Quality Assurance Project Plan

Tracking Short-Term Movements of Suspended Sediments in the Lower Duwamish Waterway

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Cover photo: Releasing artificial fluorescent-magnetic silt particles into the Lower Duwamish Waterway (February 13, 2009).

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October 2009

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TCP – Toxics Cleanup Program
SCS – Statewide Coordination Section
EAP - Environmental Assessment Program
WOS – Western Operations Section

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Abstract

A recent sediment transport model predicts that nearly all the yearly sediment load entering the Lower Duwamish Waterway (LDW) comes from the Green River. About one-half is predicted to be deposited within the LDW. However, the accumulation of sediment and sediment-associated contaminants differs by reach, water depth, settling velocity, and other factors.

This 2009 study will use artificial sediment particles with a "dual-signature" (fluorescent and magnetic) to identify short-term sediment transport pathways and patterns of sediment accumulation. The tracer particles, manufactured to mimic native sediments, will be released into the LDW and later recovered from the water column and surface sediments.

The mass and particle size distribution of the tracer particles recovered from various locations in the LDW will be described and can be compared to model predictions. Results may also be used to make inferences about patterns of transport and areas accumulating contaminants associated with incoming suspended sediments.

Each study conducted by the Washington State Department of Ecology must have an approved Quality Assurance Project Plan. The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completion of the study, a final report describing the study results will be posted to the Internet.

Background

Future cleanup actions designed to reduce exposures of wildlife and humans to contaminated sediments in the Lower Duwamish Waterway cleanup site (LDW) will likely include a combination of the following:

- Dredging to remove contaminated sediments.
- Capping contaminated sediments with clean sands or other materials.
- Allowing contaminated sediments to be buried by incoming sediments (monitored natural recovery).

Choosing appropriate cleanup remedies will depend on:

- Identifying existing sources of sediment contaminants.
- Estimating contaminant loads associated with each source.
- Gaining a better understanding of the fate of contaminants that enter the LDW, especially those associated with incoming suspended sediments.

A recent sediment transport model (STM) predicts that nearly all sediment enters the LDW from upstream (LDWG, 2008). Consequently, substantial contaminant loading is also presumed to come from the Green River[1].

The STM divides the overall LDW cleanup site into three distinct river reaches (Figure 1), based on predicted sediment stability and other factors:

- Reach 1 (River Mile 0.0 - 2.2) always contains a saline layer of water or salt wedge. There is net deposition averaging of 0.5-2.0 cm sediment per year, with minimal potential for scour.
- Reach 2 (RM 2.2 - 4.0) is also a zone of net deposition, but with consistently higher accumulation rates (>2.0 cm/yr) and moderate potential for scour.
- Reach 3 (upstream of RM 4.0-4.8) features the highest net sedimentation rates (sometimes greater than 2.0 cm/yr) but also has the greatest potential for scour.

This study will test two major STM predictions:

- Nearly all incoming sandy sediments settle out within these three reaches.
- Approximately 50% of the total mass of fine sediment entering the LDW from the Green River passes through the LDW and into the downstream waterways or Elliott Bay.

[1] This study will consider the Green River to begin at about River Mile 4.8 – just above the southern turning basin.

