

**Table 2-10. Sites Located Near Identified
Problem Areas Under Investigation by Ecology**

ACTIVE INVESTIGATION SITE	TYPE OF INDUSTRY	COMMENCEMENT BAY WATERWAY
U.S. Gypsum Plant	Gypsum manufacturer	Head of Hylebos
Elf Atochem	Chloralkali plant/former pesticide production	Head of Hylebos
Banyon Rail (out of business)	Rail track repair	Head of Hylebos
B&L Landfill	Inactive landfill	Hylebos Creek
3009 Taylor Way	Inactive sorting yard	Head of Hylebos
General Metals	Metal scrap yard	Head of Hylebos
Kaiser Aluminum and Chemical Corp.	Aluminum manufacturer	Head of Hylebos
Louisiana Pacific	Active log sort yard	Head of Hylebos
Murray Pacific No. 1	Inactive sort yard	Head of Hylebos
Tacoma Boatbuilding Co.	Shipyard	Head of Hylebos
Wasser Winters Log Yard	Inactive sort yard	Head of Hylebos
Small Boatyards	Miscellaneous marinas	Hylebos, Thea Foss
Marine Industries NW	Shipyard	Middle
AK-WA Ship Building	Shipyard	Mouth of Hylebos
Buffelen Woodworking	Woodworking	Mouth of Hylebos
Cascade Timber No. 1	Inactive log sort yard	Mouth of Hylebos
Simon & Sons	Rail and locomotive equipment	Mouth of Hylebos
Occidental Chemical	Chlorine manufacturer	Mouth of Hylebos
Port of Tacoma Industrial Yard	Port yard	Mouth of Hylebos
Sound Refinery	Oil refinery	Mouth of Hylebos
1501 Taylor Way/Brazier Forest Products	Soil contamination from unknown historical sources	Mouth of Hylebos
Cascade Timber No. 3	Inactive log sort yard	Sitcum
City of Tacoma Sitcum Storm Drains	Storm drains	Sitcum
McFarland Cascade Pole-Sitcum	Former log treatment, port maintenance	Sitcum
Milwaukee Railroad	Formerly Union Pacific	Sitcum
Norcon Plastics	Resin fabricators	Sitcum
Sealand	Container terminal	Sitcum
Sound Battery	Battery manufacturer	Sitcum
South Terminal Railyard	Rail yard	Sitcum
U.S. Oil	Log sort yard (oil spill)	Sitcum
Superior Oil	Petroleum storage	Thea Foss
D Street Petroleum	Semi-active petroleum transfer/storage	Thea Foss
Martinac	Shipyard	Thea Foss
Tacoma Coal Gas Site	Former coal-gasification plant	Thea Foss
Chevron Bulk Plant	Petroleum storage	Wheeler-Osgood

Source: Smith (personal communication 1993b).

Table 2-11. Sources of Substances of Concern Associated with Hylebos and Blair Waterways

SUBSTANCE OF CONCERN	LOCATION/SOURCES OF SUBSTANCES OF CONCERN (AFFECTED MEDIA)		BLAIR WATERWAY
	HEAD OF HYLEBOS WATERWAY	MOUTH OF HYLEBOS WATERWAY	
METALS/METALLOIDS			
Antimony	<ul style="list-style-type: none"> U.S. Gypsum Interiors (groundwater)^a 	<p>Not an identified substance of concern</p> <ul style="list-style-type: none"> Banyon Rail Services (storm water)^a 	<p>Not an identified substance of concern</p> <p>Source not identified</p>
Arsenic (unspeciated)	<ul style="list-style-type: none"> B&L Landfill (storm water, groundwater)^a Blair Backup Property (storm water)^a Elf Atochem Facility (groundwater)^a General Metals (storm water)^a Louisiana Pacific Log Yard (storm water)^a Murray Pacific Log Yard No. 1 (storm water)^a Tacoma Boatbuilding Co. Yard No. 1 (storm water)^a U.S. Gypsum interiors (groundwater)^a U.S. Gypsum Landfill (groundwater)^a Wasser Winters Log Yard (storm water)^a 	<p>Not an identified substance of concern</p>	
Cadmium	<ul style="list-style-type: none"> Don Oline Marine View Dr. Autofluff (storm water, sediments)^a 	<p>Not an identified substance of concern</p>	<p>Not an identified substance of concern</p>
Copper	<ul style="list-style-type: none"> B&L Landfill (storm water, groundwater)^a Blair Backup Property (storm water)^a Don Oline Marine View Dr. Autofluff (storm water sediments)^a 3009 Taylor Way Site (storm water)^a Elf Atochem Facility (groundwater)^a General Metals (storm water)^a Hylebos Marina (point source)^a Jones-Goodell (point source)^a Louisiana Pacific Log Yard (storm water)^a Modutech Marine, Inc. (storm water, sediments)^a Murray Pacific Log Yard No. 1 (storm water)^a Nordlund Boat Co. (point source)^a Tacoma Boatbuilding Co. Yard No. 1 (storm water)^a U.S. Gypsum Interiors (groundwater)^a Wasser Winters Log Yard (storm water)^a 	<ul style="list-style-type: none"> AK-WA Shipbuilding (storm water, process discharge)^a Banyon Rail Services (storm water)^a Brazier Forest Products (groundwater, storm water, sediments)^a Cascade Timber No. 1 (storm water)^a CMX Trucking (storm water, groundwater)^a Dick and Ole's Marina (storm water)^a Occidental Chemical (groundwater, sediments)^a Port of Tacoma storm drains (storm water, point source)^a Simon & Sons Rail and Locomotive Equipment (storm water, sediments)^a Sound Refining (storm water, point source) 	<p>Not an identified substance of concern</p> <p>Not an identified substance of concern</p>

Table 2-11. continued

SUBSTANCE OF CONCERN	LOCATION/SOURCES OF SUBSTANCES OF CONCERN (AFFECTED MEDIA)			BLAIR WATERWAY
	HEAD OF HYLEBOS WATERWAY	MOUTH OF HYLEBOS WATERWAY		
METALS/METALLOIDS (continued)				
Lead	<ul style="list-style-type: none"> B&L Landfill (storm water, groundwater)^a Blair Backup Property (storm water)^a Don Oline Marine View Dr. Autofluff (storm water, sediments)^a 3009 Taylor Way Site (storm water)^a General Metals (storm water)^a Louisiana Pacific Log Yard (storm water)^a Murray Pacific Log Yard No. 1 (storm water)^a Tacoma Boatbuilding Co. Yard No. 1 (storm water)^a U.S. Gypsum Interiors (groundwater)^a Wasser Winters Log Yard (storm water)^a 	<ul style="list-style-type: none"> AK-WA Shipbuilding (storm water, process discharge)^a Banyon Rail Services (storm water)^a Brazier Forest Products (groundwater, storm water, sediments)^a CMX Trucking (storm water, groundwater)^a Occidental Chemical (groundwater, sediments)^a Port of Tacoma storm drains (storm water, point source)^a 	Not an identified substance of concern	
Mercury	<ul style="list-style-type: none"> Mutual Fir Column^b (historical^c) Kaiser Ditch, source not identified^c Elf Alochem main outfall, storm drains, and bank seeps^{c,d} Storm drains, source not identified^c Hylebos Creek, source not identified^c 	<ul style="list-style-type: none"> Sound Refining main effluent^c Storm drains, source not identified^c 	Not an identified substance of concern	
Nickel	<ul style="list-style-type: none"> Don Oline Marine View Dr. Autofluff (storm water sediments)^a 	<ul style="list-style-type: none"> Banyon Rail Services (storm water)^a 	Not an identified substance of concern	
Zinc	<ul style="list-style-type: none"> B&L Landfill (storm water, groundwater)^a Blair Backup Property (storm water)^a Don Oline Marine View Dr. Autofluff (storm water, sediments)^a 3009 Taylor Way Site (storm water)^a General Metals (storm water)^a Hylebos Marina (point source)^a Jones-Goodell Corp. (point source)^a Louisiana Pacific Log Yard (storm water)^a Modutech Marine, Inc. (storm water, sediments)^a Murray Pacific Log Yard No. 1 (storm water)^a Nordlund Boat Company, Inc. (point source)^a Tacoma Boatbuilding Co. Yard No. 1 (storm water)^a U.S. Gypsum Interiors (groundwater)^a Wasser Winters Log Yard (storm water)^a 	<ul style="list-style-type: none"> AK-WA Shipbuilding (storm water, process discharge)^a Banyon Rail Services (storm water)^a Brazier Forest Products (groundwater, storm water, sediments)^a CMX Trucking (storm water, groundwater)^a Dick and Ole's Marina (storm water)^a Occidental Chemical (groundwater, sediments)^a Port of Tacoma Storm Drains (storm water, point source)^a Simon & Sons Rail and Locomotive Equipment (storm water, sediments)^a 	Not an identified substance of concern	

