Health Consultation

Evaluation of Organic Contaminants in Geoduck Tissue from Tracts near Wyckoff/Eagle Harbor Superfund Site
Eagle Harbor, Kitsap County, Washington

September 10, 2009

Prepared by

The Washington State Department of Health
Under a Cooperative Agreement with the
Agency for Toxic Substances and Disease Registry

Washington State Department of Health

DOH 334-216 September 2009

Health Consultation: A Note of Explanation

A health consultation is a verbal or written response from ATSDR or ATSDR's Cooperative Agreement Partners to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR or ATSDR's Cooperative Agreement Partner which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

HEALTH CONSULTATION

Evaluation of Organic Contaminants in Geoduck Tissue from Tracks near

WYCKOFF/EAGLE HARBOR SUPERFUND SITE

EAGLE HARBOR, KITSAP COUNTY, WASHINGTON

Prepared By:

The Washington State Department of Health
Under Cooperative Agreement with the
Agency for Toxic Substances and Disease Registry

Foreword

The Washington State Department of Health (DOH) has prepared this health consultation in cooperation with the Agency for Toxic Substances and Disease Registry (ATSDR). ATSDR is part of the U.S. Department of Health and Human Services and is the principal federal public health agency responsible for health issues related to hazardous waste. This health consultation was prepared in accordance with methodologies and guidelines developed by ATSDR.

The purpose of this health consultation is to identify and prevent harmful human health effects resulting from exposure to hazardous substances in the environment. Health consultations focus on specific health issues so that DOH can respond to requests from concerned residents or agencies for health information on hazardous substances. DOH evaluates sampling data collected from a hazardous waste site, determines whether exposures have occurred or could occur, reports any potential harmful effects, and recommends actions to protect public health. The findings in this report are relevant to conditions at the site during the time of this health consultation, and should not necessarily be relied upon if site conditions or land use changes in the future.

For additional information or questions regarding DOH or the contents of this health consultation, please call the health advisor who prepared this document:

Elmer Diaz
Washington State Department of Health
Office of Environmental Health Assessments
P.O. Box 47846
Olympia, WA 98504-7846
(360) 236-3357
1-877-485-7316
Website: http://www.doh.wa.gov/consults

For people with disabilities, this document is available on request in other formats. To submit a request, please call 1-800-525-0127 (TTY/TDD call 711).

For more information about ATSDR, contact the ATSDR Information Center at 1-888-422-8737 or visit the agency's Web site: www.atsdr.cdc.gov/.

Glossary

Acute	Occurring over a short time [compare with chronic].
Agency for Toxic Substances and Disease Registry (ATSDR)	The principal federal public health agency involved with hazardous waste issues, responsible for preventing or reducing the harmful effects of exposure to hazardous substances on human health and quality of life. ATSDR is part of the U.S. Department of Health and Human Services.
Cancer Slope Factor	A number assigned to a cancer causing chemical that is used to estimate its ability to cause cancer in humans.
Carcinogen	Any substance that causes cancer.
Chronic	Occurring over a long time (more than 1 year) [compare with **acute**].
Comparison value (CV)	Calculated concentration of a substance in air, water, food, or soil that is unlikely to cause harmful (adverse) health effects in exposed people. The CV is used as a screening level during the public health assessment process. Substances found in amounts greater than their CVs might be selected for further evaluation in the public health assessment process.
Contaminant	A substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects.
Dose (for chemicals that are not radioactive)	The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligram (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An “exposure dose” is how much of a substance is encountered in the environment. An “absorbed dose” is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines, or lungs.
Environmental Protection Agency (EPA)	United States Environmental Protection Agency. EPA leads the nation's environmental science, research, education and assessment efforts. The mission of the Environmental Protection Agency is to protect human health and the environment. Since 1970, EPA has been working for a cleaner, healthier environment for the American people.
Epidemiology	The study of the occurrence and causes of health effects in human populations. An epidemiological study often compares two groups of people who are alike except for one factor, such as exposure to a chemical or the presence of a health effect. The investigators try to determine if any factor (i.e., age, sex, occupation, economic status) is associated with the health effect.

Exposure	Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [**acute exposure**], of intermediate duration, or long-term [**chronic exposure**].
Hazardous substance	Any material that poses a threat to public health and/or the environment. Typical hazardous substances are materials that are toxic, corrosive, ignitable, explosive, or chemically reactive.
Ingestion	The act of swallowing something through eating, drinking, or mouthing objects. A hazardous substance can enter the body this way [see route of exposure].
Ingestion rate (IR)	The amount of an environmental medium that could be ingested typically on a daily basis. Units for IR are usually liter/day for water and mg/day for soil.
Inorganic	Compounds composed of mineral materials, including elemental salts and metals such as iron, aluminum, mercury, and zinc.
Lowest Observed Adverse Effect Level (LOAEL)	The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.
Media	Soil, water, air, plants, animals, or any other part of the environment that can contain contaminants.
Method Detection Limit (MDL)	MDL is the minimum concentration of a substance (in a given matrix) that can be measured with a 99% confidence that the analyte concentration is greater than zero.
No Observed Adverse Effect Level (NOAEL)	The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects on people or animals.
Oral Reference Dose (RfD)	An amount of chemical ingested into the body (i.e., dose) below which health effects are not expected. RfDs are published by EPA.
Organic	Compounds composed of carbon, including materials such as solvents, oils, and pesticides that are not easily dissolved in water.
Parts per billion (ppb)/Parts per million (ppm)	Units commonly used to express low concentrations of contaminants. For example, 1 ounce (oz.) of trichloroethylene (TCE) in 1 million ounces of water is 1 ppm. 1 ounce of TCE in 1 billion ounces of water is 1 ppb. If one drop of TCE is mixed in a competition size swimming pool, the water will contain about 1 ppb of TCE.

Remedial investigation	The CERCLA process of determining the type and extent of hazardous material contamination at a site.
Route of exposure	The way people come into contact with a hazardous substance. Three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact].

Summary

Introduction

The Washington State Department of Health (DOH) prepared this health consultation at the request of the Suquamish Tribe and the DOH Office of Shellfish and Water Protection (OSWP). The purpose of this health consultation is to evaluate geoduck organic contaminant data from two commercial geoduck tracts situated east and adjacent to the Wyckoff/Eagle Harbor Superfund site in Washington and make recommendations for actions that ensure the public's health is protected.

Conclusions

DOH concludes that high end geoduck consumers are unlikely to be exposed to harmful levels of organic contaminants from eating geoduck near the Wyckoff/Eagle Harbor Superfund Site (Tyee Shoal geoduck tract # 07650 and Port Blakely geoduck tract # 07700). Thus, low levels of organic contaminants present in geoduck are not expected to harm people's health.

Basis for conclusion

Geoduck sampled from tracts near the Wyckoff/Eagle Harbor Superfund Site had low levels of organic contamination.

Next steps

The Department of Health's Office of Food Safety and Shellfish will use this health consultation in the process used to certify shellfish growing areas.

For More Information

If you have concerns about your health, as it relates to exposure to harmful levels of organic contaminants near the Wyckoff/Eagle Harbor Superfund Site, you should contact the Washington State Department of Health, Toll Free 1-877-485-7316.

Purpose

The Washington State Department of Health (DOH) prepared this health consultation at the request of the Suquamish Tribe and the DOH Office of Shellfish and Water Protection (OSWP). The purpose of this health consultation is to evaluate geoduck organic contaminant data from two commercial geoduck tracts situated east and adjacent to the Wyckoff/Eagle Harbor Superfund site in Washington and make recommendations for actions that ensure the public's health is protected. DOH prepares health consultations under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR).

Background and Statement of Issues

Eagle Harbor is a 500 acre inlet on the east side of Bainbridge Island located in Central Puget Sound, Washington (Figure 1). Sediments in Eagle Harbor are contaminated with polycyclic aromatic hydrocarbons (PAHs) and wood treatment compounds from Wyckoff's former wood treating facility located at the harbor's entrance, and metals such as mercury, copper, lead, and zinc from historic shipyards.[1,2]

On the Wyckoff facility, soil and groundwater are contaminated with creosote and its accompanying PAHs, dioxins/furans and pentachlorophenol (PCP), and other wood treatment compounds. As much as one million gallons of creosote product are estimated to remain in the site's soil and groundwater.[1,2] In 1997, DOH completed a chemical contamination assessment of geoduck adjacent to Eagle Harbor and recommended that due to the potential contamination of geoduck from the Wyckoff/Eagle Harbor Superfund site 1) geoduck and sediment samples from the proposed harvest area be collected and analyzed to determine organic and metal concentrations; 2) newly collected sediment and tissue data be evaluated in a detailed human health impact assessment; and, 3) harvest of geoduck from the area outside of Eagle Harbor be postponed as a matter of prudent public health policy pending the results of recommendations one and two above.[3]

A seafood consumption advisory has been in place at Eagle Harbor since the early 1980's.[1,2] Recreational shellfish harvesting in Eagle Harbor is not advised and commercial harvest of shellfish, including geoducks from tracts near the mouth of Eagle Harbor, is prohibited partly due to chemical contamination concerns, but also as a result of a nearby municipal sewage outfall operated by the City of Bainbridge Island.

The City of Bainbridge Island plans to extend their sewage outfall further from the shore into deeper water. This will serve to dilute sewage impacts on near shore environments and potentially open up prohibited shellfish harvest sites for commercial harvest classification. However, the outfalls have not been extended due to funding issues.[4]

The Suquamish Tribe requested a health consultation from DOH OSWP to evaluate the potential chemical contamination of geoduck associated with the Wyckoff/Eagle Harbor Superfund site from two tracts adjacent to the mouth of Eagle Harbor, one in Port Blakely (#07700) and the other in the Tyee Shoal tract (#07650) in Puget Sound, and to provide information that the Tribe can use when making future tribal harvest management decisions (Figure 1). These tracts are not currently classified for commercial harvest due to pollution concerns from municipal sewage outfalls and potential chemical contamination associated with the Wyckoff/Eagle Harbor Superfund site. Because it is not known how past and current pollution may impact geoducks in this area, a necessary first step in the process of certifying this area for harvest is to determine whether contaminant concentrations are at an acceptably low level for consumers.

Methods

Prior to sampling, a quality assurance project plan (QAPP) was prepared by the Suquamish Tribe and DOH, and submitted to the U.S. EPA for approval.[5] In general, the plan identified contaminants of concern, sample size, sample preparation, and data quality objectives.

