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Assessment of Human Health Risk from Ingesting Fish and Crabs From Commencement Bay

FINAL REPORT

ASSESSMENT OF HUMAN HEALTH RISK FROM INGESTING FISH AND CRABS FROM COMMENCEMENT BAY

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1.0 INTRODUCTION

1.1 Background

The Commencement Bay area of the Puget Sound is an active port in the industrial city of Tacoma, Washington. As such, it has historically received pollution from industrial waste discharges, disposal of dredge spoils, and port-related pollution. The Nearshore/Tideflats area has been designated an EPA Superfund site as a result of concerns over elevated levels of many organic and inorganic pollutants in the sediments, evidence of biological effects in the area, and potential public health impacts from fish and shellfish consumption. The Washington State Department of Ecology has, by cooperative agreement with the U.S. Environmental Protection Agency, been designated lead agency for the Remedial Investigation of the site. As part of the Investigation an assessment of potential personal risk experienced by area residents consuming fish and shellfish from the area is required.

The purpose of this document is to quantify the level of individual risk that may be experienced by persons eating fish and crabs from Commencement Bay. This risk assessment is based on a large volume of monitoring data generated during the summer and fall of 1984 by the Washington State Department of Ecology and its consultants.

Unlike previous attempts at risk assessment for the population eating fish from Commencement Bay, this effort is not limited by a lack of data on levels of pollutants in fish tissue. It is instead hampered by (1) an inability of today's scientific instrumentation to detect very low levels of pollutants, and (2) a basic lack of data on the predictable human health effects of exposure to pollutants. Readers must bear these two limitations in mind at all times, for they have two ramifications on this risk assessment, which are discussed below.

In exposure evaluation, it is often assumed that, although a pollutant is not detected in a sample, it is potentially present at a level approximately equal to the method detection limit. For extremely harmful pollutants, the resulting risk assessment may indicate that harmful effects can be expected, though that may very well be untrue if the actual level of pollutant is substantially below the detection limit. This approach has been used in this document as a conservative approach to protection of human health.

A similar conservative approach is related to the type of health information used to predict human risk. Much of that information is taken from studies of the effects of chemicals on small laboratory animals, a common toxicological practice. Those data must then be adjusted to account for the larger size of humans, the longer lifespan and potential period of human exposure, and the possibility that humans may be more sensitive to a chemical than the animal on which the test was performed. These practices are standard procedure, and most of the health effects data used in this assessment are from the U.S.EPA, but they are acknowledged to be very conservative. For example, the unit risk scores for carcinogens are based on the upper 95 percent confidence interval of the dose-response slope. Many feel that they overpredict human risk, and that possibility must be considered here.

The conservative approach may be more justified if one takes into account the fact that this risk assessment deals in detail with only one source of exposure to the chemicals being reviewed: ingestion of fish and crabs. Some other estimated environmental exposures for some of the chemicals are presented in Section 5 for comparative purposes. It is almost certain that there is exposure to many of these chemicals through other means-- in drinking water, though inhalation of ambient air, and so on. Although risk from eating fish may not exceed some level of acceptability, that exposure along with other environmental exposures may sum to an excessive level of risk.

This risk assessment is based on the best available data and utilizes state-of-the-art monitoring data and risk analysis techniques. It is not, however, a perfect representation of the potential effects of eating Commencement Bay fish, because of the limitations discussed above. It is designed to err on the conservative side of protecting health in the Tacoma area.

1.2 Report Organization

Following this introduction, there are four sections to this report:

Section 2 discusses the methodology upon which the assessment is based. The methods for calculating the rate of fish and crab consumption and the exposed population are discussed. Next is a brief discussion of the health effects data that are used in the risk assessment, along with a summary table of the values used in the assessment of human risk. The calculations to quantify human health risk are described. Finally, the liberal and conservative aspects of this assessment are listed, along with more general uncertainties.

Section 3 summarizes the results of the survey of fish and crab tissue contamination in Commencement Bay that was undertaken in the summer and fall of 1984.

Section 4 presents the risk assessment results. Much of the information is presented in appendices in tabular form so that the derivation of results is obvious. Discussed in this text are the results that suggest that a certain pollutant may, under some circumstances, present a risk to human health.

Section 5 is the summary and analysis of results, including which chemicals appear to be of concern, whether any of the waterways presents a higher risk from fishing than do the others, and the significance of health risks relative to contaminant levels in fish from other areas.

Throughout the report, the level of contamination of seafoods caught in the Commencement Bay project reference area, Carr Inlet, will be referred to as a benchmark. Also discussed throughout the report are the limitations previously discussed, as well as others that pertain to a particular set of data or a specific scenario.

2.0 RISK ASSESSMENT METHODOLOGY

"Risk assessment" is a term loosely applied to an analysis of hazard potential in an environment. All risk assessments have two elements in common:

(1) An assessment of exposure to one or more substances

(2) An assessment of the hazard associated with exposure to a substance or collection of substances

These two elements must then be integrated into an analysis of the level of risk experienced by a group, or population. This integration can be accomplished on different levels; the risk to each exposed individual over his or her lifetime can be calculated, or the cumulative risk to the entire exposed population can be predicted as the total number of illnesses expected over a 70-year period. This report will focus on the individual risk experienced by each person eating fish and crabs from Commencement Bay, which is probably the most meaningful statistic to most persons. Projected lifetime cancer cases for the total estimated exposed population for two chemicals, PCBs and arsenic, will be presented. Also presented will be the projected number of persons at each consumption level for a range of consumptions from one pound per day to one pound per year.

Each major step in the risk assessment process-- exposure evaluation, hazard evaluation, and calculation of risk-- is discussed individually in the following sections.

2.1 Exposure Evaluation

This analysis addresses three types of exposure: ingestion of fish muscle tissue, ingestion of crab muscle tissue, and ingestion of fish livers. The first two (ingestion of fish and crab muscle tissues) are dealt with in a manner different from that for eating of fish livers.

2.1.1 Methods for Assessing Exposure to Contaminants in Fish and Crab Muscle Tissue

There are two elements to assessing exposure to the population eating fish and crabs from Commencement Bay; these interrelated elements are **estimating the exposed population,** and **estimating the rate of fish and crab ingestion.** This assessment relies on data from the Tacoma-Pierce County Health Department (TPCHD) to provide these estimates.

The TPCHD conducted a survey of recreational fishermen in 1981, questioning survey participants on the amount and type of fish they catch, the frequency of their fishing, and the fishermen's plans for their fish and crabs (whether they planned to eat the catch). This catch/consumption survey was conducted during the late summer and fall of that year, and it focused on shore fishing.

The catch/consumption survey is detailed in a report by Pierce et al. (1981). They concluded that a total of 2900 fishermen fished the shores of Commencement Bay, with varying frequency, in that year. That estimate did not include the results of the abbreviated survey of boat fishermen. We have taken that part of the survey and adjusted the results for seasonal frequency as Pierce et al. did for shore fishermen (see Appendix A for derivation). The frequency of boat fishing was assumed to be equal to the frequency of shore fishing; they may, in fact be quite dissimilar. The boat fishermen (an estimated 1170 persons) have been added to the shore fishermen to derive a new total of 4070 fishermen. This procedure assumes that the shore fishing and boat fishing populations do not overlap and that no one is "double counted;" it is quite likely that the addition of boat fishermen makes the resulting total exposed population an overestimate. Pierce et al. report that the average family size is 3.74 persons; assuming that all members eat fish, the total exposed population is 4070 x 3.74, or approximately 15,200 persons.

The data from Pierce et al. also allow estimation of the frequency of fishing, which (when combined with a value from the survey on average catch per fishing trip) can be keyed to the amount of fish and crabs eaten. Table 1 presents a frequency distribution of fish muscle tissue ingestion rates from this survey. The maximum ingestion rates reported by Pierce et al. form the basis of the distribution in Table 1 used throughout this report. The risk assessment is keyed to this table, because the risk to persons eating Commencement Bay fish and crabs daily is considerably different from the risk to persons fishing only once or twice a year and eating those fish. No data on shellfish (i.e., crab) consumption were specifically compiled by Pierce et al. or the other sources evaluated; consumption of crab was therefore assumed to follow a distribution equal to finfish consumption.

Rates of fish and crab ingestion, in grams per day, are multiplied by the average level of contaminant, in micrograms per gram of fish, to yield exposure in micrograms per day. Exposure calculations in this assessment are based on a number of scenarios, to aid decision-makers. The average level of contaminant in fish has been calculated by Tetra Tech (in preparation) for:

- each station from which fish or crabs were collected for analysis,

- each waterway or other large area (all stations within that area combined), and

- all nearshore/tideflats stations together.

In all cases, the method detection limit was used in the calculation of means if a substance was not detected. Exposure calculations have been performed with each of these averages; results will therefore be keyed to area of the Bay.

An assumption inherent in this analysis is that the fish and crabs examined for contaminants are representative of what is eaten by Commencement Bay fishermen. The assessment is again

Table 1. Population Exposed by Consumption Rate

Frequency	Frequency Percent	Ingestion Rate	Intake g/day	Population Exposed
Daily	0.2	1 lb./day	453.0	30
Weekly	6.6	1 lb./week	64.7	1005
Monthly	11.4	1 lb./mo.	15.1	1735
Bimonthly	7.3	1 lb./2 mos.	7.4	1111
Twice/year	17.2	1 lb./6 mos.	2.5	2618
Yearly	57.3	1 lb./year	1.2	8721
Total	100.0			15,220

Source: Pierce et al. (1981)

somewhat conservative at this point; all fish analyzed were English sole, which are not commonly eaten and have been found to be, as bottom-dwelling fish, among the most contaminated in Commencement Bay (Tetra Tech, unpublished Task 3 report on bioaccumulation). All shellfish analyzed were Dungeness crabs and rock crabs. Data are not sufficient to state that crabs are either more or less contaminated than other types of shellfish that may be caught in the Bay.

