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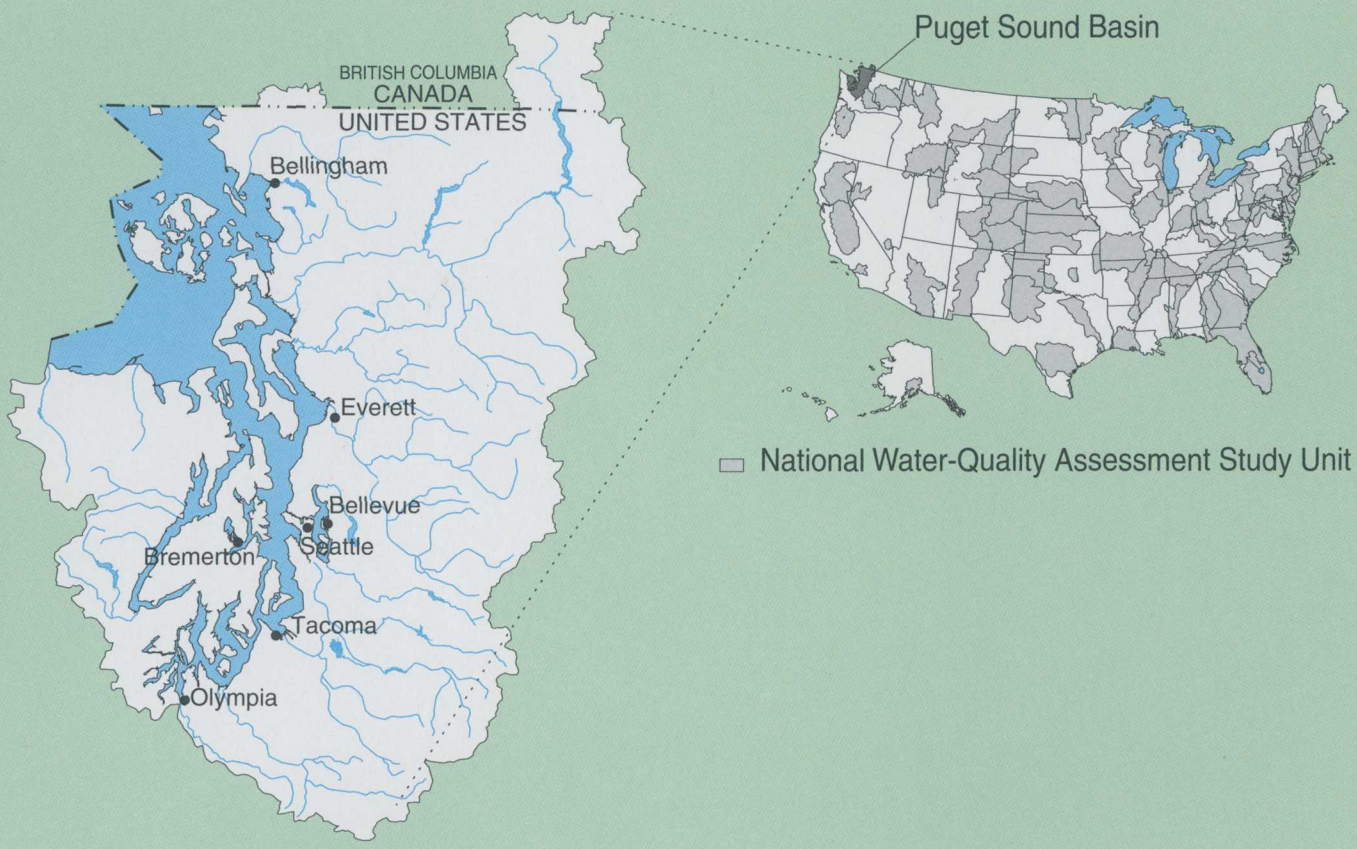
By G. C. Bortleson and J. C. Ebbert



U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 00-4118

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Water-Resources Investigations Report 00-4118

Tacoma, Washington
2000

U.S. DEPARTMENT OF THE INTERIOR
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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.

- Describe how water quality is changing over time.

- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of more than 50 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within these study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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Occurrence of Pesticides in Streams and Ground Water in the Puget Sound Basin, Washington, and British Columbia, 1996-98

By G. C. Bortleson and J. C. Ebbert

ABSTRACT

This report discusses the occurrence of pesticide compounds in surface and ground water in the Puget Sound Basin. The findings are based on data collected in 1996-1998 by the U.S. Geological Survey National Water-Quality Assessment Program, and by a separate U.S. Geological Survey study in 1994 of pesticide occurrence in public water-supply wells.

A widespread detection of pesticide compounds was observed in surface waters of the Puget Sound Basin. Fifty-five percent of the 47 pesticide compounds analyzed were detected in surface water, and 17 percent were detected in ground water. The herbicides atrazine, prometon, simazine, and tebuthiuron were among the most frequently detected in both surface and ground water. The number of pesticide compounds found in ground water influenced by agricultural, urban, and mixed land uses was far fewer than surface water influenced by the same land uses.

Herbicides were the most common type of pesticide found in a small agricultural stream, and herbicides were the only type of pesticide found in shallow ground water underlying agricultural land. Compared with small urban streams and large rivers, the highest number of individual pesticide compounds were detected in the agricultural stream. Insecticides, in addition to herbicides, were detected frequently in urban streams. Sampled urban streams showed the highest detection frequencies for the insecticides carbaryl, Diazinon, and malathion. Concentrations of Diazinon, the most common of the insecticides detected, exceeded chronic criteria for protection of aquatic life in streams influenced by agricultural, urban, and mixed land uses. On the other hand, insecticides were not detected in shallow ground water underlying urban residential areas. A relatively few herbicides, atrazine, prometon, and simazine, and the transformation product of atrazine, desethylatrazine, were detected at frequencies of 7 percent or less in shallow ground water in urban residential areas.

Seven pesticide compounds were detected at relatively high frequencies of 20 percent or more in large rivers draining mixed land use. In contrast, seven pesticide compounds in ground water from mixed land use were detected at lower frequencies of 15 percent or less. Most ground water, including shallow ground water, had no detections of pesticide compounds. In basin-wide sampling of ground water representing mixed land use, only two herbicides, atrazine and simazine, were detected in deep ground water from a single well. The concentrations of all pesticides detected in shallow and deep ground water did not exceed drinking water standards or guidelines.

INTRODUCTION

From 1996 to 1998, the U.S. Geological Survey (USGS) conducted studies to assess the occurrence of pesticides in surface and ground water in the Puget Sound Basin (fig. 1). Herbicides are used to control weeds in areas such as agricultural fields, lawns, and roadsides. Insecticides are used to control insects, mostly in agricultural and urban settings. Previous studies have indicated that the detection of pesticides in small urban streams in the heavily populated Puget Sound Basin is widespread, and pesticides found in waters are generally those that are most commonly used (Bortleson and Davis, 1997; Voss and others, 1999). This report provides a discussion of pesticide occurrence in streams and ground water in the Puget Sound Basin. For more information about the environmental setting and the factors that affect water quality in the Puget Sound Basin, see Staubitz and others (1997).

