Evaluate Contaminants in Puget Sound Roofing Materials

in Support of Implementing the Toxics and Nutrients Reduction Strategy

Contact Information:

Andrew Kolosseus
Department of Ecology
PO Box 47600
Olympia, WA 98504-7600
360-407-7543
akol461@ecy.wa.gov

Dale Norton
Department of Ecology
Environmental Assessment Program
Toxics Studies Unit
PO Box 47600
Olympia, WA 98504-7600
360/407-6765
dale.norton@ecy.wa.gov

Abstract:

The Puget Sound Toxics Loading Analysis (PSTLA) identified roofing materials as one of the largest potential anthropogenic sources of cadmium, copper, and zinc released in the Puget Sound Basin. However, a high degree of uncertainty was associated with these estimates since most of the information used to derive them was from studies conducted in other regions of the country and the world. This project will include a study to evaluate selected chemicals in runoff from various roofing materials commonly used in the Puget Sound region. Testing will be conducted in a laboratory setting to assess runoff under a variety of conditions. Roofing materials will also be analyzed for chemical content following a review of manufacturers' data where it is available. A Roofing Task Force will be organized to help gather information on chemicals in roofing products. Data generated from this project can be used to inform consumers and industry on which roofing materials are most problematic in terms of release of chemicals from roofing materiasl.

Total Amount of Funds Requested: *$ 399,809*

Summary for the Proposed Investigation:

An assessment of the anthropogenic sources and annual releases of toxic chemicals to the Puget Sound basin identified roof runoff to be a major contributor of certain metals and a comparatively minor source of phthalates (Ecology, 2011a). Information on chemical concentrations used to derive these estimates was obtained primarily from the published peer-reviewed literature and are summarized in Table 1. However, this information was not sufficient to provide annual release estimates with a high degree of certainty due to:

- A lack of region-specific data for Puget Sound.

- Few studies controlling for factors such as concentrations of metals in atmospheric deposition.

The role that chemicals loads from roof runoff play in in creating hazards to aquatic organisms is difficult to define and may depends largely on the geographical scale being evaluated. For instance, Good (1993) demonstrated that runoff from rooftops at a sawmill was toxic to rainbow trout using laboratory bioassay tests, and Yaziz et al. (1989) found that metals in 'first-flush' roof runoff exceeded relevant drinking water standards. Chemical concentrations in roof runoff, such as those shown in Table 1, may be readily compared to various criteria and thresholds to protect aquatic organisms and human health.

Table 1. Estimated Release of Selected Chemicals from Roofing in the Puget Sound Basin (source: Ecology, 2011a).

Chemical	**Range of Concentrations (ug/l)**	**Estimated Annual Release in the Puget Sound Basin (t/yr)**	**Contribution to Total Anthropogenic Release**
Arsenic	-<0.01 – 1.43	<0.01 – 0.84	19%
Cadmium	0.24 – 1.9	0.5 – 0.7	53 – 68%
Copper	4 – 1,850	12 – 43	3% - 29%
Lead	<0.1 – 52	15 - 20	2% - 12%
Zinc	24.6 – 16,317	210 – 2,800	37% - 97%
Bis(2-ethylhexyl) phthalate	No data found	0.14	<1%

At a stream sub-basin scale, assigning metals contribution to roof runoff becomes difficult since other chemical sources must be considered as well as environmental transport and attenuation factors. An example of the difficulties in doing this was demonstrated by Paulson (2011) when he attempted to conduct a copper mass-balance in two small urban sub-basins.

At a regional scale, the linkages between chemical sources and receiving water concentrations become even more tenuous. Based on information generated in the reports on sources and assessment of chemicals in the Puget Sound basin (Ecology, 2011a and 2011b), the following generalized conclusions may be drawn related to chemicals found in roof runoff and chemical hazards in general:

- Release estimates suggest that arsenic, cadmium, copper, lead, and zinc in roof runoff may be among the largest anthropogenic releases of these chemicals in the Puget Sound basin.
- A broad-scale hazard evaluation indicates that at a substantial portion of copper concentrations observed in fresh and marine waters region-wide are at levels where effects to aquatic organisms are documented. The same appears to be true for zinc in marine waters; arsenic, cadmium, copper, and bis(2-ethylhexyl) phthalate (DEHP) in freshwater sediments; and DEHP in marine sediments and freshwater and marine seafood.