Geoduck samples were collected on May 16, 2005. Scuba divers from the Suquamish Tribe collected geoduck samples from six sampling locations and one location located within a commercial geoduck tract in Agate Passage (tract # 06800) (Figure 2). The Agate Passage station is located on the northwestern side of Bainbridge Island and is the background sample station.

A geoduck sample was collected at each of the stations consisting of a composite of five geoduck clams. A total of twelve geoduck tissue samples (i.e., four at Tyee Tract, four at Blakely Tract, two at background site, and two field duplicates) were collected during standard geoduck harvesting techniques implemented by the Suquamish Tribe. A diver used a hose pressurized with water to dig the geoduck clams. The depths of the sampling locations ranged from 20 to 46 feet.[6]

Samples were individually wrapped in foil, given a unique identifier, placed on ice (or blue ice), and hand delivered to AXYS Analytical Services in British Columbia. AXYS staff dissected each geoduck in a manner similar to the way they would be cleaned prior to consumption. Edible portions of geoduck muscle tissue (neck and mantle) and gutball were separated from the shell and homogenized creating one composite sample (each composite consisted of five individual geoducks from each sampling site). Gutballs from two samples, a field duplicate sample, and a reference area (Agate Passage) were also homogenized. Portions of homogenized tissue were analyzed at AXYS for dioxins and percent lipids, and the remainder was sent to EPA Region 10 Manchester laboratory in Port Orchard, Washington for analysis of metals (including speciated arsenic), PAHs, and polychlorinated biphenyls (PCBs).

The outer skin of the neck was unfortunately not removed prior to homogenization for laboratory analysis. Thus, the inorganic portion of the data won't be considered for analysis in this report (Appendix A, Table A9 shows inorganic data). The Suquamish Tribe collected geoduck samples in the spring of 2008. The analysis of these data will be included in a separate health consultation report in the summer of 2009. **Only the organic data (i.e., 2005) will be considered for analysis in this report.**

Methods, results, quality assurance/quality control (QA/QC), and data validation are summarized in the final Quality Assurance Project Plan.[5]

Contaminants of concern

Chemical contaminants in geoduck have not been widely studied in Puget Sound, so relative to other bivalve species, little is known about how contaminant levels in geoduck vary by location or age. Recent studies by King County, Kitsap County, the Suquamish Tribe, and others have revealed that organic contaminants are seldom found in geoduck, even in areas that have been impacted by industrial use in the past.[7,8,9] Conversely, metals are commonly found in geoduck tissue.

Results and Discussion

A summary of results is presented in Table 1. A complete set of results is presented in Appendix A, Tables A1 – A5. In general, the non-edible portions had slightly higher levels of contaminants than the edible portions (Appendix A, Table A6).

The following is a summary of the main findings related to organic contaminants:

PAHs were not found frequently in geoduck samples. Low levels were found in samples closest to the former Wyckoff site (Port Blakley tract). PAHs were rarely detected in Tyee Shoal tract geoduck. Only one PAH, fluoranthene, was detected in Tyee tract geoduck necks. This chemical was the most frequently detected PAH. Carcinogenic PAHs were summed to create a benzo(a)pyrene toxic equivalent (benzo(a)pyrene (TEQ)).[10]

PCBs were found in only three samples. Aroclor 1254 was the only PCB mixture detected. Total PCBs were calculated by summing Aroclors 1248, 1254, and 1260 because these are usually the only Aroclor mixtures typically detected in Puget Sound seafood. One-half the method detection limit was assumed for non-detects (see uncertainty for non-detect results section).

Dioxins and furans were found at low levels in all samples. 2,3,7,8 tetrachlorodibenzo(p)dioxin toxic equivalents (TCDD TEQ) were summed according to World Health Organization (WHO) methodology.[11,12] TCDD TEQ levels were higher in geoduck taken from locations near the former Wyckoff facility.

Contaminant screening

The main goal of sampling geoduck from tracts near the Wyckoff/Eagle Harbor Superfund site was to determine if site contaminants in geoducks from tracts adjacent to the site (Tyee Shoal and Port Blakely) are a potential health concern (i.e., determine whether the site is impacted by contaminants that would prevent geoduck harvests). With the exception of mercury, there are no existing regulatory criteria established with regard to chemical contaminant levels in shellfish (personal communication with Michael Antee, U.S. Food and Drug Administration Pacific Region, Regional Shellfish Specialist).

Geoduck contaminant data were screened using values that DOH considers protective of tribal geoduck consumers (Appendix B). Table 1 shows the mean concentration of each contaminant measured in geoduck necks (siphon and strap) compared to health-based high-end consumer comparison values. The fact that a contaminant exceeds its health comparison value does not mean that a public health hazard exists, but rather signifies the need to consider the chemical further. The mean value or central tendency for the neck and strap portion of geoduck was used for this analysis.

Table 1. Summary of chemical contaminants in Wyckoff/Eagle Harbor area geoduck compared to background area levels and tribal consumption screening values (Wyckoff/Eagle Harbor Superfund Site, Kitsap County, Washington).

Contaminant	Units	Mean Neck (ww)	Background (Agate Passage) Neck (ww)	Tribal Use Comparison Value[a] *** (ww)	Contaminant of concern
Total PCBs	**ppb**	**8.8**	**5.4 (ND)**	**4.3**	**Yes**
9H-Fluorene	ppb	<1.6	<1.5	36,000	No
Acenaphthene	ppb	<1.6	<1.5	NA	No
Acenaphthylene	ppb	<1.6	<1.5	NA	No
Anthracene	ppb	2.5	<1.5	270,000	No
Benzo(g,h,i)perylene	ppb	<1.6	<1.5	NA	No
Fluoranthene	ppb	4.6	3.1	36,000	No
Napthalene	ppb	<1.6	<1.5	18,000	No
Napthalene, 1-methyl-	ppb	<1.6	<1.5	NA	No
Napthalene, 2-methyl-	ppb	<1.6	<1.5	3,600	No
Phenanthrene	ppb	1.3	<1.5	NA	No
Pyrene	ppb	<1.6	<1.5	895	No
Benzo(a)pyrene TEQ	**ppb**	**2.7**	**1.7**	**0.3**	**Yes**
TCDD TEQ	**ppt**	**0.166**	**0.111**	**0.02**	**Yes**

NA – Not available
BOLD values exceed comparison value
[a] Derived assuming high-end consumption rate Suquamish 90th percentile all shellfish consumption rate (consumers only) (Appendix B, Table B1)
ND = no detected, value is the method detection limit (MDL)[a] . Half the detection limit was used for undetected samples.
ww = wet weight
ppt = parts per trillion

Of all contaminants listed, only total PCBs, benzo(a)pyrene TEQs and TCDD TEQs were found

[a] MDL is the minimum concentration of a substance (in a given matrix) that can be measured with a 99% confidence that the analyte concentration is greater than zero.

above health-based comparison values protective of subsistence consumers.

Evaluating exposure to contaminants in geoduck

As mentioned above, there are no established regulatory levels with regard to chemical contaminants in seafood and shellfish (excluding mercury). The U.S. Food and Drug Administration (FDA) had previously derived action levels, tolerances, and guidance levels for poisonous deleterious substances in seafood, but these levels were not intended for enforcement purposes.[13,14] More recently, these levels were removed from FDA guidance documents to eliminate confusion.

In the absence of existing regulatory levels, DOH will assess human health risk using the methodology described below:

- Estimate how much geoduck meat is consumed by potentially exposed consumers, tribal members, and additional high-end geoduck consuming populations.

- Obtain organic contaminant data, or analyze geoduck samples for contaminant concentrations in order to estimate levels in geoduck tissue. In this case, samples taken by the Suquamish Tribe are from two main sampling sections near Wyckoff/Eagle Harbor (i.e., Port Blakely tract (#07700) and Tyee Shoal tract (#07650)) Superfund site.

- Establish what contaminants people are potentially exposed to. DOH will calculate the dose of a contaminant that a person would receive from consuming geoduck. For the purpose of this health consultation, it is assumed that all geoduck consumed are harvested from the Port Blakely and the Tyee Shoal tracts.

- Determine if the calculated exposure dose is considered safe. This is done by comparing the calculated exposure dose to an oral reference dose (RfD) specific to each chemical of concern, modeling blood lead levels in children and fetuses, and estimating a consumer's lifetime increased theoretical cancer risk.

Geoduck consumption rates

The majority of geoduck harvested in Puget Sound is exported to markets in Asia. The amount of geoduck typically consumed per person in the Asian markets is not known. However, geoducks are costly (~ $20.00 per pound), so frequent consumption is not likely; rather, geoduck are probably eaten only on special occasions. Nevertheless, it is important to estimate a reasonable geoduck consumption rate in order to estimate exposure to chemical contaminants.

Table 2 shows shellfish or geoduck consumption rates for the U.S. population, Puget Sound Native American Tribes, and Asian and Pacific Islanders (API) from King County.[15,16,17,18] Suquamish geoduck consumption rates range from one three-ounce (oz.) meal per month (75^{th} percentile Suquamish children) to 2.7 eight-ounce meals per week (95^{th} percentile Suquamish adults).

Table 2. Adult's and children's shellfish or geoduck consumption rates.

Consumption Rate (meals per month)	Daily rate- (g/day) [a]		Grams shellfish consumed per kilogram body weight per day (g/kg/day) [b]		Comparable ingestion rates
	Adults	Children	Adults	Children	
0.25 3 meals per year	1.9	0.7	0.03	0.05	Average U.S. general population marine shellfish consumption rate (1.7 g/day) Suquamish Tribe children median (consumers only) geoduck consumption rate (0.053 g/kg/day)
0.5 6 meals per year	3.7	1.4	0.05	0.09	Squaxin Island Tribe adult median shellfish consumption rate (0.065 g/kg/day) Suquamish Tribe adult median (consumers only) geoduck consumption rate (0.052 g/kg/day)
1	7.5	2.8	0.11	0.19	Tulalip Tribe adult median shellfish consumption rate (0.153 g/kg/day) Suquamish Tribe children 75th percentile (consumers only) geoduck consumption rate (0.23 g/kg/day)
2	15	5.6	0.22	0.37	Suquamish adults 80th percentile (consumers only) geoduck consumption rate (0.25 g/kg/day).
4	30	11	0.43	0.73	Suquamish adults 90th percentile (including non-consumers) geoduck consumption rate (0.39 g/kg/day) Suquamish adults 90th percentile (consumers only) geoduck consumption rate (0.44 g/kg/day) King County Asian and Pacific Islander median all shellfish consumption rate (0.50 g/kg/day) Suquamish children 95th percentile (including non-consumers) geoduck consumption rate (0.84 g/kg/day)
10	76	28	1.08	1.9	Suquamish adult 95th percentile geoduck consumption rate consumers only (1.117 g/kg/day)

[a]- assumes eight-ounce meal (227 g) for adults and three-ounce meal (85 g) for children
[b]- assumes a bodyweight of 70 kg for adults and 15 kg for children

The consumption rate used in this evaluation is based on the **95th percentile Suquamish consumers only rate for geoduck** (i.e., 1.117 g/kg/day which corresponds to ~ 2.7 eight-oz. meals per week). This rate represents geoduck as a portion of the total shellfish market basket. The 2000 Suquamish survey presents a range of total seafood ingestion rates that include many species of shellfish, as well as fin fish. Geoduck is a subgroup of all shellfish. The geoduck only rate used in this evaluation is not meant to represent a tribal subsistence consumption rate. Appendix C, Table C1 shows the exposure assumptions.