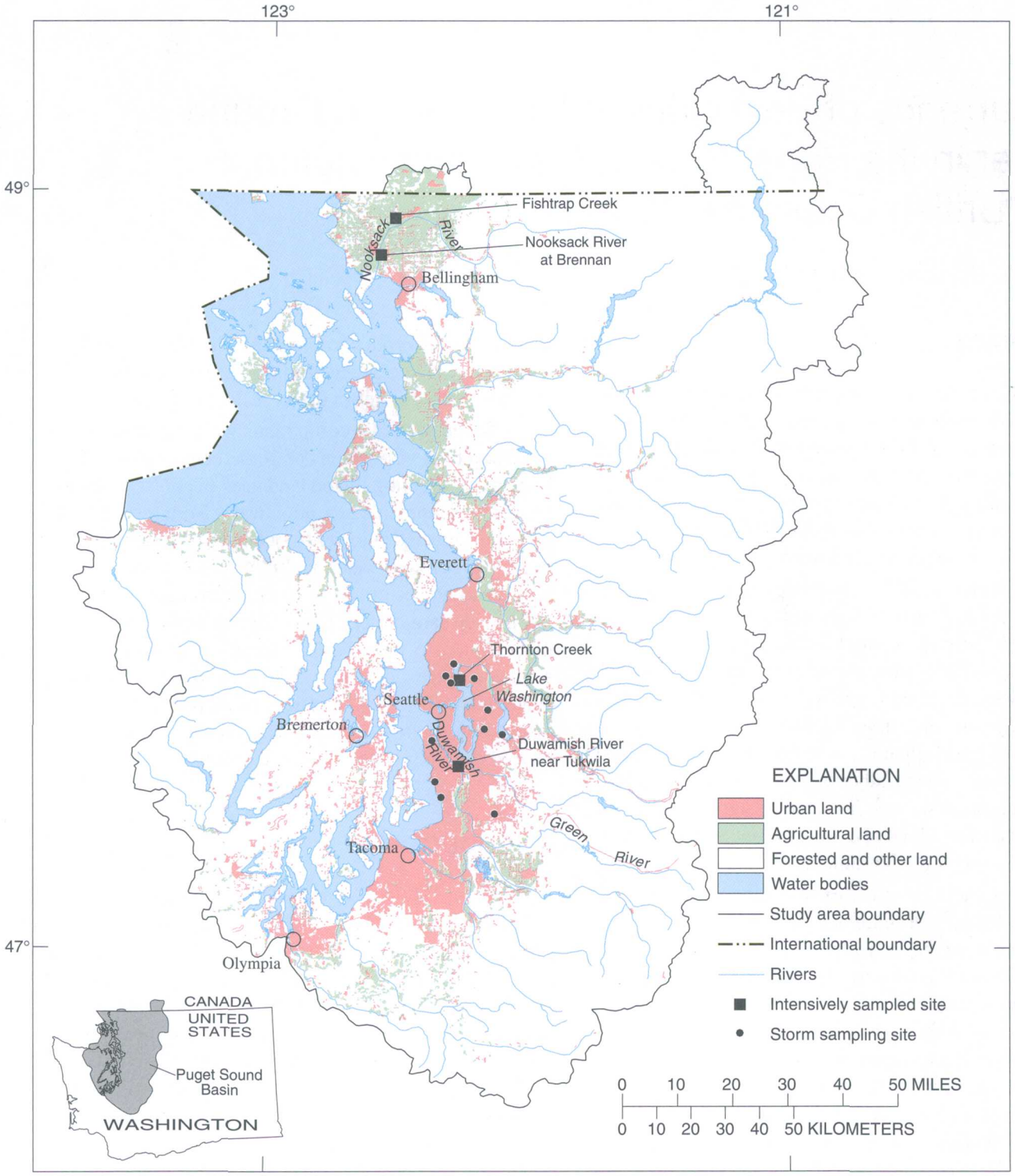

Figure 1. Surface-water sites sampled by the U.S. Geological Survey's National Water-Quality Assessment Program in the Puget Sound Basin.

STUDY DESIGN AND METHODS

This study was designed to obtain data on the spatial distribution and occurrence of pesticides in streams and ground water at different sampling scales in the Puget Sound Basin. Surface- and ground-water samples were analyzed for 43 pesticides and 4 transformation products (table 1). This suite of 47 pesticide compounds, which was analyzed for in all samples, allows for a comparison of pesticides detected among small streams, large rivers, and shallow and deep ground water within different land uses.

It should be noted that for most of the ground-water samples, an additional suite of pesticide compounds was collected and analyzed as part of the National Water-Quality Assessment (NAWQA) study, but for purposes of consistency of comparison in this study, only the single suite of 47 pesticide compounds is discussed in this report. All the pesticides measured during the NAWQA study are presented in other reports (see http://wa.water.usgs.gov/ps.pub.html).

Surface-Water Sampling

Two sampling approaches were used to determine the occurrence of pesticides in streams of the Puget Sound Basin. One approach was to sample four streams intensively over a period ranging from 1 to 2 years; they included two small streams and two large rivers (fig. 1). The small streams were Thornton Creek, an urban stream draining to Lake Washington, and Fishtrap Creek, an agricultural stream draining to the Nooksack River. The two large rivers were sampled at downstream sites draining mixed land uses. The Nooksack River at Brennan drains mostly forest in the uplands and mostly agricultural land in the lowlands. The Duwamish River near Tukwila, which was sampled in an urban setting, drains mostly forest in the uplands and mixed land uses in the lowlands (fig. 1). The two small streams and two large rivers were sampled monthly and during storms for a total of about 18 samples per site per year. Except for Thornton Creek, samples at the other three sites were collected from March 1996 through April 1997. Thornton Creek was sampled from March 1996 through May 1998.

In addition to the 4 streams sampled intensively, 10 small urban streams (fig. 1) were sampled for pesticides from 2 to 4 times each during periods of spring storm runoff in 1998. Thornton Creek shown in figure 1 was sampled at three locations, one of which was an intensively sampled site. The streams were all sampled over a short time period during spring storms when the largest number of pesticides are likely to be transported in surface runoff and detected in streams (Voss and others, 1999).

Ground-Water Sampling

Ground water was sampled at local and basin-wide scales (fig. 2). Locally, ground water was sampled from 27 wells in urban residential areas near Tacoma and Olympia and 22 wells in an agricultural area of the Nooksack River Basin (fig. 2). These wells were installed at depths ranging from 20 to 137 feet deep in coarse-grained glacial deposits, where pesticide infiltration to the water table is more likely than fine-grained deposits (fig. 3).

