}Ce	1000
^{14}C	100	^{96}Tc	100	^{141}Ce	100
^{22}Na	100	^{97}Tc	1000	^{143}Ce	100
^{32}P	100	^{97m}Tc	100	^{144}Ce	10
^{33}P	1 000	^{99}Tc	100	^{143}Pr	100
^{35}S	100	^{97}Ru	1000	^{147}Nd	100
^{36}Cl	100	^{103}Ru	100	^{147}Pm	1000
^{45}Ca	100	^{106}Ru	10	^{149}Pm	100
^{47}Ca	100	^{105}Rh	1000	^{151}Sm	1000
^{46}Sc	100	^{103}Pd	1000	^{153}Sm	100
^{47}Sc	100	^{105}Ag	100	^{152}Eu	100
^{48}Sc	100	^{110m}Ag	100	^{154}Eu	100
^{48}V	100	^{111}Ag	100	^{155}Eu	1000
^{51}Cr	10 000	^{109}Cd	100	^{153}Gd	1000
^{52}Mn	100	^{115}Cd	100	^{160}Tb	100
^{53}Mn	10 000	^{115m}Cd	100	^{169}Er	1000
^{54}Mn	100	^{111}In	1000	^{171}Tm	1000
^{55}Fe	1 000	^{114m}In	100	^{175}Yb	1000
^{59}Fe	100	^{113}Sn	100	^{182}Ta	100
^{56}Co	100	^{125}Sn	100	^{181}W	1000
^{57}Co	1 000	^{122}Sb	100	^{185}W	1000
^{58}Co	100	^{124}Sb	100	^{186}Re	100
^{60}Co	100	^{125}Sb	100	^{185}Os	100
^{59}Ni	1 000	^{123m}Te	100	^{191}Os	100
^{63}Ni	1 000	^{127}Te	1000	^{193}Os	100
^{65}Zn	100	^{127m}Te	100	^{190}Ir	100
^{71}Ge	10 000	^{129}Te	1000	^{192}Ir	100
^{73}As	1 000	^{129m}Te	100	^{191}Pt	1000
^{74}As	100	^{131}Te	1000	^{193m}Pt	1000
^{76}As	100	^{131m}Te	100	^{198}Au	100
^{77}As	1 000	^{132}Te	100	^{199}Au	1000
^{75}Se	100	^{125}I	10	^{197}Hg	1000
^{82}Br	100	^{126}I	10	^{203}Hg	100
^{86}Rb	100	^{129}I	1000	^{200}Tl	1000
^{85}Sr	100	^{131}I	10	^{201}Tl	1000
^{89}Sr	100	^{129}Cs	1000	^{202}Tl	1000
^{90}Sr	10	^{131}Cs	1000	^{204}Tl	100
^{90}Y	100	^{132}Cs	100	^{203}Pb	1000
^{91}Y	100	^{134}Cs	10	^{206}Bi	100
^{93}Zr	100	^{135}Cs	100	^{207}Bi	100
^{95}Zr	100	^{136}Cs	100	^{210}Bi[b]	100
^{93m}Nb	1 000	^{137}Cs	10	^{210}Pb[b]	0.1
^{94}Nb	100	^{131}Ba	1000	^{210}Po[b]	0.1
^{95}Nb	100	^{140}Ba	100	^{223}Ra[b]	1
^{224}Ra[b]	1	^{235}U[b]	1	^{242}Cm	10
^{225}Ra	1	^{236}U[b]	1	^{243}Cm	1
^{226}Ra[b]	1	^{237}U	100	^{244}Cm	1
^{228}Ra[b]	0.1	^{238}U[b,c]	10	^{245}Cm	1