Non-cancer Hazard Evaluation

Estimated doses for average U.S. and Suquamish Tribe shellfish and geoduck consumption were calculated (shown in Appendix C) in order to evaluate the potential for *non-cancer* adverse health effects in children and adults that might result from exposure to contaminants in geoduck harvested from the study area. This was intended to represent a reasonable range for children's and adult's exposure to contaminants from geoduck consumption. These estimated doses were then compared to either EPA's RfD or ATSDR's minimal risk level (MRL). These are doses below which non-cancer adverse health effects are not expected to occur ("safe" doses). They are derived from toxic effect levels obtained from human population and laboratory animal studies. These toxic effect levels are divided by multiple "safety factors" to give the lower, more protective RfD or MRL. A dose that exceeds the RfD or MRL indicates only the potential for adverse health effects. The magnitude of this potential can be inferred from the degree to which this value is exceeded by the exposure dose. If the estimated exposure dose is only slightly above the RfD or MRL, then that dose will fall well below the toxic effect level. The higher the estimated dose is above the RfD or MRL, the closer it will be to the toxic effect level.

<u>Estimates of non-cancer hazards for Wyckoff/Eagle Harbor area geoduck consumers</u>

Exposure assumptions and dose calculations are shown in Appendix C, Table C1. In order to determine if an exposure dose represents a hazard of non-cancer human health effects, exposure doses are compared to the RfD (or MRL) to obtain a hazard quotient (HQ) where:

HQ = estimated dose/RfD

This provides a convenient method to measure the relative health hazard associated with a dose. As the hazard quotient exceeds one and approaches an actual toxic effect level, the dose becomes more of a health concern.

When this approach is applied to consumption of geoduck from tracts near Wyckoff/Eagle Harbor, children from the Suquamish Tribe consuming geoduck at median rates (~ three 3-oz meals per year) do not exceed a hazard quotient of one for the contaminants of concern. This means that children would not likely be exposed to contaminants that would result in adverse non-cancer effects from consumption of geoduck. Children that are high-end geoduck consumers (i.e. greater than 75th percentile) from the Suquamish Tribe would also not exceed a hazard quotient of one associated with organic contaminant exposure.

Adults eating 2.7 eight-oz. meals per week (high-end consumption equal to Suquamish 95th percentile adults – geoduck consumers only) do not exceed a hazard quotient of one attributable to exposure to organic contaminants in geoduck. The same is true for consumers that eat both the neck and gutball (i.e., whole body). Hazard quotients for average U.S. shellfish consumers and typical tribal geoduck consumers are less than one for all contaminants (Appendix C, Table C2). Overall, estimated doses for children and adults are below the RfD indicating that non-cancer health effects are not expected to occur from consumption of geoduck at Wyckoff/Eagle Harbor site.

Theoretical Cancer Risk

Theoretical cancer risk is estimated by calculating a dose similar to that described in the previous section and multiplying it by a cancer potency factor, also known as the cancer slope factor. Some cancer potency factors are derived from human population data. Others are derived from laboratory animal studies involving doses much higher than are encountered in the environment. Use of animal data requires extrapolation of the cancer potency obtained from these high dose studies down to real-world exposures. This process involves much uncertainty.

Current regulatory practice suggests that there is no "safe dose" of a carcinogen and that a very small dose of a carcinogen will give a very small cancer risk. Theoretical cancer risk estimates are, therefore, not yes/no answers but measures of chance (probability). Such measures, however uncertain, are useful in determining the magnitude of a theoretical cancer threat because any level of a carcinogenic contaminant carries associated risk. Validity of the "no safe dose" assumption for all cancer-causing chemicals is not clear. Some evidence suggests that certain chemicals considered to be carcinogenic must exceed a threshold of tolerance before initiating cancer. For such chemicals, risk estimates are not appropriate. More recent guidelines on cancer risk from EPA reflect the existence of thresholds for some carcinogens. However, EPA still assumes no threshold unless sufficient data indicate otherwise. This consultation assumes that there is no threshold for carcinogenicity.

Theoretical cancer Risk

Cancer risk estimates do not reach zero no matter how low the level of exposure to a carcinogen. Terms used to describe this risk are defined below as the number of excess cancers expected in a lifetime:

Term		# of Excess Cancers
moderate	is approximately equal to	1 in 1,000
low	is approximately equal to	1 in 10,000
very low	is approximately equal to	1 in 100,000
slight	is approximately equal to	1 in 1,000,000
insignificant	is less than	1 in 1,000,000

Cancer Risk = Estimated Dose x Cancer Slope Factor

Theoretical cancer risk is expressed as a probability. For instance, a theoretical cancer risk of 1×10^{-5} can be interpreted to mean that a person's overall risk of obtaining cancer increases by 0.00001, or if 100,000 people were exposed, there might be one extra cancer in that population above normal cancer rates. The reader should note that these estimates are for excess cancers that might result in addition to those normally expected in an unexposed population. Theoretical cancer risks quantified in this document are an upper-bound theoretical estimate. Actual risks are likely to be much lower.

Guidance from EPA recognizes that early life exposures associated with some chemicals requires special consideration with regard to theoretical cancer risk. Mutagenic chemicals in particular have been identified as causing higher cancer risks when exposure occurs early in life when compared with the same amount of exposure during adulthood. Adjustment factors have been established to compensate for higher risks from early life exposures to these chemicals. A factor of ten is used to adjust early life exposures before age two, and a factor of three is used to adjust exposures between the ages of 2 and 15.

The following uncertainties correspond to both cancer and non-cancer effects:

Uncertainty for tribal members that consume whole geoduck body

A Suquamish survey indicates that at least some tribal members do consume whole geoduck bodies (adults 12%, children 5%). Whole body includes the neck and gutball. An exposure scenario was assumed for these tribal members. This scenario assumed that half of the weight of geoduck came from the neck and the other half came from the gutball, thus adding the concentrations of both the neck and the gutball divided by two results in the average concentration for the whole body (see Appendix A, Table A7 and Appendix C, Tables C2 and C3). In reality, gutball ratios are much lower when compared to the neck and strap. The sampling results clearly demonstrated this (e.g., the gutball weight was 1/3rd -1/4th lower than the neck/strap weight). DOH considers that this approach is very conservative for consumers (i.e., tribal members) that may eat whole bodies, assuming that half of the weight came from the gutball and the other half came from the neck/strap.

Uncertainty Non-detect Results

One-half the reported detection limit for non-detect samples (U) were included in the sampling data set. Some uncertainty is associated with any approach dealing with non-detected chemicals. Non-detect results do not indicate whether the contaminant is present at a concentration just below the detection limit[b], present at a concentration just above zero, or absent from the sample. Therefore, contaminants that were evaluated as non-detects can lead to an overestimation of risk if the actual concentrations are just above zero, or absent from the sample.

<u>Theoretical cancer risk estimates for Wyckoff/Eagle Harbor geoduck consumers</u>

When the above approach is applied to consumption of geoduck from tracts near Wyckoff/Eagle Harbor, lifetime increased theoretical cancer risks range from 3.1×10^{-7} to 5.2×10^{-6} for children (low-end to high-end estimates) and 2.0×10^{-6} to 7.3×10^{-5} for adults (high-end consumption equal to Suquamish 95th percentile adults –geoduck consumers only) (Appendix C, Table C3). Overall, the theoretical combined cancer risk is considered to be very low to insignificant. Theoretical cancer risk would not exceed EPA's range of cancer risks if cumulative exposure was assumed from childhood into adulthood (average time cancer of 70 years). The range of cancer risks considered acceptable by EPA is $1\text{x}10^{-6}$ to $1\text{x}10^{-4}$. The Quality Assurance Project Plan (QAPP) sampling objectives specifies that the cancer risk level should not be greater than $1\text{x}10^{-5}$.[19] Theoretical cancer risk estimates for consumers that eat both the neck and gutball (i.e., whole body) also fall between EPA's range of cancer risks if cumulative exposure is assumed from childhood into adulthood (average time cancer of 70 years).

[b] Detection limit is defined as the lowest concentration of a chemical within an environmental matrix that a method or equipment can detect.

Chemical mixtures

The approach that DOH has outlined in this health consultation focuses largely on evaluating chemical-specific exposures. That is, the likelihood of adverse health effects was evaluated on a chemical-by-chemical basis for the ingestion exposure pathway. In reality, exposures can involve multiple chemicals. DOH's approach for the assessment of exposure to chemical mixtures includes reviewing available chemical mixtures studies for noncancer and cancer health effects.

1. ***Non-cancer health effects***. Relatively few studies have assessed toxic interactions of non-carcinogenic chemicals in low dose ranges. The studies that do exist suggest that a mixture produces no adverse health effects in dosed animals when the components of that mixture are present at levels below their respective no-observed-adverse-effect levels (NOAEL)—i.e., at concentrations that would have produced no adverse effects in animals treated separately with those component chemicals [20,21,22,23,24,25,26]. In two of these experiments [24,25], all of the component chemicals affected the same target organ, but through different mechanisms. In two others [21,23], the chemicals had different target organs and exhibited different modes of action, as do most chemicals in typical environmental mixtures. Subsequent experiments have shown similar results.[27,20,28]

   For every chemical detected in geoduck near Wyckoff Eagle Harbor Superfund site, the maximum, as well as the average, concentrations detected would result in ingestion doses orders of magnitude lower than all known levels of effect. Therefore, based on the available chemical mixture studies, DOH concludes that the combined exposure to all of these chemicals at the levels detected in geoduck near Wyckoff/Eagle Harbor Superfund site is unlikely to produce harmful non-cancer health effects for tribal geoduck consumers.