In a basin-wide survey of ground-water quality, 30 existing domestic wells (fig. 2), with well screens finished in coarse-grained glacial deposits, were randomly selected for sampling with the aid of a computer model (Scott, 1990). These wells were deeper than the urban residential and agricultural wells but still relatively shallow, often between 40 and 80 feet deep (fig. 3). Although not part of the NAWQA study, data from 78 public water-supply wells sampled for pesticides in 1994 are included in this report. These wells were sampled by the USGS as part of a cooperative project with the State of Washington Department of Health (Ryker and Williamson, 1996). Most of the sampled wells were deeper than 100 feet (fig. 3), and they are generally less vulnerable to contamination from pesticides than shallow wells. It should be noted that some of the public water-supply wells and domestic wells are within the areas where wells were installed to sample ground water in urban and agricultural areas (fig. 2).

Sampling and Analytical Methods

Methods of collecting surface- and ground-water samples are described by Wagner and Roberts (1998). After collection, about 1 liter of sample water was filtered through a 0.7-micrometer glass-fiber filter, and pesticides were extracted from the filtrate by pumping it through a solid-phase extraction cartridge as described by Shelton (1994). Filtration and extraction of most samples were done in the field immediately after collection; however, some of the samples

Table 1. Pesticide detections in surface and ground water in the Puget Sound Basin
[µg/L, micrograms per liter; H, herbicide; I, insecticide; T, transformation product; D, detected; --, not detected]

Pesticide	Trade or common name(s)	Type of pesticide	Chemical Abstract Services registry number	Method detection limit (µg/L)	Sample type	
					Surface water	Ground water
Acetochlor	Guardian	H	15972-60-8	0.002	D	--
Alachlor	Lasso	H	15972-60-8	0.002	D	--
Atrazine	AAtrex	H	1912-24-9	0.001	D	D
Azinphos-methyl	Guthion	I	86-50-0	0.001	--	--
Benfluralin	Balan, Benefin	H	1861-40-1	0.002	--	--
Butylate	Sutan +, Genate Plus	H	2008-41-5	0.002	--	--
Carbaryl	Sevin, Savit	I	63-25-2	0.003	D	--
Carbofuran	Furadan	I	1563-66-2	0.003	D	--
Chlorpyrifos	Lorsban, Dursban	I	2921-88-2	0.004	D	--
Cyanazine	Bladex	H	21725-46-2	0.004	--	--
DCPA	Dacthal	H	1861-32-1	0.002	D	D
p,p'-DDE	none	T	72-55-9	0.006	--	D
Desethylatrazine (DEA)	none	T	6190-65-4	0.002	D	D
Diazinon	Diazinon	I	333-41-5	0.002	D	--
Dieldrin	Panoram D-31	I	60-57-1	0.001	--	--
2,6-Diethylanaline	none	T	579-66-8	0.003	--	--
Disulfoton	Di-Syston	I	298-04-4	0.017	--	--
EPTC	Eptam, Eradicane	H	759-94-4	0.002	D	--
Ethalfluralin	Sonalan, Curbit EC	H	55283-68-6	0.004	--	--
Ethoprop	Mocap	I	13194-48-4	0.003	D	--
Fonofos	Dyfonate	I	944-22-9	0.003	--	--
alpha-HCH	none	T	319-84-6	0.002	--	--
gamma-HCH	Lindane	I	58-89-9	0.004	D	--
Linuron	Lorox, Linex	H	330-55-2	0.002	D	--
Malathion	malathion	I	121-75-5	0.005	D	--
Methyl parathion	Penncap-M	I	298-00-0	0.006	--	--
Metolachlor	Dual, Pennant	H	51218-45-2	0.002	D	--
Metribuzin	Lexone, Sencor	H	21087-64-9	0.004	D	--
Molinate	Ordram	H	2212-67-1	0.004	D	--
Napropamide	Devrinol	H	15299-99-7	0.003	D	D
Parathion	several	I	56-38-2	0.004	--	--
Pebulate	Tillam	H	1114-71-2	0.004	D	--
Pendimethalin	Prowl, Stomp	H	40487-42-1	0.004	--	--
cis-Permethrin	Ambush, Pounce	I	57608-04-5	0.005	--	--
Phorate	Thimet, Rampart	I	298-02-2	0.002	--	--
Prometon	Pramitol	H	1610-18-0	0.018	D	D
Pronamide	Kerb	H	23950-58-5	0.003	D	--
Propachlor	Ramrod	H	1918-16-7	0.007	--	--
Propanil	Stampede	H	709-98-8	0.004	--	--
Propargite	Comite, Omite	I	2312-35-8	0.013	D	--
Simazine	Aquazine, Princep	H	122-34-9	0.005	D	D
Tebuthiuron	Spike	H	34014-18-1	0.01	D	D
Terbacil	Sinbar	H	5902-51-2	0.007	D	--
Terbufos	Counter	I	13071-79-9	0.013	--	--
Thiobencarb	Bolero	H	28249-77-6	0.002	--	--
Triallate	Far-Go	H	2303-17-5	0.001	--	--
Trifluralin	Treflan, Trilin	H	1582-09-8	0.002	D	--