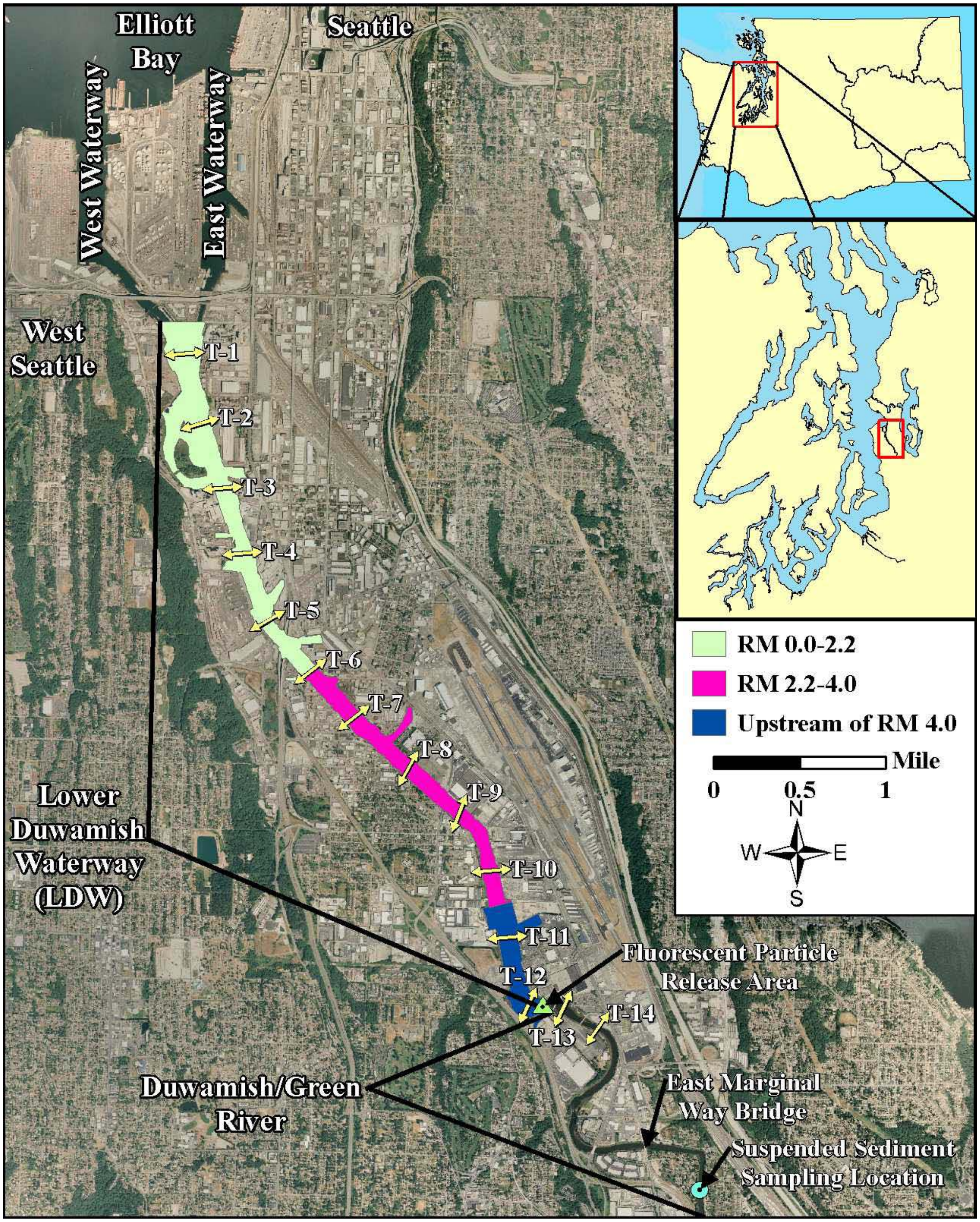

Figure 1. The Lower Duwamish Waterway (LDW) study area.

The three STM reaches are shown with background shading. Native sediment samples will be collected along transects in or near the LDW cleanup site (yellow arrows) and farther upstream (blue circle). Tracers will be released just above the turning basin (green triangle at RM 4.8) and recovered within the LDW.

Project Description and Objectives

Description

This study will measure short-term patterns of transport and deposition of suspended sediments that enter the LDW site. The approach taken will be to release artificial sediment particles into the water column near the upstream boundary of the LDW (Figure 1) and later recover them from the waterway. The study will not assess movements of sediments coming from sources within the waterway (stormwater outfalls, bedded sediments that are resuspended, bank erosion).

Artificial sediment particles will be manufactured to mimic many of the characteristics of two fractions of native sediments: silts and fine-to-medium sands. These particles will act as tracers because they will also have fluorescent and magnetic properties distinguishing them from native sediments. This QA Project Plan will refer to the *dual-signature* sediment tracers simply as *fluorescent tracers* or just *tracers*.

The fluorescent tracers will be recovered from surface water and bottom sediment samples collected up to two months after being released. Results from the analysis of number, mass, and size distribution of tracers in the recovered samples will reveal transport pathways and short-term patterns of sediment deposition.

Although similar tracer technologies have been used in many areas of the world (Black et al, 2007), this is the first study of its kind to be conducted in the Puget Sound region. Results will be helpful for evaluating the potential to use sediment tracers in regional studies of:

- The fates of dredged material disposed in open water.
- Rates of shoreline erosion.
- Net rates of sedimentation.
- Sources of particulate matter in stormwater discharges.