2. ***Cancer health effects***. Relatively few studies have assessed toxic interactions of carcinogenic chemicals in low dose ranges. Assuming additive effects, the cumulative cancer risk estimate for each chemical is the sum of the individual chemical risk estimates. If the sum of the cancer risk exceeds a level of concern for significant impact on lifetime cancer risk, the mixture constitutes a potential health hazard due to additivity. DOH's approach is to select a risk of $1x10^{-4}$ as the level of concern for cumulative cancer risk.[29] The combined exposure to all of these chemicals is associated with a low increased risk of developing cancer. High end geoduck consumers that eat the whole body will most likely be at risk of developing cancer if cumulative exposure is assumed from childhood into adulthood (average time cancer of 70 years) (Appendix C, Table C3).

Uncertainty on cumulative effects

DOH recognizes there are uncertainties in evaluating the cumulative effects of chemical mixtures. Because relatively few chemical mixture studies have assessed toxic interactions in low dose ranges, there is uncertainty when assessing the cumulative effect of developing cancer over lifetime for tribal geoduck consumers at Wyckoff/Eagle Harbor.

Chemical Specific Toxicity

Below are general summaries of contaminants of concern (COC) health effects. The public health implications of exposure to these COCs from consumption of geoduck tissues are discussed in the next section.

Dioxins and Furans, and cPAHs TEQ concentrations

Although several dioxin and furan congeners were analyzed in tissue, only a single value, called a dioxin toxic equivalent (TEQ), is presented in this health consultation. Each dioxin/furan, or dioxin-like PCB congener, is multiplied by a Toxic Equivalency Factor (TEF) to produce the dioxin TEQ. The TEQs for each chemical are then summed to give the overall 2,3,7,8-tetrachlorodibenzo-p-dioxin TEQ. The TEQ approach is based on the premise that many dioxins/furans and dioxin-like PCB congeners are structurally and toxicologically similar to 2,3,7,8-tetrachlorodibenzo-p-dioxin. TEFs are used to account for the different potencies of dioxins and furans relative to 2,3,7,8-tetrachlorodibenzo-p-dioxin, and are available for ten chlorinated dibenzofurans and seven chlorinated dibenzodioxins using the World Health Organization (WHO) methodology.[30] A Similar TEQ approach is developed for each cPAH based on the relative potency to benzo(a)pyrene.

Dioxins and furans

Dioxins and furans (dioxins) consist of about 210 structural variations of dioxin congeners, which differ by the number and location of chlorine atoms on the chemical structure. The primary sources of dioxin releases to the environment are the combustion of fossil fuels and wood; the incineration of municipal, medical, and hazardous waste; and certain pulp and paper processes. Dioxins also occur at very low levels from naturally occurring sources and can be found in food, water, air, and cigarette smoke.

The most toxic of the dioxin congeners, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) can cause chloracne (a condition of acne like lesions on the face and neck). Exposure to high levels of dioxins can cause liver damage, developmental effects and impaired immune function.[31] Long-term exposure to dioxins could increase the likelihood of developing cancer. Studies in rats and mice exposed to TCDD resulted in thyroid and liver cancer.[32] EPA considers TCDD to be a probable human carcinogen and developed a cancer slope factor of $1.5\text{x } 10^{5}$ mg/kg/day.[33,34]

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are generated by the incomplete combustion of organic matter, including oil, wood, and coal. They are found in materials such as creosote, coal, coal tar, and used motor oil. Based on structural similarities, metabolism, and toxicity, PAHs are often grouped together when one is evaluating their potential for adverse health effects. EPA has classified some PAHs as probable human carcinogens – called cPAHs – (B2) as a result of *sufficient* evidence of carcinogenicity in animals and *inadequate* evidence in humans.[35]

Benzo(a)pyrene is the only cPAH for which EPA has derived a cancer slope factor. The benzo(a)pyrene cancer slope factor was used as a surrogate to estimate the total cancer risk of cPAHs in sediment. It should be noted, benzo(a)pyrene is considered the most carcinogenic of the cPAHs. The use of its cancer slope factor as a surrogate for total cPAH carcinogenicity may overestimate risk. To address this issue, DOH made an adjustment for each cPAH based on the relative potency to benzo(a)pyrene or TEQ.[35]

Dietary sources make up a large percentage of PAH exposure in the U.S. population, and smoked or barbecued meats and fish contain relatively high levels of PAHs. The majority of dietary exposure to PAHs for the average person comes from ingestion of vegetables and grains (cereals).[35]

Polychlorinated biphenyls (PCBs)

PCBs are a mixture of man-made organic chemicals. There are no known natural sources of PCBs in the environment. The manufacture of PCBs stopped in the U.S. in 1977, because of evidence that PCBs could build up in the environment and cause toxic health effects. Although no longer manufactured, PCBs can still be found in certain products such as old fluorescent lighting fixtures, electrical devices or appliances containing PCB capacitors made before PCB use was stopped, old microscope oil, and old hydraulic oil. Prior to 1977, PCBs entered the environment (soil, sediment, water, air) during the manufacture and use of PCBs. Today, PCBs can still enter the environment from poorly maintained hazardous waste sites, illegal or improper dumping of PCB wastes such as old hydraulic oil, leaks from electrical transformers that contain PCB oils, and disposal of old consumer products that contain PCBs.[36]

PCBs enter the environment as mixtures of individual components known as congeners. There are 209 variations of PCB congeners, which differ on the number and location of chlorine atoms on the chemical structure. Most PCBs commercially produced in the U.S. are composed of standard mixtures called Aroclors. The conditions for producing each Aroclor favor the synthesis of certain congeners, giving each Aroclor a unique pattern based on its congener composition. No Aroclor contains all 209 congeners. Once in the environment, PCBs do not easily breakdown and may stay in the soil for months or years. PCBs stick to soil and sediment and will not usually move deep into the soil with rainfall. Small amounts of PCBs can be found in almost all outdoor and indoor air, soil, sediments, surface water, and animals. As a result, PCBs are found worldwide. PCBs bioaccumulate in the food chain and are stored in the fat tissue. The major dietary source of PCBs is fish. PCBs are also found in meats and dairy products.[36]

When direct exposure to contaminants occurs, PCBs can get into people's bodies by ingestion, inhalation, and dermal (skin) contact. Some of the PCBs that enter the body are metabolized and excreted from the body within a few days; others stay in the body fat and liver for months and even years. PCBs collect in milk fat and can enter the bodies of infants through breast-feeding. Skin irritation, vomiting, nausea, diarrhea, abdominal pain, eye irritation, and liver damage can occur in people exposed to PCBs.[36]

Comparison with Background

Chemical contaminants in geoduck have not been widely studied in Puget Sound, so little is known about how contaminant levels in geoduck vary by location or age. Geoducks were not sampled as part of the Puget Sound Ambient Monitoring Program (PSAMP) or the majority of other studies, but limited data have been collected by King County Department of Natural Resources (Brightwater), Kitsap County, and others.[8,7,9] Appendix A, Table A8 shows a comparison of contaminant levels in geoduck from the current study to levels found in other limited Puget Sound geoduck samples.

In order to evaluate health impacts, the results from the Wyckoff/Eagle Harbor site (Port Blakely and Tyee Shoal tracts) were compared to levels in geoduck from other areas. In general, total PCB and benzo (a) pyrene levels in geoduck tend to be higher in Wyckoff/Eagle Harbor compared to other sites. Dioxin levels in combined tracts near Eagle Harbor are also higher than other locations, except for Port Angeles, which show similar levels (Appendix A, Table A8).

Child Health Considerations

ATSDR recognizes that infants and children may be more vulnerable to exposures than adults when faced with contamination of air, water, soil, or food. This vulnerability is a result of the following factors:

- Children are smaller and receive higher doses of chemical exposure per body weight.

- Children's developing body systems are more vulnerable to toxic exposures, especially during critical growth stages in which permanent damage may be incurred.

Special consideration was given to children's exposure to contaminants in this health consultation by evaluating children's exposure to organic contaminants in geoduck separate from adults; acknowledging that children are more susceptible to chemical toxicity than adults.

Conclusions

Although there are some uncertainties in this evaluation, DOH used conservative assumptions to determine the public health implications of exposures to contaminants while consuming geoduck. The true risk to the public is difficult to assess accurately and depends on a number of factors such as the concentration of chemicals, consumption rates, frequency and duration of exposure, and the genetic susceptibility of an individual. In general:

1. Geoduck sampled from Wyckoff/Eagle Harbor site (Port Blakely and Tyee Shoal tracts) had higher levels of organic contaminants than other similar study areas (Appendix A, Table A8).[7,8,9,37,38] It is unknown whether these levels appear to be impacted by the potential contaminant sources. Based on the levels of organic contaminants found at this site, DOH concludes that high end geoduck consumers are unlikely to be exposed to harmful levels of organic contaminants from eating geoduck near the Wyckoff/Eagle Harbor Superfund site (Tyee Shoal geoduck tract # 07650 and Port Blakely geoduck tract

07700).

2. The potential for non-cancer hazards and theoretical cancer risk is low. The overall lifetime cancer risk of cumulative exposure assumed from childhood into adulthood is considered acceptable by EPA ($1x10^{-6}$ to $1x10^{-4}$). This is also within the range of $1x10^{-5}$ cancer risk level specified in the QAPP sampling objectives.[19] Thus, low levels of organic contaminants present in geoduck are not expected to harm people's health.

    - Although PAHs are the primary contaminant of concern associated with cleanup efforts at Wyckoff/Eagle Harbor site, they were detected only at low levels in geoduck. PAHs were found at the highest levels in samples adjacent to Wyckoff/Eagle Harbor site (concentrations were low from a human health perspective).

    - Low levels of PCBs and dioxins and furans were found in some samples, but not at levels of concern for human health.

3. Geoducks have not been widely sampled in Puget Sound and therefore, little is known about intra-species and geographic variability of contaminants in tissue.

4. Human bioavailability of organic contaminants from shellfish consumption is a source of uncertainty.

Recommendations

1. The OSWP should use this health consultation to guide their decision of certifying geoduck from Wyckoff/Eagle Harbor tracts in Puget Sound.