Table 2-11. continued

SUBSTANCE OF CONCERN	LOCATION/SOURCES OF SUBSTANCES OF CONCERN (AFFECTED MEDIA)		BLAIR WATERWAY
	HEAD OF HYLEBOS WATERWAY	MOUTH OF HYLEBOS WATERWAY	
ORGANIC COMPOUNDS			
Semivolatile Organic Compounds			
LPAH	<ul style="list-style-type: none"> Kaiser Aluminum and Chemical Corp. (storm water, process water)^a 	<ul style="list-style-type: none"> Source not identified, oil and grease noted at Banyon Rail Services^a Oil spills^e Sound Refining^{b,c} PRI Northwest^{b,c} Cenex^{b,c} Occidental Chemical Corp.^{b,c} Tacoma Public Utilities, Steam Plant No. 2^{b,c} 	Not an identified substance of concern
HPAH	<ul style="list-style-type: none"> Kaiser Aluminum and Chemical Corp. (storm water, process water)^a 	<ul style="list-style-type: none"> Source not identified, oil and grease noted at Banyon Rail Services^a Oil spills^c Sound Refining^{b,c} PRI Northwest^{b,c} Cenex^c Occidental Chemical Corp.^{b,c} 	Source not identified
PCBs	<ul style="list-style-type: none"> Don Oline Marine View Dr. Autofluff (storm water, sediments)^a General Metals (storm water)^a 	<ul style="list-style-type: none"> Brazier Forest Products (groundwater, sediments, historic soils)^a Port of Tacoma storm drains^{a,b} Occidental Chemical Seep No. 1^e Locomotive yards^e 	Not an identified substance of concern
Chlorinated benzenes	<ul style="list-style-type: none"> Elf Atochem outfall^{e,f} 	<ul style="list-style-type: none"> Occidental Chemical^a 	Source not identified
Chlorinated butadienes	<ul style="list-style-type: none"> Elf Atochem outfall^{e,f} 	<ul style="list-style-type: none"> Occidental Chemical^e 	Not an identified substance of concern
Phthalate esters	Source not identified	Not an identified substance of concern	Source not identified
Phenol	<ul style="list-style-type: none"> Found in Kaiser Ditch, source not identified^e Found in East Channel Ditch, source not identified^e 	<ul style="list-style-type: none"> Buffelen Woodworking (groundwater, sediments)^a Sound Refining (storm water, point source)^a 	Source not identified
Pentachlorophenol	Not an identified substance of concern	<ul style="list-style-type: none"> Buffelen Woodworking (sediments)^a 	Source not identified
Methylphenols	Not an identified substance of concern	<ul style="list-style-type: none"> Not an identified substance of concern 	Source not identified

Table 2-11. continued

SUBSTANCE OF CONCERN	LOCATION/SOURCES OF SUBSTANCES OF CONCERN (AFFECTED MEDIA)		
	HEAD OF HYLEBOS WATERWAY	MOUTH OF HYLEBOS WATERWAY	BLAIR WATERWAY
Methylphenanthrene	<ul style="list-style-type: none"> Kaiser Aluminum and Chemical Corp.^e 	Source not identified	Not an identified substance of concern
Benzyl alcohol	Source not identified	Source not identified	Not an identified substance of concern

^a **Source:** Head of Hylebos and Mouth of Hylebos Source Control Milestone Reports.

^b **Source:** Potential source, not confirmed.

^c **Source:** Tetra Tech (1985).

^d Elf Atochem indicates that the Tacoma plant has never used mercury cells in the production of chlor-alkali commodities, and Ecology has not identified mercury in plant waste water.

^e **Source:** Tetra Tech (1987).

^f Elf Atochem indicates that the Tacoma plant has never handled or produced chlorinated benzenes and butadienes.

Table 2-12. Sources of Substances of Concern Associated with Sitcum Waterway, Milwaukee Waterway, Middle Waterway, and the Ruston-Pt. Defiance Shoreline

SUBSTANCE OF CONCERN	LOCATION/SOURCES OF SUBSTANCES OF CONCERN (AFFECTED MEDIA)			
	SITCUM WATERWAY	MILWAUKEE WATERWAY	MIDDLE WATERWAY	RUSTON-PT DEFIANCE SHORELINE
METALS/METALLOIDS				
Antimony	Not an identified substance of concern	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> ASARCO Tacoma Smelter (surface water, groundwater, slag)^a
Arsenic (unspecified)	<ul style="list-style-type: none"> Port of Tacoma Terminal 7 (surface water, sediments)^d McFarland Cascade Pole (surface water, groundwater)^d Cascade Timber Log Sort Yard No. 3 (surface water)^{d,e} General Chemical (groundwater)^{d,e} Liquid Air Products (surface water)^{d,e} Norcore Plastics (surface water)^{d,e} Pacific Storage (surface water)^{d,e} South Intermodal Railroad (surface water)^{d,e} Sealand (surface water)^{d,e} Union Pacific Railroad (groundwater)^{d,e} 	Not an identified substance of concern	<ul style="list-style-type: none"> Maritime Industries (Cooks Marine Specialties, Foss Tug, Marine Industries NW)^{b,c} 	<ul style="list-style-type: none"> ASARCO Tacoma Smelter (surface water, groundwater, slag)^a ASARCO Tacoma Smelter (surface water, groundwater, slag)^a
Cadmium	Not an identified substance of concern	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> ASARCO Tacoma Smelter (surface water, groundwater, slag)^a
Copper	<ul style="list-style-type: none"> Port of Tacoma Terminal 7 (surface water, sediments)^d McFarland Cascade Pole (surface water, groundwater)^d Storm Drains SI-176 & SI-717, source not identified^f Cascade Timber Log Sort Yard No. 3 (surface water)^{d,e} General Chemical (groundwater)^{d,e} Liquid Air Products (surface water)^{d,e} Norcore Plastics (surface water)^{d,e} Pacific Storage (surface water)^{d,e} South Intermodal Railroad (surface water)^{d,e} Sealand (surface water)^{d,e} Union Pacific Railroad (groundwater)^{d,e} 	Not an identified substance of concern	<ul style="list-style-type: none"> Simpson Tacoma Kraft^{b,f} 	<ul style="list-style-type: none"> ASARCO Tacoma Smelter (surface water, groundwater, slag)^a ASARCO Tacoma Smelter (surface water, groundwater, slag)^a

Table 2-12. continued

SUBSTANCE OF CONCERN	LOCATION/SOURCES OF SUBSTANCES OF CONCERN (AFFECTED MEDIA)		
	SITCUM WATERWAY	MILWAUKEE WATERWAY	MIDDLE WATERWAY
METALS/METALLOIDS (continued)			
Lead	<ul style="list-style-type: none"> • Sound Battery (surface water)^d • Port of Tacoma Terminal 7 (surface water, sediments)^d • McFarland Cascade Pole (surface water, groundwater)^d • Storm Drains SI-176 & SI-717, source not identified^f • Cascade Timber Log Sort Yard No. 3 (surface water)^{d,e} • General Chemical (groundwater)^{d,e} • Liquid Air Products (surface water)^{d,e} • Norcore Plastics (surface water)^{d,e} • Pacific Storage (surface water)^{d,e} • South Intermodal Railroad (surface water)^{d,e} • Sealand (surface water)^{d,e} • Union Pacific Railroad (groundwater)^{d,e} 	Not an identified substance of concern	<ul style="list-style-type: none"> • Maritime Industries (Cooks Marine Specialties, Foss Tug, Marine Industries NW)^{b,c}
Mercury	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> • Maritime Industries (Cooks Marine Specialties, Foss Tug, Marine Industries NW)^{b,c} • Simpson Tacoma Kraft^f
Nickel	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> • ASARCO Tacoma Smelter (surface water, groundwater, slag)^a

Table 2-12. continued

SUBSTANCE OF CONCERN	LOCATION/SOURCES OF SUBSTANCES OF CONCERN (AFFECTED MEDIA)			RUSTON-PT DEFIANCE SHORELINE
	SITCUM WATERWAY	MILWAUKEE WATERWAY	MIDDLE WATERWAY	
METALS/METALLOIDS (continued)				
Zinc	<ul style="list-style-type: none"> Port of Tacoma Terminal 7 (surface water, sediments)^d McFarland Cascade Pole (surface water, groundwater)^d Cascade Timber Log Sort Yard No. 3 (surface water)^{d,e} Allied Chemical (historical; groundwater)^f Storm Drains SI-176 & SI-717, source not identified^f General Chemical (groundwater)^{d,e} Liquid Air Products (surface water)^{d,e} Norcore Plastics (surface water)^{d,e} Pacific Storage (surface water)^{d,e} South Intermodal Railroad (surface water)^{d,e} Sealand (surface water)^{d,e} Union Pacific Railroad (groundwater)^{d,e} 	Not an identified substance of concern	<ul style="list-style-type: none"> Maritime Industries Cooks Marine Specialties, Foss Tug, Marine Industries NW)^{b,c} 	<ul style="list-style-type: none"> ASARCO Tacoma Smelter (surface water, groundwater, slag)^a
ORGANIC SUBSTANCES				
Semivolatile Organic Compounds				
HPAH	<ul style="list-style-type: none"> Found in Storm Drain SI-172^d, all sources may not have been identified Collins Transport (surface water)^d Union Pacific Railroad (groundwater)^d McFarland Cascade Pole (surface water, groundwater)^d Oil spills^c Fire at Tacoma Boat (1970s)^c 	Not an identified substance of concern	Oil spills ^{b,c}	<ul style="list-style-type: none"> ASARCO Tacoma Smelter (surface soils)^a
HPAH	<ul style="list-style-type: none"> Found in Storm Drain SI-172^d, all sources may not have been identified Union Pacific Railroad (groundwater)^d McFarland Cascade Pole (surface water, groundwater)^d Oil spills^c Fire at Tacoma Boat (1970s)^c 	Not an identified substance of concern	Oil spills ^{b,c}	<ul style="list-style-type: none"> ASARCO Tacoma Smelter (surface soils)^a
PCBs	Not an identified substance of concern	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> ASARCO Tacoma Smelter (surface soils)^a

Table 2-12. continued

SUBSTANCE OF CONCERN	LOCATION/SOURCES OF SUBSTANCES OF CONCERN (AFFECTED MEDIA)			
	SITCUM WATERWAY	MILWAUKEE WATERWAY	MIDDLE WATERWAY	RUSTON-PT DEFIANCE SHORELINE
ORGANIC SUBSTANCES (continued)				
Semivolatile Organic Compounds				
Chlorinated benzenes	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> Storm drain, source not identified^d Simpson Tacoma Kraft^{b,f} 	Not an identified substance of concern
Phthalate esters	Not an identified substance of concern	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> ASARCO Tacoma Smelter (surface soils, surface water, groundwater)^a
Phenol	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> Wood products industries (Simpson Tacoma Kraft, Coast Kraft)^{b,i} 	Not an identified substance of concern
Pentachlorophenol	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> Simpson Tacoma Kraft^{b,f} Coast Kraft^{b,i} 	Not an identified substance of concern
Methylphenols	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> Spillover from Simpson (St. Paul Waterway)^{b,i} 	<ul style="list-style-type: none"> Wood wastes^{b,c}
Dibenzofuran	<ul style="list-style-type: none"> Oil spills^c Fire at Tacoma Boat (1970s)^c 	Not an identified substance of concern	Source not identified	<ul style="list-style-type: none"> ASARCO Tacoma Smelter (surface soils)^a

^a Source: Parametrix (1989a).