Objectives

Specific objectives of the study are to:

1. Manufacture sediment tracers that mimic suspended sediments from the Green River.
2. Release the tracers into the water column so as not to substantially alter existing concentrations of suspended solids.
3. Recover the tracers from the water column and surface sediments within the LDW site on three occasions after their release.

The study will provide field data helpful for evaluating whether fine-grained suspended sediments pass through the LDW. Results may increase confidence in STM predictions or be used to calibrate the model.

Organization and Schedule

Ecology personnel that will be involved in the study, along with their titles and roles, are listed in Table 1. Other Ecology staff may assist with field operations.

The contractor, Partrac Ltd (Partrac), will:

- Review and comment on Ecology's study design.
- Measure key physical properties of native sediment samples provided by Ecology.
- Manufacture fluorescent tracers to agreed specifications.
- Help Ecology staff release the tracers into the LDW.
- Quantify the number, mass, and size distribution of tracer particles in recovery samples.
- Report and interpret all results for tracers found in recovery samples in a report to Ecology.

In a final report, Ecology will discuss the potential implications of the tracer study on evolving decisions related to remediation of the LDW.

The proposed schedule for field sampling, laboratory analysis, and report preparation is shown in Table 2. Tracer release is planned to occur no later than February 2009. Sampling to recover tracers from the LDW will start immediately after their release and will extend for up to two months (no later then April 2009).

Partrac will submit a draft report to Ecology in May, 2009, with the final report due in June 2009. Ecology will incorporate the major conclusions of the Partrac report into its final report by September 2009.

Table 1. Organization of project staff and responsibilities.

Staff (EAP unless otherwise noted)	Title	Responsibilities
Brad Helland Toxics Cleanup Program Northwest Regional Office (425) 649-7138	EAP Client	Clarifies scope of the project. Reviews and approves final QA Project Plan and final study report.
Tom Gries Toxics Studies Unit, SCS (360) 407-6327	Project Manager	Prepares QA Project Plan. Oversees sampling and transfer of samples to Partrac. Conducts QA review, analyzes, and helps interpret data. Prepares final report.
Janice Sloan Toxics Studies Unit, SCS (360) 407-6553	Field Lead	Directs field sampling efforts. Records field information. Assists with data analysis and preparation of final report.
Dale Norton Toxics Studies Unit, SCS (360) 407-6765	Unit Supervisor for Project Manager	Approves budget for tracer study. Reviews and approves the QA Project Plan. Tracks progress of study. Reviews and approves final report.
Will Kendra SCS (360) 407-6698	Section Manager for Project Manager	Reviews and approves QA Project Plan and final report.
Dr. Kevin Black Partrac, Ltd Glasgow, Scotland	Contractor	Responsibilities are listed on page 10 of this QA Project Plan.

EAP – Environmental Assessment Program.
QA – Quality Assurance.
SCS – Statewide Coordination Section.

Table 2. Proposed schedule for completing field sampling, laboratory analysis, and reporting.

Field and laboratory work	Due date	Lead staff
Field work completed	April 2009	Janice Sloan, Tom Gries, and Kevin Black
Laboratory analyses completed	May 2009	
Environmental Information System (EIM) database		
EIM user study ID	na	
Product	Due date	Lead staff
EIM data loaded	na	na
EIM QA	na	na
EIM complete	na	na
Final report		
Author lead / support staff	Tom Gries / Janice Sloan	
Schedule		
Draft due to supervisor	June 2009	
Draft due to client/peer reviewer	June 2009	
Draft due to external reviewer(s)	na	
Final due to publications coordinator	August 2009	
Final report due on web	September 2009	

na = not applicable.

Quality Objectives

Data quality objectives for this study address representativeness, comparability, and acceptability of results as each applies to the (1) manufacture, release, and recovery of tracers from the environment and (2) analysis of fluorescent tracers.

Tracers will be manufactured to have properties within tolerance limits defined by the same properties measured in native suspended and deposited sediments. The tracers will be manufactured to mimic native silts and fine-to-medium sands.

Tracer particles will be released into the water column of the river in a manner that does not substantially alter in-situ concentrations of suspended sediment. Samples of recovered tracers will represent their distribution in the receiving environment by virtue of the sampling strategy.

Finally, quality control samples (blanks, duplicates, matrix spikes) will be analyzed along with samples of recovered tracers to ensure qualitative and quantitative results are acceptable. Results will also be adjusted for the presence of any native sediment with fluorescent and magnetic properties.