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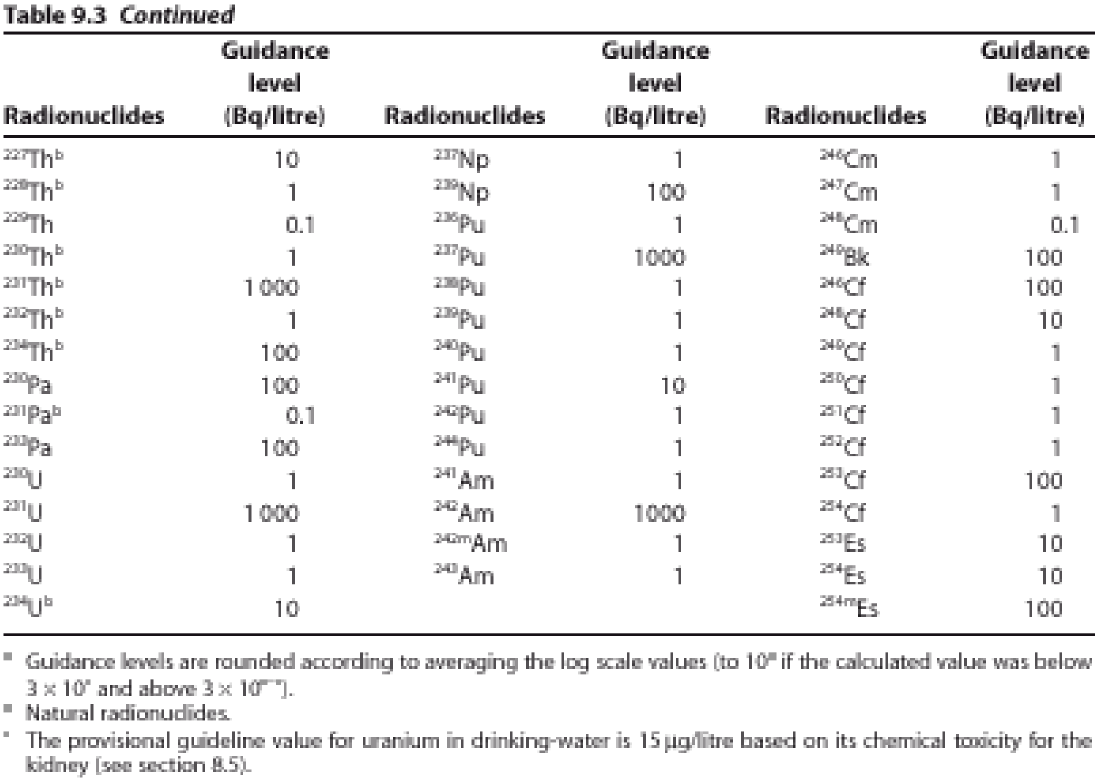

Table 9.3 *Continued*

Radionuclides	Guidance level (Bq/litre)	Radionuclides	Guidance level (Bq/litre)	Radionuclides	Guidance level (Bq/litre)
$^{227}Th^{b}$	10	^{237}Np	1	^{246}Cm	1
$^{228}Th^{b}$	1	^{239}Np	100	^{247}Cm	1
^{229}Th	0.1	^{236}Pu	1	^{248}Cm	0.1
$^{230}Th^{b}$	1	^{237}Pu	1000	^{249}Bk	100
$^{231}Th^{b}$	1 000	^{238}Pu	1	^{246}Cf	100
$^{232}Th^{b}$	1	^{239}Pu	1	^{248}Cf	10
$^{234}Th^{b}$	100	^{240}Pu	1	^{249}Cf	1
^{230}Pa	100	^{241}Pu	10	^{250}Cf	1
$^{231}Pa^{b}$	0.1	^{242}Pu	1	^{251}Cf	1
^{233}Pa	100	^{244}Pu	1	^{252}Cf	1
^{230}U	1	^{241}Am	1	^{253}Cf	100
^{231}U	1 000	^{242}Am	1000	^{254}Cf	1
^{232}U	1	^{242m}Am	1	^{253}Es	10
^{233}U	1	^{243}Am	1	^{254}Es	10
$^{234}U^{b}$	10			^{254m}Es	100

[a] Guidance levels are rounded according to averaging the log scale values (to 10^{n} if the calculated value was below 3×10^{n} and above $3 \times 10^{n-1}$).

[b] Natural radionuclides.

[c] The provisional guideline value for uranium in drinking-water is 15 µg/litre based on its chemical toxicity for the kidney (see section 8.5).

9.4 Monitoring and assessment for dissolved radionuclides

9.4.1 Screening of drinking-water supplies

The process of identifying individual radioactive species and determining their concentration requires sophisticated and expensive analysis, which is normally not justified, because the concentrations of radionuclides in most circumstances are very low. A more practical approach is to use a screening procedure, where the total radioactivity present in the form of alpha and beta radiation is first determined, without regard to the identity of specific radionuclides.