2. Future monitoring projects should identify contaminant sources and consider analysis of metals in geoduck over a broader area in order to determine intra-species variability of contaminant levels throughout Puget Sound.

Public Health Action Plan

Actions Taken

1. Sampling and analysis of geoduck for organic contaminants has been conducted to determine whether or not potential chemicals from the Wyckoff/Eagle Harbor Superfund site are present at levels of health concern in two tracts adjacent to the mouth of Eagle Harbor (Port Blakely and Tyee Shoal).

2. Geoduck contaminant data from the Port Blakely and Tyee Shoal tracts have been evaluated by DOH and presented within this health consultation.

Actions Planned

1. The Department of Health's Office of Food Safety and Shellfish will use this health consultation in the process used to certify shellfish growing areas.

Preparer of Report

Elmer Diaz
Washington State Department of Health
Office of Environmental Health Assessments
Site Assessment Section

Designated Reviewer

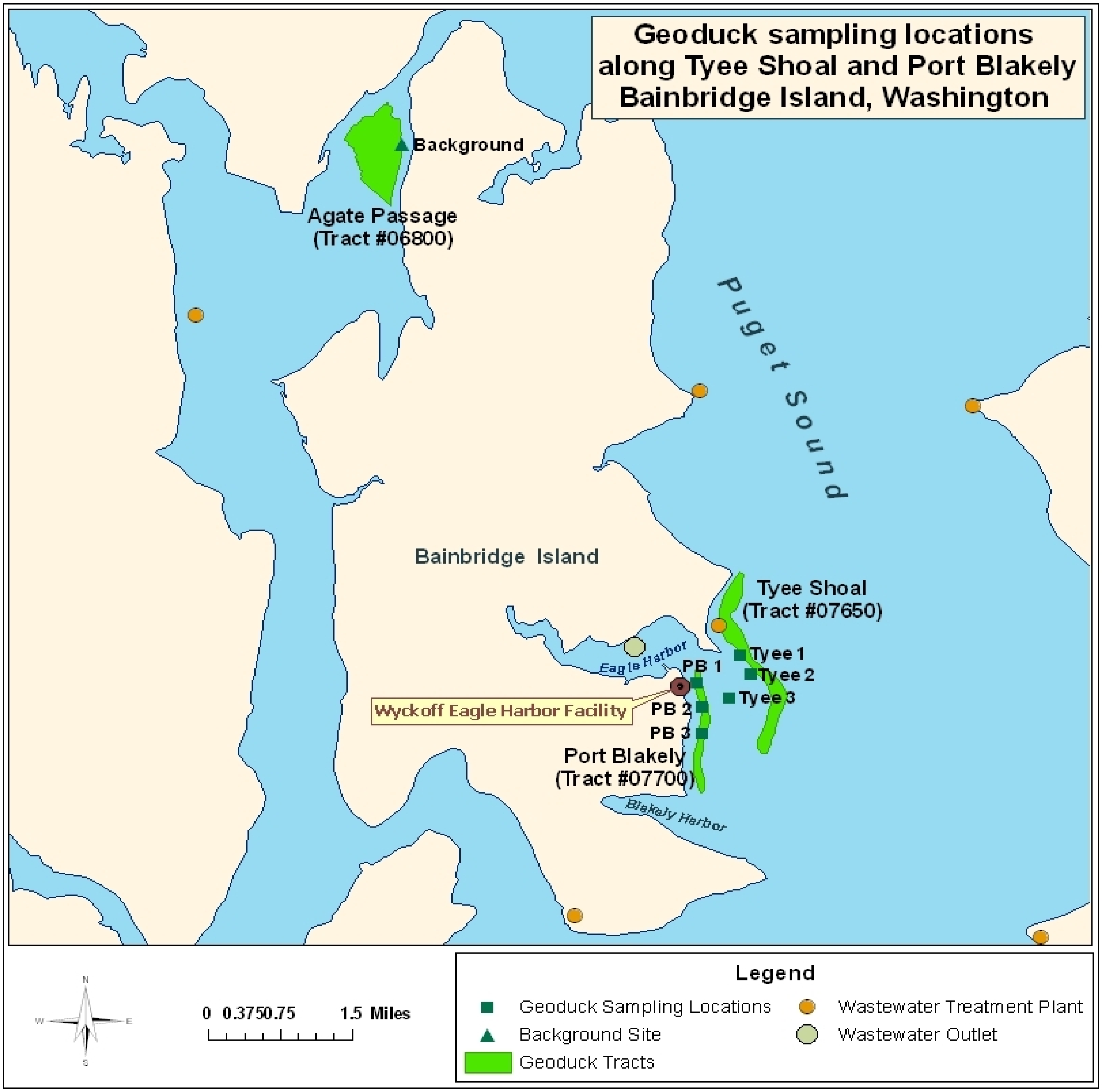
Dan Alexanian, Manager
Site Assessment Section
Office of Environmental Health Assessments
Washington State Department of Health

ATSDR Technical Project Officer

Audra Henry
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Cooperative Agreement Program Evaluation Branch

Figure 1. Geoduck site location and tracts of interest (Wyckoff/ Eagle Harbor Superfund Site, Kitsap County, Washington).

Figure 2. Geoduck background site location and tracts of interest (Wyckoff/Eagle Harbor Superfund Site, Kitsap County, Washington).



Appendix A: Sampling Results

Table A1. Non-carcinogenic PAH concentration results (ppb) for geoduck collected from Wyckoff/Eagle Harbor Superfund Site, Bainbridge Island, Kitsap County, Washington.

Contaminant	Port Blakely #1	Port Blakely #2	Port Blakely #3	Port Blakely #1 Gutball	Tyee #1	Tyee #1 Field Duplicate	Tyee #2	Tyee #3	Tyee #1 Gutball	Tyee #1 Gutball Field Duplicate	Reference: Agate Passage	Reference: Agate Passage Gutball
Non-carcinogenic PAHs												
9H-Fluorene	**1.7**	1.6 U	1.5 U	**4.7**	1.6 U	1.6 U	1.6 U	1.6 U	1.5 U	1.6 U	1.5 U	0.78 U
Acenaphthene	1.6 U	1.6 U	1.5 U	**3**	1.6 U	1.6 U	1.6 U	1.6 U	**1.1 J**	**0.86 J**	1.5 U	0.4 J
Acenaphthylene	**1.7**	**1.2 J**	1.5 U	**1.9**	1.6 U	1.6 U	1.6 U	1.6 U	**0.43 J**	1.6 U	1.5 U	0.78 U
Anthracene	**7.5**	**4.4**	**1.7**	**8.5**	**1.3 J**	1.6 U	1.6 U	1.6 U	**1.6 J**	**1.1 J**	1.5 U	0.78 U
Benzo(g,h,i)perylene	1.6 U	1.6 U	1.5 U	**4.9**	1.6 U	1.6 U	1.6 U	1.6 U	**1.6**	1.6 U	1.5 U	0.78 U
Fluoranthene	**10**	**6.9**	**3.9**	**23**	**3.4**	**3.8**	2.7 U	2.1 U	**7**	**6.4**	3.1	2
Napthalene	1.6 U	1.6 U	1.5 U	**2.5**	1.6 U	1.6 U	1.6 U	1.6 U	1.5 U	1.6 U	1.5 U	0.78 U
Napthalene, 1-methyl-	1.6 U	1.6 U	1.5 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.5 U	1.6 U	1.5 U	0.78 U
Napthalene, 2-methyl-	1.6 U	1.6 U	1.5 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.5 U	1.6 U	1.5 U	0.78 U
Phenanthrene	**3.6**	2.2 U	1.5 U	**14**	1.6 U	1.6 U	1.6 U	1.6 U	**2.2**	1.8 U	1.5 U	0.78 U
Pyrene	1.7 U	1.6 U	1.5 U	**11**	1.6 U	1.6 U	1.6 U	1.6 U	**3**	1.8 U	1.5 U	0.78 U

U = not detected, value is the method detection limit. Half the detection limit was used for undetected samples.
J = below reporting limit, value is an estimate
BOLD values exceed reference Agate Passage values

Table A2. Carcinogenic PAH concentration results (ppb) for geoduck collected from Wyckoff/Eagle Harbor Superfund Site, Bainbridge Island, Kitsap County, Washington.

Contaminant	Port Blakely #1	Port Blakely #2	Port Blakely #3	Port Blakely #1 Gutball	Tyee #1	Tyee #1 Field Duplicate	Tyee #2	Tyee #3	Tyee #1 Gutball	Tyee #1 Gutball Field Duplicate	Reference: Agate Passage	Reference: Agate Passage Gutball
Carcinogenic PAHs												
Benzo(a)anthracene	**7.4**	**3.8**	2.0 U	**12**	1.6 U	1.6 U	1.6 U	1.6 U	2.4 U	1.8 U	1.5 U	0.78 U
Benzo(a)pyrene	3.8 U	**2.2**	1.5 U	**8.3**	1.6 U	1.6 U	1.6 U	1.6 U	**1.6**	1.6 U	1.5 U	0.78 U
Benzo(b)fluoranthene	**9.7**	**5.4**	**2.6**	**16**	1.7 U	2.2 U	1.6 U	1.6 U	**3.4**	**2.8**	1.5 U	0.78 U
Benzo(k)fluoranthene	**2.9**	**1.6**	1.5 U	**5.5**	1.6 U	1.6 U	1.6 U	1.6 U	**1.2 J**	1.6 U	1.5 U	0.78 U
Chrysene	**1.5 J**	1.6 U	1.5 U	**8.2**	1.6 U	1.6 U	1.6 U	1.6 U	**1.6**	1.6 U	1.5 U	0.78 U
Dibenzo[a,h]anthracene	1.6 U	1.6 U	1.5 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.5 U	0.78 U
Indeno(1,2,3-cd)pyrene	1.6 U	1.6 U	1.5 U	**4.9**	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.5 U	0.78 U
Benzo(a)pyrene TEQ ND = 0	1.7	3.1	0.3	11.7	0	0	0	0	2.0	0.28	0	0
Benzo(a)pyrene TEQ ND = ½ detection limit	4.5	4.0	1.9	12.5	1.9	1.9	1.8	1.8	3.0	2.1	1.7	0.90

U = not detected, value is the method detection limit. Half the detection limit was used for undetected samples.
J = below reporting limit, value is an estimate
BOLD values exceed reference Agate Passage values
ND – non-detect values

Table A3. Dioxin and furan concentration (ppt) results for geoduck collected from Wyckoff/Eagle Harbor Superfund Site, Bainbridge Island, Kitsap County, Washington.