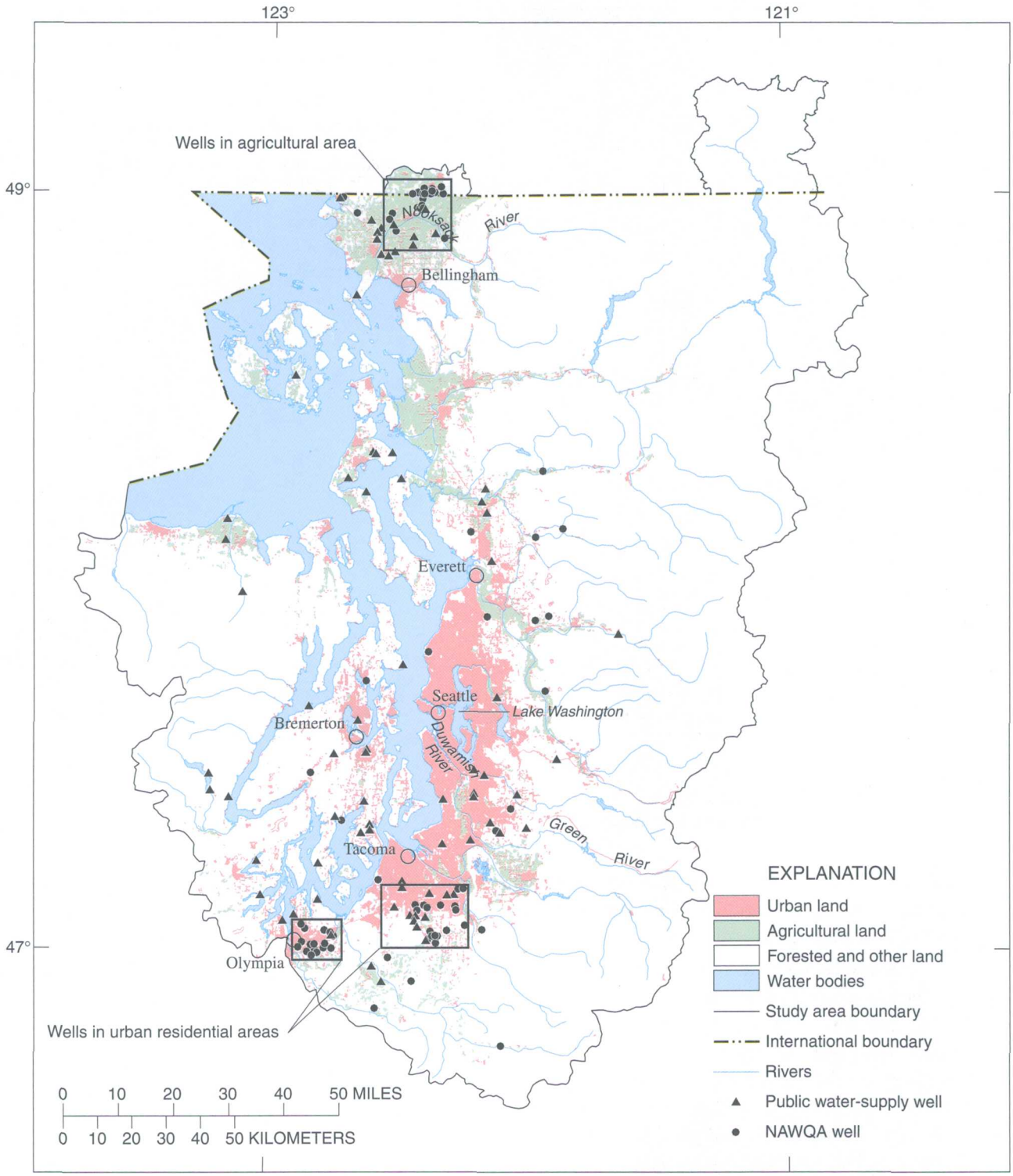

Figure 2. Ground-water sites sampled by the U.S. Geological Survey's National Water-Quality Assessment Program in the Puget Sound Basin.

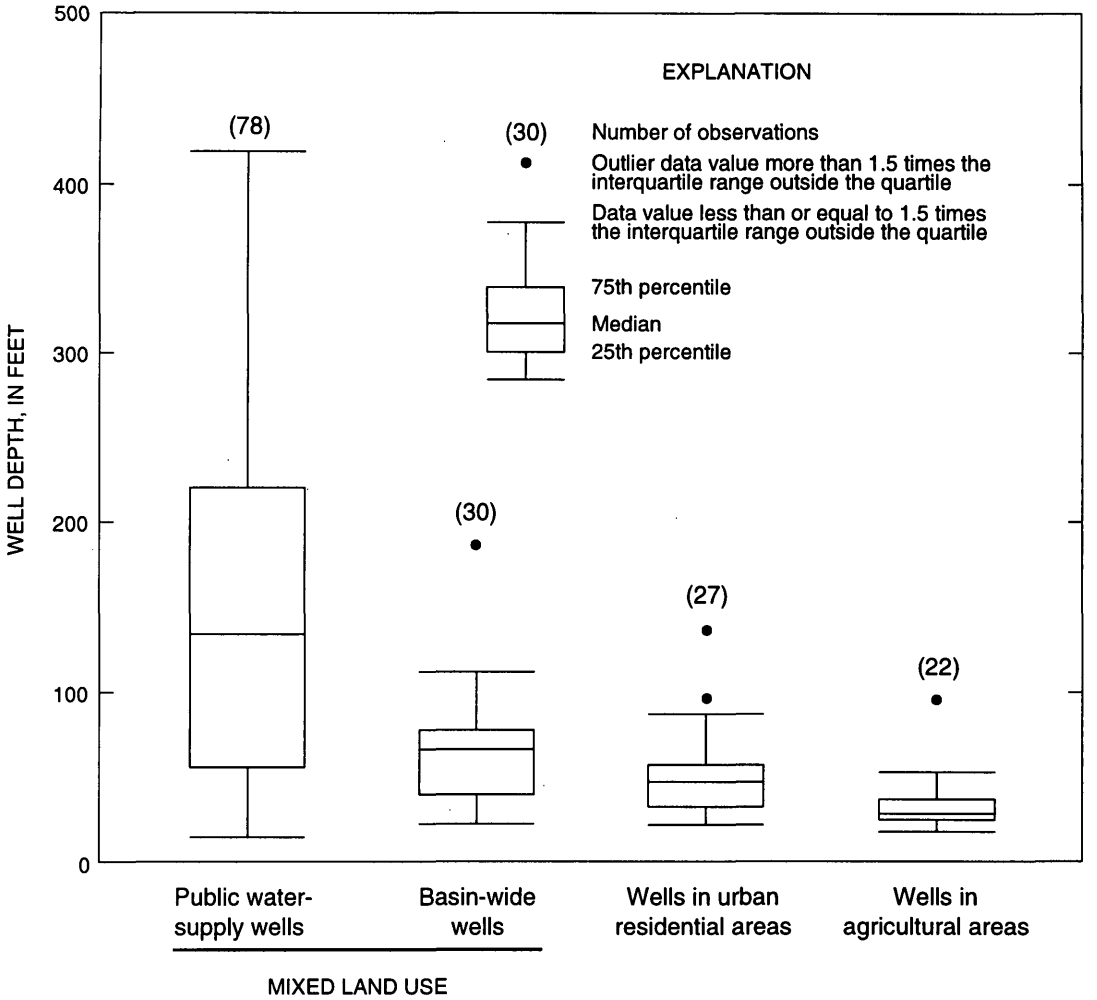

Figure 3. Depths of sampled wells. Two values for public supply wells (612 feet and 1,240 feet) not shown.

collected from public water-supply wells were shipped on ice to the USGS National Water Quality Laboratory (NWQL) for filtration and extraction.

Samples were analyzed for 47 pesticide compounds at the NWQL using gas chromatography and mass spectrometry (Zaugg and others, 1995). The compounds and method detection limits in micrograms per liter are shown in table 1. Quality assurance included the analysis of blank, spiked, and replicate samples. Results indicated good laboratory performance and no sample contamination.