Based on these generalized conclusions, it appears that gaining a better understanding of region-specific information on chemicals in roof runoff is warranted. Understanding the impact of roof runoff at a smaller geographical scale may be of secondary importance.

Project Goals

The **working goals** of the project are as follows:

- Work with stakeholders to obtain information about the chemical make-up of different roofing materials.
- Determine concentration of selected chemicals in various roofing materials through actual testing
- Determine concentrations of selected chemicals leached from specific roofing materials by testing runoff.

These goals may be revised with additional input from Ecology Green Building Coordinator (GBC). Study **objectives** will also be clarified with input from the GBC. The following sections outline the study approach to meet the working goals. While specific objectives have yet to be clarified, tasks developed from the study approach should provide sufficient information to scope the cost and schedule estimates for the project.

Approach to Evaluate Chemicals in Roofing Materials

The conceptual model of the study is shown in Figure 1. This flowchart illustrates steps to be conducted by the Ecology Technical Lead for the project (ovals) as well as the Technical Lead's relationship with GBC and a Roofing Task Force that will provide input (rectangles). Steps to be conducted by a contractor are shown in triangles. The tasks to be detailed in subsequent sections are generally exclusive to the Technical Lead responsibilities. Relationship with the GBC and the Roofing Task Force are shown since they will affect the project schedule, but tasks associated with their roles are not shown.