^b Source: Potential source, not confirmed.

^c Source: Tetra Tech (1987).

^d Source: Ecology (1991).

^e Source: Confirmed source of metals, the specific trace elements were not noted.

^f Source: Tetra Tech (1985).

Table 2-13. Sources of Substances of Concern Associated with St. Paul, Wheeler-Osgood, and Thea Foss Waterways

SUBSTANCE OF CONCERN	LOCATION/SOURCES OF SUBSTANCES(AFFECTED MEDIA)		
	ST. PAUL WATERWAY	WHEELER-OSGOOD WATERWAY	HEAD OF THEA FOSS WATERWAY
METALS/METALLOIDS			
Cadmium	Not an identified substance of concern	<ul style="list-style-type: none"> Found in storm drains, source not identified^b 	<ul style="list-style-type: none"> American Plating (historical)^{a,b} Found in storm drains, source not identified^b
Copper	<ul style="list-style-type: none"> Simpson Tacoma Kraitt^{c,d} 	<ul style="list-style-type: none"> Found in storm drains, source not identified^b 	<ul style="list-style-type: none"> Martinac Shipbuilding^{a,b} Tacoma Spur Coal Gasification^{a,b} American Plating (historical)^{a,b} Found in storm drains (Nalley Valley and South Tacoma drains), source not identified^{b,d}
Lead	Not an identified substance of concern	<ul style="list-style-type: none"> Found in storm drains, source not identified^b 	<ul style="list-style-type: none"> Martinac Shipbuilding^{a,b} Tacoma Spur Coal Gasification^{a,b} American Plating (historical)^{a,b} Abandoned Gas Station (groundwater)^{a,d} Petroleum storage tanks^{a,d} Found in storm drains (Nalley Valley and South Tacoma drains), source not identified^{b,d}
Mercury	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> American Plating (historical)^{a,b} Found in storm drains, source not identified^b
Nickel	<ul style="list-style-type: none"> Simpson Tacoma Kraitt^b 	Not an identified substance of concern	<ul style="list-style-type: none"> American Plating (historical)^{a,b} Found in storm drains, source not identified^b
Zinc	Not an identified substance of concern	<ul style="list-style-type: none"> Found in storm drains, source not identified^b 	<ul style="list-style-type: none"> Martinac Shipbuilding^{a,b} Tacoma Spur Coal Gasification^{a,b} American Plating (historical)^{a,b} Found in storm drains (Nalley Valley and South Tacoma drains), source not identified^{b,d}

Table 2-13. continued

SUBSTANCE OF CONCERN	LOCATION/SOURCES OF SUBSTANCES(AFFECTED MEDIA)		
	ST. PAUL WATERWAY	WHEELER-OSGOOD WATERWAY	HEAD OF THEA FOSS WATERWAY
ORGANIC SUBSTANCES			
Semivolatile Organic Compounds			
LPAH	<ul style="list-style-type: none"> Simpson Tacoma Kraft^b (naphthalene and 2-methylnaphthalene) 	<ul style="list-style-type: none"> Found in storm drains, source not identified^b Chevron^{a,b} Oil spills^{a,b} Marina fires^{a,b} Tar pits^{a,b} 	<ul style="list-style-type: none"> Found in storm drains, source not identified^b Chevron^{a,b} Oil spills^{a,b} Marina fires^{a,b}
HPAH	<ul style="list-style-type: none"> Not an identified substance of concern 	<ul style="list-style-type: none"> Found in storm drains, source not identified^b Chevron^{a,b} Oil spills^{a,b} Marina fires^{a,b} Tar pits^{a,b} 	<ul style="list-style-type: none"> Found in storm drains, source not identified^b Woodworth & CCo. Asphalt Plant^{a,d} Flick Foundry^{a,d} D St. Petroleum (groundwater)^{a,b} Oil spills^{a,b} Marina fires^{a,b}
PCBs	<ul style="list-style-type: none"> Not an identified substance of concern 	<ul style="list-style-type: none"> Not an identified substance of concern 	<ul style="list-style-type: none"> Source not identified
Chlorinated benzenes	<ul style="list-style-type: none"> Not an identified substance of concern 	<ul style="list-style-type: none"> Carstens Packing House^{a,b} Hygrade Foods^{a,b} 	<ul style="list-style-type: none"> Storm drains, source not identified^b
Chlorinated butadienes	<ul style="list-style-type: none"> Not an identified substance of concern 	<ul style="list-style-type: none"> Not an identified substance of concern 	<ul style="list-style-type: none"> Not an identified substance of concern
Phthalates	<ul style="list-style-type: none"> Not an identified substance of concern 	<ul style="list-style-type: none"> Not an identified substance of concern 	<ul style="list-style-type: none"> Not an identified substance of concern
Phenol	<ul style="list-style-type: none"> Simpson Tacoma Kraft^b 	<ul style="list-style-type: none"> Found in storm drains, source not identified^b Chevron^{a,b} Oil spills^{a,b} Marina fires^{a,b} Tar pits^{a,b} 	<ul style="list-style-type: none"> Found in storm drains, source not identified^b D St. Petroleum (groundwater)^{a,b} Oil spills^{a,b} Marina fires^{a,b}

Table 2-13. continued

SUBSTANCE OF CONCERN	LOCATION/SOURCES OF SUBSTANCES(AFFECTED MEDIA)			
	ST. PAUL WATERWAY	WHEELER-OSGOOD WATERWAY	HEAD OF THEA FOSS WATERWAY	MOUTH OF THEA FOSS WATERWAY
ORGANIC SUBSTANCES (continued)				
Semivolatile Organic Compounds				
Methyl phenols	<ul style="list-style-type: none"> Simpson Tacoma Kraft^b 	<ul style="list-style-type: none"> St. Regis Door Mill (historical)^{a,d} Tar pits^{a,b} Tacoma Spur Coal Gasification^{a,b} 	<ul style="list-style-type: none"> Union Pacific Railroad^{a,b} N. Pacific Plywood^{a,b} Harmon Cabinets^{a,d} Tacoma Spur Coal Gasification^{a,b} Storm drains^{a,b} 	Not an identified substance of concern
2-Methoxyphenol	<ul style="list-style-type: none"> Simpson Tacoma Kraft^b 	Not an identified substance of concern	Not an identified substance of concern	Not an identified substance of concern
Benzyl alcohol	Not an identified substance of concern	Not an identified substance of concern	<ul style="list-style-type: none"> Storm drains^{a,b} 	Not an identified substance of concern

^a Source: Potential source, not confirmed.

^b Source: Tetra Tech (1987).

^c Source: Ecology (1990).

^d Source: Tetra Tech (1985).

head of Hylebos Waterway. Additional information is included from the remedial investigation report (Tetra Tech, 1985) and the feasibility study assessing the potential success of source control (Tetra Tech, 1987).

Identified sources of contaminants for the head of Hylebos Waterway include log sort yards where slag from the ASARCO Tacoma Smelter was used as ballast. The Elf Atochem site was formerly occupied by the Pennwalt Corporation. Elf Atochem also owns property that was formerly a log sort yard. The Blair Backup Property is one of the Puyallup Tribe Land Settlement properties that has recently been cleaned up and includes the former Cascade Timber No. 2 Log Sort Yard site and the former Ohio Ferro-Alloy Plant (which manufactured chromium and ferrosilicate from about 1941 to 1971). The Kaiser Ditch is a drainage channel from the Kaiser Aluminum and Chemical Co; the ditch at one time received flow from plant settling ponds, process water sewers, and storm drains (Smith, personal communication 1993c).

2.3.2.2 Mouth of Hylebos Waterway

The list of problem chemicals for the head of Hylebos Waterway was also used when identifying sources to the mouth of the Hylebos Waterway (Ecology, 1992). Confirmed and potential sources of contaminants are listed in Table 2-11. The data are primarily from the CB/NT mouth of Hylebos Waterway milestone reports (Smith, personal communication 1993a; Ecology, 1992); any additional sources identified in the CB/NT remedial investigation report (Tetra Tech, 1985) or feasibility study assessment of the potential success of source control (Tetra Tech, 1987) were also included.

The PRI Northwest property was formerly owned by Fletcher Oil (a petroleum distributor) and may be contaminated with buried sludges from Occidental Chemical. The Occidental Chemical site was formerly occupied by Hooker Chemical Co.

2.3.2.3 Blair Waterway

A specific source investigation has not been conducted for Blair Waterway. Information about SOCs was taken from the remedial investigation report (Tetra Tech, 1985) (Table 2-11).