Contaminant	Port Blakely #1	Port Blakely #2	Port Blakely #3	Port Blakely #1 Gutball	Tyee #1	Tyee #1 Field Duplicate	Tyee #2	Tyee #3	Tyee #1 Gutball	Tyee #1 Gutball Field Duplicate	Reference: Agate Passage	Reference: Agate Passage Gutball
2,3,7,8-TCDD	K 0.048	K D 0.047	K D 0.037	0.038	K D 0.034	K D 0.035	K D 0.027	K D 0.026	K D 0.030	K D 0.029	K D 0.031	K 0.026
1,2,3,7,8-PeCDD	0.127	0.075	0.063	0.116	K D 0.070	D 0.063	D 0.050	< 0.0240	D 0.058	D 0.060	K 0.052	0.05
1,2,3,4,7,8-HxCDD	0.071	0.042	0.03	0.104	D 0.036	D 0.031	D 0.025	< 0.0240	D 0.040	D 0.055	0.027	0.03
1,2,3,6,7,8-HxCDD	0.298	0.182	0.158	0.518	D 0.165	D 0.146	K D 0.130	0.074	D 0.207	D 0.227	0.124	0.114
1,2,3,7,8,9-HxCDD	0.088	K 0.052	0.048	0.25	D 0.074	K D 0.042	D 0.053	< 0.0240	D 0.127	D 0.096	K 0.036	0.061
1,2,3,4,6,7,8-HpCDD	1.41	0.918	0.819	6.2	D 0.732	D 0.373	D 0.526	0.32	D 1.94	D 1.90	0.201	0.748
OCDD	12.8	8.03	5.98	42.8	D 4.79	D 4.07	D 3.96	D 3.08	D 12.6	D 12.3	D 1.84	4.09

D = dilution data
K = peak detected bud did not meet quantification criteria; result reported represents the estimated maximum possible concentration
< = Less than the detection limit
2,3,7,8-TCDD = Tetra chlorodibenzo-p-dioxin
1,2,3,7,8-PeCDD = Penta chlorodibenzo-p-dioxin
1,2,3,4,7,8-HxCDD = Hexa chlorodibenzo-p-dioxin
1,2,3,4,6,7,8-HpCDD = Hepta chlorodibenzo-p-dioxin
OCDD = Octa chloro dibenzo-p-dioxin

Table A4. Dioxin and furan concentration (ppt) results for geoduck collected from Wyckoff/Eagle Harbor Superfund Site, Bainbridge Island, Kitsap County, Washington.

Contaminant	Port Blakely #1	Port Blakely #2	Port Blakely #3	Port Blakely #1 Gutball	Tyee #1	Tyee #1 Field Duplicate	Tyee #2	Tyee #3	Tyee #1 Gutball	Tyee #1 Gutball Field Duplicate	Reference: Agate Passage	Reference: Agate Passage Gutball
2,3,7,8-TCDF	0.564	D 0.431	D 0.368	0.427	D 0.369	D 0.379	D 0.304	D 0.178	D 0.307	D 0.372	D 0.328	0.282
1,2,3,7,8-PeCDF	0.026	< 0.0250	< 0.0250	0.062	D 0.033	< 0.0247	< 0.0246	< 0.0240	K D 0.034	K D 0.040	< 0.0250	< 0.0250
2,3,4,7,8-PeCDF	0.149	0.104	0.091	0.146	D 0.092	D 0.102	D 0.078	0.048	D 0.093	K D 0.109	0.097	0.08
1,2,3,4,7,8-HxCDF	0.052	0.031	0.033	0.128	D 0.047	D 0.034	D 0.033	< 0.0240	D 0.072	D 0.075	< 0.0250	0.032
1,2,3,6,7,8-HxCDF	< 0.0240	< 0.0250	< 0.0250	0.054	< 0.0250	< 0.0247	< 0.0246	< 0.0240	< 0.0240	D 0.025	< 0.0250	< 0.0250
1,2,3,7,8,9-HxCDF	< 0.0240	< 0.0250	< 0.0250	< 0.0250	< 0.0250	< 0.0247	< 0.0246	< 0.0240	< 0.0240	< 0.0239	< 0.0250	< 0.0250
2,3,4,6,7,8-HxCDF	0.041	0.029	< 0.0250	0.065	K D 0.026	D 0.028	< 0.0246	< 0.0240	K D 0.038	D 0.042	< 0.0250	< 0.0250
1,2,3,4,6,7,8-HpCDF	0.163	0.133	0.14	0.964	D 0.129	D 0.091	D 0.118	0.083	D 0.390	D 0.371	K 0.079	K 0.168
1,2,3,4,7,8,9-HpCDF	< 0.0240	< 0.0250	< 0.0250	0.065	< 0.0250	< 0.0247	< 0.0246	< 0.0240	D 0.028	K D 0.026	< 0.0250	< 0.0250
OCDF	0.194	0.162	0.192	2.22	D 0.134	D 0.104	D 0.118	D 0.112	D 0.636	D 0.586	D 0.031	0.166
TEQ (WHO 2005) ND=0	0.297	0.183	0.158	0.431	0.071	0.155	0.119	0.040	0.185	0.167	0.0796	0.129
TEQ (WHO 2005) ND=1/2DL	0.311	0.199	0.174	0.432	0.101	0.171	0.137	0.072	0.201	0.184	0.111	0.146

D = dilution data ; DL = detection limit
K = peak detected bud did not meet quantification criteria; result reported represents the estimated maximum possible concentration
< = Less than the detection limit
2,3,7,8-TCDF = Tetra chlorodibenzo furan; 1,2,3,7,8-PeCDF = Penta chlorodibenzo furan; 1,2,3,4,7,8-HxCDF = Hexa chlorodibenzo furan; 1,2,3,4,6,7,8-HpCDF = Hepta chlorodibenzo furan; OCDF = Octachlorodibenzo furan

Table A5. PCB concentration (ppb) results for geoduck collected from Wyckoff/Eagle Harbor Superfund Site, Bainbridge Island, Kitsap County, Washington.

Contaminant	Port Blakely #1	Port Blakely #2	Port Blakely #3	Port Blakely #1 Gutball	Tyee #1	Tyee #1 Field Duplicate	Tyee #2	Tyee #3	Tyee #1 Gutball	Tyee #1 Gutball Field Duplicate	Reference: Agate Passage	Reference: Agate Passage Gutball
Aroclor 1016	3.9 U	3.9 U	3.7 U	3.9 U	3.7 U	3.8 U	3.6 U	3.6 U	3.4 U	3.3 U	3.6 U	3.7 U
Aroclor 1221	3.9 U	3.9 U	3.7 U	3.9 U	3.7 U	3.8 U	3.6 U	3.6 U	3.4 U	3.3 U	3.6 U	3.7 U
Aroclor 1232	3.9 U	3.9 U	3.7 U	3.9 U	3.7 U	3.8 U	3.6 U	3.6 U	3.4 U	3.3 U	3.6 U	3.7 U
Aroclor 1242	3.9 U	3.9 U	3.7 U	3.9 U	3.7 U	3.8 U	3.6 U	3.6 U	3.4 U	3.3 U	3.6 U	3.7 U
Aroclor 1248	3.9 U	3.9 U	3.7 U	3.9 U	3.7 U	3.8 U	3.6 U	3.6 U	3.4 U	3.3 U	3.6 U	3.7 U
Aroclor 1254	**8.5**	**8.4**	**5.9**	**4.8 J**	3.7 U	**5.5 J**	3.6 U	3.6 U	3.4 U	3.3 U	3.6 U	3.7 U
Aroclor 1260	3.9 U	3.9 U	3.7 U	3.9 U	3.7 U	3.8 U	3.6 U	3.6 U	3.4 U	3.3 U	3.6 U	3.7 U
Total PCBs	12.4	12.3	9.6	8.7	5.6	9.3	5.4	5.4	5.1	5.0	5.4	5.6

Note: Total PCBs were derived by summing concentrations of Aroclors 1248, 1254, and 1260. ½ the method detection limit was assumed for "U" qualified (non-detect) results
U = not detected, value is the method detection limit. Half the detection limit was used for undetected samples.
J = below reporting limit, value is an estimate
BOLD values exceed reference Agate Passage values

Table A6. Summary of chemical contaminants in Wyckoff/Eagle Harbor area geoduck compared to background area levels and tribal consumption screening values (Wyckoff/Eagle Harbor Superfund Site, Kitsap County, Washington).

Contaminant	Units	Mean		Maximum		Background Area (Agate Passage)		Tribal Use Comparison Value (ww)**
		Neck (ww)	Gut (ww)	Neck (ww)	Gut (ww)	Neck (ww)	Gut (ww)	
Total PCBs	ppb	**8.8**	**6.9**	**12.4**	**8.7**	**5.4 (ND)**	**5.6 (ND)**	4.3
9H-Fluorene	ppb	<1.6	2.8	1.7	4.7	<1.5	<0.78	36,000
Acenaphthene	ppb	<1.6	2	<1.6	3	<1.5	0.4	NA
Acenaphthylene	ppb	<1.6	1.2	1.7	1.9	<1.5	<0.78	NA
Anthracene	ppb	2.5	5.0	7.5	8.5	<1.5	<0.78	270,000
Benzo(g,h,i)perylene	ppb	<1.6	3.1	<1.6	4.9	<1.5	<0.78	NA
Fluoranthene	ppb	4.6	15	10	23	3.1	2.0	36,000
Napthalene	ppb	<1.6	1.6	<1.6	2.5	<1.5	<0.78	18,000
Napthalene, 1-methyl-	ppb	<1.6	<1.6	<1.6	<1.6	<1.5	<0.78	NA
Napthalene, 2-methyl-	ppb	<1.6	<1.6	<1.6	<1.6	<1.5	<0.78	3,600
Phenanthrene	ppb	1.3	8.1	3.6	14	<1.5	<0.78	NA
Pyrene	ppb	<1.6	7.0	<1.6	11	<1.5	<0.78	895
Benzo(a)pyrene TEQ	ppb	**2.7**	**7.5**	**4.5**	**12.5**	**1.7**	0.90	0.3
TCDD TEQ*	**ppt**	0.166	**0.272**	**0.311**	**0.432**	0.111	0.146	0.02

NA – Not available
BOLD values exceed comparison value
* TEQ ND=1/2 DL
**Derived assuming high-end consumption rate Suquamish 90th percentile all shellfish consumption rate (consumers only) (Appendix B, Table B1)
ww = wet weight
J – Below reporting limit, value is an estimate
ND – non-detected values.. Half the detection limit was used for undetected samples.