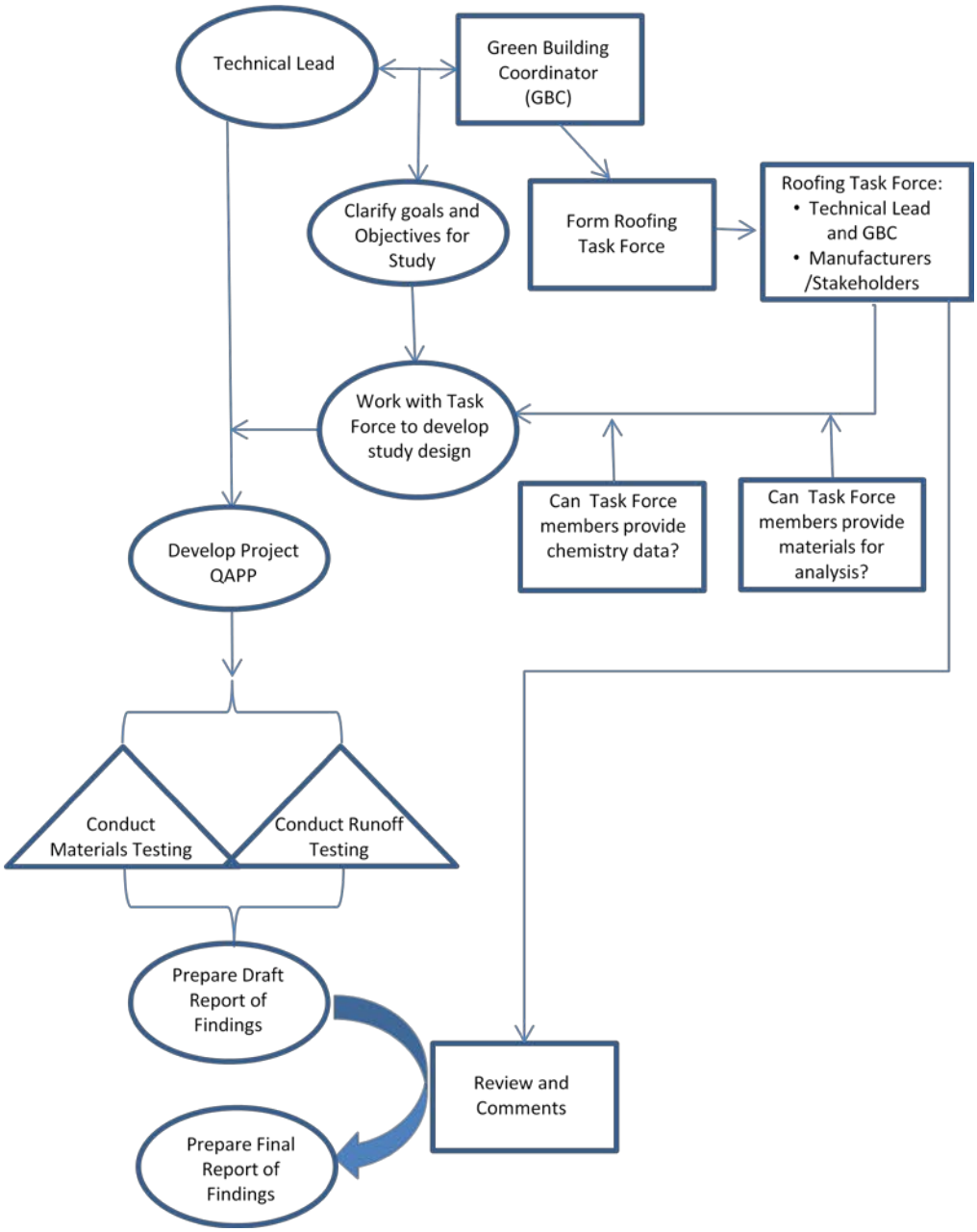

Figure 1. Conceptual Model of Project Roles. Good

The Technical Lead will work with the GBC to clarify the goals of the project and study objectives. Once the goals and objectives are established, the GBC will assemble and coordinate the Roofing Task Force. The purpose of the Task Force is to help gather information on roofing products. The Task Force will presumably include representatives of the roofing manufacturing industry. Roofing Task Force members may be able to provide useful information such as market data, product testing methodologies and test results, and data on chemical make-up of roof materials. Roofing Task Force members may be able to provide physical samples of roofing

materials for chemical analysis and runoff testing. The Roofing Task Force will also provide input to the study design and review the report of findings.

Basic Study Design

As stated previously, the working goals of the project are to determine the concentrations of selected chemicals leached from specific roofing materials and to obtain information about the chemical make-up of different roofing materials. These two study components are discussed briefly below.

Materials Testing

The materials testing component of the project focuses on assessing the chemical make-up of the roofing materials. Materials test results obtained prior to runoff testing may be used to select materials for the runoff tests. Data generated from direct analysis of the physical materials has other benefits such as information that can lead to development of end-of-life disposal and recycling options.

For roof materials, it is conceivable that different components of a manufactured product will be analyzed separately. For instance, the granules found on asphalt composite roofs may be analyzed separately from the asphalt/fiber substrate, and paint from metal roofs may be analyzed separately from the metal base.

As mentioned previously, Roofing Task Force members may be able to provide useful information such as market data, product testing methodologies and test results, and data on chemical make-up of roof materials. Roofing Task Force members may be able to provide physical samples of roofing materials for chemical analysis and runoff testing. Until the extent of the Roofing Task Force contributions are known, the scope and sample design for the materials testing component is uncertain.

Methods to extract aliquots of material for analysis (i.e. to sample the material) will be done in a controlled and consistent manner, and will be included in a detailed sampling plan.Good Materials will be analyzed for metals and a subset of PVC samples will be analyzed for phthalates. Analytical and preparation methods may need to be modified for some matrices. A cursory review of testing methods prescribed by American Society for Testing and Materials (ASTM) did not yield any methods applicable to the tests described here.

Table 2 shows a list of potential materials for chemical testing. Sample numbers may depend on the number and variety of brands and types available.

Table 2. Possible Roofing Materials for Testing.

Variable / Material	Types/ Brands
Asphalt composite (whole)	30
Asphalt composite granules	30
Wood shake/shingle (whole)	10
Wood shake/shingle coating treatment	10
Built-up surface material (whole)	10
Built-up surface paint or coating	10
Metal roof (whole)	15
Metal roof paint	15
Concrete tile (whole)	10
Concrete tile glaze or coating	10
Clay tile (whole)	10
Clay tile glaze or coating	10
PVC	10
Other roof types	20
TOTAL	200

Runoff Testing

The goal of runoff testing is to acquire data about concentrations of chemicals released and transported from rooftops due to precipitation. Runoff testing provides information with a higher degree of environmental relevance than materials testing since chemicals released from rooftops are typically transported in runoff to storm and combined sewers, lawns and soils, and driveways/parking lots and streets.