Objectives for manufacturing, release, recovery, and analysis of tracers in this study are listed in Table 3.

Table 2. Specifications and measurement quality objectives (MQOs) for the manufacture, release, recovery, and analysis of fluorescent sediment tracer particles.

Parameter		Sensitivity DL/RL	Precision RPD/RSD	Bias	Accuracy
Manufacture (compared to final specifications)					
Specific gravity or density (g/cm^3)		0.1	± 5%	± 5%	± 6%
Settling velocity (mode) ($cm\ sec^{-1}$)		0.2	± 20%	± 20%	± 20%
Tracer PSD (minimum, mode, maximum) (% by phi size)		0.2	± 20%	± 20%	± 20%
Release					
Water column TSS (EPA Method 2540D) (mg/l)		0.5	± 20%	± 20%	± 20%
Tracer Analysis					
Tracer particles	Number counted	1 in 300 magnetic particles examined	N/A	N/A	N/A
Tracer concentration	Number / liter	0.5 (assumes 2L filtered)	± 25%	± 25%	± 25%
	Number / m^2	5 (assumes 1 / 0.2 m^2)	± 25%	± 25%	± 25%
Tracer mass (dry mg)	Instrument	0.1	± 20%	± 30%	N/A
	Sample mg/m^2	0.5	± 25%	± 25%	± 25%

See the Appendix for definitions of abbreviations used in this table.

Sampling Process Design (Experimental Design)

Fluorescent tracers will be used to study transport and short-term patterns of deposition of suspended sediment entering the LDW from the Green River. The tracers, manufactured to mimic native sediments, will be released near the upstream boundary of the LDW and recovered from within the site. Recovery of some tracers will show pathways and short-term fate of fine-to-medium suspended sand-sized particles (63-250 µm diameters). Recovery of other tracers will show that finer particles (<63 µm) pass through the LDW and enter Puget Sound.

The conceptual design for the study (Figure 2) recognizes that the tracers must be:

1. Manufactured to effectively mimic native suspended sediments.
2. Released in a way that simulates ambient conditions (TSS).
3. Recovered from locations within the LDW chosen to address the study goal.
4. Measurable (abundance, mass, and size distribution) in recovery samples.

In addition, Partrac's professional expertise will be vital to the study design, implementation, and interpretation of results.

Manufacture

The quantity of tracers manufactured will be based on the expected dilution in the waterway, ability to recover particles two months after deployment, and budget. Two batches of tracers, approximately 100 kilograms each, will be manufactured. A red-colored batch of tracers will have hydraulic properties similar to native *sand* particles (63-250 µm in diameter). A second batch of yellow-green tracers will have properties similar to native *silts* (30-63 µm diameters) [2]. In particular, the modal settling velocity of the batches will mimic the settling velocities of sands and silts measured in samples of native suspended and surface sediments. Each batch will also have magnetic properties that allow them to be concentrated from water and sediment samples before being quantified (Figure 3). Prior to their release, the tracers will be combined and pre-wet to reduce surface charges and surface tension that can cause particles to float.

Release

Tracers will be released near the southern turning basin no later than February 2009. The daily flow entering the waterway at this time is expected to exceed the annual daily mean (1,350 cfs), and may be as much as 2,000-3,000 cfs. The STM predicts such daily flows to carry 30-55 mg/L of mostly fine suspended particles that will be transported well into or through the LDW. The release will occur in a manner that creates a discrete plume of tracers but does not substantially alter ambient levels of suspended solids.

[2] Tracers <30 µm are difficult to manufacture in a way that accurately represents the properties of native particles of the same size.