Screening levels for drinking-water below which no further action is required are 0.5 Bq/litre for gross alpha activity and 1 Bq/litre for gross beta activity. The gross beta activity screening level was published in the second edition of the Guidelines and, in the worse case (radium-222), would lead to a dose close to the guidance RDL of 0.1 mSv/year. The screening level for gross alpha activity is 0.5 Bq/litre (instead of the former 0.1 Bq/litre), as this activity concentration reflects values nearer the radionuclide-specific guidance RDL.

9.4.2 Strategy for assessing drinking-water

If either of the screening levels is exceeded, then the specific radionuclides producing this activity should be identified and their individual activity concentrations measured. From these data, an estimate of committed effective dose for each radionuclide should be made and the sum of these doses determined. If the following additive formula is satisfied, no further action is required:

$${}_{i}\ \frac{C_i}{GL_i} \leq 1$$

where:
C_i =the measured activity concentration of radionuclide i, and
GL_i =the guidance level value (see Table 9.3) of radionuclide i that, at an intake of 2 litres/day for 1 year, will result in a committed effective dose of 0.1mSv/year.

Where the sum exceeds unity for a single sample, the RDL of 0.1mSv would be exceeded only if the exposure to the same measured concentrations were to continue for a full year. *Hence, such a sample does not in itself imply that the water is unsuitable for consumption* but should be regarded as an indication that further investigation, including additional sampling, is needed. Gross beta and gross alpha activity screening has to be repeated first, then radionuclide-specific analysis conducted only if sub-sequently measured gross values exceed the recommended practical screening values (1Bq/litre and 0.5Bq/litre, respectively).

The application of these recommendations is summarized in Figure 9.2.

The gross beta measurement includes a contribution from potassium-40, a beta emitter that occurs naturally in a fixed ratio to stable potassium. Potassium is an essential element for humans and is absorbed mainly from ingested food. Potassium-40 does not accumulate in the body but is maintained at a constant level independent of intake. The contribution of potassium-40 to beta activity should therefore be sub-tracted following a separate determination of total potassium. The specific activity of potassium-40 is 30.7Bq/g of potassium. However, not all the radiation from potassium-40 appears as beta activity. The beta activity of potassium-40 is 27.6Bq/g of stable potassium, which is the factor that should be used to calculate the beta activity due to potassium-40.

9.4.3 Remedial measures

If the RDL of 0.1mSv/year is being exceeded on aggregate, then the options available to the competent authority to reduce the dose should be examined. Where remedial measures are contemplated, any strategy considered should first be justified (in the sense that it achieves a net benefit) and then optimized in accordance with the recommendations of ICRP (1989,1991) in order to produce the maximum net benefit.