Runoff testing will be conducted in a laboratory setting rather than *in situ* environmental circumstances in order to control for confounding factors such as contaminants in rainwater and chemical build-up over time due to dry deposition. Recent analysis of metals in atmospheric deposition in the Puget Sound basin (Brandenberger et al., 2010) suggests that, depending on the type of roof and location, metals found in atmospheric deposition may make up a substantial portion of the metals found in rooftop runoff. The QAPP might propose collecting and analyzing a limited number of runoff samples from the same (new) building materials that are also being tested in the lab setting? This might confirm the supposition that aerial deposition is provides a significant portion of the metals in actual roof runoff.

In order to test runoff from roof materials, samples of the material will be sprayed with rainwater in order to simulate actual precipitation. Since the testing will be done in a controlled environment, the effect of variables such as pH, roof slope, and the intensity and duration of "rainfall" may be assessed. Runoff will be collected and analyzed for metals and conventional parameters. A subset of samples will also be analyzed for phthalates.

Information on runoff testing methodologies will be solicited from the Roofing Task Force for this component of the project. A cursory review of testing methods prescribed by ASTM did not yield any methods applicable to the test concept described here.

The selection of roofing materials to be tested should be guided by the preponderance of existing roofing types and estimates of future roofing trends. It is anticipated that some of this information may be provided by the Roofing Task Force.

Current understanding of the existing roofing stock is based on a study of chemical sources in the Puget Sound basin (Ecology, 2011a) which used county and city assessor's data to generate estimates of the roofing footprint (area and type) for the entire Puget Sound basin (Table 3). Assessor's data were overlain with land cover and precipitation data to estimate the annual runoff volume.

Table 3. Estimates of Roof Area and Roof Runoff in the Puget Sound Basin.

Roof Type	**Roof Area**		**Roof Runoff**	
	(millions of m^2)	**Percent of Total Roof Area**	**(billions of liters/yr)**	**Percent of Total Roof Runoff**
Asphalt Composite	396	71%	584	72%
Built-up	74	13%	103	13%
Wood Shingle/Shake	36	6%	54	7%
Metal	30	5%	43	5%
Concrete Tile	16	3%	23	3%
Clay Tile	0.3	<1%	0.4	<1%
Copper	1.9	<1%	2.4	<1%
Masonite	1.6	<1%	2.3	<1%
Other	1.6	<1%	2.2	<1%
Total	557	100%	814	100%

Existing estimates show that five roof types – asphalt, built-up, wood shingle/shake, metal, and concrete tile – comprise 98% and nearly 100% of the roof area and roof runoff, respectively. It should be noted that these estimates of roof area and runoff are based on limited data (discussed in Appendix B of Ecology, 2011a) and may not reflect current trends in the residential and commercial building industry.

In addition to the types of roofing cover, other components that are incorporated into roofing and are exposed to precipitation should also be tested. These include, but should not be limited to; flashing materials, vent covers, gutters, and downspouts.

Table 4 shows the number of samples suggested for each material. It should be remembered that these sample numbers were derived for planning purposes and may change as the sample design

becomes more refined. Once the materials are tested using typical or "moderate" conditions, a subset of the samples may be selected for additional testing with varying conditions (Table 4).

Table 4. Matrix of Possible Materials and Variables for Testing Roof Runoff.

Variable	**Types/ Brands**	**All Variables**	**pH of Rain**		**Roof Slope**		**Rain Intensity**		**Rain Duration**		
Material		**moderate**	**low**	**high**	**shallow**	**steep**	**low**	**high**	**short**	**long**	**TOTAL**
Asph. Comp. (New)	10	10	2	2	2	2	4	4	4	4	34
Asph. Comp. (Old)	5	5	2	2	--	--	2	2	2	2	17
Wood (New)	5	5	2	2	2	2	2	2	2	2	21
Wood (Old)	2	2	--	--	--	--	--	--	2	2	6
Built-up (New)	5	5	2	2	--	--	2	2	2	2	17
Built-up (Old)	2	2	--	--	--	--	--	--	2	2	6
Metal (New)	10	10	2	2	2	2	2	2	4	4	30
Metal (Old)	5	5	2	2	--	--	--	--	2	2	13
Concr. Tile (New)	5	5	2	2	2	2	2	2	2	2	21
Concr. Tile (Old)	2	2	--	--	--	--	--	--	2	2	6
PVC (New)	5	5	--	--	--	--	--	--	2	2	9
PVC (Old)	5	5	--	--	--	--	--	--	2	2	9
Other Mater. (New)	10	10	2	2	2	2	2	2	2	2	26
Other Mater. (Old)	5	5	2	2	--	--	--	--	2	2	13
Flashing	10	10	2	2	--	--	2	2	2	2	22
Vent Covers	5	5	2	2	--	--	--	--	2	2	13
Gutter	10	10	2	2	2	2	4	4	4	4	34
Downspout	5	5	2	2	2	2	--	--	2	2	17
Other Components	10	10	2	2	--	--	2	2	2	2	22
	TOTAL	116	28	28	14	14	24	24	44	44	336