2.1.2 Exposure from Ingestion of Fish Livers

A subgroup of special interest in this assessment is the population that eats fish livers. Although this group is believed to be small, their exposure to contaminants in Commencement Bay fish may be higher than that of individuals eating muscle tissue because many chemicals are known to concentrate in organs such as the liver.

The assessment of exposure from eating livers is based on maximum observed values in composites of livers from fish caught at the sampling stations in the bioaccumulation study. Means were not used because several livers were pooled for each chemical analysis, and the maximum observed values actually represent the mean of several liver samples.

No data on the amount of fish liver eaten are available from the TPCHD survey or other sources consulted. It was therefore assumed that the amount of liver eaten is proportional to the amount of fish muscle eaten; i.e., that persons who do eat livers would consume the livers from all the fish they catch and consume. The average proportion of liver weight to muscle weight for 13 species of Commencement Bay fish is 0.12 (Gahler et al. 1982), the factor that is used in scaling exposures. Table 2 presents data on the frequency distribution of liver consumption as a function of muscle tissue consumption. This is certainly an upper bound estimate; it is unlikely that consumption of fish livers would ever exceed the range of intakes in Table 2.

Table 2. Ingestion of Fish Livers

Frequency	Fish Intake g/day	Liver Intake g/day
Daily	453.0	54.4
Weekly	64.7	7.8
Monthly	15.1	1.8
Bimonthly	7.4	0.9
Twice/year	2.5	0.3
Yearly	1.2	0.1

Source: Derived from Pierce et al. (1981) and Gahler et al. (1982)

2.2 Health Effects (Hazard Assessment) Methodology

Table 3 summarizes the available data, from the U.S. Environmental Protection Agency, on the human health effects of chemicals monitored for in Commencement Bay fish tissues. The chemicals listed in this table can be classified as having either carcinogenic or noncarcinogenic effects. These effects are associated with different types of data and are treated differently in the risk assessment process. Although some chemicals have multiple effects, only the most significant (in severity or in terms of occurring at the lowest dose) are discussed.

Chemicals that are called "carcinogens" in this assessment are substances that the EPA considers possible cancer-causing agents; they have not in all cases been implicated as causes of cancer in humans. Most of the available data on these chemicals are derived from animal studies, both for evidence and strength of carcinogenicity. The presumption in the scientific community today is that carcinogenicity is not a threshold effect; any exposure, no matter how low, can be associated with a quantifiable cancer risk. The potency of the carcinogen is expressed as a risk score, which is the probability of effect per unit dose of chemical, in units of $(mg/kg/day)^{-1}$. The unit cancer risk scores in this study are those published by the U.S.EPA's Carcinogen Assessment Group (USEPA 1984).

Noncarcinogens are usually assumed to exhibit thresholds, that is, to cause some ill effect only after a certain dose is exceeded. That dose is given the term the No Observed Effect Level, or NOEL, by toxicologists. Since NOELs have been derived almost exclusively from studies of small mammals, the measured NOEL is usually divided by some safety factor to estimate a level that can be considered safe for humans. The safety factor takes into account the variability in the toxicity of a chemical between the experimental species and humans and within the human population as well as other deficiencies in the experimental data. This resulting value is the one used in this assessment,

Table 3. Health Effects Data

CHEMICAL CARCINOGENS	RISK SCORE per mg/kg/day	HEALTH EFFECT
acrylonitrile	0.552	brain tumors
aldrin	11.4	liver tumors
arsenic	14	skin cancer
benzene	0.052	leukemia
benzidine	234	bladder cancer
beryllium	4.86	leukemia
carbon tetrachloride	0.083	liver tumors
chlordane	1.61	liver cancer
chromium	41	when inhaled; no value for ingested
hexachlorobenzene	1.67	liver tumors
dichloroethane (1,2)	0.037	circulatory hemangiosarcomas
trichloroethane (1,1,2)	0.0573	hepatocellular carcinomas
trichloroethane (1,1,1)	0.0016	liver tumors
tetrachloroethene	0.035	liver tumors
trichloroethene	0.019	liver tumors
tetrachloroethane (1,1,2,2)	0.201	hepatocellular carcinomas
hexachloroethane	0.0142	hepatocellular carcinomas
trichlorophenol (2,4,6)	0.0199	hepatocellular carcinomas, adenomas
chloroform	0.183	hepatocellular carcinomas
DDT	8.42	liver adenocarcinoma
dichloroethylene (1,1 and 1,2)	1.04	kidney adenocarcinoma
dieldrin	30.4	liver tumors
dinitrotoluene	0.311	mammary tumors, hepatocellular carcinoma
tetrachlorodioxin	425000	hepatocellular and other carcinomas
diphenylhydrazine	0.768	hepatocellular carcinomas and adenomas
halomethanes	0.183	liver tumors
heptachlor	3.37	hepatocellular carcinoma
heptachlor epoxide	3.76	hepatocellular carcinoma
hexachlorobutadiene	0.0775	renal tubular adenoma and carcinoma
hexachlorocyclohexane (HCH)	4.75	liver tumors
alpha	11.1	liver tumors
beta	1.84	liver tumors
gamma (Lindane)	1.33	liver tumors
dimethyl nitrosamine	25.9	liver cancer
diethyl nitrosamine	43.5	liver cancer
dibutyl nitrosamine	5.43	bladder and esophogeal cancer
NN diphenylamine nitrosamine	0.0049	bladder tumors
N-nitrosodipropylamine	31	mammary tumors and hepatocarcinoma in mice
dibenzo(a,i)pyrene	476	lung cancer-inhalation
benzo(a)pyrene	11.5	stomach papillomas, carcinomas
DEHP	0.0141	liver,kidney cancer

Sources: USEPA (1983,1984)

Table 3. Health Effects Data

CARCINOGENS	RISK SCORE per mg/kg/day	HEALTH EFFECT
PCBs	4.34	hepatocellular carcinoma
toxaphene	1.13	hepatocellular carcinoma and adenoma
tetrachloroethylene	0.04	hepatocellular carcinoma
trichloroethylene	0.0126	hepatocellular carcinoma
vinyl chloride	0.0175	liver angiosarcoma
BCEE	28	various carcinomas

CHEMICAL NONCARCINOGENS	ADI ug/day	SAFETY FACTOR	HEALTH EFFECT
acrolein	1100	1000	unknown via oral exposure
DDD	3010	1	hunched appearance, increades urination
DDE	350	1	hepatic necrosis in rats
a-endosulfan	280	100	brain and kidney damage
b-endosulfan	280	100	brain and kidney damage
endosulfan sulfate	280	100	brain and kidney damage
endrin	70	100	nervous system, leukocytosis, kidney degeneration
endrin aldehyde	70	100	nervous system, leukocytosis, kidney degeneration
antimony	292	100	altered blood chemistry
cadmium	700	?	renal tubular necrosis in humans
chromium-VI	175	1	kidney tubular necrosis
chromium-III	357000	1	sterility
cyanide	330	100	hypoxia (oxygen blockage)
lead	100	?	brain dysfunction and anemia in humans
mercury	20	10	ataxia,cerebellar atrophy, impaired vision in humans
manganese	10000	?	neurological dysfunction in humans
nickel	1460	1000	fetal mortality or reduced body weight
selenium	700	10	liver and endrocrine gland effects
silver	16	5	kidney hemorrhage, liver, stomach, and intestine damage
thallium	37	1000	nerve, kidney, liver, and stomach damage
zinc	15000	100	copper deficiency and anemia in humans
fluorotrichloromethane	201000	10	cardiac arrythmia
dichloroethane (1,1)	8100	?	liver function changes
dichloropropane (1,2)	980	1	liver function changes
dichloropropane (1,3)	180	1000	liver function changes
dichloropropylene (1,3)	180	1000	liver function changes
hexachlorocyclopentadiene	36	100	no oral effects known
bis 2-chloroisopropyl ether	70	10	no oral effects known
chlorobenzene	1008	1000	nervous system depression; liver, kidney necrosis
dichlorobenzene (1,2)	107000	100	cirrhosis of liver
dichlorobenzene (1,3)	140000	100	cirrhosis of liver
dichlorobenzene (1,4)	161000	100	cirrhosis of liver
trichlorobenzene (1,2,4)	464	10	liver metabolism changes in monkeys

Sources: USEPA (1983,1984)

Table 3. Health Effects Data

CHEMICAL NONCARCINOGENS	ADI ug/day	SAFETY FACTOR	HEALTH EFFECT
ethylbenzene	1600	1	weight increase, kidney effects
nitrobenzene	4000	10	blood cyanosis in humans by inhalation or dermal exposure
toluene	134000	100	nervous system effects and cardiac arrythmia
total xylenes	160000	10	maternal toxicity
phenol	6800	500	kidney and liver damage
chlorophenol	6900	1000	increased nervous response in humans
dichlorophenols	7000	1000	convulsions in cats
pentachlorophenol	2100	100	micro-level changes in human liver and kidney via inhalation
nitrophenols	140	1000	effects unknown
dinitrophenol	140	1	numerous for 2,4- eyes, skin, nerves, liver, spleen in humans
dimethylphenol	7000	190	liver, spleen pathology
dinitro-o-cresol	71	10	effects on human skin when inhaled
diethylphthalate	875000	100	decreased growth
dimethylphthalate	1800	10	kidney effects on humans when inhaled
di-n-butylphthalate	1800	10	brain abnormalities in humans when inhaled
di-n-octylphthalate	1800	10	effects unknown
acenaphthene	18	?	enzyme blood changes in humans when inhaled
fluoranthene	420	1	mortality at high dose via dermal contact
naphthalene	18000	10	cataracts in humans (inhalation), rats (oral)

Sources: USEPA (1983,1984)

Table 3. Health Effects Data

NOTES:
All effects for rats unless otherwise noted
Carcinogen data from 1984 document; some values may have changed
Noncarcinogenic ADIs from 1983- latest published data; many values under review
See text for explanation of safety factor

Sources: USEPA (1983,1984)

and it is termed the Acceptable Daily Intake (ADI). Effects are considered possible in a sensitive subpopulation when the exposure or dose exceeds the ADI; or, as it is usually expressed here, if the ratio of exposure to the ADI equals or exceeds 1. ADIs are set with chronic (70 year) exposure as the time frame, and that exposure duration is usually factored into the safety factor. Safety factors can range from 1 if the data are of good quality, based on long-term human (usually occupational) exposure to 1000 if the original health data are from short-term studies of small lab animals.