PESTICIDE OCCURRENCE IN SURFACE AND GROUND WATER

Slightly more than one half of the pesticide compounds (26 of 47 analyzed) were detected in surface water, indicating a widespread presence of pesticides in waters of the Puget Sound Basin. As expected, more pesticide compounds were detected in streams than in ground water, due in large part to adsorption and degradation of pesticides in soil and sediment as water infiltrates to ground water. Of the 47 pesticide compounds of interest, 55 percent were detected in streams and 17 percent were detected in ground water. Atrazine, prometon, simazine, and tebuthiuron are commonly used herbicides in the Puget Sound Basin (Tetra Tech Incorporated, 1988; Bortleson and Davis, 1997; and Majewski, 1997), and these four herbicides were the most frequently detected in both streams and ground water (table 2). Furthermore, atrazine, prometon, simazine, and tebuthiuron also are among the most frequently detected herbicides in streams and ground water nationwide (Gilliom and others, 1999).

Table 2. Pesticide detections in surface and ground water by land use
[H, herbicide; I, insecticide; T, transformation product; NAWQA, USGS National Water-Quality Assessment Program]

		Pesticide detections, as a percentage of total number of samples (Number of detections in parentheses)					
		Agricultural land use		Urban land use		Mixed land use	
Pesticide	Type of pesticide	Small stream (Fishtrap Creek)	Shallow ground water	Small streams	Shallow ground water	Large rivers	Public water-supply and NAWQA basin-wide wells
Acetochlor	H	12 (4)	0	1 (1)	0	2 (1)	0
Alachlor	H	6 (2)	0	0	0	0	0
Atrazine	H	97 (31)	41 (9)	45 (36)	7 (2)	63 (29)	15 (17)
Carbaryl	I	9 (3)	0	20 (16)	0	0	0
Carbofuran	I	3 (1)	0	0	0	0	0
Chlorpyrifos	I	0	0	6 (5)	0	0	0
DCPA	H	6 (2)	0	1 (1)	0	0	1 (1)
p,p'-DDE	T	0	0	0	0	0	3 (3)
Desethylatrazine (DEA)	T	97 (31)	45 (10)	5 (4)	4 (1)	24 (11)	11 (13)
Diazinon	I	44 (14)	0	84 (67)	0	20 (9)	0
EPTC	H	19 (6)	0	4 (3)	0	0	0
Ethoprop	I	6 (2)	0	0	0	2 (1)	0
gamma-HCH (Lindane)	I	0	0	10 (8)	0	0	0
Linuron	H	9 (3)	0	0	0	0	0
Malathion	I	3 (1)	0	21 (17)	0	4 (2)	0
Metolachlor	H	44 (14)	0	9 (7)	0	41 (19)	0
Metribuzin	H	6 (2)	0	0	0	0	0
Molinate	H	3 (1)	0	0	0	0	0
Napropamide	H	22 (7)	4 (1)	9 (7)	0	2 (1)	0
Pebulate	H	6 (2)	0	0	0	2 (1)	0
Prometon	H	69 (22)	0	91 (73)	4 (1)	35 (16)	4 (5)
Pronamide	H	3 (1)	0	1 (1)	0	4 (2)	0
Propargite	I	0	0	0	0	2 (1)	0
Simazine	H	97 (31)	36 (8)	45 (36)	4 (1)	59 (27)	7 (8)
Tebuthiuron	H	66 (21)	14 (3)	5 (4)	0	33 (15)	2 (2)
Terbacil	H	6 (2)	0	0	0	2 (1)	0
Trifluralin	H	3 (1)	0	11 (9)	0	0	0
Total number of sites		1	22	12	27	2	108
Number of sites with compounds detected		1	12	12	3	2	22
Total number of samples		32	22	80	27	46	108
Number of compounds detected		24	5	17	4	15	7

The transformation product of atrazine, desethylatrazine (DEA), was detected in ground water and streams influenced by all land uses. Both atrazine and DEA are relatively soluble and often coexist if water is contaminated with the parent herbicide compound, atrazine (Larson and others, 1997). On the other hand, a transformation product of DDT, *p,p'*-DDE, was detected in ground water but not in streams. The parent compound DDT is not readily soluble in water, and if detected in the aquatic environment, it is usually found attached to bed sediment or in fish (U.S. Geological Survey, 1999a). Although DDT has been banned for use in the United States, it is not unusual for the relatively soluble *p,p'*-DDE to be detected in ground water (Barbash and Resek, 1996).

Agricultural Land Use

Herbicides were the most common type of pesticide found in Fishtrap Creek (an agricultural stream, fig. 1) and were the only type of pesticide found in shallow ground water beneath agricultural areas (table 2). The five herbicides, atrazine, metolachlor, prometon, simazine, tebuthiuron, and the transformation product DEA were detected in more than 40 percent of the samples from Fishtrap Creek (table 2). Atrazine, simazine, and DEA were found at lower detection rates (36-45 percent) in shallow ground water underlying agricultural land. The insecticide Diazinon was found in 44 percent of the samples from Fishtrap Creek, but it was not found in shallow ground water.

Overall, about one half of the 47 pesticide compounds analyzed were detected in Fishtrap Creek (table 2). The high frequency of pesticide detections in Fishtrap Creek is related to agricultural as well as urban influences. An urban influence exists from nearby towns in the basin, even though Fishtrap Creek is located primarily in an agricultural setting. For example, simazine, prometon, and tebuthiuron are considered primarily urban herbicides (U.S. Geological Survey, 1999a), but they were detected at high frequencies in Fishtrap Creek. In particular, prometon is not applied to cropland, so its presence in streams is due to nonagricultural applications. Also, the insecticide Diazinon was detected at a high frequency in Fishtrap Creek, but it is not detected at a high frequency in most agricultural settings, compared to urban settings nationwide (Gilliom and others, 1999; U.S. Geological Survey, 1999a).

Urban Land Use

In addition to herbicides, insecticides were detected frequently in urban streams. Sampled urban streams showed the highest detection rates for the three insecticides carbaryl, Diazinon, and malathion (table 2). Diazinon and malathion are among the most frequently used insecticides in the Puget Sound Basin (Tetra Tech Incorporated, 1988; Majewski, 1997). Other insecticides detected less often were chlorpyrifos and lindane. Insecticides are commonly used for home, garden, and commercial purposes in urban areas. The more frequent occurrence of insecticides in urban streams, compared with agricultural streams, is common throughout the United States (Gilliom and others, 1999). The herbicides atrazine, prometon, and simazine also were detected at high frequencies in small urban streams (table 2).

A relatively few pesticide compounds were detected at frequencies of 7 percent or less in shallow ground water of urban residential areas. DEA and the herbicides atrazine, prometon, and simazine, were the same as those most frequently detected in urban streams. Insecticides were not detected in shallow ground water below urban residential land.

Mixed Land Use

Seven pesticide compounds, atrazine, Diazinon, metolachlor, prometon, simazine, tebuthiuron, and DEA, were detected in large rivers at frequencies of 20 percent or greater. Large rivers integrate the effects of urban and agricultural influences, as well as those of upland forests. The integration of influences is shown by the fact that 14 of the 15 pesticides detected in large rivers were the same group of pesticides detected in either urban or agricultural streams (table 2).