Uncertainties in the Basic Study Design

A large uncertainty regarding this component of the project is due to the ability (and willingness) of roof material manufacturers to provide data on the chemical make-up of the materials. Data provided by knowledgeable parties could potentially change the sample design and alter the number of samples needed for analysis. In addition, if sample materials are provided by manufacturing representatives it could substantially reduce the amount of materials needed to be purchased. Neither does the project propose testing common roof materials once they've aged/become worn. This may or may not substantially affect real or simulated runoff concentrations

Other considerations that could potentially affect the study design, and therefore the project cost and schedule, include the following:Good

- Addition/subtraction of chemical parameters
- Requirements for whole metals analysis, dissolved metals analysis, or both
- Extent to which analytical methods will require modification
- Cost of contracting out the testing components of the project
- Acquisition of new and used roof materials

- Methods to simulate weathering of materials

Project Components

The details of the specific tasks required to complete evaluation of roofing materials will ultimately depend on the study design that is guided by the study goals and objectives and input from the Roofing Task Force. The tasks outlined here are developed without knowledge of what the specific study objectives will be. The specific tasks described here are generally associated with the ovals displayed in the conceptual model flowchart (Figure 1).

Task 1: Clarify Project Goals and Objectives, Organize Roofing Task Force, and Ongoing Involvement with Roofing Task Force

This task primarily involves the GBC whose responsibility includes clarifying the project goals and study objectives along with the Technical Lead. This should be done prior to formation of a Roofing Task Force in order to provide guidance to the Task Force and to serve as a foundation for the project so that prospective Task Force members will understand the basis for their involvement.

Once the project goals and study objectives are clarified, the GBC will form a Roofing Task Force to help guide the study. The GBC will assume a leadership role for the Task Force, and will act as a liaison between the Task Force and the Technical Lead.

The Technical Lead's involvement in this task is limited to working with the GBC to clarify goals and objectives, and presenting updates and reports to the Roofing Task Force.

Estimated FTE for GBC:	***0.40 FTE***
Estimated FTE for Technical Lead:	***0.15 FTE***
Completion Date:	***6/30/2012 to 10/31/2013***

Task 2: Design Study and Develop QAPP

This task primarily involves the Technical Lead. The Technical Lead will work with members of the Roofing Task Force to design the study. This includes review of the literature for information on chemical make-up of roofing materials, factors affecting chemical concentrations in roof runoff, and testing methods. As noted previously, the degree to which the Task Force will be able to assist with this task is not known.

The Quality Assurance Project Plan (QAPP) will be developed as part of this task. The Technical Lead will be responsible for writing the QAPP and ushering it through the approval process. As with the study design, the Roofing Task Force may provide input on draft versions of the QAPP. The QAPP should follow EPA, Ecology, and EAP program guidelines, and will be approved by Ecology's QA officer or the QA Coordinator for NEP projects.

Estimated FTE for GBC:	***0.06 FTE***
Estimated FTE for Technical Lead:	***0.40 FTE***
Completion Date:	***11/30/2012***

Task 3: Coordinate Runoff Testing and Analyze Data

Scoping for this task is done with the assumption that the runoff testing will be conducted by a contractor. The contractor will conduct the work according to the final QAPP.

The Technical Lead will help plan and oversee the work done by the contractor by acting as the project manager. This will include ensuring compliance with QAPP, decision-making to help the project stay on budget and schedule, and assessing the quality and usability of the data.

The data analysis component is included under this task. The Technical Lead will assume the primary responsibility for the data analysis, but this may be done in coordination with the contractor performing the runoff testing.