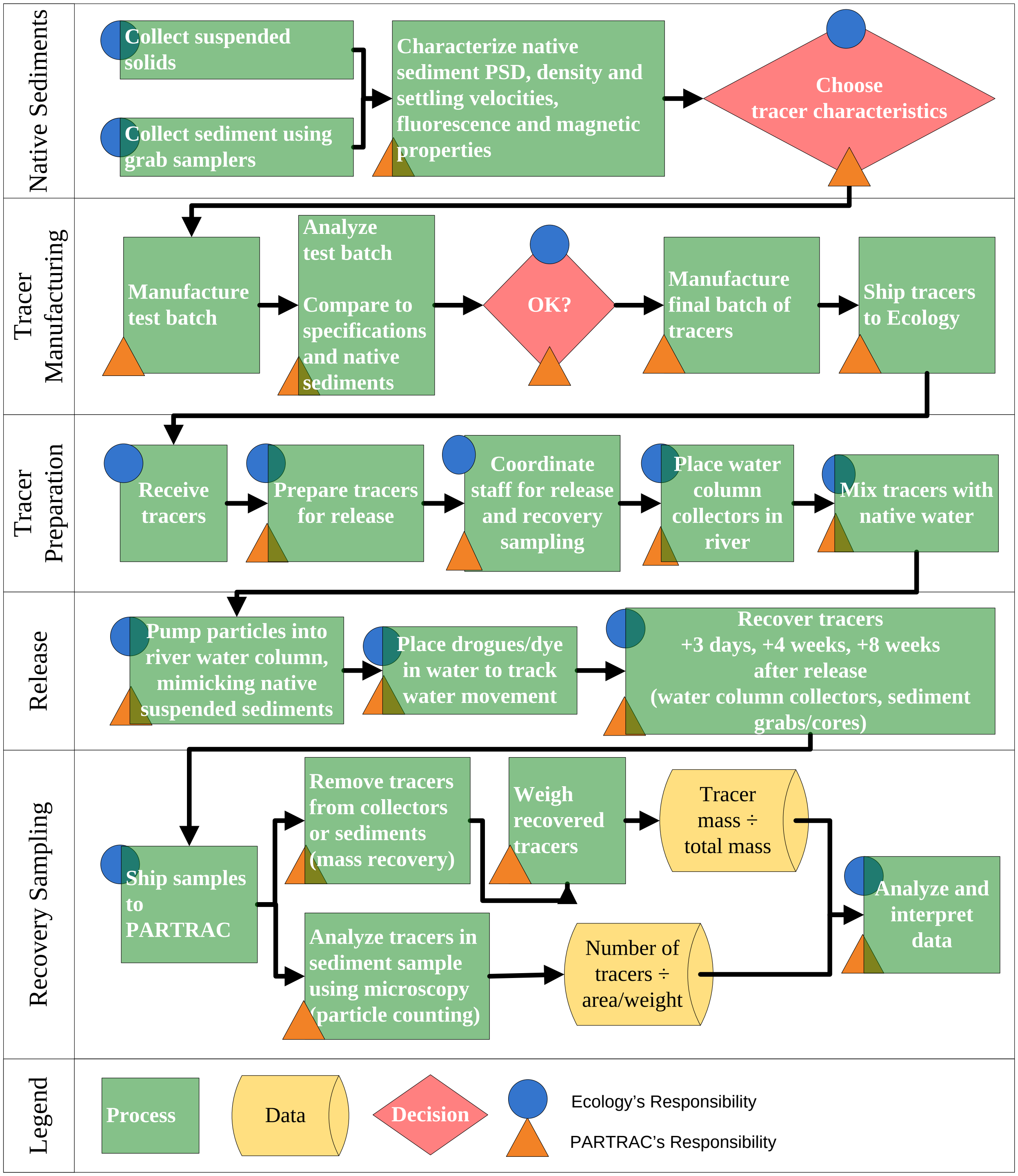

Figure 2. Sampling process design, sampling procedures, and measurement procedures.