2.3.2.4 Sitcum Waterway

Confirmed and potential sources for contaminants measured in Sitcum Waterway sediments are listed in Table 2-12. These data are primarily from the CB/NT Sitcum Waterway source control status report (Ecology, 1991); any additional sources identified in the CB/NT remedial investigation report (Tetra Tech, 1985) or feasibility study assessment of the potential success of source control (Tetra Tech, 1987) were also included. The list of SOCs for Sitcum Waterway was taken from Tetra Tech (1987).

2.3.2.5 Milwaukee Waterway

Only a few SOCs have been identified for Milwaukee Waterway, although most of the exceedances were identified in an intertidal sample. No source investigation is expected for the Milwaukee Waterway.

2.3.2.6 Middle Waterway

The source investigation being conducted by Ecology has not been completed and current information is not yet available. SOCs were taken from the CB/NT feasibility study assessment of the potential success of source control (Tetra Tech, 1987). Potential sources identified are included in Table 2-12 (Tetra Tech, 1985; 1987).

2.3.2.7 St. Paul Waterway

The primary source of contaminants to the St. Paul Waterway has been identified as the Simpson Tacoma Kraft facility. The facility was formerly operated by Champion International and the St. Regis Paper Company. The source investigation determined that Simpson released copper, cyanide, and chloroform at concentrations of concern (Godbout, 1990). The Simpson facility was also determined to be a source of phenolic compounds, methylphenols, and methylated benzenes (Ecology, 1990). No other sources of contaminants were identified, but several saw mills and an industrial supply company are also located in the vicinity of the waterway. Dioxins were not tested by Ecology and hence were not discussed in source investigation documents.

SOCs in St. Paul Waterway identified during CB/NT sediment investigations are listed in Table 2-13. All SOC, except for diterpernoid hydrocarbons and retene, were identified as resulting from the Simpson Kraft plant (Tetra Tech, 1987).

2.3.2.8 Ruston-Pt. Defiance Shoreline

The ASARCO Tacoma Smelter has been identified as a source of contaminants measured in the Ruston-Pt. Defiance sediments (Parametrix, 1989a; Tetra Tech, 1987). No other sources of contaminants have been investigated or identified as a potential source, but industries, businesses, and dischargers include the Point Defiance Ferry Terminal, Tacoma Yacht Club, Point Defiance Park, Tacoma North Sewage Treatment Plant, Tacoma Fire Station # 5 Pier, and the Continental Grain Co. & Tacoma Elevator Wharf.

2.3.2.9 Wheeler-Osgood Waterway

The source investigation being conducted by Ecology has not been completed and current information is not yet available. SOC were taken from the CB/NT feasibility study assessment of the potential success of source control (Tetra Tech, 1987). Potential sources identified are included in Table 2-13 (Tetra Tech, 1985; 1987).

2.3.2.10 Head of Thea Foss (City) Waterway

A Source Control Milestone Report was not available for the head of Thea Foss Waterway. Sources for SOC listed in Table 2-13 were taken from the CB/NT remedial investigation report (Tetra Tech, 1985) and feasibility study assessment of the potential success of source control (Tetra Tech, 1987). Although many potential sources were noted, few sources were actually confirmed. The distribution of contaminants at the head of Thea Foss Waterway indicates that many of the contaminants are discharged by the twin 96-in. storm drain outfalls located there (Tetra Tech, 1987).

2.3.2.11 Mouth of Thea Foss (City) Waterway

A Source Control Milestone Report was not available for the mouth of Thea Foss Waterway. SOCs were taken from the CB/NT feasibility study assessment of the potential success of source control (Tetra Tech, 1987). Identified potential sources of SOCs are listed in Table 2-13.

2.4 TRANSPORT AND FATE OF SUBSTANCES OF CONCERN

Transport and fate are two major factors that control the distribution and bioavailability of SOCs in the environment. The transport of SOCs is controlled by the movement of the environmental media. If a particular substance is associated primarily with a single medium, its movement can be easily predicted from the movement of that medium. Once transported, the fate of SOCs is controlled by interactions with the natural media in the environment (i.e., air, water, and soils/sediments). These interactions, which can be predicted with reasonable accuracy for most substances, control the strengths of the association between the substance and the affected media, and the exchange among them. The sections below summarize relevant information regarding these two major factors, and then consider the potential transport scenarios for those substances.

2.4.1 Physical Transport Processes

The physical processes that affect the transport of SOCs in various media are discussed below.

2.4.1.1 Air Transport

Wind and Weather Patterns

Based on averages calculated in 1960, the prevailing wind direction in the Tacoma area is from the southwest during the storm season (between October and May) and from the north during the summer months (June to September) (Dames & Moore, 1981d). Local topography is expected to alter surface winds to some extent. The high bluffs on both the northern and southern sides of the bay tend to channel the winds along the long axis of the bay, adding a

stronger east-west component in the inner bay than noted in the main Puget Sound trough (Ebbesmeyer et al., 1986).

The highest wind speeds tend to be associated with the winter storms of November through January. Winter winds average 4-5 m/s, compared to average speeds of 2-3 m/s in summer (Ebbesmeyer et al., 1986). Seventy-five percent of the annual rainfall (about 40 in.) in the Commencement Bay area occurs in the winter between October and March (Dames & Moore, 1981d).

Air Quality Data

The Tacoma area has had a history of poor air quality, primarily associated with particulate matter and conventional pollutants (carbon monoxide, ozone, nitrogen dioxide, and sulfur dioxide) (PSAPCA, 1992). Limited studies of the atmospheric transport of the SOCs have been made; air samples from stations near the ASARCO Tacoma Smelter have been analyzed for lead and arsenic particulates (Anderson, personal communication 1993; Dames & Moore, 1981d). Since the 1970s, the methods for calculating exceedances for air quality parameters have changed. For example, in 1987, the national particulate matter standard was changed from measurement of total suspended particulates (TSP) to measurement of the particulate portion with diameters smaller than or equal to 10 micrometers (PM₁₀; the fraction of the TSP that is considered readily respirable by humans) (PSAPCA, 1992). The Puget Sound region is currently considered in attainment (i.e., compliance) of applicable standards for sulfur dioxide, lead, and nitrogen dioxide, but has been designated out of compliance with standards for particulate matter, carbon monoxide, and ozone (PSAPCA, 1992).

Air quality data have been collected since 1972 and are available from the Puget Sound Air Pollution Control Agency (PSAPCA). Annual data summary reports are prepared each year, but contain limited analysis of the data.

Sources and Quantity of Air Emissions

During the late 1970s, an increasing trend in the number of TSP violations was recorded in the Port of Tacoma area (at the Tacoma Fire Station, located between Sitcum and Blair Waterways (Dames & Moore, 1981d). Short-term state standards for sulfur dioxide were also

exceeded in Tacoma near Commencement Bay during this time period. Lead concentrations in the Tacoma area did not exceed air quality standards in the late 1970s.

A large portion of the airborne particulate matter, both past and current, is believed to result from crustal dust (Fry, personal communication 1993). The former ore unloading operation at E. 11th Street near the Tacoma Fire Station air monitoring station is believed to have been a source of occasional high maximum particulate concentrations (Fry, personal communication 1993). The ore unloading operation moved to another city in January 1991.

Quantities of pollutants released as air emissions from industrial sources in Commencement Bay were calculated based on information available in 1980 (Dames & Moore, 1981d). At that time, the major sources of particulates included the St. Regis Mill and the ASARCO Tacoma Smelter (Dames & Moore, 1981d). The ASARCO Tacoma Smelter is no longer in existence. The quantity of particulate matter released by industrial sources in 1980 was estimated to be about 3,200 metric tons per year. An estimated 75,000 metric tons per year of sulfur dioxide was released, primarily by ASARCO. It was estimated that industrial sources released 99 percent of point source emissions in the Commencement Bay area.

Using data from the late 1970s, the remedial investigation (Tetra Tech, 1985) estimated potential loadings of particulates to the waterways from airborne sources. Based on estimates that were considered likely to overestimate the actual deposition, the remedial investigation concluded that the contribution of particulate matter was negligible compared to that of runoff and riverine sources (Tetra Tech, 1985). Monitoring studies have indicated that source control efforts, as well as changes in the industrial base in the tideflat area, have been successful in reducing the atmospheric levels of particulates. During 1990 and 1991, Tacoma PM₁₀ annual averages showed a continued decrease from concentrations measured during the 1980s (PSAPCA, 1992). The reason for the recent reduction in airborne particulates in the Tacoma area has not been determined, but could be due to reductions in industrial emissions (Fry, personal communication 1993). The PSAPCA is currently negotiating emission limits with about 15 sources in the Commencement Bay area, including five large sources (Anderson, personal communication 1993). Significant reductions in emissions from pulp mills have been achieved by replacing old boilers (Anderson, personal communication 1993).

Only national air quality parameters are regularly monitored; however, testing for airborne arsenic was also conducted in the Tacoma area. Two studies conducted in the Tacoma area during 1974 and 1977 determined that the ASARCO Tacoma Smelter was the dominant source of ambient arsenic (Dames & Moore, 1981d). Between 1977 and 1979, airborne arsenic was measured at the ASARCO stack and parking lot; maximum daily concentrations measured at those locations were 14 and 52 $\mu\text{g}/\text{m}^3$, respectively (Dames & Moore, 1981d). In addition to arsenic, dust particles from the ASARCO site also contained other trace elements including antimony, chromium, copper, lead, and nickel (Parametrix, 1989a). Tests conducted for the ASARCO remedial investigation determined that arsenic comprised 5.3 percent of the fugitive dust migrating from the ASARCO site. Contamination in embayments within the windborne range of the smelter has been attributed to emissions of particulate-bound elements. As noted above, the winds are predominately from the south and north, and the windborne contamination appears to be consistent with that pattern, extending from Vashon Island at the north to Fox Island at the south, but with limited apparent impact in the bay itself (Crececius et al., 1975). Additional air particulate data were not collected for the ASARCO remedial investigation. Instead, air transport models were prepared and compared to data collected by the PSAPCA.