This task also includes laboratory analysis of roofing materials. Depending on the findings of the literature review and information provided by the Roofing Task Force, some preliminary materials testing may be done prior to runoff testing to aid in selection of materials for the runoff component.

Estimated FTE for GBC: ***0 FTE***
Estimated FTE for Technical Lead: ***0.40 FTE***
Completion Date: ***3/31/2013***

Task 4: Prepare Draft Report of Findings

A draft report of findings will be prepared and presented to the Roofing Task Force and technical peers for their review. The Technical Lead will have the responsibility for completing of the draft report of findings. The report will present background information, goals and objectives, study design and methods, results, and discussion of the findings. To the extent practical, the potential environmental relevance of the findings will be discussed as well.

Estimated FTE for GBC: ***0.02 FTE***
Estimated FTE for Technical Lead: ***0.40 FTE***
Completion Date: ***6/30/2013***

Task 5: Prepare Final Report of Findings

The Technical Lead will compile review comments prior to completion of the final report. Where appropriate, the report will be revised to accommodate comments.

The Technical Lead will work with publications staff to ensure compatibility with agency and program Plain Talk and publication format standards. The Technical Lead will work with agency Public Information Officers craft messages where needed.

There will be no EIM data entry for this project since EIM only contains environmental data not product testing results.Good

Estimated FTE for GBC: ***0.02 FTE***
Estimated FTE for Technical Lead: ***0.15 FTE***

Completion Date: ***10/31/2013***

Supporting the Puget Sound Action Agenda & Biennial Science Plan

This project directly implements priority objective C1.2 Near Term Action 5: Safer Roofing Alternatives (Action Agenda, 9/29/11 Draft). Specifically, this priority objective states that: *Ecology will establish a task force that will oversee a study evaluating toxic materials (including phthalates and toxic metals) in roofing materials and recommend strategies for promoting less-toxic alternatives by 2013. To support the task force's work, Ecology will solicit information from manufacturers on the presence of toxic chemicals in roofing materials. If data cannot be obtained from manufacturers or previously published studies, Ecology will create and implement a sampling strategy. The task force will use this information to develop its recommendations.*

Alignment with EPA's Strategic Plan

This proposal supports the following goal of the 2011-2015 EPA Strategic Plan:

Goal 2-Protecting Americas Waters- Restore and Protect the Puget Sound Basin.

Alignment with Work Plan for Toxics/Nutrients

Roofing materials were identified as one of the largest potential anthropogenic sources of metals in the Puget Sound basin (Ecology, 2011a). This project is specifically included in the Ecology work plan for the toxics and nutrients prevention, reduction, and control grant application (Task A1- Toxics Science)

Scope of Work, Deliverables, Timeline, and Budget

Table 6 summarizes the tasks to complete the project along with associated deliverables, timeline, and budget. The total cost of the project is estimated to be $371,048.

Task	Title	Description	Deliverable	Due Date
1	Roofing Task Force	Clarify project Goals and objectives, organize Roofing Task Force, and ongoing involvement with Roofing Task Force.	• Clarify project goals • Organize Roofing Task Force	6/30/12 to 10/31/2013
2	Prepare QAPP	Prepare draft and final QAPP.	• Final QAPP posted on website	11/30/12
3	Coordinate Testing	Coordinate with contractor to conduct runoff testing of various roofing materials under controlled conditions. Conduct materials testing.	• Data on selected chemicals in roofing materials and in runoff from roofing materials	3/31/13
4	Draft Report	Prepare draft report of findings and submit to Roofing Task Force and appropriate peers for review.	• Draft report of findings	6/30/13
5	Final Report	Incorporate review comments into a final report of findings.	• Final report posted on publications website	10/31/13

Anticipated Outputs and Outcomes

Outputs

- Draft and final QAPP.
- Draft and final report.
- Data on metals and phthalates found in various roofing materials.
- Data on metals and phthalates in runoff from various roofing materials.

Outcomes

- Data generated from this project can be used to inform consumers and industry on which roofing materials are most problematic in terms of chemicals released to the environment.
- Information may be used to support development of source control options to reduce metals from roofing materials.
- Data can be used for development of alternatives assessment for most problematic roofing materials.
- Data on the concentrations of chemicals released from specific roofing materials *may* be used to develop loading models at various geographical scales.Difficult
- Data on the chemical make-up of roofing materials may be useful to develop life-cycle analyses or decisions on post-use options.