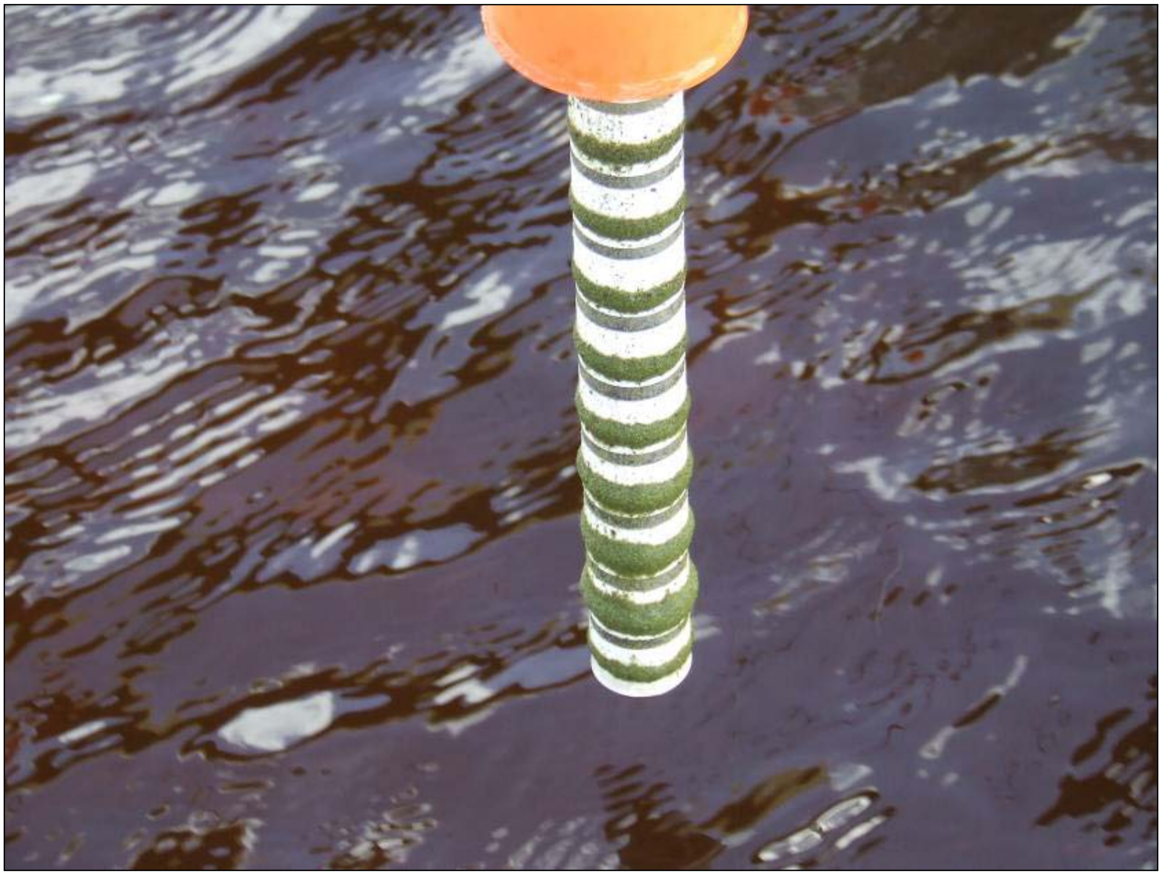

Figure 3. Bar magnet used in the Florida Everglades floc transport project, showing green-colored tracers adhering to nine magnetic poles.
(Photo courtesy Partrac Ltd.)

Recovery

Sampling to recover tracers from the water column and from surface sediments will occur throughout the LDW over a two-month period, as summarized in Table 4.

Table 3. Summary of sampling strategy for recovering sediment tracers.

Sample type		When sampled			
		Day of release	≤ 7 days	+ 1 month	+ 2 months
Water (pump and filter)		≤ 20	-	-	-
Sediment (surface grab)	non-random	-	29	27	27 (archive)
	random	-	21 (7/reach)	21	21
Magnet (surface water)		6	32	32	-
Total		≤ 26	82	66	48

Surface water sampling will start prior to tracers being released and continue until drogues indicate the water mass carrying fine tracers has passed through the LDW. The two focus areas for water sampling will be:

- Immediately downstream of the release zone (to assess mixing and dilution of tracers).
- Near the entrance to the West Waterway that is the main exit from the LDW to Puget Sound (to show that fine tracers pass through the LDW).

Approximately 48-50 surface sediment samples will be collected on each of three occasions: within a few days of releasing tracers, after one month, and after two months. 27 of these samples will be from subjectively-chosen locations oriented along the longitudinal axis of the waterway. Figure 4 shows there will be one 'west bench', one 'central channel', and one 'east bench' location each for 12 transects across the channel. The transects will be spaced approximately 0.4 miles apart to provide a longitudinal profile of the fate of tracers. Many of these locations were sampled to help assess properties of native sediments.

The first sampling event (only) will also collect surface sediment from bench and mid-channel locations along two transects upstream of the release point. Sediment from each transect will be composited to produce two samples for analysis. The purpose of upstream sampling is to evaluate very short-term sediment transport associated with salt-water intrusions or reverse flows.

Figure 5 shows 63 randomly-chosen locations. Seven unique locations in each of the reaches identified by the STM will be sampled on each of three occasions. The intensity of sediment sampling after one-month and two-month intervals may be modified based on results from previous samplings. This sampling design element may be useful for identifying differences in accumulation rates between reaches over time.