2.4.1.2 Groundwater Transport

Existing groundwater data are limited to information derived from early studies of the CB/NT site and to individual site investigations. At the time of the CB/NT remedial investigation, usable groundwater flow information had not been collected at the individual sites. Thus, a very general discussion of the groundwater regime was presented in the remedial investigation report (Tetra Tech, 1985), as summarized below.

The tidelflat area is underlain by three groundwater zones: shallow, perched groundwater in the fill deposits; a shallow water table aquifer; and a deeper, confined aquifer. The middle aquifer consists of sands varying from about 7 to 50 m in thickness. In some areas, this middle aquifer is separated from the fill by a silt layer typically 7-15 m thick, but in other areas the fill is directly in contact with the middle sands. The deep aquifer also consists of sands that are separated from the middle sands by a silt layer.

Depth to water in the fill and in the middle sands ranges from 0 to 3 m near the bay, extending to as deep as 17 m toward the southeastern portion of the port area. Flow volumes

in these water-bearing zones are unknown, but flow direction is expected to be toward the waterways. At sites where measurements have been made (see discussion below), groundwater was observed to discharge to the waterways. Flow near the surface is also known to be influenced by the tides, and flow reversal can occur near the shores of the waterways. Flow in the deep aquifer is confined by the deeper silt layer and is assumed to discharge at depth to Commencement Bay. As with the shallow zones, no flow rate estimates were available for the deep aquifer (Tetra Tech, 1985).

As part of site-specific remedial investigations, groundwater investigations at individual sites have been performed or are ongoing. Available data from these studies are summarized below:

Hylebos Waterway

- Kaiser Aluminum — From 1985 to 1987, HPAHs were measured in groundwater below the Kaiser facility at concentrations less than 10 $\mu\text{g/L}$ (Tetra Tech, 1988).
- U.S. Gypsum — Groundwater at this site is believed to be contaminated by waste from landfills or other practices. In 1982-1983, arsenic concentrations exceeded the drinking water standard of 0.05 mg/L at eight of the nine monitoring wells. Lead concentrations also exceeded the drinking water standard of 0.5 mg/L in some samples. Zinc and copper were also measured, but at concentrations below the drinking water standards of 5 and 1 mg/L, respectively (Tetra Tech, 1988).
- B&L Landfill — Studies indicate that landfill leachate was a source of metals contamination (Tetra Tech, 1988).
- Elf Atochem — In 1987, arsenic was measured in groundwater at concentrations greater than 1,000 mg/L. A groundwater plume extended to the northeast from the Pentite disposal area. Chlorinated hydrocarbons were also measured in a seep sample (Tetra Tech, 1988). The remedial investigation determined that arsenic was discharging to the waterway from the site at a rate of approximately 8-50 lbs/day (4-23 kg/day) (Smith, personal communication 1993c), but may have been discharging at a rate as low as 4 lbs/day. Remedial activities conducted under the Washington Model Toxics Control Act have removed contaminant sources within the Pentite disposal area.
- General Metals — PCBs were measured in 6 of 15 groundwater samples at concentrations ranging from 1.2 to 6.3 $\mu\text{g/L}$ (Sweet Edwards/EMCON, 1988; 1989); these concentrations are 40 to 210 times the marine chronic AWQC. Arsenic, copper, nickel, and zinc concentrations (dissolved) were measured in

groundwater samples from onsite monitoring wells at concentrations greater than the marine acute AWQC (Ecology, 1990a). Pentachlorophenol was also detected in one well at concentrations greater than the marine acute AWQC (Ecology, 1990a). Shallow groundwater was present in the unconsolidated fill at depths of less than 3 m (Ecology, 1990a).

- Occidental Chemical — During a Resource Conservation and Recovery Act (RCRA) investigation, chloroform, trichloroethene, tetrachloroethane, methylene chloride, vinyl chloride, 1,1-dichloroethene, trans-1,2-dichloroethene, carbon tetrachloride, 1,1,2,2-tetrachloroethane, and 1,1,2-trichloroethane were identified as SOCs in groundwater (Smith, personal communication 1993a). Groundwater was estimated to flow to the Hylebos Waterway at low tide. The groundwater flow rate at a depth of 50 feet was estimated to be 0.05 ft/day.

Ruston–Pt. Defiance Shoreline

- ASARCO Tacoma Smelter — At this site, a surface fill layer consisting of slag and granular fill, alluvium, and native beach deposits is underlain by an aquitard. Contaminated groundwater flows from source areas through the fill layer to Commencement Bay (Parametrix, 1989a). Considering tidal fluctuations, the net discharge of groundwater to the bay was estimated to be 6×10^{-3} L/s (0.09 gallons/minute) per meter of shoreline, which is approximately 6.6 L/s (105 gpm) along the plant area shoreline. Arsenic, copper, and zinc were measured in about 90 percent of the groundwater samples (unfiltered). Arsenic was measured at concentrations up to 31 mg/L (Parametrix, 1989a). Antimony, mercury, selenium, silver, and thallium were measured in groundwater samples at low frequency (less than 25 percent). Dimethylaniline was also measured in a few groundwater samples at concentrations up to 150 mg/L (Parametrix, 1989a).

2.4.1.3 Surface Water Circulation

Circulation in the main portion of Commencement Bay has received limited study (Ebbesmeyer et al. 1986; Baker and Walker, 1982; Curl et al., 1987). The major features of Commencement Bay include a very shallow surface layer (2-5 m thick) consisting of low-salinity water from the Puyallup River and a more uniform, saline deep layer. The surface layer is affected by tidal flows, but is also strongly affected by wind stress. During most of the year, the winds are dominantly from southerly directions, which tend to force the surface water into a weak counterclockwise movement. Under these conditions, the river plume moves to the north and west along the northern shore of the bay and across the mouths of the waterways lying to the north of the river mouth. During periods of winds from the north, which occur most frequently during the summer and early fall, the plume is probably forced

south, but this flow is less well documented. Aerial photographs and satellite imagery have shown the plume to be present in all areas of the bay. Transit of the plume across the bay and into the East Passage or into the Narrows appears to be fairly rapid, with an estimated travel time of a few days. Surface currents have been estimated from the hydraulic model to be about 14 cm/s (Ebbesmeyer et al., 1986)

The deeper waters of the bay are continuous with the East Passage water of the main basin of Puget Sound. Circulation is dominated by tidal flows, although the flows are also influenced by the longer-term changes in flow that occur in the main basin. Net flow in the deep waters is poorly established because of the short times that current measurements have been made, but the net movement appears to be slow. Baker and Walker (1992) reported that the flow in the deep water was clockwise and steady, with some indication of flow reversal (counterclockwise flow) in the very deep water. Tide-induced currents have been estimated to be about 5 cm/sec, but vary over the tidal cycle (Baker and Walker, 1982; Ebbesmeyer et al., 1986). These flows were thought to possibly reflect eddy currents from the adjacent tidal flows in the main basin, but it is not clear whether such circulation is the norm for the bay (Ebbesmeyer et al., 1986). These tidal currents are quite strong compared to many other deep-water areas of Puget Sound and are sufficient to induce substantial resuspension of the finer sediments of the deep bay. The limited measurements indicate that net flow was slow compared to the surface layer; it was estimated that it would take on the order of 3 weeks for a water parcel to traverse the long axis of the bay (Curl et al., 1987).

Circulation in the waterways has also been studied to a limited extent. Only one study (Loehr et al., 1981) was identified in the remedial investigation studies of circulation in the waterways. Since then, Ecology has initiated a program of limited monitoring of currents in the waterways. One of the major considerations to be drawn from these studies is that the circulation in the waterways is very complex and driven primarily by a combination of tidal flows and wind stress. The circulation described below has been derived from a limited series of studies. As a result, the generalities presented below must be considered with care.

Currents in the waterways, in general, varied longitudinally and with depth. Currents are generally stronger at the mouths of the waterways and decrease toward the heads in response to the greater amount of water that moves past points closer to the bay during a tide change. Flows near the bottom in the Hylebos Waterway decreased from speeds that were frequently greater than 10 cm/sec at the mouth to speeds that almost never exceeded 2 cm/sec at the

head (Norton and Barnard, 1992 a,b). Comparable speeds were measured at all depths in the 1980 drogoue studies. Similar speeds in near-bottom waters were observed in the Sitcum and City Waterways in the Ecology studies, although the current speeds near the mouths were generally less in the shorter waterways than in the Hylebos Waterway, probably reflecting the lesser volume of water that exchanges on each tide cycle in the smaller waterways. In the drogoue studies, the currents in all waterways were dominantly long-channel, but often had substantial cross-channel movements, a further indication of the variability of the flow, including the presence of eddies. In addition, the Loehr et al. (1981) study indicated that there were net inflows of surface and deep water to the waterways, with a balancing net outflow at mid depths. The Ecology studies (Norton and Barnard, 1992a,b) did not measure near surface circulation, nor did they calculate net flows.