Collaboration

The information generated for this project may be used by other aspects of the Green Building Initiative and may be used by local jurisdictions to make decisions related to low-impact development.

Outreach and Information Transfer

The results of this project will be made available to the public through:

- Final QAPP and report of findings via Ecology's publication system.

Past Performance and Programmatic Capability

To be added

Detailed Budget by Description

Line Item	Detailed Description	EPA Funds
Personnel	ES-4 GBC (0.5 FTE) and ES-4 Technical Lead (1.5 FTE); annual salary: $58,320/yr Total cost ES-4 (2.0) FTE = $116,640	$116,640
Fringe Benefits	ES-4 benefits rate: 33.50 % of salary; cost: $39,096	$39,096
Travel	Travel to meetings and to testing facilities	$1,500
Equipment	None	$0
Supplies	Purchase of roofing materials for testing	$10,000
Contractual	Sample preparation to be performed by contractor	$50,000
Laboratory	Sample analysis (materials and runoff)	$129,
Total Direct Charges		**$346,236**
Indirect Charges	34.4% of salary and benefits	$53,573
Grand Total		**$399,809**

Logic Model

Vision	Resource Protecting	Strategies	Linkages to Action Agenda	Inputs	Activities	Outputs	Short-Term Outcomes	Long-Term Outcomes
Reduce toxics and nutrients.	Fish and other Puget Sound biota.	Control and manage sources of metals, and to a lesser extent, phthalates.	C1. Reduce release of chemicals by implementing toxic chemical and pollution policy and programs. C1.2 Near Term Action 5: Safer Roofing Alternatives	$371,048 from Toxics /Nutrients grant	Organize and lead Roofing Task Force Design study to assess selected chemicals in roofing materials with input from Roofing Task Force. Conduct testing on selected chemicals in roofing materials and testing on runoff from roofing materials. Prepare and publish report of findings.	(1) Final QAPP. (2) Final Report. (3) Data on metals and phthalates found in various roofing materials. (4) Data on metals and phthalates in runoff from various roofing materials.	(1) Alternatives assessment for roofing materials. (2) Better alternatives implemented for roofing materials. (3) Educational outreach to inform consumers on lower impact roofing materials.	Metals and phthalate inputs to Puget Sound reduced. Biological impairments to Puget Sound from metals and phthalates reduced.

References

Brandenberger, J.M., P. Louchouarn, L-J. Kuo, E.A. Crecelius, V. Cullinan, G.A. Gill, C. Garland, J. Williamson, and R. Dhammapala, 2010. Control of Toxic Chemicals in Puget Sound, Phase 3: Study of Atmospheric Deposition of Air Toxics to the Surface of Puget Sound. Prepared for Washington State Department of Ecology, Olympia, WA by Battelle Marine Sciences Laboratory, Sequim, WA. 90 pages + appendices.

Ecology, 2011a. Control of Toxic Chemicals in Puget Sound Phase 3: Primary Sources of Selected Toxic Chemicals and Quantities Released in the Puget Sound Basin. Washington State Department of Ecology, Olympia, WA. Publication No. 11-03-024. www.ecy.wa.gov/biblio/1103024.html

Ecology, 2011b. Control of Toxic Chemicals in Puget Sound: Assessment of Toxic Chemical Loads in the Puget Sound Basin, 2007-2011. Washington State Department of Ecology, Olympia, WA. Publication No. 11-03-055. www.ecy.wa.gov/biblio/1103055.html

Good, J., 1993. Roof runoff as a diffuse source of metals and aquatic toxicity in stormwater. Water Science Technology 28 (3-5): 317-321.

Paulson, A.J., B. Carter, and R. Shiebley, 2011 (Draft). Control of Toxic Chemicals in Puget Sound: Assessment of Toxic Chemicals in the Puget Sound Basin Addendum No. 1 – Evaluation of Fate and Transport Mechanisms for Primary Releases of Copper, Polychlorinated Biphenyls, and Polybrominated Diphenyl Ethers in the Puget Sound Basin.

Yaziz, M.I., H. Gunting, N. Sapari, and A.W. Ghazali, 1989. Variations in rainwater quality from roof catchments. Water Research 23 (6):761-765.