Ground water from domestic and public water-supply wells sampled basin-wide represent water from mixed land-use sources. With two exceptions, the pesticides detected in domestic and public water-supply wells were the same as those in shallow ground water underlying agricultural or urban land; however, all the pesticides in ground water sampled basin-wide were detected at frequencies of 15 percent or less (table 2). One reason detection rates of pesticides in samples from domestic and public water-supply wells sampled basin-wide were low is because many of these wells are deeper than wells sampled in agricultural and urban areas (fig. 3).

Comparison of Shallow and Deep Ground Water

The domestic and public water-supply wells sampled basin-wide were divided into shallow and deep wells. Fifty-one wells over 100 feet deep were designated as deep wells, and 106 wells less than or equal to 100 feet deep were designated as shallow wells (table 3).

Only two herbicides, atrazine and simazine, were detected in a single deep well. However, a total of eight pesticide compounds were detected in shallow wells (table 3). In the shallow wells, atrazine and DEA were the only pesticide compounds detected at relatively high frequencies. Simazine was detected at the third highest frequency in shallow ground water.

EXTENT OF PESTICIDE CONTAMINATION AND POSSIBLE CONCERNS

The data indicate that, in all the streams and rivers sampled, multiple pesticides occur. The number of pesticides detected in streams and rivers ranged from 3 to 23, and the most common number detected was 6 (fig. 4). Of most concern, especially in small streams, are the effects on aquatic life, as none of the small streams sampled is a source of drinking water for humans.

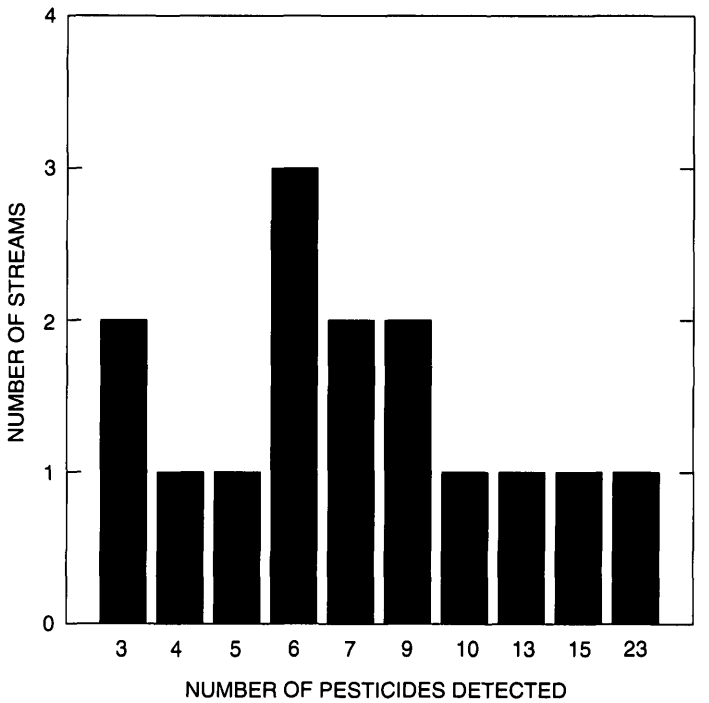

Figure 4. Number of pesticide detections per stream. Numbers not shown were zero detections.

Table 3. Pesticide detections in shallow and deep water
[≤, less than or equal to; >, greater than; H, herbicide; T, transformation product]

Pesticide	Type of pesticide	Pesticide detections, as a percentage of total number of samples (Number of detections in parentheses): Shallow ground water (≤100 feet)	Deep ground water (>100 feet)
Atrazine	H	25 (27)	2 (1)
DCPA	H	1 (1)	0
Desethylatrazine (DEA)	T	23 (24)	0
p,p'-DDE	T	3 (3)	0
Napropamide	H	1 (1)	0
Prometon	H	6 (6)	0
Simazine	H	15 (16)	2 (1)
Tebuthiuron	H	5 (5)	0
Total number of samples		106	51
Number of compounds detected		8	2

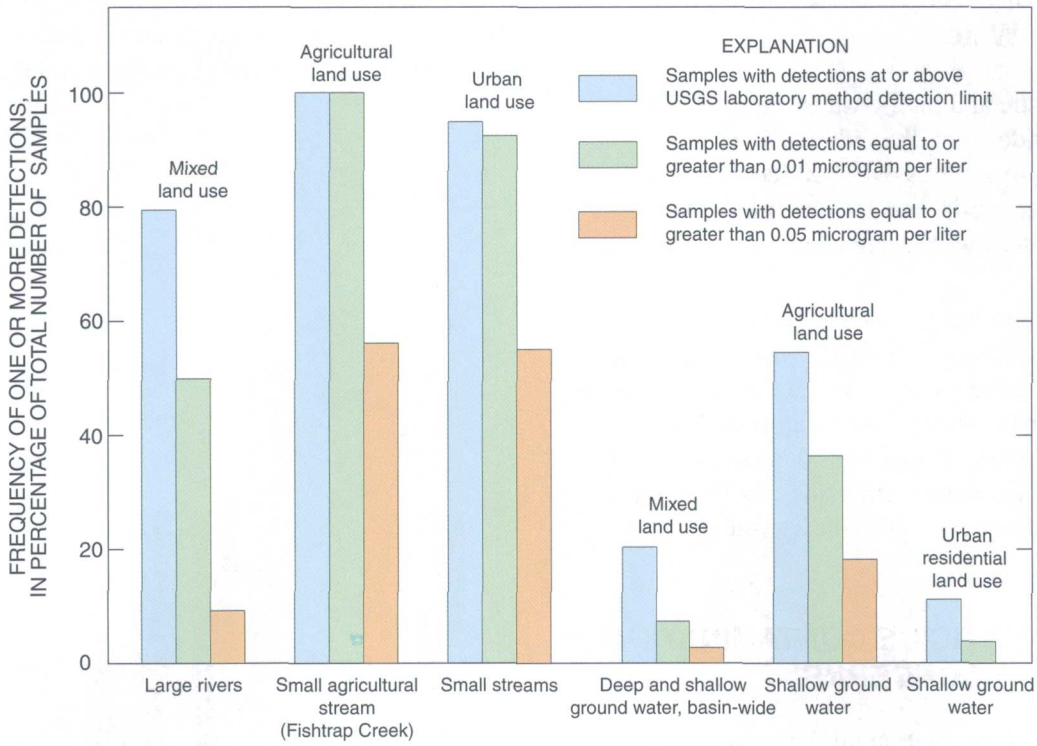

Figure 5. Pesticide detections in surface and ground water.