As in the outer bay, surface flows in the waterways were found to be strongly influenced by winds. Opposing winds could reverse the tidal flows in the surface layer. In addition, the primary source of fresh water for the waterways, except perhaps the Hylebos Waterway, is from the Puyallup River. The effect of this input from the river is to create a pycnocline within a few meters of the surface that is strongest and deepest near the mouths of the waterway. Because the plume from the Puyallup River most frequently moves north upon discharge into the bay, the pycnocline may be steeper in the Milwaukee, Sitcum, Blair, and Hylebos Waterways than in those waterways lying southwest of the river. In the Hylebos Waterway, inputs from Hylebos Creek (and other sources) increase the freshwater component in the surface waters throughout the waterway. The density gradients thus created tend to diminish the mixing of surface and deeper waters. However, the salinity gradient (pycnocline) tends to diminish with increasing distance into the waterway, indicating the increased mixing of surface to deep waters within the waterways.

Exchange of water between each waterway and the outer bay has been estimated based on the volumes replaced with each tidal exchange (Loehr et al., 1981). The estimates were made based on two assumptions: 1) the new water coming in with each tide completely replaces the water in the waterway and 2) the incoming water completely mixes with the water present. The range of replacement times generated by these calculations is shown in Table 2-14.

Table 2-14. Flushing Rates of Commencement Bay Waterways

WATERWAY	FLUSHING RATE, DAYS (NO MIXING)	FLUSHING RATE, DAYS (COMPLETE MIXING)
Hylebos Waterway	1.8	10.3
Blair Waterway	0.5	4.2
Sitcum Waterway	3.0	16.1
Milwaukee Waterway	3.0	15.9
Middle Waterway	2.7	14.8
Thea Foss Waterway	1.5	9.1

Source: Loehr et al. (1981).

No actual measurements of the flushing rates in the waterways have been made, and it would be expected that specific hydrographic conditions, including tide heights, wind speed and direction, and freshwater inputs, would substantially affect the actual flushing rates. The flushing rates in Table 2-14 must therefore be considered only a rough guide to the actual exchange, primarily by indicating the relative amount of the water in the waterways that is exchanged on an average tide. Note, for example, that because the waterways are relatively deep and thus have large volumes compared to the tidal prism, the Sitcum, Milwaukee, and Middle Waterways are estimated to flush more slowly than the larger waterways. These data may be misleading for two reasons. First, flushing in the smaller waterways may be influenced by wind-induced circulation that could substantially alter the flushing rate. Second, the estimates above are averages for the whole waterway and do not reflect the complexity of flows that may occur. For example, it would be expected that actual flushing would be greatest near the mouths, where flows and water exchange are greatest, and least near the heads. Thus, water near the mouths may be entirely exchanged on most tide cycles, while water near the head may only be replaced slowly. These longitudinal differences have not been measured.

2.4.1.4 Sedimentation

Sedimentation in Commencement Bay and particularly in the waterways has received limited study, but is the subject of ongoing study by Ecology in association with the source control efforts.

Curl et al. (1987) deployed sediment traps in association with the current meters discussed in the last section. These traps established that sedimentation in the bay itself (outside of the waterways) was limited. Much of the suspended material in the deeper portions of the water column was considered to have originated from cycles of deposition and resuspension of bottom materials by tide flows. Most of this resuspension took place in a layer near the bottom in deep water, but tongues of higher-particulate water were also noted moving from the head of the bay at mid-depth, particularly from the Puyallup River area. This material also appears to be from the resuspension of bottom deposits associated with normal tide-induced currents, but the events may be more episodic than those occurring in the deep water (Baker and Walker, 1982). A large portion of the remainder of the particulate material originates with inflowing water from the main basin of Puget Sound. These data indicate that contaminants associated with particles settling in the outer bay would tend to distribute via resuspension over wide areas, including substantial transport out of the bay.

The major source of particulate matter to the bay is the Puyallup River, which discharges on the order of 500,000 metric tons of suspended particulate matter per year (Dexter et al., 1981). The discharge tends to be greater as the river flow increases, with higher concentrations of particulates present in the river during the spring snow-melt runoff. The mass of particulate material provided to the bay by the river has diminished as a result of the settling that takes place behind the dams in the upper portions of the watershed, but this decrease in particle loading has been balanced to some degree by increased erosion in the lower watershed caused by human disturbance of the soils from construction and agriculture.

The majority of the particulate matter in the plume is advected out of the bay in a thin surface layer (less than 5 m thick) (Curl et al., 1987). The particulate matter from the Puyallup River is carried with the advected river plume into the waterways (Curl et al., 1987; Loehr, 1981). As discussed in Section 2.4.1.3, the predominant direction of the plume after discharge is probably toward the north, with eventual transport northward around Browns Point into the main basin (Curl et al., 1987; Ebbesmeyer et al., 1986). The plume also moves south at least a portion of the time, responding primarily to wind stress from the north on the surface layers (Ebbesmeyer et al., 1986). Tide flow carries the plume into the waterways (Ebbesmeyer et al., 1986; Loehr et al., 1981).

Within the waterways, circulation and the transport and deposition of particulate matter are not well established. The limited rate of water movement in most of the waterways favors

the deposition of particulate matter, both from local sources and that diverted into the waterways by tidal flows. The heads of the waterways are particularly still, while near the mouths the tide-induced currents are sufficient to prevent substantial deposition (Norton and Barnard, 1992a,b). In addition, human activities can alter the deposition pattern. In particular, ship propeller disturbance (i.e., prop wash), as well as actual scraping of ships' hulls on the bottom, can resuspend and move sediments in the waterways. The latter effects depend on a number of variables and are difficult to predict especially because of the lack of data to document where such effects may be particularly important.

Sedimentation rates in the bay and in the waterways have been estimated by two independent techniques: dated cores and sediment traps. Dated cores collected by Crecelius et al. (1985) and by Link (1982) reported sedimentation rates of 0.7-1 cm/yr for the deeper portions of the bay. These measurements yielded an estimated mass accumulation rate of about 3.5 kg/m²/yr. Greater sedimentation rates are expected at the disposal sites and near the mouth of the Puyallup River, but rates have not been measured. Sediment traps deployed in the bay measured sedimentation rates of about 30 kg/m²/yr in the deep water, most of which was considered to be the result of resuspension (Baker et al., 1985). Sedimentation rates in the bulk of the water column, which may better reflect the net sedimentation, were about 1.8 kg/m²/yr.

In the waterways, a limited number of cores were collected as part of the feasibility study, intended to provide data to estimate the rate of "natural recovery" of the contaminated sediments. These data are summarized in Table 2-15. Because of the high level of human activity in the waterways, which can result in both the removal of sediments by dredging for navigation and episodic sediment inputs associated with shore development, actual sedimentation rates are likely to be variable within the waterways. However, because all of the waterways are basically straight basins, there is little reason to expect that morphological features will induce current anomalies that would create major erosional or shoaling areas. The general consistency of the sediment texture throughout the waterways is consistent with this conclusion.

Table 2-15. Sedimentation Rates Based on an Analysis of Sediment Cores for Various Areas Within Commencement Bay

WATERWAY	ESTIMATED SEDIMENTATION RATE	
	cm/yr	kg/m ² /yr
Hylebos Waterway		
Head	0.77	9.9
Mouth	1.77	25
Sitcum Waterway	1.65	24
St. Paul Waterway	0.70	10
Middle Waterway	0.27	4.3
Thea Foss Waterway		
Head	0.43	6
Wheeler-Osgood Waterway	0.31	3.8
Mouth	0.67	9.5
Ruston-Pt. Defiance Shoreline	<0.12	<2

Source: Tetra Tech (1988).

Ecology has recently initiated a waterway monitoring program involving the deployment of sediment traps (Norton and Barnard, 1992a,b). These traps are intended to monitor the concentrations of the SOCs on the particles in the waterways as a measure of how important are the local sources of those substances. The concentrations should decrease as the sources are controlled, reducing the overall inputs to the waterways. To date, sediment trap data are available for deployments in the Hylebos, Sitcum, and Thea Foss Waterways. The sedimentation rates indicated by these measurements are summarized in Table 2-16. As was the case with the sedimentation rate measured in the traps from deep in the outer bay, the data from the traps in the waterways was considered to indicate a substantial amount of resuspension of bottom materials. As a result, the trap-based estimates are assumed to overestimate the net sedimentation rate. Seasonal sampling indicated that sedimentation rates were higher in summer and early fall and lowest in winter and early spring. These trends are consistent with the general trend in sediment loading from the Puyallup River. Both of the measures of sedimentation were in substantial agreement and, even recognizing their limitations, can be used as estimates of the sedimentation rates in the waterways at the present time. Because more accurate sedimentation rates are needed in the future, additional measurements will probably be needed.

**Table 2-16. Sedimentation Rates Based
on Sediment Trap Data for Commencement Bay Waterways**

WATERWAY	ESTIMATED SEDIMENTATION RATE	
	cm/yr ^a	kg/m ² /yr ^a
Hylebos Waterway		
Head	1.4–7.2	9–38
Middle	0.9–5.4	7–34
Mouth	1.6–3.5	17–33
Sitcum Waterway	2.3–5.7	35

Source: Norton and Barnard (1992a,b).

^a Not corrected for resuspension.

Because flows are not strong in most areas and net flows tend to be into the waterways at both the surface and the bottom, the waterways are likely to be good sediment traps. With the major source of particulate matter outside of the waterways, net movement of sediments should be into the waterways. In addition, the greater tidal currents observed in the outer bay act to limit sedimentation in the deeper areas, and, in particular, the fine sediments of the Puyallup River plume appear to undergo very limited settling in the deeper waters of the outer bay. The distributions of the SOC_s are consistent with these patterns (i.e., contamination is limited to the sediments of the waterways, with much lower concentrations found in the sediments outside of the waterways and in the deeper bay). The obvious exception to this observation is the slag deposit near the ASARCO Smelter along the Ruston-Pt. Defiance Shoreline. Dense, coarse particles and large chunks of slag have been deposited over a large area of the nearshore and bottom slope zones near the smelter. The slag materials are too large and dense to be moved by the tidal currents in that area.