2.3 Risk Assessment Calculations

The exposure and effects data discussed above are combined in this step of the assessment to calculate risk to the individuals ingesting fish from Commencement Bay. Just as there are two types of effects data, there are two types of risk calculations. These are outlined below.

Risk is assessed on a chemical-by-chemical basis throughout this report. There is evidence for many combinations of chemicals that interaction occurs, either as synergistic effects (magnifying the probability or severity of an effect), as additive effects (combining similar effects of two chemicals), or as antagonistic effects (preventing an effect entirely or lessening its severity). The evidence of these interactions is relatively weak. Furthermore, while the combined effect of two chemicals may be known, the combined effect of the complex mixture of Commencement Bay pollutants is definitely unknown.

2.3.1 Calculation of Carcinogenic Risk

As described previously, risk scores (the health effects data used in risk assessment for carcinogens) are in units of risk per mg chemical/kg human body weight/day $(mg/kg/day)^{-1}$.

Multiplying exposure in mg/kg/day by the risk score will yield a unitless probability of cancer in an individual, or individual risk. The entire train of logic is presented below:

$$\text{conc. chemical}, \frac{ug}{g} \times \text{ingestion rate}, \frac{g}{day} = \text{exposure}, \frac{ug}{day}$$

$$\text{exposure}, \frac{ug}{day} \times 10^{-3}\frac{mg}{ug} /70 \text{ kg person} = \text{exposure in mg/kg/day}$$

$$\text{exposure, mg/kg/day} \times \text{unit risk, (mg/kg/day)}^{-1} = \text{individual risk}$$

Environmental risks are usually expressed in these terms. Various levels of individual risk may be considered acceptable, depending on a number of circumstances. An individual risk level of 10^{-6} indicates that one in one million persons exposed to that level of contaminant would be expected to develop cancer over an `average' lifetime of 70 years, assuming continuous exposure. For comparative purposes, consider the following statistical risks over a 70-year lifetime (NY State Department of Health 1981):

death from a hurricane- 2.8×10^{-5}

death by an aviation accident- 7.0×10^{-5}

fatal automobile accident- 1.8×10^{-2}

death from being struck by lightning- 3.5×10^{-5}

Individual risk can be multiplied by the number of persons exposed at that level to estimate the total number of persons expected to develop cancer among the exposed population over the 70-year lifetime. That calculation has not been performed for all chemicals in this risk assessment. It has been performed only for the chemicals with the highest absolute risks; calculations indicate that, for the vast majority of chemicals, both individual and cumulative risk (i.e. cases) are very low.

2.3.2 Noncarcinogenic Risk Calculations

Because noncarcinogenic chemicals exert a threshold effect, the assessment of risk at a calculated level of exposure entails simply comparing the exposure to the ADI. If exposure exceeds the ADI, all persons exposed at that level are assumed to be affected; if exposure is equal to or less than the ADI, none of the individuals are affected. There is no provision in this method for degree of effect. However, the ratio of exposure to the ADI indicates the weight of evidence of projected effects to a limited degree.

2.4 Summary of Limitations in this Risk Assessment

It was stated earlier that this risk assessment is designed to be a reasonable indicator of risk to the population eating fish from Commencement Bay. Some methods used are by their nature conservative (tending to overpredict risks) and some are liberal (not considering factors that may make actual risk higher than is indicated herein). Some methods simply entail uncertainties that cannot be defined as either liberal or conservative.

Conservative Factors

The currently-accepted approach to risk assessment is generally conservative.

The maximum potential ingestion rate used in this assessment, one pound of fish per day, is acknowledged to be high.

Exposure is assumed to occur continuously for 70 years.

Nondetected chemicals are assessed by assuming that the level of contaminant is equal to the method detection limit (rather than much less, or even zero).

Contaminant levels in English sole, a bottom fish, are used to represent levels in all fish eaten; sole are thought to be more highly contaminated than most fish.

Potential antagonistic effects between chemicals that occur together are not accounted for.

Liberal Factors

Not all contaminants present can be analyzed by the laboratory equipment available at this time; risk from those chemicals cannot be accounted for.

It is possible that fish other than English sole may be contaminated at higher levels than the sole in this survey.

Possible additive or synergistic effects of multiple chemicals are not quantified.

General Uncertainties

Tissue levels can vary by season. All data were collected in the summer and fall months.

Cooking fish may alter the chemical constituents, and measurements of contaminant levels in raw fish may not accurately represent exposure levels.

3.0 COMMENCEMENT BAY FISH AND SHELLFISH SURVEY RESULTS

The monitoring data upon which this assessment is based came from a comprehensive survey of Commencement Bay performed in mid-1984. Among the media sampled were fish muscle tissue, fish livers, and crab muscle tissue. The sampling was performed at defined stations throughout Commencement Bay and at a reference site, Carr Inlet. The reference site was chosen to represent an area in Puget Sound where the sediments were relatively uncontaminated. Appendix B shows the location of each sampling site. Further details on the 1984 monitoring can be obtained from a report currently under preparation (Tetra Tech).

Appendix C lists the numerous compounds that were never detected in the fish sampled during this survey, as well as the method detection limits of the analysis. The fish were all English sole, chosen to aid in a conservative analysis because these bottom fish generally reach contamination levels higher than do other fish. The human health risk that would result if fish with levels of these substances equal to the method detection limit were routinely ingested is evaluated.

Appendices D, E, and F are the summaries of organics levels in fish and crab muscle tissue, metals in fish and crab muscle tissue, and all contaminant levels in fish liver samples, respectively. The compounds that were detected in fish muscle tissue are further summarized in Table 4. The mean for the Commencement Bay data is compared to the corresponding mean for the Carr Inlet reference area.

Table 4 indicates that detected chemical levels in Commencement Bay fish often, but not always, exceed levels in the Carr Inlet reference area. Many chemicals listed in this table were never detected in Carr Inlet samples. The absolute frequency of detection of each chemical at each site is part of the summaries in the Appendices; relative frequency is indicated in Table 4.

Table 4. Chemicals Detected in Fish and Crabs

Detected in Only One Fish Sample

Chemical	Site	Mean	Mean-Carr Inlet
Fluoranthene	MD-70	29.0	ND
1,3-Dichlorobenzene	CI-70	54.0	ND

Detected in Fish in Only One Waterway

Chemical	Site	Mean	Mean-Carr Inlet
Dimethylphthalate	Blair	37.0	ND
HCB	HY-72	26.0	ND
HCBD	HY-72	43.0	ND

Detected in Fish from More than One Waterway

Chemical	Mean	Mean-Carr Inlet
DEHP	194.0	35.0
Butyl benzyl phthalate	13.0	ND
Di-n-octyl phthalate	49.0	18.0
Di-n-butyl phthalate	425.0	21.0
Diethyl phthalate	11.0	ND
fluorotrichloroethane	11.0	92.0
tetrachloroethene	66.0	7.0
Ethylbenzene	15.0	5.0
Toluene	11.0	11.0
Naphthalene	134.0	54.0
Xylenes	55.0	ND
PCBs	210.0	36.0
Antimony	1010.0	1070.0
Arsenic	4070.0	7940.0
Cadmium	26.9	203.0
Chromium	197.2	190.0
Lead	218.0	218.0
Nickel	100.3	115.0
Selenium	331.0	171.0
Silver	11.9	8.0
Zinc	3650.0	3720.0
Mercury	59.5	55.0

Table 4. (continued)

Chemicals Detected in Only One Crab Sample

Chemical	Site	Mean	Mean-Carr Inlet
Phenanthrene	MD-70	20.0	ND
Fluoranthene	MD-70	12.0	ND

Chemicals Detected in Crabs from More than One Waterway

Chemical	Mean	Mean-Carr Inlet
DEHP	28.0	1331.0
Di-n-butyl phthalate	172.0	540.0
Naphthalene	75.0	ND
PCBs	104.0	22.0
Antimony	1063.2	1000.0
Arsenic	1980.0	2370.0
Cadmium	150.0	92.0
Chromium	214.7	237.0
Lead	478.0	195.7
Nickel	88.0	107.0
Selenium	194.0	138.6
Silver	138.4	197.0
Zinc	39890.0	47420.0
Mercury	10.3	44.6

Note: ND denotes not detected
All values in ppb (ng/g) wet weight

Tetra Tech (a project consultant) has determined that some of the liver data are questionable; those data (all metals) are noted "Q" on the summaries in the Appendix. Laboratory analysis of the complex liver tissue was difficult, resulting in qualified values for arsenic, chromium, selenium, and lead. The listed values are thought to be overestimates of the true level by as much as a factor of 2 (for lead) to 11 (for chromium) (personal communication with Robert Barrick, Tetra Tech, January, 1985).