Passive magnet samplers will be deployed in the water column to sequester tracers that pass nearby. Samples will be recovered within days and after one month of being released. The magnets will be deployed:

- At roughly regular intervals in each reach of the LDW (Figure 6).
- With special emphasis near the entrance to the West Waterway (so the abundance and mass of fine tracers that pass out of the LDW can be evaluated).
- In the upper water column (where fine silts are expected to remain suspended).
- At fixed depths similar to the water level of the low tide following the release.

Measurement and Interpretation

The number, size distribution, and estimated mass of tracer particles recovered in water, sediment, and magnet samples will be analyzed by Partrac and compared to the parent tracers that were released. Ecology will rely heavily on Partrac's experience to interpret results for each sample collected, as well as the overall results. Note that the proposed design is not intended to track the fate of all tracers and may not be robust enough to support calculation of a mass balance for suspended sediments.

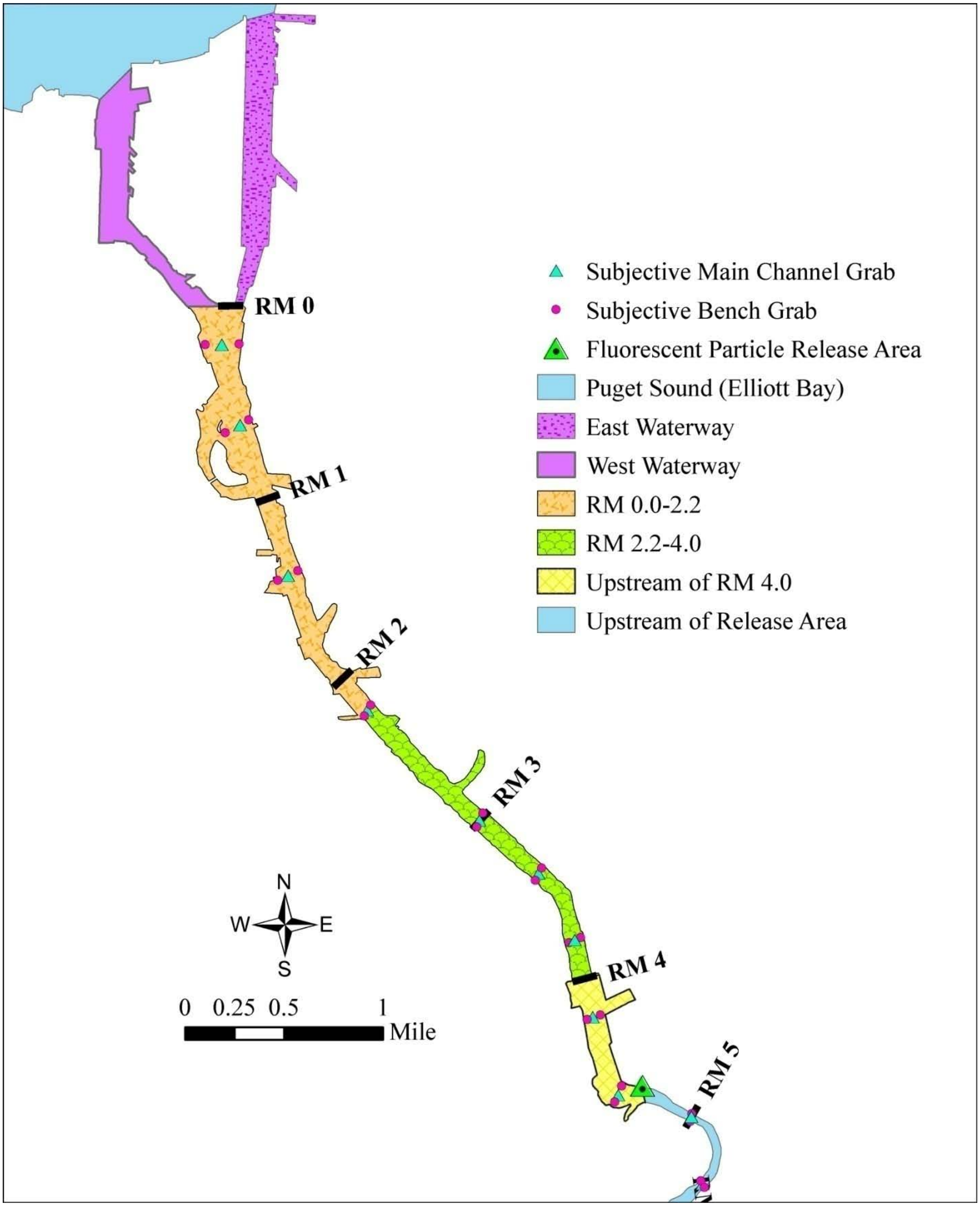

Figure 4. Subjectively-chosen target sediment sampling locations.
RM - River mile.