The frequency of detecting one or more pesticides in individual samples was highest for Fishtrap Creek, an agricultural stream with some urban influence, followed by urban streams, and then large rivers draining mixed land use (fig. 5). By showing detection frequencies at the method detection limit (see table 1) and at two arbitrary reporting limits, 0.01 and 0.05 micrograms per liter, information about relative concentrations can be obtained from figure 5. For example, concentrations of pesticides equal to or greater than 0.05 micrograms per liter were found in only about 10 percent of the samples from large rivers, compared with 50 percent for urban and agricultural streams, indicating the relatively lower concentrations in large rivers. At least three pesticide compounds were found in each sample collected from Fishtrap Creek, while about 5 percent of samples from urban streams and 20 percent of samples from large rivers contained no pesticides (fig. 6). Pesticides transported to the large rivers are diluted by the volume of water in the rivers and by high-quality water from forested headwaters.

Thirteen of the 26 pesticide compounds detected in surface water have aquatic-life criteria established by the U.S. Environmental Protection Agency or other agencies. Minimum and maximum concentrations of pesticides found in small streams and large rivers are shown in table 4 if the chronic criteria for the protection of aquatic life have been established for the compound. Three insecticides, chlorpyrifos, Diazinon, and lindane, exceeded aquatic-life criteria in a total of six occurrences (table 4). Concentrations of Diazinon, the most common insecticide detected, exceeded aquatic-life criteria in streams influenced by agricultural, urban, and mixed land use. The maximum concentrations for chlorpyrifos, Diazinon, and lindane were 0.074, 0.501, and 0.095 micrograms per liter, respectively.

In contrast to streams, most ground water, including shallow ground water, contained no pesticides (fig. 7). Additionally, the frequency of detecting one or more pesticides in individual ground-water samples was lower than that for streams and rivers (fig. 5), and fewer pesticide compounds were found in ground-water samples (fig. 6). Ground water sampled

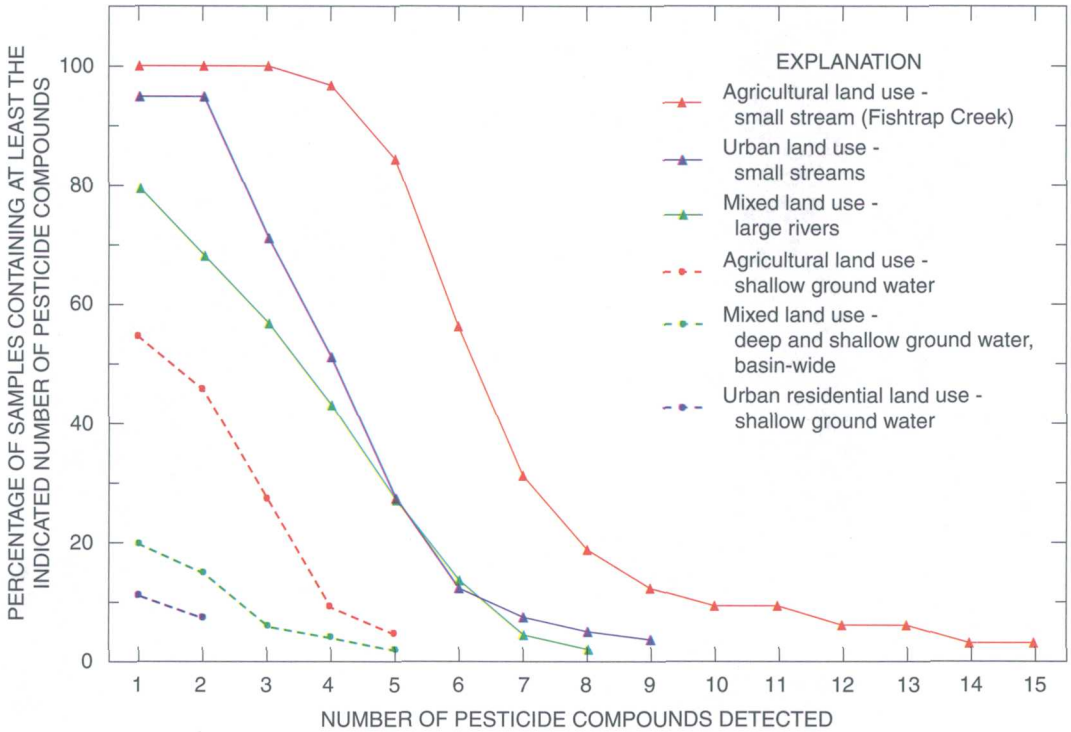

Figure 6. Frequency of one or more pesticide detections in surface and ground water.

Table 4. Minimum and maximum concentrations of pesticides in surface water, and chronic criteria for the protection of freshwater aquatic life

[Chronic criteria are from U.S. Geological Survey (1999b); concentrations are in micrograms per liter; **bold** type indicates value above criterion; H, herbicide; I, insecticide; e, estimated value; nd, not detected]

Pesticide	Type of pesticide	Chronic criteria	Agricultural stream		Concentration range for urban streams		Large rivers	
			Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Atrazine	H	1.8	0.012	1.4	e 0.002	0.021	e 0.003	0.042
Carbaryl	I	0.2	e 0.074	e 0.133	e 0.003	e 0.046	nd	nd
Carbofuran	I	1.8	e 0.005	e 0.005	nd	nd	nd	nd
Chlorpyrifos	I	0.041	nd	nd	0.006	**0.074**	nd	nd
Diazinon	I	0.08	e 0.004	**0.113**	e 0.003	**0.501**	e 0.004	**0.083**
Lindane	I	0.01	nd	nd	**0.019**	**0.095**	nd	nd
Linuron	H	7	0.03	0.32	nd	nd	nd	nd
Malathion	I	0.1	0.025	0.025	0.01	0.087	e 0.003	e 0.005
Metolachlor	H	7.8	e 0.002	0.037	0.004	0.141	e 0.002	0.013
Metribuzin	H	1	0.012	0.025	nd	nd	nd	nd
Simazine	H	10	e 0.004	1	e 0.002	5	e 0.003	0.194
Tebuthiuron	H	1.6	e 0.003	0.095	0.025	0.03	e 0.003	0.087
Trifluralin	H	0.2	0.005	0.005	e 0.002	0.007	nd	nd