As discussed previously, exposure and risk calculations presented in the next section will be based on calculated means for a waterway or the overall project area, depending on what areal assessment is being accomplished. Those means are listed in the appendices and are therefore not presented here.

4.0 RISK ASSESSMENT RESULTS

4.1 Risks for Chemicals Detected in Tissue Samples

The bulk of this risk analysis is focused on the compounds that were detected in one or more samples of Commencement Bay fish and crabs. Appendix G contains all the exposure and risk calculations performed for this report; this section discusses those contaminants previously identified in Table 4 as being present in fish muscle or liver tissue or crab muscle tissue samples. The significance of these results is discussed further in Section 5 of this report.

4.1.1 Risk via Fish Muscle Tissue Ingestion

The following paragraphs will present a chemical-by-chemical discussion of the human health risks associated with chemicals present in Commencement Bay fish muscle tissue. The data from which this summary was derived are presented in Tables G-1 and G-2 in Appendix G. No risks were calculated for barium, iron, or copper, essentially nontoxic metals (for which no ADIs have been set) found in numerous fish and crabs. Chemicals are discussed individually below, and presented in rough order of decreasing concern (i.e., risk).

Recall from Table 1 that results are keyed to ingestion rate as a function of fishing frequency. The maximum ingestion rate of 453 g/day equates with fishing daily and eating a pound of fish each day. Thirty persons in the Tacoma area are believed to be exposed at that rate. The 1005 persons eating a pound a fish per week average 64.7 g/day consumption. Persons fishing monthly (around 1735 people) are assumed to eat a pound of fish per month, or 15.1 g/day. The average daily ingestion rate for persons eating a pound of fish every two months (approximately 1111 persons) is 7.4 g/day. The majority of persons responding to the catch/consumption survey said they fish only twice a year or once a year in the Bay (2618 and 8721 persons, respectively). Persons fishing twice yearly have an average ingestion rate of 2.5 g/day, while persons fishing yearly average 1.2 g fish/day. These ingestion rates and populations were used in the assessment of both fish and crab consumption.

CARCINOGENS

PCBs

Polychlorinated biphenyls were found in fish throughout Commencement Bay and in Carr Inlet fish. Calculated average individual lifetime risks (i.e., based on the calculated bay-wide average fish muscle tissue levels) for eating fish from Commencement Bay fish, by ingestion rate, are:

1 lb./day	6×10^{-3}
1 lb./week	8×10^{-4}
1 lb./month	2×10^{-4}
1 lb./2 months	9×10^{-5}
1 lb./6 months	3×10^{-5}
1 lb./year	2×10^{-5}

The risk associated with eating fish from Commencement Bay (using average bay-wide PCB levels in the muscle tissue) is five times higher than the risk associated with eating Carr Inlet fish. There is some variability among fish taken from different waterways. At the highest ingestion rate, the lifetime individual risks from eating fish from different areas vary as shown below:

City WW	1×10^{-2}
Hylebos WW	9×10^{-3}
Blair WW	7×10^{-3}
Middle and Sitcum WWs	5×10^{-3}
Milwaukee WW	3×10^{-3}
Ruston Shore	2×10^{-3}
St. Paul WW	1×10^{-3}
Carr Inlet	1×10^{-3}

The highest risks are associated with eating fish from the Hylebos and City Waterways. Risks from eating fish taken from along the Ruston shore decrease by more than a factor of two with distance from the waterways. The adverse health effect associated with PCB exposure is cancer of the liver; it is not, however, a proven human carcinogen.

Arsenic

Recent studies (Crecelius and Apts 1984) of arsenic in fish tissue indicates that only an average of 0.12 percent of the measured arsenic is present in the toxic inorganic form. That factor has therefore been applied to the calculated exposures and risks in this analysis. The resulting predictions indicate that the average lifetime individual risk associated with eating fish from Commencement Bay, based on bay-wide average levels, is:

1 lb./day	4×10^{-4}
1 lb./week	6×10^{-5}
1 lb./month	1×10^{-5}
1 lb./2 months	7×10^{-6}
1 lb./6 months	2×10^{-6}
1 lb./year	1×10^{-6}

These risks are approximately equal to the risks associated with eating fish from other areas, i.e. Carr Inlet. The average individual lifetime risk associated with eating one pound of fish daily from each of the waterways is presented below:

City WW	3×10^{-4}
Hylebos WW	3×10^{-4}
Blair WW	7×10^{-4}
Middle WW	2×10^{-4}
Sitcum WW	2×10^{-4}
Milwaukee WW	2×10^{-4}
Ruston Shore	7×10^{-4}
St. Paul WW	2×10^{-4}
Carr Inlet	7×10^{-4}

There is less than an order of magnitude difference among all the areas. The carcinogenic effect suspected for persons ingesting arsenic in its inorganic form is skin cancer.

Hexachlorobenzene

Hexachlorobenzene was found in two fish caught in the Hylebos Waterway at levels very near the method detection limit. The level at which it was present indicates that the lifetime individual carcinogenic risk of ingesting fish contaminated at this level for 70 years would vary as follows:

1 lb./day	1×10^{-4}
1 lb./week	2×10^{-5}
1 lb./month	4×10^{-6}
1 lb./2 months	2×10^{-6}
1 lb./6 months	7×10^{-7}
1 lb./year	3×10^{-7}

Risk from consuming fish from Carr Inlet at the maximum 1 lb. per day ingestion rate and assuming the compound is present at the method detection limit is 0.7×10^{-4}, a very slight difference from the Hylebos Waterway risk at this ingestion rate. The adverse human health effect associated with exposure to hexachlorobenzene is liver tumors.

Hexachlorobutadiene

Hexachlorobutadiene was found in two fish taken from the Hylebos Waterway. It was also found at just above the detection limit. The average individual carcinogenic risk associated with eating fish with this level of HCBD ranges as follows:

1 lb./day	2×10^{-5}
1 lb./week	3×10^{-6}
1 lb./month	7×10^{-7}
1 lb./2 months	3×10^{-7}
1 lb./6 months	1×10^{-7}
1 lb./year	5×10^{-8}

This level of risk differs only slightly from that predicted for eating fish from Carr Inlet with levels of HCBD equal to the method detection limit. The maximum individual risk above is 2 x 10^{-5}, while the maximum individual risk at the method detection limit also rounds to 2 x 10^{-5}. Cancer of the kidneys is the adverse health effect associated with exposure to HCBD.

Bis 2-ethylhexyl Phthalate (DEHP)

This chemical was found in numerous fish throughout Commencement Bay as well as in the reference area. It is a ubiquitous pollutant, and currently considered a relatively weak carcinogen. Unpublished data indicate, however, that EPA may reconsider the carcinogenicity of the phthalate and instead set an ADI for noncarcinogenic effects. Assuming that the compound is a carcinogen, the average individual lifetime risk throughout Commencement Bay from ingesting this fish contaminant for 70 years is presented by ingestion rate below:

1 lb./day	2 x 10^{-5}
1 lb./week	3 x 10^{-6}
1 lb./month	6 x 10^{-7}
1 lb./2 months	3 x 10^{-7}
1 lb./6 months	1 x 10^{-7}
1 lb./year	5 x 10^{-8}

There is some incremental increase in risk from Commencement Bay fish over Carr Inlet fish. Below is the average individual lifetime risk associated with eating a pound of fish daily from each area in which DEHP was detected in fish:

City WW	2 x 10^{-5}
Hylebos WW	3 x 10^{-6}
Blair WW	4 x 10^{-5}
Milwaukee WW	2 x 10^{-5}
Ruston Shore	2 x 10^{-5}
Carr Inlet	3 x 10^{-6}

DEHP exposure is associated with possible cancer of the liver and kidneys.

Tetrachloroethene

This common environmental pollutant was found in many of the fish samples from the City, St. Paul, and Hylebos Waterways (the only areas studied for volatile organics). The average individual lifetime risk from eating fish from Commencement Bay, by ingestion rate, is:

1 lb./day	1×10^{-5}
1 lb./week	2×10^{-6}
1 lb./month	5×10^{-7}
1 lb./2 months	2×10^{-7}
1 lb./6 months	8×10^{-8}
1 lb./year	4×10^{-8}

By waterway, the maximum individual risk attributable to tetrachloroethene from eating a pound of fish per day is:

City WW	8×10^{-6}
St. Paul	2×10^{-5}
Hylebos WW	2×10^{-5}
Carr Inlet	3×10^{-6}

Tetrachloroethene is a suspected human liver carcinogen when ingested.

NONCARCINOGENS

Ratio of Exposure to ADI $\geq$ 1

Antimony

Average antimony exposure is predicted to exceed the ADI for persons eating a pound of fish daily for 70 years from both Commencement Bay and Carr Inlet (with ratios of exposure to ADI of 1.6 for both areas). Ratios are less than 1 for all other ingestion rates studied. The predicted effect is listed as altered blood chemistry.

Lead

Individual exposures to lead from fish from Commencement Bay and Carr Inlet are about equal to the ADI for persons eating one pound of fish daily. This indicates that there is no incremental increase in risk over the reference area and that lead in fish muscle tissue may pose a health problem for persons consuming fish from both areas of Puget Sound. This is especially true if the ADI, which is currently under review at EPA, is lowered further. Brain dysfunction is the effect associated with chronic exposure to dietary lead. Again, there is little difference between levels in fish caught at different sites.

Mercury

Persons eating a pound of fish daily, from either Commencement Bay or Carr Inlet, would be expected to exhibit some toxicity as a result of the presence of mercury. The ratio of exposure to the ADI is 1.35 for the Commencement Bay average and 1.2 for fish from Carr Inlet. For the other ingestion rates, no effect (i.e., atrophy of the brain) would be expected.