Table A7. Mean values of chemical contaminants for neck and gutball in Wyckoff/Eagle Harbor area geoduck compared to tribal consumption screening values (Wyckoff/Eagle Harbor Superfund Site, Kitsap County, Washington).

Contaminant	Units	Mean		Whole body† (average of neck and gut)	Tribal Use Comparison Value[a] ***
		Neck	Gut		
Total PCBs	ppb	**8.8**	**6.9**	**7.9**	4.3
9H-Fluorene	ppb	<1.6	2.8	2.2	36,000
Acenaphthene	ppb	<1.6	2	1.8	NA
Acenaphthylene	ppb	<1.6	1.2	1.4	NA
Anthracene	ppb	2.5	5.0	3.8	270,000
Benzo(g,h,i)perylene	ppb	<1.6	3.1	2.4	NA
Fluoranthene	ppb	4.6	15	9.8	36,000
Napthalene	ppb	<1.6	1.6	<1.6	18,000
Napthalene, 1-methyl-	ppb	<1.6	<1.6	<1.6	NA
Napthalene, 2-methyl-	ppb	<1.6	<1.6	<1.6	3,600
Phenanthrene	ppb	1.3	8.1	4.7	NA
Pyrene	ppb	<1.6	7.0	4.3	895
Benzo(a)pyrene TEQ	ppb	**2.7**	**7.5**	**5.1**	0.3
TCDD TEQ*	**ppt**	**0.166**	**0.272**	**0.3**	0.02

† See uncertainty section for tribal members that consume whole geoduck body.
NA – Not available
BOLD values exceed comparison value
* TEQ ND=1/2 DL
[a] Derived assuming high-end consumption rate Suquamish 90th percentile all shellfish consumption rate (consumers only) (Appendix B, Table B1)
All results are reported in wet weight

Table A8. Average concentrations of organic contaminants found (mg/kg) in geoduck neck and strap

Contamimant	Tyee Tract (Eagle Harbor) [a]	Port Blakely Tract (Eagle Harbor) [a]	Combined Tracts (Eagle Harbor) [a]	Agate Passage [a]	Bright water [b]	Kingston [c]	Nisqually [c]	Skiff Pt [c]	Port Angeles (Rayonier) [d]	Dungeness Bay [d]	Freshwater Bay [d]	Richmond Beach [e]
N	4 (C)[e*]	3 (C)	7 (C) [e]	1 (C)	9 (I)	2 (C)	1 (C)	1 (C)	3 (I)	3 (I)	3 (I)	60 (I)
PCBs, total	6.9	11.4	8.4	5.5	ND (13 ppb per Aroclor)	<13	<10	<10	5.7	2.9	2.9	NA
Benzo(a)pyrene TEQ (ND = ½ DL)	2.1	6.5	3.5	1.5	ND (MDL >50 ppb per PAH)	ND (MRL > 40 ppb per PAH)	ND (MRL > 40 ppb per PAH)	ND (MRL > 40 ppb per PAH)	0.41	0.17	0.16	NA
Dioxin TEQ (ND = ½ DL)	0.12	0.23	0.17	0.11	NA	NA	NA	NA	0.18	0.07	0.04	NA

NA – Not analyzed, ND – Not detected
MDL – Method detection limit, MRL – Method reporting limit
(C) - Composite sample (5 geoducks per sample)
(I) – Individual sample
N = Number of samples
a- Suquamish Tribe samples from Port Blakely and Tyee Shoal tracts near Wyckoff/Eagle Harbor and reference sample from Agate Passage. Whole body concentrations were calculated based on weighted concentrations corresponding to gutball weight and neck and strap weight.
b- King County Department of Resources and Parks Brightwater Marine Outfall Geoduck Tissue Study
c- Kingston Wastewater Treatment Plant Outfall Project
d- Rayonier Mill Remedial Investigation.
e- Suquamish Tribe samples from tracts near Richmond Beach average in all sample locations
* Sample size includes one field duplicate

Appendix B: Contaminant Screening Process

The information in this section describes how the contaminants of concern in shellfish were chosen from a set of many contaminants. A contaminant's maximum shellfish concentration was compared to a screening value (comparison value), and if the contaminant's concentration is greater than that value, then it is considered further.

Comparison values were calculated using EPA's chronic reference doses (RfDs) and cancer slope factors (CSFs). RfDs represent an estimate of daily human exposure to a contaminant below which non-cancer adverse health effects are unlikely.

This screening method ensured consideration of contaminants that may be of concern for shellfish consumers. The equations below show how comparison values were calculated for both non-cancer and cancer endpoints associated with consumption of shellfish.

$$CV_{non\text{-}cancer} = \frac{RfD * BW}{SIR * CF}$$

$$CV_{cancer} = \frac{AT * BW}{Risk\ Level * SIR * CF * EF * ED}$$

Table B1. Parameters used to calculate comparison values used in the shellfish contaminant screening process (Wyckoff/Eagle Harbor Superfund Site, Kitsap County, Washington).

Abbreviation	Parameter	Units	Value	Comments
CV	Comparison Value	mg/kg	Calculated	
RfD	Reference Dose	mg/kg-day	Chemical Specific	Published by EPA
SIR	Shellfish Ingestion Rate	g/day	34.76	Suquamish 90th percentile geoduck consumption rate (consumers only)
			142.4	EPA fish consumption advisory guidance
			363.4	Suquamish 90th percentile all shellfish consumption rate (consumers only)
BW	Bodyweight	kg	79	Adult
			17	Child
CF	Conversion Factor	kg/g	0.001	kilograms per gram
AT	Averaging Time	Days	25550	Days in 70 year lifetime
EF	Exposure Frequency	Days	365	Days per year

ED	Exposure Duration	Years	70	Years consuming geoduck
Risk Level	Lifetime cancer risk	Unitless	$1x10^{-5}$	
CPF	Cancer Potency Factor	kg-day/mg	Chemical Specific	Published by EPA

Appendix C: Exposure dose calculations and assumptions

Average and upper-bound general population exposure scenarios were evaluated for consumption of shellfish from Wyckoff/Eagle Harbor. Exposure assumptions given in Table C1 below were used with the following equations to estimate contaminant doses associated with shellfish consumption.

$$\text{Dose}_{(\text{non-cancer (mg/kg-day)})} = \frac{C \times CF_1 \times IR \times CF_2 \times EF \times ED}{AT_{\text{non-cancer}}}$$

$$\text{Cancer Risk} = \frac{C \times CF_1 \times IR \times CF_2 \times EF \times ED \times CPF}{AT_{\text{cancer}}}$$

Table C1. Exposure Assumptions

Parameter	Value	Unit	Comments
Concentration (C) – High-end	Variable	ug/kg	Average value.
Conversion Factor$_1$ (CF_1)	0.001	mg/ug	Converts contaminant concentration from micrograms (ug) to milligrams (mg)
Ingestion Rate (IR) – median Suquamish children - geoduck	0.05	g/kg/day	~ 3 three-oz. meals per year
Ingestion Rate (IR) – 75th percentile Suquamish children - geoduck	0.23	g/kg/day	~ 1 three-oz. meal per month
Ingestion Rate (IR) – 95th percentile Suquamish children (includes non-consumers) - geoduck	0.84	g/kg/day	~ 1 three-oz. meal per week
Ingestion Rate (IR) – U.S. average adults - all shellfish	0.03	g/kg/day	~ 3 eight-oz. meals per year
Ingestion Rate (IR) – median Tulalip adults - all shellfish	0.11	g/kg/day	~ 1 eight-oz. meal per month
Ingestion Rate (IR) – 95th percentile adults Suquamish – geoduck (consumers only)	1.117	g/kg/day	~ 2.7 eight-oz. meal per week
Conversion Factor$_2$ (CF_2)	0.001	kg/g	Converts mass of fish from grams (g) to kilograms (kg)
Exposure Frequency (EF)	365	days/year	Assumes daily exposure consistent with units of ingestion rate given in g/day
Exposure Duration (ED)	70	years	Number of years eating shellfish (adults)
Averaging Time$_{non-cancer}$ (AT)	25550	days	70 years
Averaging Time$_{cancer}$ (AT)	25550	days	70 years
Minimal Risk Level (MRL) or Oral Reference Dose (RfD)	Contaminant-specific	mg/kg/day	Source: ATSDR, EPA
Cancer Potency Factor (CPF)	Contaminant-specific	mg/kg-day^{-1}	Source: EPA

Table C2. Non-cancer hazards associated with exposure to contaminants of concern in geoduck sampled from tracts #s 07650 and 07700 at Wyckoff/Eagle Harbor Superfund Site, Kitsap County, Washington.

Chemical	Mean Concentration	RfD (mg/kg/day)	Child Hazard Quotient			Adult Hazard Quotient		
			Median Suquamish	75th Suquamish	95th Suquamish (includes non-consumers)	Average U.S	Median Tulalip (All Shellfish)	95th Suquamish*
PCBs (ppb)	8.8	0.00002	<0.1	0.1	0.5	<0.1	<0.1	0.4
Dioxin TEQ (ppt)	0.17	1.0E-9[a]	<0.1	<0.1	0.2	<0.1	<0.1	0.2
Whole body‡								
PCBs (ppb)	7.9	0.00002	<0.1	<0.1	0.3	<0.1	<0.1	0.4
Dioxin TEQ (ppt)	0.3	1.0e-9	<0.1	<0.1	0.3	<0.1	<0.1	0.3

* 95th Suquamish includes consumers only.
† See uncertainty section for tribal members that consume whole geoduck body.
‡ Value derived from whole body (Table A7).
[a] ATSDR chronic oral minimal risk level (MRL) based on neurological effects in monkeys.

Table C3. Theoretical cancer risk associated with exposure to contaminants of concern in geoduck sampled from tracts #s 07650 and 07700 at Wyckoff/Eagle Harbor Superfund Site, Kitsap County, Washington.