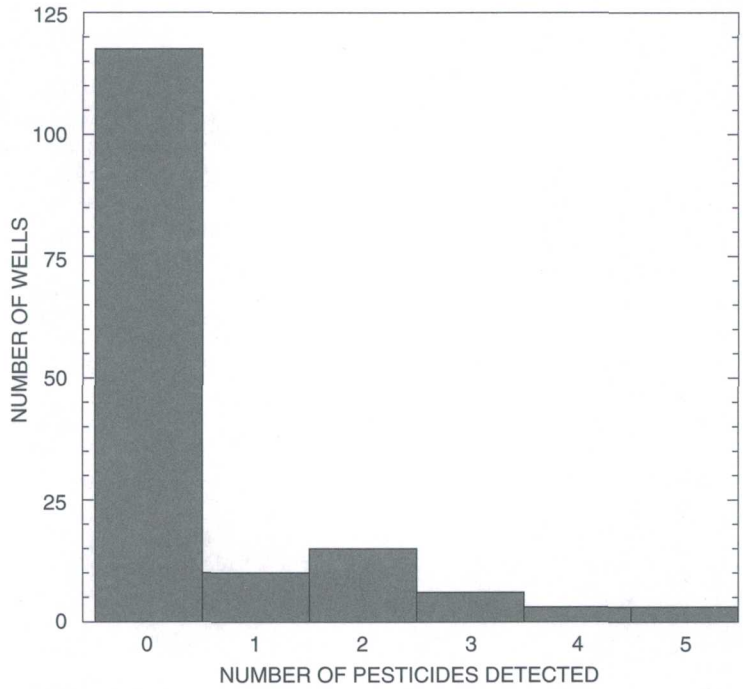

Figure 7. Number of pesticide detections per well.

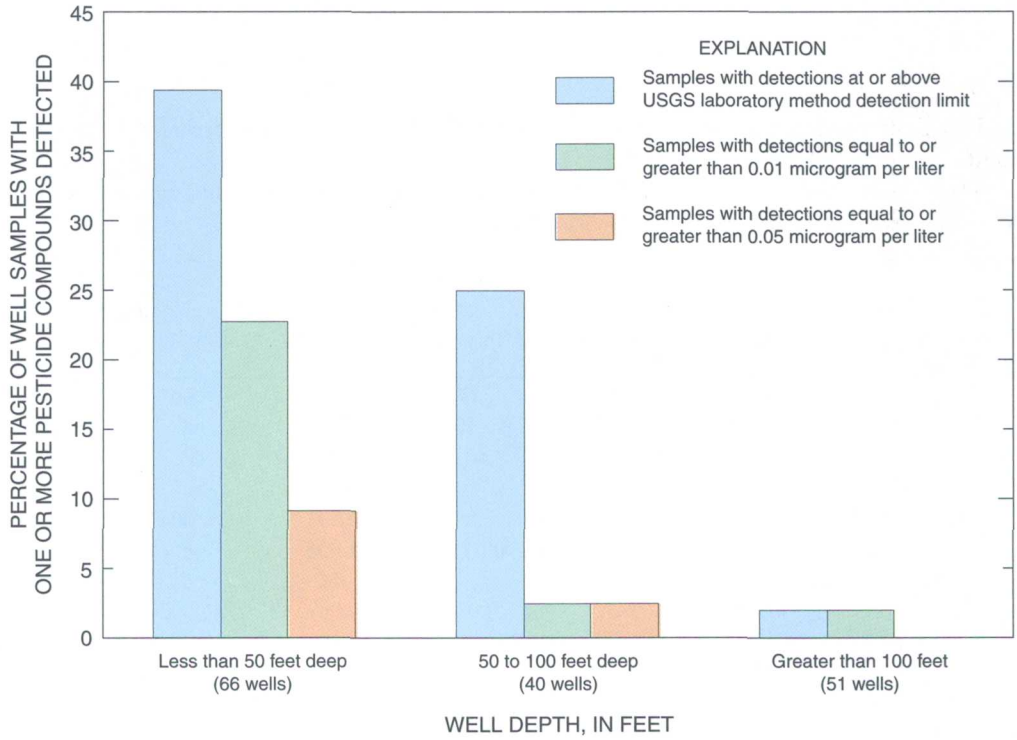

Figure 8. Pesticide detections in ground water by well depth.

from below urban residential land had the fewest pesticides per sample, but for surface water, large rivers had the fewest pesticides per sample (fig. 6).

Pesticides were detected in ground water underlying urban, agricultural, and mixed land-use settings. Of concern is that pesticides that are most heavily used and applied to the land are detected not only in streams but also in ground water. Water infiltrating through soil and sediment to ground water reduces considerably the detection rate of pesticides, compared with streams. However, shallow ground water is much more likely to contain pesticides than deep ground water (fig. 8). For example, about 40 percent of the samples from wells less than 50 feet contained one or more pesticides, whereas only 1 of 51 wells more than 100 feet deep contained pesticides (fig. 8).

The presence of pesticides in ground water raises a question about health concerns because ground water in the basin is often used for drinking water. In the Puget Sound Basin, concentrations of pesticides in ground water did not exceed drinking water standards, and only two herbicides, atrazine and simazine, were detected in 1 of the 51 wells (mostly public water-supply wells) deeper than 100 feet.

SUMMARY

A widespread detection of pesticide compounds was observed in surface waters of the Puget Sound Basin. As expected, more pesticide compounds were detected in surface water than ground water, due in large part to adsorption and degradation of pesticides infiltrating through soil and sediment. Water sampled from large rivers had the fewest pesticides per sample, compared with streams in urban and agricultural land-use settings. In contrast to surface water, most ground water, including shallow ground water, had no detections of pesticides. Fifty-five percent of the 47 pesticide compounds of interest were detected in streams, and 17 percent were detected in ground water. The herbicides atrazine, prometon, simazine, and tebuthiuron were the most frequently detected herbicides in surface and ground water. The number of pesticide compounds found in ground water was far fewer than those found in streams. Ground water sampled from the urban residential areas had the fewest pesticides per sample, compared with agricultural and mixed land-use areas.

Herbicides were the most common type of pesticide found in Fishtrap Creek (an agricultural stream) and the only type of pesticide found in shallow ground water underlying agricultural land. The herbicide compounds, atrazine, metolachlor, prometon, simazine, tebuthiuron, and desethylatrazine (a transformation product of atrazine) were detected in more than 40 percent of the samples from Fishtrap Creek. In shallow ground water below agricultural land, the herbicide compounds atrazine, simazine, and desethylatrazine were detected at lower frequencies (36-45 percent). Insecticides, in addition to herbicides, were detected frequently in urban streams. Sampled urban streams showed the highest detection rate for the three insecticides carbaryl, Diazinon, and malathion. Concentrations of the insecticide Diazinon, the most common, exceeded chronic criteria for aquatic life in streams influenced by agricultural, urban, and mixed land uses. On the other hand, no insecticides were found in shallow ground water below urban residential land. The herbicide compounds atrazine, prometon, simazine, and desethylatrazine were found in less than 7 percent of the samples from shallow ground water in urban areas.

Seven pesticide compounds were found at relatively high frequencies of 20 percent or more in large rivers. Most ground water, including shallow ground water, had no detections of pesticide compounds. In basin-wide sampling of deep ground water representing mixed land use, only two herbicides, atrazine and simazine, were detected in water from a single well. No pesticides in ground water were found to exceed drinking water standards or guidelines.

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