Ratio of Exposure to ADI $\leq$ 1

The calculated ratio of exposure to ADI is, in all cases, less than one for the following chemicals detected in Commencement Bay fish:

Fluoranthene
1,3 Dichlorobenzene
Dimethylphthalate
Butyl benzyl phthalate

Di-n-butyl phthalate
Di-n-octyl phthalate
Diethyl phthalate
Fluorotrichloromethane
Ethylbenzene
Toluene
Naphthalene
Xylenes
Cadmium
Chromium
Manganese
Nickel
Selenium
Silver
Zinc
DDE

No adverse human health effects would be expected from any of these contaminants in Commencement Bay or Carr Inlet fish.

4.1.2 Risks via Ingestion of Crab Muscle Tissue

Complete calculations of exposure and risk from ingestion of Commencement Bay crabs are presented in Tables G-3 and G-4 of Appendix G to this report.

CARCINOGENS

PCBs

Polychlorinated biphenyls were found in crabs throughout Commencement Bay and in Carr Inlet crabs. Calculated average individual lifetime risks (based on the bay-wide mean level) for eating crabs from Commencement Bay are:

1 lb./day	3×10^{-3}
1 lb./week	4×10^{-4}
1 lb./month	1×10^{-4}
1 lb./2 months	5×10^{-5}
1 lb./6 months	2×10^{-5}
1 lb./year	8×10^{-6}

The maximum individual average risk from eating a pound of crab each day for 70 years from each area in which it was detected is summarized below:

City WW	2×10^{-3}
Middle WW	1×10^{-3}
Sitcum WW	7×10^{-3}
Milwaukee WW	2×10^{-3}
Carr Inlet	1×10^{-3}

PCBs were not detected in crabs taken from the other study areas. The method detection limits attained for some of the crab muscle tissue analyses were higher than the measured levels in the waterways listed above. Predicted risks from eating crabs from the Hylebos and Blair Waterways, based on the method detection limit, would therefore exceed the risks listed above, while risks attributable to Carr Inlet crabs would be about 1×10^{-3}. The adverse effect associated with PCB ingestion is cancer of the liver.

Arsenic

Recent studies (Crecelius and Apts 1984) of arsenic in seafood indicates that only an average of 0.12 percent of the measured arsenic is present in the toxic inorganic form. That factor has therefore been applied to the calculated exposures and risks in this analysis. The resulting predictions of average individual lifetime risk, by ingestion rate, are:

1 lb./day	2×10^{-4}
1 lb./week	3×10^{-5}
1 lb./month	7×10^{-6}
1 lb./2 months	4×10^{-6}
1 lb./6 months	1×10^{-6}
1 lb./year	6×10^{-7}

Risks differ little among the various waterways and sampling areas, as shown by the maximum individual lifetime risks that would result from eating a pound of crab daily from each area:

City WW	3×10^{-4}
Hylebos WW	2×10^{-4}
Blair WW	1×10^{-4}
Middle WW	2×10^{-4}
Sitcum WW	2×10^{-4}
Milwaukee WW	1×10^{-4}
St. Paul WW	2×10^{-4}
Carr Inlet	2×10^{-4}

No crabs were collected from the Ruston shoreline stations. Skin cancer is the effect predicted for ingestion of inorganic arsenic.

Bis 2-ethylhexyl Phthalate (DEHP)

This chemical was found in crabs in the City and Milwaukee Waterways as well as in the reference area. It is a ubiquitous pollutant, and a relatively weak carcinogen. The average individual lifetime risk throughout Commencement Bay from ingesting this crab contaminant for 70 years is presented by ingestion rate below:

1 lb./day	3×10^{-6}
1 lb./week	4×10^{-7}
1 lb./month	9×10^{-8}
1 lb./2 months	4×10^{-8}
1 lb./6 months	1×10^{-8}
1 lb./year	7×10^{-9}

The differences between risks from eating crabs from the different areas are more pronounced than for most other contaminants. The list below is the individual lifetime risk associated with eating a pound of crab muscle each day for 70 years from the areas in which DEHP was detected:

City WW	5×10^{-6}
Milwaukee WW	3×10^{-6}
Carr Inlet	1×10^{-4}

As seen above, risks from Carr Inlet crabs are substantially higher than risks from Commencement Bay crabs. As stated previously, liver and kidney cancer is believed to be associated with ingestion of DEHP.

NONCARCINOGENS

Ratio of Exposure to ADI ≥ 1

Antimony

Average antimony exposure is predicted to exceed the ADI (with a ratio of 1.65) for persons eating a pound of crab caught in Commencement Bay each day for 70 years. Carr Inlet crabs, if eaten at the rate of a pound per day for 70 years, would also lead to exposure exceeding the ADI (ratio of 1.5). No exceedance of the ADI is predicted for the lower rates of ingestion. The predicted effect is listed as altered blood chemistry. Similar ratios were calculated for ingestion of antimony in fish.

Lead

Individual exposures to lead from crabs from Commencement Bay and Carr Inlet are equal to or exceed the ADI (by as much as a factor of 4) for persons eating a pound of crab daily. Crabs from the Sitcum Waterway appear to be associated with significantly higher ratios of exposure to ADI than the other sites. This indicates that, although there is no incremental increase in risk over the reference area (except in the Sitcum), lead may pose a significant health threat to persons eating crabs from both areas of Puget Sound. This is especially true if the ADI, which is currently under review at EPA, is lowered further. The adverse health effect for which the ADI is set for lead is brain dysfunction, especially in children.

Silver

Exposure could exceed the ADI for silver (by a factor of 5 in some cases) for persons eating a pound of crab daily for 70 years. The ratio of the average, one pound per day Commencement Bay exposure level to the ADI, 3.92, is slightly less than the corresponding ratio for crabs from Carr Inlet (around 5.6). The adverse effect predicted when exposure exceeds the ADI is damage to the digestive system.

Zinc

The maximum ratio of exposure to ADI for zinc (from eating a pound of crab each day for 70 years) is consistently around 1.3, regardless of the location from which crabs were taken. Adverse effects from zinc might therefore be expected in persons eating one pound of crab on a daily basis; no effect is expected for persons eating less than a pound per day. The health effect of concern with zinc exposure is a change in blood chemistry resulting in anemia and copper deficiency. No increase over the reference area is noted.

Mercury

Persons eating a pound of crab daily, from either Commencement Bay or Carr Inlet, would be expected to exhibit some toxicity (brain atrophy and related effects) as a result of the presence of mercury. The bay-wide average ratio of exposure to ADI for Commencement Bay crabs is 2.33 at the pound/day ingestion rate; the corresponding Carr Inlet ratio is 1.01. For the lower ingestion rates, no effect would be expected. When the data are evaluated by waterway, it is clear that the highest risk (with a ratio of exposure to ADI of 5) is presented by crabs from the Hylebos. Ratios of exposure to ADI are about 4 in the Sitcum, around 2.5 in Milwaukee WW crabs, and near 1 for all other locations.

Ratio of Exposure to ADI ≤ 1

The following chemicals are not expected to lead to adverse human health effects due to their presence in crabs from Commencement Bay. The ratio of exposure to ADI is, in all cases, less than 1 for:

Phenanthrene
Di-n-butyl phthalate
Naphthalene
Fluoranthene
Cadmium
Chromium
Manganese
Nickel
Selenium
DDE

4.1.3 Risks From Ingestion of Fish Livers

A total of 21 chemicals were detected in at least one fish liver composite sample from Commencement Bay. Table G-5 presents exposure and risk calculations for these 21 substances; the findings are summarized below.

Four of the chemicals present are considered carcinogens: hexachlorobenzene, hexachlorobutadiene, PCBs, and arsenic. Maximum individual lifetime risks (based on daily consumption of 0.12 pounds of fish liver) was the highest for PCBs, with a risk of 2×10^{-2}, slightly higher than the predicted risk for fish muscle tissue contaminated with PCBs. The individual risk from hexachlorobenzene in fish liver was, for the 0.12 pound per day ingestion rate, around 10^{-4}. Maximum lifetime individual risk for hexachlorobutadiene was 10^{-5} for persons eating 0.12 pounds of fish liver daily. All other carcinogenic risks were predicted to be much lower. As this is a worst-case scenario, and risks from less frequent ingestion of liver are very low, it is unlikely that this route of exposure is of great concern. A possible exception is PCBs. Better estimates of liver ingestion rates would improve this analysis.

All ratios of exposure to ADI for the noncarcinogens present in fish livers from Commencement Bay are less than 0.1. No effects attributable to these chemicals would be expected from liver ingestion.

One compound detected frequently in livers, and for which analysis is thought to be conclusive, is benzyl alcohol. No health effects information could be found regarding this chemical. It is not known whether this chemical is present due to biological degradation of another contaminant or is itself a direct contaminant. The highest levels of contamination (and, therefore, potential risk) were found in livers of fish caught in the waterways. Only benzyl alcohol, phenol, di-n-butyl phthalate, PCBs, and naphthalene were detected in Ruston shore fish livers.

Risks associated with eating livers from fish caught in Carr Inlet are somewhat lower than risks associated with Commencement Bay fish livers. The only organic compounds detected in livers from Carr Inlet fish were naphthalene, phenanthrene, PCBs, and di-n-butyl phthalate; all but the PCBs were found at levels associated with insignificant risk from noncarcinogenic effects. There was little difference between levels of organics in Carr Inlet and Commencement Bay fish livers, with the exception of PCBs, which were present in Commencement Bay fish livers at levels approximately fifteen times the levels at which they were present in Carr Inlet fish liver composites. Maximum individual carcinogenic risks from PCBs in Carr Inlet crabs are around 1×10^{-3}.