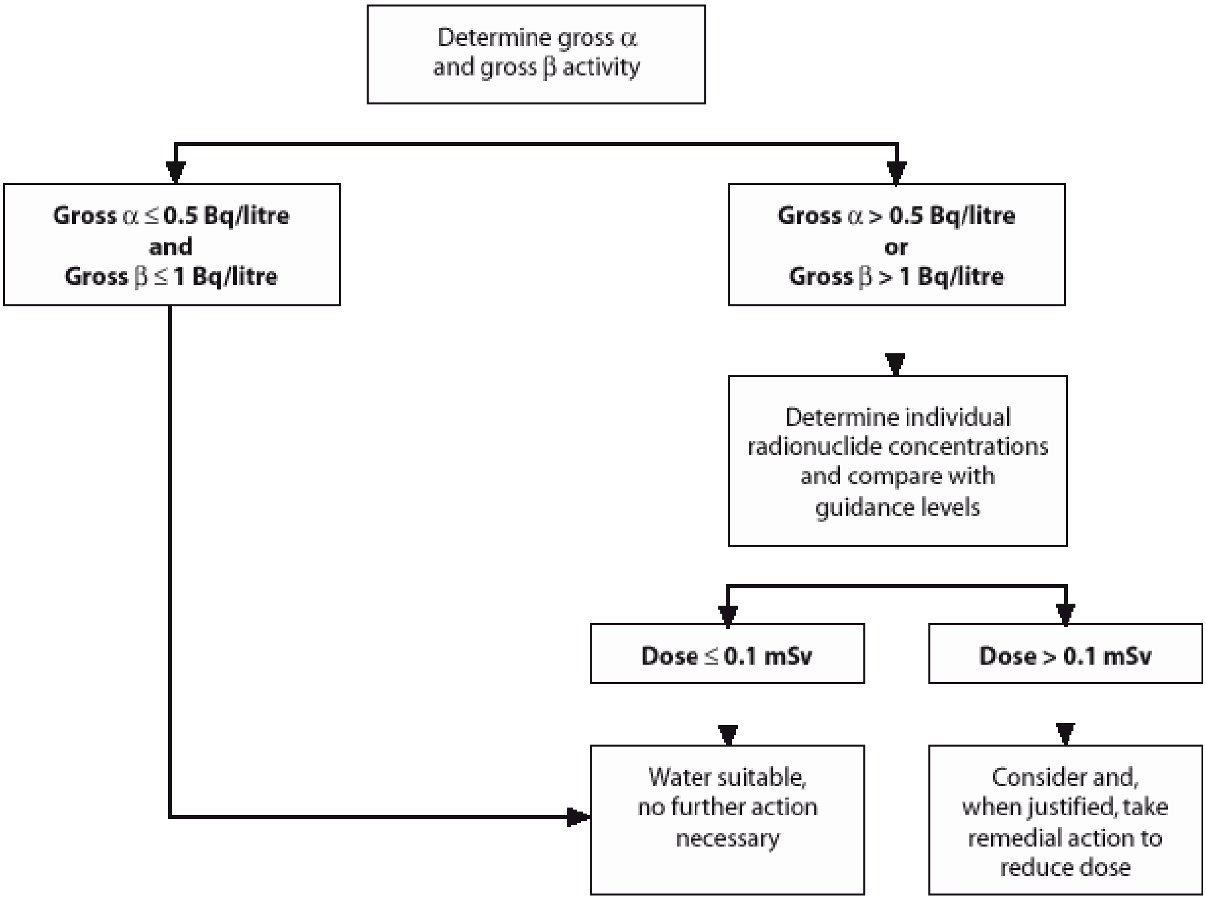

Figure 9.2 Application of screening and guidance levels for radionuclides in drinking-water

9.5 Radon

9.5.1 Radon in air and water

The largest fraction of natural radiation exposure comes from radon, a radioactive gas (see Table 9.1 and Figure 9.1), due to decay of radium contained in rocks and soil as part of the uranium radionuclide chain. The term radon in general refers mostly to radon-222. Radon is present virtually everywhere on Earth, but particularly in the air over land and in buildings.

Underground rock containing natural uranium continuously releases radon into water in contact with it (groundwater). Radon is readily released from surface water; consequently, groundwater normally has much higher concentrations of radon than surface water. The average concentration of radon is usually less than 0.4Bq/litre in public water supplies derived from surface waters and about 20Bq/litre from ground-water sources. However, some wells have been identified with higher concentrations, up to 400 times the average, and in rare cases exceeding 10kBq/litre.

For assessing the dose from radon ingestion, it is important that water processing technology before consumption is taken into account. Moreover, the use of some groundwater supplies for general domestic purposes will increase the levels of radon in the air, thus increasing the dose from inhalation. This dose depends markedly on the form of domestic usage and housing construction (NCRP, 1989). The amount and form of water intake, the other domestic uses of water and the construction of houses vary widely throughout the world.

UNSCEAR (2000) refers to a US NAS (1999) report and calculates the "average doses from radon in drinking water to be as low as 0.025 mSv/year via inhalation and 0.002 mSv/year from ingestion" compared with the inhalation dose of 1.1 mSv/year from radon and its decay products in air.

9.5.2 Risk

One report estimates that 12% of lung cancer deaths in the USA are linked to radon (radon-222 and its short-lived decay products)in indoor air (US NAS,1999). Thus, radon causes about 19 000 deaths (in the range of 15 000 –22 000) due to lung cancer annually out of a total of about 160 000 deaths from lung cancer, which are mainly as a result of smoking tobacco (US NRC, 1999).