2.4.1.5 Anthropogenic Influences

The major alterations affecting circulation in the study area (and groundwater flow) and the potential transport of contamination are the dredge and fill operations that have formed the waterways from the old river delta and confined the Puyallup River to its present limited channel. These changes were discussed in detail in the cumulative change report (U.S. ACOE et al., 1993); the overall effect is summarized in Figure 2-1. Figure 2-1 depicts the general layout of the study area approximately as it is at present, and shows those locations where

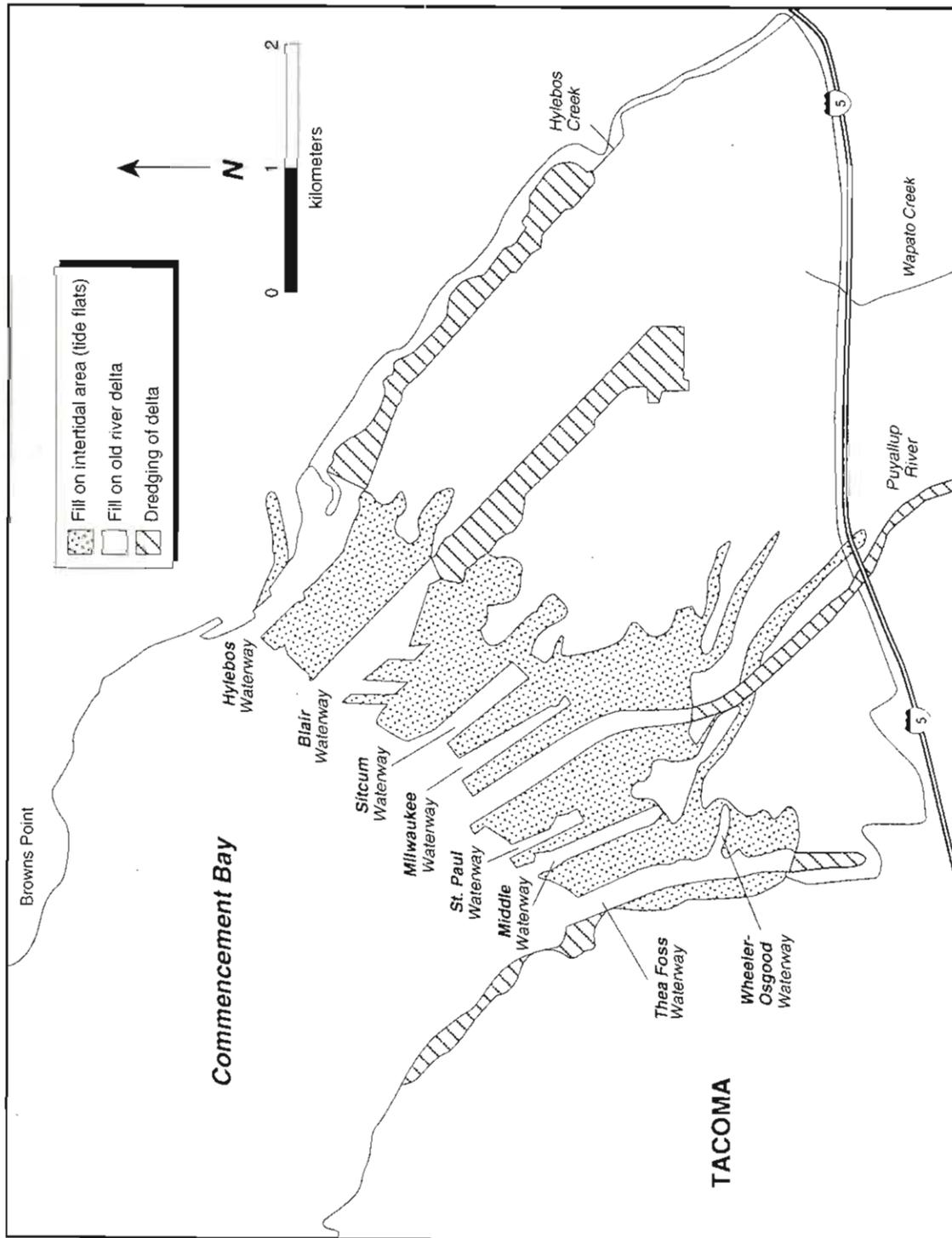


Figure 2-1. Summary of dredge and fill activities in the nearshore/industrial area.

the original delta was altered by filling (i.e., the outer portions of the land between the waterways and along the Ruston–Pt. Defiance Shoreline) and by dredging (i.e., the heads of the longer waterways). As noted in the cumulative impacts study (U.S. ACOE et al., 1993), some of the waterways have undergone additional and repeated dredging to allow deeper-draft ships to enter, to maintain the open channels, and to accommodate site-specific shoreline development projects. The major change for consideration, however, is simply the change from an open dendritic delta with extensive mud flats to a series of closed-ended waterways that provide relatively limited circulation and water exchange. The net effects of the morphology of the waterways are reduced circulation and the trapping of sediments. In addition, the channelization of the river has probably resulted in a greater movement of suspended and bedload sediments past the delta and into the bay itself. The coarser material continues to build the inner shelf slowly seaward at intermediate depths (along the 20-m contour), but most of the finer material is probably transported from the bay (although some is transported into and accumulates in the waterways). No change was identified that would be expected to significantly alter the wind speed or direction over the study area or bay. Groundwater flow has been modified by the filling and dredging in the port area and by groundwater withdrawal for potable and industrial use. No summary of the latter was available.

2.4.2 Fate of Substances of Concern

Major aspects of the environmental fate of the SOCs are summarized in Table 2-17. The factors have been divided into two major categories: 1) those affecting the transport *per se* (i.e., the strength of the association between the substances and the water, sediments, and particulate matter), and 2) factors such as the potential degradation and volatilization rates that affect the persistence of the substances in the natural system. For the general level of interpretation at this point in the assessment, the major considerations are whether the substance associates to a high degree with solid particles and hence tends to accumulate in the sediments and whether the substance is reasonably persistent under the normal conditions found in the study area.

Table 2-17. Summary of Transport and Fate Information for Substances of Concern

SUBSTANCE	TRANSPORT					FATE		
	SOLUBILITY	WATER/SEDIMENT PARTITIONING	WATER/BIOTA PARTITIONING	BIO-MAGNIFICATION	DEGRADATION	VOLATILIZATION	CHEMICAL REACTIVITY	PHOTOLYSIS
METALS/METALLOIDS								
Antimony	Insoluble; forms soluble compounds in natural waters that are quite mobile ^a	The formation of stibine in sediment beds may remobilize antimony		Minor ^a	Persistent	In reducing environments, such as sediment beds, volatile stibine (SbH ₃) may be formed; airborne transport as particulates may occur ^a	Present as the soluble oxide or antimonite (+3) salt in most natural waters ^a	
Arsenic	Occurs in natural systems as arsenate or arsenite, which are quite soluble	Generally mobile; cycles through the environment ^a	Metabolism by organisms to arsenical compound increases mobility in aquatic environment ^a	Minor ^a	Persistent	Although the vapor pressure of arsenic is negligible, arsine and methylated arsenic compounds are highly volatile ^b	Of four oxidation states, +3 and +5 are the most important; complexation by organic compounds is also important ^a	Not applicable ^b
Cadmium	Insoluble; cadmium salts are water soluble ^a	Relatively mobile in aquatic environment; sorbs to sediments and complexes with organic material ^a		Concentrates in biota, but does not biomagnify ^c	Persistent	Vapor pressure = 1mm Hg at 394 °C ^a	Hydrolysis product: Cd(OH) ⁺ ^b	Not applicable ^b
Copper	The most common salts are soluble in water; however, many copper salts are not ^a	Mobile, but adsorbs to organic matter, clays, and other material; organic acids may mobilize from sediments ^a	Biological factors are important in determining the distribution and occurrence of copper in the ecosystem ^a	Accumulates in plants and animals, but does not generally biomagnify ^a	Persistent	Atmospheric transport of copper compounds can occur; vapor pressure=1mm Hg at 1,628 °C ^a	Common oxidation states are +1 and +2; the speciation of copper in solution depends on pH, temperature, alkalinity, and chemicals organic and inorganic ligands ^a	Redox reactions can be photocatalyzed

Table 2-17. continued

SUBSTANCE	TRANSPORT				FATE			
	SOLUBILITY	WATER/SEDIMENT PARTITIONING	WATER/BIOTA PARTITIONING	BIO-MAGNIFICATION	DEGRADATION	VOLATILIZATION	CHEMICAL REACTIVITY	PHOTOLYSIS
METALS/METALLOIDS (continued)								
Lead	Some organic compounds are soluble; lead minerals and most naturally forming compounds are insoluble ^a	Strong partitioning to sediments results from adsorption to inorganic solids, organic materials, and hydrous iron and manganese oxides ^a	Biomethylation by microorganisms can remobilize lead into the environment ^a	Bioaccumulates in organisms, but does not biomagnify in the food chain ^a	Persistent	Probably not important in most aquatic environments ^a	Strongly complexed to organic materials ^a , lead is most soluble and bioavailable in aquatic environments with low pH, low organic matter, and suspended sediments ^d	Photolysis of lead compounds occurs in the atmosphere ^a , lead halides subjected to photolysis produce PbO
Mercury	Solubility depends on the chemical species (elemental, inorganic, or organic compounds); soluble in water = 81.3 µg/l at 30°C ^a	Adsorbs to sediments ^a	Can be remobilized by microbial conversion to methyl and dimethyl compounds ^a	Strongly bioaccumulated by organisms ^a	Persistent	Mercury can volatilize to the atmosphere from aquatic and terrestrial sources ^a , methylmercury is highly volatile ^b	Sorption is strongest to organic materials ^a , oxidation states are O, I, II; inorganic species are readily converted to methylmercury ^b	Photolysis breaks down airborne compounds and may be important in aquatic environments ^a
Nickel	Many nickel salts are highly soluble ^a	Highly mobile; sorption is decreased in organic-rich, polluted waters ^a		Not important ^a	Persistent	Not important; vapor pressure = 1 mm Hg at 1,810°C ^a	Almost always found in the divalent oxidation state in aquatic systems ^a	Not important ^a
Zinc	Some zinc salts are soluble ^a	Concentrations in sediments always exceed concentrations in ambient water; tends to desorb from sediments with increased salinity ^a		Strongly bioaccumulated but does not biomagnify ^a	Persistent	Vapor pressure = 1 mm Hg at 487°C ^a	Tends to be more readily sorbed at high pH than at low pH; sorbed by hydrous iron and manganese oxides, clay minerals, and organic material ^a	