4.2 Risks for Chemicals Not Detected in Tissue Samples

Tables 5 and 6 present the results of assessing human health risk on a worst-case basis for substances that were never detected in either fish muscle or liver tissue. This assessment is conservative in three senses:

- Exposure was assumed to occur at the chemical's method detection limit; the actual level could be anything between zero and the method detection limit.
- Exposures and risk were calculated for the highest intake rates of fish and liver (453 g/day for fish, 54.4 g/day for liver).

Table 5. Worst-Case Risk for Nondetected Noncarcinogenic Chemicals

	Fish and Crab		Fish Liver	
	Detection Limit ug/g	Ratio of Exposure to ADI	Detection Limit ug/g	Ratio of Exposure to ADI
Chlorobenzene	0.005	0.002	NA	
Isophorone	0.01	0.0004	0.025	0.0022
Chloroethane	0.01	0.0000647143	NA	
Dichloropropane-1,2	0.01	0.005	NA	
Chloromethane	0.01	0.0001	NA	
Bromomethane	0.01	0.003	NA	
Dichloropropylene-1,3	0.01	0.03	NA	
Chlorophenol-2,	0.02	0.001	0.05	0.0004
Dichlorophenol-2,4	0.02	0.001	0.05	0.0004
Nitrophenol-2,	0.02	0.06	0.05	0.0194
Trichlorobenzene-1,2,4	0.02	0.02	0.05	0.0059
Dichlorobenzene-1,2	0.02	0.00008	0.05	0.00003
Dichlorobenzene-1,4	0.02	0.00006	0.05	0.00002
Nitrobenzene	0.02	0.002	0.1	0.0014
Phenol	0.02	0.001	detected	
Dimethylphenol-2,4	0.04	0.001	0.05	0.0004
DDD	0.05	0.008	0.2	0.004
a-Endosulfan	0.05	0.08	0.2	0.04
b-Endosulfan	0.05	0.08	0.2	0.04
Endosulfan sulfate	0.05	0.08	0.2	0.04
Endrin	0.05	0.3	0.2	0.2
Endrin aldehyde	0.05	0.3	0.2	0.2
Nitrophenol-4,	0.1	0.3	0.2	0.1
Dinitrophenol-2,4	0.1	0.3	0.2	0.1
Acrolein	0.1	0.0001	NA	
Dimethylphthalate	detected		0.025	0.001
Diethylphthalate	detected		0.025	0.00000002
Di-n-octyl phthalate	detected		0.025	0.00001
Dibenzofuran	detected		0.025	0.0022
Dichlorobenzene-1,3	detected		0.05	0.00002
Trichlorophenol-2,4,5	detected		0.1	0.001
DDE	detected		0.2	0.03
Dinitro-o-cresol-4,6	detected		0.2	0.2

NA = not analyzed for

Table 6. Worst-Case Risk for Nondetected Carcinogenic Chemicals

	Fish and Crabs		Fish Liver	
	Detection Limit ug/g	Risk at 1 lb. per day Ingestion Rate	Detection Limit ug/g	Risk at .12 lb per day Ingestion Rate
Beryllium	detected		0.002	2.00E-06
Gamma-HCH	0.004	3.44E-05	0.2	2.07E-04
Aldrin	0.004	2.95E-04	0.2	1.77E-03
Carbon tetrachloride	0.005	2.69E-06	NA	
Trichloroethane-1,1,1	0.005	5.18E-08	NA	
Dichloroethane-1,1	0.005	2.80E-04	NA	
Trichloroethane-1,1,2	0.005	1.85E-06	NA	
Chloroform	0.005	5.92E-06	NA	
Chlorodibromomethane	0.005	5.92E-06	NA	
Dichloroethylene-1,2	0.005	6.73E-05	NA	
Trichloroethylene	0.005	6.15E-07	NA	
Benzene	0.005	1.68E-06	NA	
Dieldrin	0.008	1.57E-03	0.2	4.72E-03
High molecular weight PAH	0.01	7.44E-04	0.275	2.46E-03
Dichloroethane-1,2	0.01	2.39E-06	NA	
Bromoform	0.01	1.18E-05	NA	
Bromodichloromethane	0.01	1.18E-05	NA	
Dichloroethylene-1,1	0.01	6.73E-05	NA	
Vinyl chloride	0.01	1.13E-06	NA	
Nitrosodipropylamine	0.02	4.01E-03	0.05	1.16E-03
Trichlorophenol-2,4,6	0.02	2.58E-06	0.1	1.55E-06
BCEE	0.02	3.62E-03	0.05	1.09E-03
Dinitrotoluene	0.02	4.03E-05	0.1	2.42E-05
Chlordane	0.05	5.21E-04	0.2	2.50E-04
DDT	0.05	2.72E-03	0.2	1.31E-03
Heptachlor	0.05	1.09E-03	0.2	5.23E-04
Heptachlor epoxide	0.05	1.22E-03	0.2	5.84E-04
a-HCH	0.05	3.59E-03	0.2	1.72E-03
b-HCH	0.05	5.95E-04	0.2	2.86E-04
d-HCH	0.05	5.95E-04	0.2	2.86E-04
Acrylonitrile	0.1	3.57E-04	NA	
DEHP	detected		0.025	2.74E-06
NDPhA	detected		0.05	1.90E-07
Hexachloroethane	detected		0.1	1.10E-06

NA = not analyzed for

- The health data are, by their nature, generally conservative (as discussed in Section 2).

Table 5 indicates that, even with this highly conservative assessment method, exposure to noncarcinogenic chemicals never exceeds the Acceptable Daily Intake (ADI) (see Table 5).

Maximum potential individual risks to the carcinogenic chemicals range from 10^{-2} to 10^{-8}, with the majority in the 10^{-5} and 10^{-6} range, as seen in Table 6 and summarized below. Ingestion of a pound per day of fish muscle tissue could result in the following maximum individual lifetime cancer risks greater than 10^{-6}:

aldrin	4×10^{-3}
1,1 dichloroethane	3×10^{-4}
1,2 dichloroethylene	7×10^{-5}
PAHs	2×10^{-3}
bromoform	1×10^{-5}
bromodichloromethane	1×10^{-5}
1,1 dichloroethylene	7×10^{-5}
bis (chloroethyl) ether	4×10^{-3}
dinitrotoluene	4×10^{-5}
n-nitrosodipropylamine	4×10^{-3}
acrylonitrile	4×10^{-4}

For PAHs, it is assumed that the maximum risk, as calculated above, would result from the presence of benzo(a)pyrene, a carcinogen, at its detection limit; quantitative risk data for other potentially carcinogenic PAHs are not available. It is important to note that the risks calculated above and in Table 6 apply only to a small group of persons eating fish daily and that they are overstated even for that group (for the reasons listed at the beginning of this subsection). The more common ingestion rates of one pound per week to one pound per year result in correspondingly lower risk levels.

Of the eleven carcinogenic substances or chemical classes listed above, only two (PAHs and n-nitrosodipropylamine) were detected at quantifiable levels in the 1984 survey of Commencement Bay sediments (Tetra Tech, in preparation). PAHs are, by their chemical nature, common in sediments but are not persistent in fish muscle tissue; they are rapidly metabolized. A recent study of English sole exposed to sediments contaminated with labeled benzo(a) pyrene (Stein et al. 1984) indicated that the compound was present after a short time only as metabolites in the liver and bile. N-nitrosodipropylamine was found in only two of the 151 samples of sediment from the bay analyzed for that compound.

5.0 SUMMARY AND INTERPRETATION OF RISK ANALYSIS

The following conclusions are derived from the discussion above. Many of the compounds detected in fish or crab muscle tissue or in fish liver tissue were present at levels that correspond to carcinogenic risks less than 10^{-6} or, for noncarcinogens, ratios of exposure to the ADI of less than 1.0. Those substances are not discussed below; only chemicals for which exposure exceeds the ADI or for which predicted carcinogenic risk exceeds 10^{-6} are addressed in this section. Risks are discussed in terms of both relative risk, comparing risk associated with eating Commencement Bay fish to corresponding risks from Carr Inlet fish and other environmental exposures, and as absolute risk experienced by the sportfishing population and their families.

Means were calculated setting nondetected values equal to the method detection limit, which (along with other assumptions) may result in an overstatement of risk. Recall also that 70 years of continuous exposure is assumed to occur and all statements of risk are predicated upon that assumption.

The results presented in the previous section lead to the conclusions summarized below and in Table 7.