US NAS (1999) reports an approximately 100-fold smaller risk from exposure to radon in drinking-water (i.e.,183 deaths each year). In addition to the 19 000 deaths from lung cancer caused by radon in indoor air, a further 160 were estimated to result from inhaling radon that was emitted from water used in the home. For comparison, about 700 lung cancer deaths each year were attributed to exposure to natural levels of radon while people are outdoors.

The US NAS (1999) also assessed that the risk of stomach cancer caused bydrinking-water that contains dissolved radon is extremely small, with the probability of about 20 deaths annually compared with the 13 000 deaths from stomach cancer that arise each year from other causes in the USA.

9.5.3 Guidance on radon in drinking-water supplies

Controls should be implemented if the radon concentration of drinking-water for public water supplies exceeds 100 Bq/litre. Any new drinking-water supply should be tested prior to being used for general consumption. If the radon concentration exceeds 100 Bq/litre, treatment of the water source should be undertaken to reduce the radon levels to well below 100 Bq/litre. If there are significant amounts of radon-producing minerals around the water source, then it may be appropriate for larger drinking-water supplies to test for radon concentration periodically – for example, every 5 years.

9.6 Sampling, analysis and reporting

9.6.1 Measuring gross alpha and gross beta activity concentrations

To analyse drinking-water for gross alpha and gross beta activities (excluding radon), the most common approach is to evaporate a known volume of the sample to dryness and measure the activity of the residue. As alpha radiation is easily absorbed within a thin layer of solid material, the reliability and sensitivity of the method for alpha determination may be reduced in samples with a high TDS content.

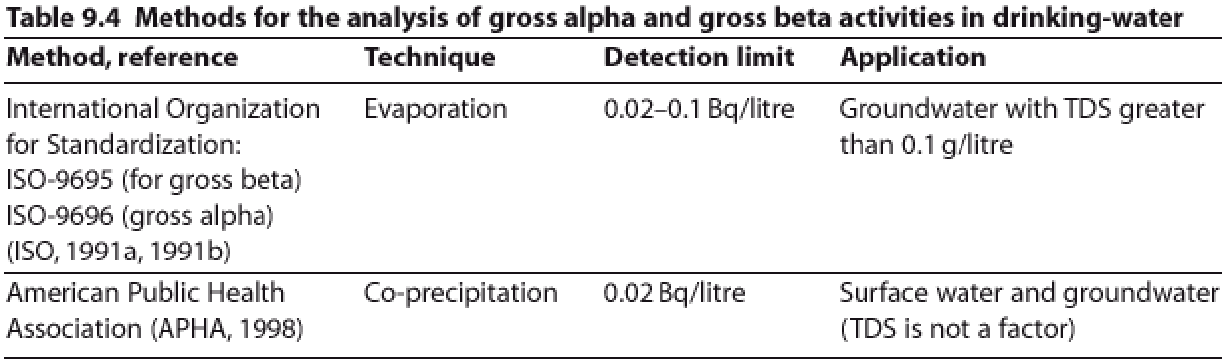

Table 9.4 Methods for the analysis of gross alpha and gross beta activities in drinking-water

Method, reference	Technique	Detection limit	Application
International Organization for Standardization: ISO-9695 (for gross beta) ISO-9696 (gross alpha) (ISO, 1991a, 1991b)	Evaporation	0.02–0.1 Bq/litre	Groundwater with TDS greater than 0.1 g/litre
American Public Health Association (APHA, 1998)	Co-precipitation	0.02 Bq/litre	Surface water and groundwater (TDS is not a factor)

Where possible, standardized methods should be used to determine concentrations of gross alpha and gross beta activities. Three procedures for this analysis are listed in Table 9.4.

The determination of gross beta activity using the evaporation method includes the contribution from potassium-40. An additional analysis of total potassium is therefore required if the gross beta screening value is exceeded.

The co-precipitation technique (APHA, 1998) excludes the contribution due to potassium-40; therefore, determination of total potassium is not necessary. This method is not applicable to assessment of water samples containing certainfission products, such as caesium-137. However, under normal circumstances, concentrations offission products in drinking-water supplies are extremely low.