Chemical	Mean Concentration	CSF (mg/kg/day)	Child Cancer Risk [a]			Adult Cancer Risk [b]		
			Median Suquamish	75th Suquamish	95th Suquamish (includes non-consumers)	Average U.S	Median Tulalip (All Shellfish)	95th * Suquamish
Benzo(a)pyrene TEQ (ppb)	2.7	7.3 [a]	9.2E-8	4.2E-7	1.5E-6	5.9e-7	3.0e-6	2.2e-5
PCBs (ppb)	8.8	2	8.2e-8	3.8e-7	1.4e-6	5.3e-7	2.7e-6	1.9e-5
Dioxin TEQ (ppt)	0.17	1.5E+5 [a]	1.2e-7	5.4e-7	2.0e-6	7.7e-7	3.9e-6	2.9e-5
Total Cancer Risk			2.9E-7	1.3E-6	4.9E-6	1.9E-6	9.6E-6	7.0E-5
Whole body‡								
Benzo(a)pyrene TEQ (ppb)	5.1	7.3 [a]	1.7E-7	8.0E-7	2.9E-6	1.1E-6	5.7E-6	4.2E-5
PCBs (ppb)	7.9	2	7.3E-8	3.4E-7	1.2E-6	4.7E-7	2.4E-6	1.8E-5
Dioxin TEQ (ppt)	0.3	1.5E+5 [a]	2.1E-7	9.6E-7	3.5E-6	1.4E-6	6.9E-6	5.0E-5
Total Cancer Risk			4.5E-7	2.1E-6	7.6E-6	3.0E-6	1.5E-5	**1.1E-4**

a- ten-fold adjustment factored into early life exposures prior to age 2, three-fold adjustment between age 2 to 6 years accounts for contaminants that may be mutagens

b- Cancer risk presented do not represent cumulative lifetime exposure from childhood to adulthood due to lack of consumption data from 7 to 15 year old children. EPA cancer class B2, probable human carcinogen (inadequate human, sufficient animal studies)

* 95th Suquamish includes consumers only

‡ Value derived from whole body (Table A7)

Certification

This Evaluation of Contaminants in Geoduck Tissue from Wyckoff/Eagle Harbor Tracts Superfund Site in Puget Sound Health Consultation was prepared by the Washington State Department of Health under a cooperative agreement with the federal Agency for Toxic Substances and Disease Registry (ATSDR). It was completed in accordance with approved methodology and procedures existing at the time the Evaluation of Contaminants in Geoduck Tissue from Tracts at Wyckoff/Eagle Harbor Health Consultation were initiated. Editorial review was completed by the Cooperative Agreement partner.

Audra Henry

Audra Henry, Technical Project Officer
CAT, DHAC, ATSDR

The ATSDR Division of Health Assessment and Consultation (DHAC), has reviewed this health consultation and concurs with the findings.

Alan W Yarbrough

Alan Yarbrough, Team Lead, CAT, DHAC, ATSDR

Reference List

1. U.S. Army Corps of Engineers, Seattle District Seattle Washington. Second Five-Year Review Report for the Wyckoff / Eagle Harbor Superfund Site Bainbridge Island, Kitsap County, Washington. 9-26-2007.

2. U.S. Environmental Protection Agency Region 10. 1-9-2007. Wyckoff/eagle Harbor Site Description. http://yosemite.epa.gov/r10/nplpad.nsf/88d393e4946e3c478825631200672c95/bcea9fa44b93dc82852565920079c127!OpenDocument

3. Washington State Department of Health. Assessment of Geoduck Chemical Contamination Adjacent to Eagle Harbor. 1997.

4. (Cleland, B, Diaz, E, and Office of Shellfish and Water Protection, Washington Department of Health, Bainbridge Island Sewage Outfalls, personal communication, 4-22-2009)

5. Suquamish Tribe and Washington State Department of Health. Quality Assurance Project Plan Wyckoff / Eagle Harbor Geoduck Tissue and Sediment Sampling. 2005.

6. Suquamish Tribe Fisheries Department. Final Wyckoff/Eagle Harbor Geoduck Tissue and Sediment Field Sampling Report. 2006.

7. URS Greiner Woodward Clyde. A preliminary investigation of geoduck (*panope abrupta*) tissue chemistry for the Kingston Wastewater Treatment Plant outfall project. 3-31-1999.

8. Marine and Sediment Assessment Group. King County Department of Natural Resources and Parks: Wastewater Treatment Division. Brightwater Marine Outfall Geoduck Tissue Study: Final Report. 2002.

9. Malcolm Pirnie. Draft Remedial Investigation for the marine environment near the former Rayonier Mill site: Port Angeles, Washington. 2005.

10. Schoeny, R., Poirier, K., and U.S. Environmental Protection Agency. Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons. 1993. EPA/600/R-93/089 (NTIS PB94116571).

11. U.S. Environmental Protection Agency. 2009. Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds National Academy Sciences (NAS) Review Draft. http://www.epa.gov/ncea/pdfs/dioxin/nas-review/

12. National Academy of Sciences. Health Risks from Dioxin and Related Compounds: Evaluation of the EPA Reassessment. 2006.

13. U.S. Food and Drug Administration. National Shellfish Sanitation Program Guide for the Control of Molluscan Shellfish. 2003.

14. CH2M.Hill. Revised Risk Assessment Eagle Harbor Operable Unit: Wyckoff/Eagle Harbor site Kitsap County, Washington. 1991.

15. CH2M Hill. Revised Risk Assessment Eagle Harbor Operable Unit: Wyckoff/Eagle Harbor site Kitsap County, Washington. 1991.

16. The Suquamish Tribe. 2000. Fish Consumption Survey of the Suquamish Indian Tribe of the Port Madison Indian Reservation, Puget Sound Region.

17. United States Environmental Protection Agency. Asian and Pacific Islander Seafood Consumption Study in King County, WA. 1999. EPA910/R-99-003.

18. Toy KA, Polissar NL Liao S and Gawne-Mittelstaedt GD. A Fish Consumption Survey of the Tulalip and Squaxin Island Tribes of the Puget Sound Region. 1996.

19. Suquamish Tribe and Washington State Department of Health. Final 2.0 Quality Assurance Project Plan Wyckoff / Eagle Harbor Geoduck Tissue and Sediment Sampling. 2005.

20. Feron, V. J. and Groten, J. P. 2002. Toxicological evaluation of chemical mixtures. Food Chem.Toxicol. 40:825-839.

21. Groten, J. P., Sinkeldam, E. J., Muys, T., Luten, J. B., and van Bladeren, P. J. 1991. Interaction of dietary Ca, P, Mg, Mn, Cu, Fe, Zn and Se with the accumulation and oral toxicity of cadmium in rats. Food Chem.Toxicol. 29:249-258.

22. Groten, J. P. 2000. Mixtures and interactions. Food Chem.Toxicol. 38:S65-S71.

23. Jonker, D., Woutersen, R. A., van Bladeren, P. J., Til, H. P., and Feron, V. J. 1990. 4-week oral toxicity study of a combination of eight chemicals in rats: comparison with the toxicity of the individual compounds. Food Chem.Toxicol. 28:623-631.

24. Jonker, D., Woutersen, R. A., van Bladeren, P. J., Til, H. P., and Feron, V. J. 1993. Subacute (4-wk) oral toxicity of a combination of four nephrotoxins in rats: comparison with the toxicity of the individual compounds. Food Chem.Toxicol. 31:125-136.

25. Jonker, D., Jones, M. A., van Bladeren, P. J., Woutersen, R. A., Til, H. P., and Feron, V. J. 1993. Acute (24 hr) toxicity of a combination of four nephrotoxicants in rats compared with the toxicity of the individual compounds. Food Chem.Toxicol. 31:45-52.

26. Wade, M. G., Foster, W. G., Younglai, E. V., McMahon, A., Leingartner, K., Yagminas, A., Blakey, D., Fournier, M., Desaulniers, D., and Hughes, C. L. 2002. Effects of subchronic exposure to a complex mixture of persistent contaminants in male rats: systemic, immune, and reproductive effects. Toxicol.Sci. 67:131-143.

27. Feron, V. J., Cassee, F. R., and Groten, J. P. 1998. Toxicology of chemical mixtures: international perspective. Environ.Health Perspect. 106 Suppl 6:1281-1289.

28. Groten, J. P., Schoen, E. D., van Bladeren, P. J., Kuper, C. F., van Zorge, J. A., and Feron, V. J. 1997. Subacute toxicity of a mixture of nine chemicals in rats: detecting interactive effects with a fractionated two-level factorial design. Fundam.Appl.Toxicol. 36:15-29.

29. Agency for Toxic Substances and Disease Registry (ATSDR). Guidance manual for the assessment of joint toxic action of chemical mixtures. 2004.

30. van den, Berg M., Birnbaum, L. S., Denison, M., De, Vito M., Farland, W., Feeley, M., Fiedler, H., Hakansson, H., Hanberg, A., Haws, L., Rose, M., Safe, S., Schrenk, D., Tohyama, C., Tritscher, A., Tuomisto, J., Tysklind, M., Walker, N., and Peterson, R. E. 2006. The 2005 World Health Organization reevaluation of human and Mammalian toxic equivalency factors for dioxins and dioxin-like compounds. Toxicol.Sci. 93:223-241.

31. Agency for Toxic Substances and Disease Registry (ATSDR). 2008. Toxicological Profile for Chlorinated Dibenzo-p-dioxins (CDDs). http://www.atsdr.cdc.gov/toxprofiles/tp104.html

32. National Toxicology Program. Carcinogenesis bioassay of 2,3,7,8- tetrachlorodibenzo-p-dioxin in Swiss-Webster mice (gavage study). 1982. DHHS Publication no 82-1765; 1982.

33. U.S. Environmental Protection Agency. Health assessment document for polychlorinated dibenzo-p-dioxins. 1985. EPA report no. 600/8-84/014.

34. U.S. Environmental Protection Agency. Report on the peer review of the dioxin reassessment documents: toxicity equivalency factors for dioxin and related compounds (Chapter 9) and integrated risk characterization document. 2000.

35. Agency for Toxic Substances and Disease Registry (ATSDR). 1995. Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs). http://www.atsdr.cdc.gov/toxprofiles/tp69.html

36. ATSDR. 2000. Toxicological Profile for Polychlorinated Biphenyls (PCBs). http://www.atsdr.cdc.gov/toxprofiles/tp17.html.http://www.atsdr.cdc.gov/toxprofiles/tp17.pdf

37. Washington State Department of Health, Office of Environmental Health Assessments. Evaluation of Selected Metals in Geoduck Tissue From Tracts 09950 and 10400, Dumas Bay, Puget Sound, King and Pierce Counties, Washington. 4-18-2007.

38. Washington State Department of Health. Evaluation of contaminants in geoduck tissue from tracts near Richmond Beach, King County, Washington. 2009.