Maximum individual lifetime risks for persons eating fish from Commencement Bay are 10^{-6} or greater because of the levels of six contaminants: PCBs, arsenic, hexachlorobenzene, hexachlorobutadiene, tetrachloroethene, and bis(2-ethylhexyl phthalate (DEHP). Average risks at the highest rate of ingestion, based on bay-wide mean levels, are as follows:

PCBs	6×10^{-3}
arsenic	4×10^{-4}
hexachlorobenzene	1×10^{-4}
hexachlorobutadiene	2×10^{-5}
DEHP	2×10^{-5}
tetrachloroethene	1×10^{-5}

Table 7. Summary of Risk Assessment

Carcinogens	Ingestion Rate	Carr Inlet Risk	Commencement Bay Risk	Ratio*
PCBs	1 lb./day	1E-03	6E-03	6
	1 lb./week	1E-04	8E-04	
	1 lb./month	3E-05	2E-04	
	1 lb./2 mos	2E-05	9E-05	
	1 lb./6 mos	6E-06	3E-05	
	1 lb./year	3E-06	2E-05	
Arsenic	1 lb./day	9E-04	4E-04	0.44
	1 lb./week	1E-04	6E-05	
	1 lb./month	3E-05	1E-05	
	1 lb./2 mos	1E-05	7E-06	
	1 lb./6 mos	5E-06	2E-06	
	1 lb./year	2E-06	1E-06	
HCB	1 lb./day	7E-05	1E-04	1.4
	1 lb./week	1E-05	2E-05	
	1 lb./month	1E-06	4E-06	
	1 lb./2 mos	7E-07	2E-06	
	1 lb./6 mos	2E-07	7E-0	
	1 lb./year	1E-07	3E-07	
HCBD	1 lb./day	2E-05	2E-05	1.0
	1 lb./week	3E-06	3E-06	
	1 lb./month	4E-07	7E-07	
	1 lb./2 mos	2E-07	3E-07	
	1 lb./6 mos	7E-08	1E-07	
	1 lb./year	3E-08	5E-08	
Tetrachloro-ethene	1 lb./day	2E-06	1E-05	5.0
	1 lb./week	2E-07	2E-06	
	1 lb./month	5E-08	5E-07	
	1 lb./2 mos	3E-08	2E-07	
	1 lb./6 mos	9E-09	8E-08	
	1 lb./year	4E-09	4E-08	
DEHP	1 lb./day	3E-06	2E-05	6.7
	1 lb./week	5E-07	3E-06	
	1 lb./month	1E-07	6E-07	
	1 lb./2 mos	5E-08	3E-07	
	1 lb./6 mos	2E-08	1E-07	
	1 lb./year	8E-09	5E-08	

Table 7. (continued)

Noncarcinogens	Ingestion Rate	Carr Inlet Ratio Exposure/ADI	C. Bay Ratio Exposure/ADI	Ratio*
Antimony	1 lb./day	1.66	1.57	0.9
	1 lb./week	0.24	0.22	
	1 lb./month	0.03	0.05	
	1 lb./2 mos	0.02	0.03	
	1 lb./6 mos	0.01	0.01	
	1 lb./year	0.005	0.005	
Lead	1 lb./day	0.99	0.99	1.0
	1 lb./week	0.14	0.14	
	1 lb./month	0.03	0.03	
	1 lb./2 mos	0.02	0.02	
	1 lb./6 mos	0.01	0.01	
	1 lb./year	0.005	0.005	
Mercury	1 lb./day	1.20	1.35	1.1
	1 lb./week	0.18	0.19	
	1 lb./month	0.04	0.04	
	1 lb./2 mos	0.02	0.02	
	1 lb./6 mos	0.01	0.01	
	1 lb./year	0.005	0.005	
Zinc (crabs)	1 lb./day	1.43	1.20	0.8
	1 lb./week	0.20	0.17	
	1 lb./month	0.05	0.04	
	1 lb./2 mos	0.02	0.02	
	1 lb./6 mos	0.01	0.01	
	1 lb./year	0.005	0.005	
Silver (crabs)	1 lb./day	5.58	3.92	0.7
	1 lb./week	0.80	0.56	
	1 lb./month	0.19	0.13	
	1 lb./2 mos	0.09	0.06	
	1 lb./6 mos	0.03	0.02	
	1 lb./year	0.01	0.01	

Risk via fish muscle tissue ingestion unless noted otherwise

* Ratio of risk from Commencement Bay seafood to risk from Carr Inlet seafood

Individual risks at lower ingestion rates are proportionately lower.

Three carcinogenic compounds are present in fish and crab muscle tissues at levels different from the levels in Carr Inlet fish and crab muscle tissues-- PCBs, tetrachloroethene, and DEHP. In the following discussion, all risks are individual risks at the highest level of consumption (one pound per day). The exposure that could result from eating Commencement Bay fish and crabs can also be put in perspective by comparing the levels at which they are present in Commencement Bay fish to levels in fish from other areas. Table 8 summarizes some readily available information on these three chemicals as well as the other pollutants discussed in this summary.

The risk due to consumption of fish containing PCB is higher for fish from Commencement Bay (6×10^{-3}) than for fish from Carr Inlet (1×10^{-3}). The calculated risk due to consumption of fish decreases as one moves away from the City Waterway (1×10^{-2}) toward the Ruston shoreline (2×10^{-3}). It should be noted that the major dietary source of PCBs is fish. PCBs are common pollutants of fish and other aquatic organisms. It is apparent from Table 8 that the PCB levels in fish from Commencement Bay are well within the reported ranges for fish taken from other industrialized areas.

The risk due to consumption of tetrachloroethene in Commencement Bay fish (1×10^{-5}) exceeds the risk due to that pollutant from ingestion of Carr Inlet fish (3×10^{-6}). Volatiles were not assayed for in the Ruston samples. In the waterways, risks ranged from 2×10^{-5} in the Hylebos and St. Paul Waterways to 8×10^{-6} in the City Waterway. The levels of this common industrial solvent in fish caught throughout the U.S. are listed in Table 8; levels in Commencement Bay fish are at the high end of the range. Exposure to DEHP is commonly experienced in the U.S. because this chemical is a component of all plastic vinyl products, as shown in Table 8. The calculated risks due to the presence of DEHP in fish averaged 2×10^{-5} in Commencement Bay and 3×10^{-6} in Carr Inlet. The mean values of DEHP in this

Table 8. Comparative Exposure for Contaminants of Concern

CHEMICAL	AVERAGE LEVEL IN FISH FROM COMMENCEMENT BAY ppb (ng/g)	CARR INLET ppb (ng/g)	OTHER AREAS ppb (ng/g)	DESCRIPTION OF DATA	SOURCE	OTHER ENVIRONMENTAL EXPOSURES ug/day
PCBs	210	36	320	Delaware Bay, 7 fish, 1982	Belton et al. 1982	8.7 (dietary) USEPA 1980
			14 to 410	Los Angeles, 1980, 65 samples of croaker	Gossett et al. 1983	
			300 to 3280	Hudson River, 8 species, 1981 survey	Belton et al. 1982	
			100 to 13100	New Bedford Harbor, 1978-1980	Weaver 1983	
			1100	polluted areas of U.S., Dover sole	see Appendix H	
			16	reference areas of U.S., Dover sole	see Appendix H	
			555	polluted areas of U.S., starry flounder	see Appendix H	
			25.5	reference areas of U.S., starry flounder	see Appendix H	
HCB	11	<10	0.9	polluted areas of U.S., winter flounder	see Appendix H	0.074 USEPA 1980
			0.92	reference areas of U.S., winter flounder	see Appendix H	
HCBD	40	<40	unknown			unknown
DEHP	194	35	290	332 Japanese shellfish samples	Versar 1982	55 to 14,230 Versar 1982
			30	FDA (1974), Mobile Bay, AL	Versar 1982	
			1200	FDA (1974), San Francisco, CA	Versar 1982	
			14600	Survey of hatchery salmon	Versar 1982	
Tetra-chloroethene	66	7	<1 to 41	marine fish in North Atlantic	Pearson and McConnell	0.0018 to 17.6 from consumer products Versar 1981
antimony	1009.3	1070	unknown			
mercury	59.5	55.4	96.0	NOAA survey of 1179 flatfish	NOAA 1978	3.4 (dietary) USEPA 1980
			55	polluted areas of U.S., Dover sole	see Appendix H	
			157	reference areas of U.S., Dover sole	see Appendix H	
			60	polluted areas of U.S., winter flounder	see Appendix H	
			40	reference areas of U.S., winter flounder	see Appendix H	
lead	218 (fish)	218	73	polluted areas of U.S., Dover sole	see Appendix H	113 (total) USEPA 1980
			78	reference areas of U.S., Dover sole	see Appendix H	
	479 (crab)	196	900	polluted areas of U.S., Eastern rock crab	see Appendix H	
			500	reference areas of U.S., Eastern rock crab	see Appendix H	
silver	138 (crab)	197	390	polluted areas of U.S., American lobster	see Appendix H	30 (dietary) USEPA 1980
			555	reference areas of U.S., American lobster	see Appendix H	
			270	polluted areas of U.S., Eastern rock crab	see Appendix H	
			250	reference areas of U.S., Eastern rock crab	see Appendix H	
zinc	39895 (crab)	47430	40080	polluted areas of U.S., Eastern rock crab	see Appendix H	15000 Recommended Daily Allowance
			37245	reference areas of U.S., Eastern rock crab	see Appendix H	
arsenic	4070	7940	3400 to 17000	Discovery Bay, Puget Sound, 1982	Gahler et al. 1982	3.4 to 34000 in Tacoma Schaum 1982
			1700	polluted areas of U.S., California mussel	see Appendix H	
			2000	reference areas of U.S., California mussel	see Appendix H	

survey of fish and crab muscle tissue are well within the range of values reported elsewhere for similar studies, as seen in Table 8.

Predicted maximum individual lifetime risks from consumption of fish exceeds 10^{-6} for both Commencement Bay and Carr Inlet due to the presence of arsenic. The risk due to consuming fish containing arsenic was calculated by assuming that 0.12% is in the inorganic form. Risks from Commencement Bay fish are around 4×10^{-4}, while risks from eating Carr Inlet fish are around 7×10^{-4}. Although absolute estimated risks are on the order of 10^{-4} for persons eating a pound of fish muscle tissue daily, available data (see Table 8) indicate that seafood in general contains arsenic at levels approximately equal to those found in this study.

Two carcinogens were detected only in fish from the Hylebos Waterway. Hexachlorobenzene and hexachlorobutadiene were detected in only two of the fifteen fish taken from the Hylebos Waterway. The levels at which they were detected were only slightly higher than the method detection limits, corresponding to risks of 1×10^{-4} and 2×10^{-5} for hexachlorobenzene and hexachlorobutadiene, respectively; risks from Carr Inlet fish, as calculated from the method detection limit, were 7×10^{-5} and 2×10^{-5} respectively. Risks from these pollutants in Carr Inlet fish, in which they were not detected, could be anywhere between zero and the maximum risks calculated above.