9.6.2 Measuring potassium-40

It is impractical to use a radioactive measurement technique to determine the concentration of potassium-40 in a water sample due to the lack of sensitivity in gammaray analysis and the difficulty of chemically isolating the radionuclide from solution. Because of the .fixed ratio between potassium -40 and stable potassium, chemical analysis for potassium is recommended. A measurement sensitivity of 1 mg/litre for potassium is adequate, and suitable techniques that can readily achieve this are atomic absorption spectrophotometry and specific ion analysis. The activity due to potassium-40 can then be calculated using a factor of 27.6 Bq of beta activity per gram of total potassium.

9.6.3 Measuring radon

There are difficulties in deriving activity concentrations of radon-222 in drinking-water arising from the ease with which radon is released from water during handling. Stirring and transferring water from one container to another will liberate dissolved radon. According to the widely used Pylon technique (Pylon, 1989, 2003), detection of radon in drinking-water is performed using a water degassing unit and Lucas scintillation chambers. Water that has been left to stand will have reduced radon activity, and boiling will remove radon completely.

9.6.4 Sampling

New water sources should be sampled (e.g., every 3 months for the first 12 months) to determine their suitability for drinking-water supply before design and construction to characterize the radiological quality of the water supply and to assess any seasonal variation in radionuclide concentrations. This should include analysis for radon and radon daughters.

Once measurements indicate the normal range of the supply, then the sampling frequency can be reduced to, for example, annually or every 5 years. However, if sources of potential radionuclide contamination exist nearby (e.g., mining activity or nuclear reactors), then sampling should be more frequent. Less significant surface and underground water supplies can be sampled less frequently.

Levels of radon and radon daughters in groundwater supplies are usually stable over time. Monitoring of water for radon and its daughters can therefore be relatively infrequent. Knowledge of the geology of the area should be considered in determining whether the source is likely to contain significant concentrations of radon and radon daughters. An additional risk factor would be the presence of mining in the vicinity; in such circumstances, more frequent monitoring may be appropriate.

Guidance on assessing water quality, sampling techniques and programmes and the preservation and handling of samples is given in the Australian and New Zealand Standard (AS, 1998).

9.6.5 Reporting of results

The analytical results for each sample should contain the following information:

— sample identifying code or information;
— reference date and time for the reported results (e.g., sample collection date);
— identification of the standard analytical method used or a brief description of any non-standard method used;
— identification of the radionuclide (s) or type and total radioactivity determined;
— measurement-based concentration or activity value calculated using the appropriate blank for each radionuclide;
— estimates of the counting uncertainty and total projected uncertainty; and
— minimum detectable concentration for each radionuclide or parameter analysed.

The estimate of total projected uncertainty of the reported result should include the contributions from all the parameters within the analytical method (i.e., counting and other random and systematic uncertainties or errors).

Acceptability aspects

The most undesirable constituents of drinking-water are those capable of having a direct adverse impact on public health. Many of these are described in other chapters of these Guidelines.

To a large extent, consumers have no means of judging the safety of their drinking-water themselves, but their attitude towards their drinking-water supply and their drinking-water suppliers will be affected to a considerable extent by the aspects of water quality that they are able to perceive with their own senses. It is natural for consumers to regard with suspicion water that appears dirty or discoloured or that has an unpleasant taste or smell, even though these characteristics may not in them- selves be of direct consequence to health.

The appearance, taste and odour of drinking-water should be acceptable to the consumer.

The provision of drinking-water that is not only safe but also acceptable in appearance, taste and odour is of high priority. Water that is aesthetically unacceptable will undermine the confidence of consumers, lead to complaints and, more importantly, possibly lead to the use of water from sources that are less safe.

It is important to consider whether existing or proposed water treatment and distribution practices can affect the acceptability of drinking-water. For example, a change in disinfection practice may generate an odorous compound such as trichloramine in the treated water. Other effects may be indirect, such as the disturbance of internal pipe deposits and bio films when changing between or blending waters from different sources in distribution systems.

The acceptability of drinking-water to consumers is subjective and can be influenced by many different constituents. The concentration at which constituents are objectionable to consumers is variable and dependent on individual and local factors, including the quality of the water to which the community is accustomed and a variety of social, environmental and cultural considerations. Guideline values have not been established for constituents influencing water quality that have no direct link to adverse health impacts.