Table 2-17. continued

SUBSTANCE	TRANSPORT				FATE			
	SOLUBILITY	WATER/SEDIMENT PARTITIONING	WATER/BIOTA PARTITIONING	BIO-MAGNIFICATION	DEGRADATION	VOLATILIZATION	CHEMICAL REACTIVITY	PHOTOLYSIS
ORGANIC COMPOUNDS								
Chlorine	Soluble in water (7.3 g/L at 20°C) ^a	Reacts with organic matter and oxidizable inorganic matter to form other compounds ^a			The presence of ammonia or amines can result in the formation of more persistent chloramines ^a	Volatilization can occur, producing HCl in the atmosphere; vapor pressure = 4,800 mm Hg at 20°C ^a	Reacts quickly to form HCl and HOCl in water; chloroform and other chlorinated hydrocarbons may be formed; "chlorine-produced oxidants" are formed in saltwater ^a	
Hexachlorobenzene (chlorinated benzenes)	Low water solubility (10 µg/L at 25°C) ^a	Sorbs to organic material in sediments; may desorb at times ^a		Bioaccumulates in organisms, but may not biomagnify in the food web ^a	Persistent in the environment	May be volatile because of high activity level in water and low water solubility; vapor pressure = 1x10 ⁻⁵ mm Hg at 20°C ^a		Photolysis is possible ^a
Hexachlorobutadiene (chlorinated butadienes)	Soluble in water (2 mg/L at 20°C) ^a	Binds to organic material in sediments ^a			Somewhat persistent ^a	Volatilization is an important transport process; vapor pressure = 0.15 mm Hg at 20°C ^a		
Naphthalene (LPAH)	Soluble in water (34.4 mg/L at 25°C) ^a	Strongly adsorbs to suspended and sedimentary particulates, especially those high in organic matter ^a		Bioaccumulation is probably short-term due to metabolism by many aquatic organisms ^a	Oxidation by chlorine or ozone may be significant where the oxidants are present ^a	Vapor pressure = 0.087 mm Hg at 25°C ^a . Volatilization is related to environmental conditions and mixing rates; atmospheric transport can occur ^a	Oxidation is probably too slow to be significant ^a	Photolysis of naphthalene to quinones may be important ^a

Table 2-17. continued

SUBSTANCE	TRANSPORT				FATE			
	SOLUBILITY	WATER/SEDIMENT PARTITIONING	WATER/BIOTA PARTITIONING	BIO-MAGNIFICATION	DEGRADATION	VOLATILIZATION	CHEMICAL REACTIVITY	PHOTOLYSIS
ORGANIC COMPOUNDS (continued)								
Pentachlorophenol	Solubility in water = 14 mg/L at 20°C; the sodium salt of pentachlorophenolate is highly soluble in water ^a	Has low mobility, but is more mobile than PAHs ^d		Fish and bivalves bioconcentrate pentachlorophenol ^d	Readily degrades in the environment by chemical, microbial, and photochemical processes ^d	Volatilization is not likely due to low vapor pressure (1.1×10^{-4} mm Hg at 20°C) ^a	Degradation occurs by oxidation and dechlorination ^d	Irradiation by sunlight or ultraviolet light produces degradation products ^d
Phenol	Soluble in water (93,000 mg/L at 25°C)	Sorption is not an important fate process ^a		Bioaccumulation is probably not important ^a	Biodegradation can be significant in aquatic systems ^a	May volatilize from surface waters to the atmosphere; vapor pressure = 0.3513 mm Hg at 25°C ^a	May be oxidized in highly aerated waters that contain iron and copper ^a	Photo-oxidation may be important ^a
Bis(2-ethylhexyl) phthalate (phthalate esters)	Solubility in water = 0.4 mg/L at 25°C ^a	Adsorbs to suspended solids and particulates, and complexes with natural organic substances ^a	Uptake by unicellular and multicellular organisms occurs	Biomagnification is possible due to high K_{ow} ^a	Relatively persistent ^a	Probably not important; vapor pressure = 2×10^{-7} mm Hg at 20°C ^a		Not important ^a
LPAH	Relatively insoluble in water ^a	Strongly adsorbs to suspended particulates, especially those high in organic carbon ^a		Although rapidly accumulated, most marine organisms (other than bivalve molluscs and some crustaceans) rapidly metabolize and excrete ^{a,c}	Does not degrade under anaerobic conditions; will degrade under aerobic conditions, but rates vary ^a			

Table 2-17. continued

SUBSTANCE	TRANSPORT					FATE		
	SOLUBILITY	WATER/SEDIMENT PARTITIONING	WATER/BIOTA PARTITIONING	BIO-MAGNIFICATION	DEGRADATION	VOLATILIZATION	CHEMICAL REACTIVITY	PHOTOLYSIS
ORGANIC COMPOUNDS (continued)								
HPAH	Relatively insoluble in water ^a	Strongly adsorbs to suspended particulates, especially those high in organic carbon ^a		Although rapidly accumulated, most marine organisms (other than bivalve molluscs and some crustaceans) rapidly metabolize and excrete ^{a,c}	Persistent, but can be degraded slowly by microbes ^a	Not volatile; atmospheric transport occurs by airborne particulate matter ^a	Oxidation by chlorine and ozone may occur ^a	Dissolved compounds may undergo rapid photolysis ^a
PCBs	Low water solubility (0.003–0.6 mg/L) ^a	Adsorbs to organic material in sediments ^a	Stored in adipose (fat) tissues of organisms ^a	Bioaccumulates in organisms and can be biomagnified ^a	Persistent; chlorine content and chlorine substitution patterns affect degradation	Vapor pressure = 10 ⁻³ to 10 ⁻⁵ mm Hg at 20°C; a high activity coefficient in water causes a higher rate of volatilization than would be expected ^a		Can be slowly photolyzed by ultraviolet light ^a
Polychlorinated dibenzo- <i>p</i> -dioxins (PCDDs)	Insoluble in water ^a	Most PCDDs will be sorbed to particulates ^a	Stored in adipose (fat) tissues of organisms ^a	Bioaccumulates, although some compounds are metabolized	Persistent; certain microorganisms will degrade PCDDs ^a	Vapor pressure = 10 ⁻⁶ mm Hg at 25°C ^a		Does not undergo photodegradation unless solvents are present that act as hydrogen donors ^a
2,3,7,8-Tetra-chlorodibenzo- <i>p</i> -dioxin	Low solubility in water (0.2 µg/L at 20°C) ^a	Highly sorbed to sediments; will be sorbed to particulates in water ^a	Has a strong tendency to accumulate in lipid tissue	Bioaccumulates	Relatively persistent	Vapor pressure = 10 ⁻⁶ mm Hg at 25°C ^a		

Table 2-17. continued

SUBSTANCE	TRANSPORT				FATE			
	SOLUBILITY	WATER/SEDIMENT PARTITIONING	WATER/BIOTA PARTITIONING	BIO-MAGNIFICATION	DEGRADATION	VOLATILIZATION	CHEMICAL REACTIVITY	PHOTOLYSIS
ORGANIC COMPOUNDS (continued)								
Tetrachloroethylene	Solubility in water = 150 to 200 mg/L at 20°C ^a	Adsorbs to organic materials ^a		Can be bioaccumulated to some degree ^a		Rapidly volatilizes to the atmosphere; vapor pressure = 14 mm Hg at 20°C ^a	Reacts in the atmosphere with hydroxyl radicals to produce HCl, CO, CO ₂ , and carboxylic acid ^a	
Trichloroethene	Solubility in water = 1,000 mg/L at 20°C ^a	Adsorbs to organic materials ^a ; not expected to significantly sorb to sediments, although it is detected in sediments ^b	Not expected to partition to aquatic biota ^b	Can be bioaccumulated to some degree ^a	Biodegradation occurs under both aerobic and anaerobic conditions; biodegradation products include other chlorinated alkenes (e.g., cres- and trans-1,2-dichloroethylene) ^d	Rapidly evaporates from surface water to the atmosphere; vapor pressure = 60 mm Hg at 20°C ^{a,b}	Reacts in the atmosphere with hydroxyl radicals to produce HCl, CO, CO ₂ , and carboxylic acid ^a	

^a Source: Clement Associates (1985).

^b Source: Kadeg et al. (1992).

^c Source: Mearns et al. (1991).

^d Source: Eisler, R. Series of reports on chemical hazards to fish, wildlife, and invertebrates. Patuxent Wildlife Research Center, U.S. Fish and Wildlife Service, Laurel, MD.