Limiting consumption of fish to one half pound a day would result in exposure less than the Acceptable Daily Intake for all noncarcinogenic substances detected. Three chemicals are present in fish at levels that would cause exposure to exceed the ADI at a one pound per day consumption rate. Those three chemicals are metals: antimony, lead, and mercury. Only for the pound per day rate of ingestion could exposure exceed the ADI. There is essentially no difference in the levels of these metals, regardless of where the tissue samples were collected, and therefore no difference in risk between Commencement Bay and the Carr Inlet reference area. For comparison, reported levels of these chemicals in fish tissues from other areas are summarized in Table 8.

Most chemicals that were analyzed for but not detected in fish muscle tissue were also not detected in sediments. For two chemicals that were not detected in fish muscle, but were detected in sediments, calculated risks at the method detection limit were greater than 10^{-6}. As discussed previously in Section 4, the majority of the chemicals not detected in fish or crab muscle tissue (35 of 48) were also not detected in sediment analyses. The two chemicals were detected in sediments and, if present in fish at the method detection limit, would result in maximum risks greater than 10^{-6}: PAHs (3×10^{-3}) and n-nitrosodipropylamine (4×10^{-3}). Neither of these is, however, expected to persist in fish muscle at levels near the detection limit. PAHs have been shown to be fairly rapidly cleared from muscle of English sole (Stein et al. 1984), appearing as liver and bile metabolites. N-nitroso-dipropylamine was detected in only 2 of 151 sediment samples, both from the Blair Waterway. These findings constitute evidence that the chemicals analyzed for but not detected in this study are not a significant threat to human health.

In general, fish from the waterways are more contaminated with the chemicals of concern listed above than are fish from the Ruston shoreline area. The Ruston shoreline and the City Waterway have been found by Pierce et al. (1981) to be the areas most frequently fished. Risks from eating fish caught in the Ruston area are elevated above the bay-wide average for arsenic only. Recall that for arsenic the highest risks were predicted for eating fish from the Carr Inlet reference area. The assessment of PCB risk, if addressed on a station-by-station basis, indicates that PCB levels decline, as one moves toward Pt. Defiance, with distance from the waterways. The City Waterway was found to have the highest predicted individual lifetime risks from PCBs and DEHP; risks attributable to the other carcinogens assessed were average or below average as compared to the other areas of the Bay and Carr Inlet. The PCB and DEHP risks at the City Waterway, though elevated, were within a factor of 10 of the calculated risks for the other areas.

Carcinogenic risks from PCBs were also higher in the Hylebos Waterway fish than in other areas. In addition, the Hylebos Waterway was the only waterway in which hexachlorobenzene and hexachlorobutadiene were detected in fish muscle tissues. Risk from the presence of tetrachloroethene was also highest from ingestion of this waterway's fish. Recall, however, that volatiles were monitored for only in the Hylebos, St. Paul, and City Waterways and Carr Inlet.

Finally, for no pollutant found in Commencement Bay fish tissue were measured levels above the range reported elsewhere, as seen from the data in Table 8.

Risk from ingestion of fish liver is difficult to estimate; available data indicate that maximum individual lifetime risks due to the presence of three carcinogens detected in liver composites could exceed 10^{-6}. At an ingestion rate of 0.12 pounds per day, the risk from PCBs in liver is 10^{-2}; the risk from hexachlorobenzene, 10^{-4}; and the risk from hexachlorobutadiene, 10^{-5}. For no noncarcinogen did predicted exposure from ingestion of livers exceed the ADI.

Risks from ingesting crab muscle tissue are approximately the same as risks from eating fish muscle tissue. Bay-wide average risks, based on consuming a pound per day, were as follows:

PCBs	3×10^{-3}
Arsenic	2×10^{-4}
DEHP	3×10^{-6}

Risks for all other carcinogens were less than 10^{-6}. Average risks from eating Commencement Bay crabs were greater than risks from Carr Inlet crabs only for PCBs (with average Carr Inlet risks of 1×10^{-3}). Risks were equal in both areas for arsenic, and DEHP risks were higher in Carr Inlet crabs than in Commencement Bay crabs. Exposure exceeded the ADI for the following contaminants for persons consuming one pound of crab muscle daily: antimony, lead, silver, zinc, and mercury. The differences between Commencement Bay and Carr Inlet levels of the noncarcinogens were slight; only for mercury did Commencement Bay levels (ratio of exposure to ADI of 2.33) exceed Carr Inlet levels (ratio of exposure to ADI of 1.01). Consumption of less than one pound of crab muscle per week would bring exposure consistently below the ADI for all noncarcinogens.

The highest estimated incidence of cancer in the exposed population of 15,220 persons is one to two cases of cancer in 70 years, attributable to PCBs causing cancer of the liver. For all other carcinogens, the predicted incidence is less than 1 case. All available data indicate that the chemical associated with the highest individual lifetime cancer risk is PCBs; the next highest risk is attributable to arsenic. Table 9 presents a calculation of the maximum predicted cancer cases attributable to the two chemicals over a 70-year exposure period. Only for PCBs does the predicted number of cases exceed 1, even with the conservative approach taken in this assessment (continuous exposure for 70 years, etc.). As arsenic exposure is predicted to result in fewer than 1 case over 70 years, and it is the second highest in individual risk, the presence of no other chemical is likely to produce cancer among the exposed population under the types of circumstances presented in this assessment.

Auto wrecks,
over 7 yrs
21 out of 15,000

Table 9. Projected Lifetime Cancer Cases

PCBs

Frequency	Fish Intake g/day	Exposure mg/kg/day	Individual Risk	Population	Cases
Daily	453.0	1.36E-03	5.90E-03	30	0.18
Weekly	64.7	1.94E-04	8.42E-04	1005	0.85
Monthly	15.1	4.53E-05	1.97E-04	1735	0.34
Bimonthly	7.4	2.22E-05	9.63E-05	1111	0.11
Twice/year	2.5	7.50E-06	3.26E-05	2618	0.09
Yearly	1.2	3.60E-06	1.56E-05	8721	0.14
			Total	15220	1.69

Arsenic

Frequency	Fish Intake g/day	Exposure mg/kg/day	Individual Risk	Population	Cases
Daily	453.0	3.16E-05	4.42E-04	30	0.01
Weekly	64.7	4.51E-06	6.31E-05	1005	0.06
Monthly	15.1	1.05E-06	1.47E-05	1735	0.03
Bimonthly	7.4	5.16E-07	7.22E-06	1111	0.01
Twice/year	2.5	1.74E-07	2.44E-06	2618	0.01
Yearly	1.2	8.37E-08	1.17E-06	8721	0.01
			TOTAL	15220	0.13

6.0 REFERENCES

Belton TJ, Ruppel BE, Lockwood K. 1982. PCBs in fish: a comprehensive survey. Trenton, NJ: Department of Environmental Protection.

Crecelius EA, Apts CW. 1984. Concentration and speciation of arsenic in flatfish and crabs collected from Commencement Bay. Draft report. Tacoma, WA: Tacoma-Pierce Co. Health Department.

Gahler AR, et al. 1982. Chemical contaminants in edible, non-salmonid fish and crabs from Commencement Bay, Washington. Seattle, WA: USEPA, Region X.

Gossett RW, Puffer HW, Arthur RH, Young DR. 1983. DDT, PCB, and benzo(a)pyrene levels in white croaker (Genyonemus lineatus) from Southern California. Mar. Poll. Bull. 14(2), 60-65.

New York State Department of Health. 1981. Organic chemicals in drinking water. Albany, NY: NYSDH.

NOAA. 1978. National Oceanographic and Atmospheric Administration. Report on the chance of U.S. seafood consumers exceeding the current acceptable daily intake for mercury and recommended regulatory controls. Washington, DC: NOAA, National Marine Fisheries Service.

Pierce D, Noviello D, Rogers S. 1981. Commencement Bay seafood consumption study- preliminary report. Tacoma, WA: Tacoma-Pierce County Health Department.

Schaum J. 1983. Assessment of human exposure to arsenic. Tacoma, Washington.

Stein JE, Hom T, Varanasi U. 1984. Simultaneous exposure of English sole (Parophrys vetulus) to sediment-associated xenobiotics: Part 1- uptake and disposition of ^{14}C-polychlorinated biphenyls and ^{3}H-benzo(a)pyrene. Marine Env. Res. 13: 97-113.

Tetra Tech. In preparation. Commencement Bay nearshore/tideflats waterways/shoreline remedial investigation.

USEPA. 1980. U.S. Environmental Protection Agency. Ambient water quality criteria documents for the priority pollutants. Washington, DC: Office of Water Regulations and Standards.

USEPA. 1983. U.S. Environmental Protection Agency. Health assessment summary of 300 hazardous organic constituents. Unpublished file memorandum from Michael Dourson. Cincinnati, OH: USEPA Environmental Criteria and Assessment Office.

USEPA. 1984. U.S. Environmental Protection Agency. Health assessment document for tetrachloroethylene. External review draft report. Washington, DC: USEPA Office of Health and Environmental Assessment.

Versar, Inc. 1981. TSPC solvents exposure assessment. Washington, DC: USEPA Office of Toxic Substances.

Versar, Inc. 1982. Exposure assessment for DEHP. Washington, DC: USEPA Office of Toxic Substances.

Weaver G. 1984. PCB contamination in and around New Bedford, Mass. Environmental Science and Technology 18(1), 22A-27A.