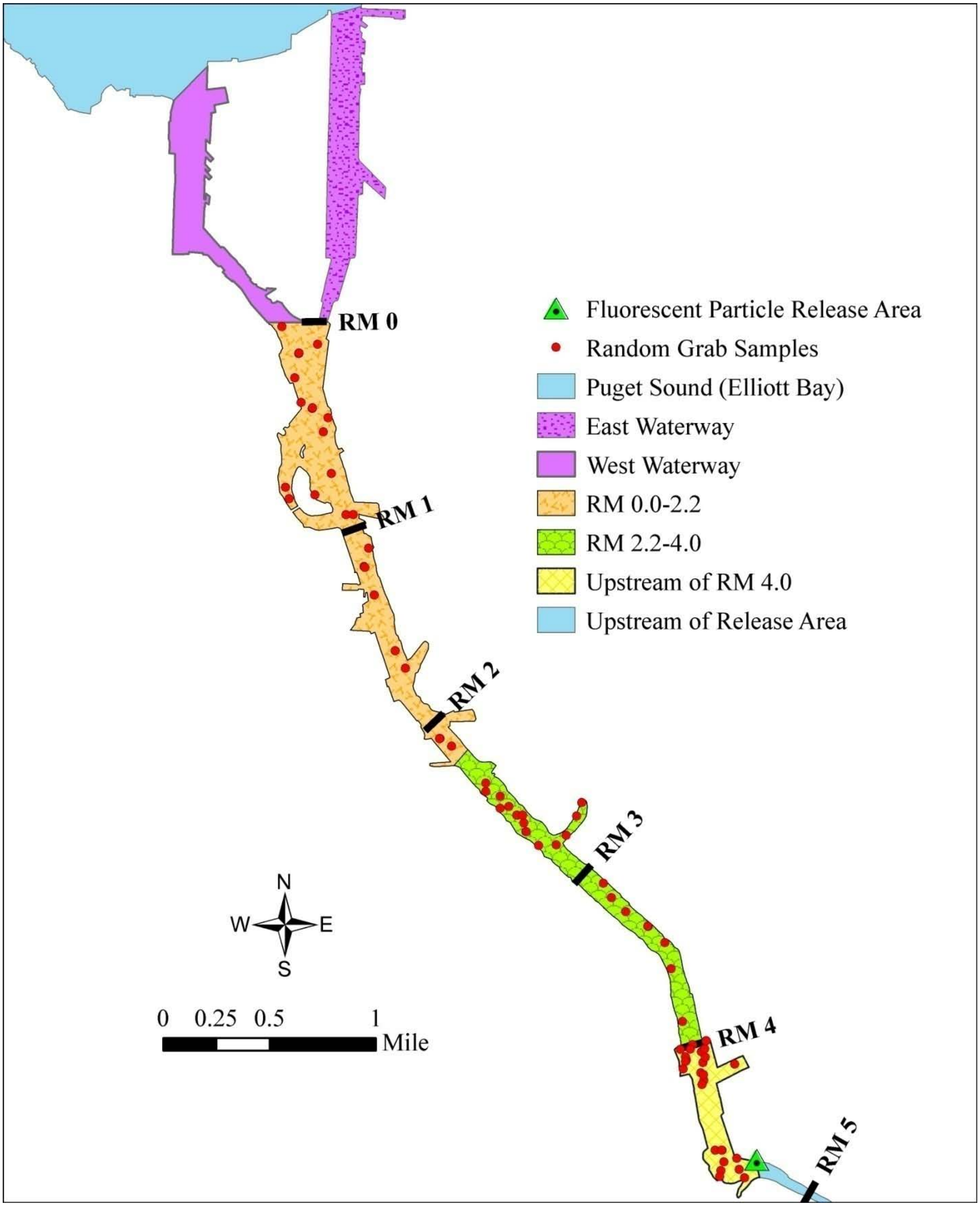

Figure 5. Randomly-chosen target sediment sampling locations.
RM - River mile.

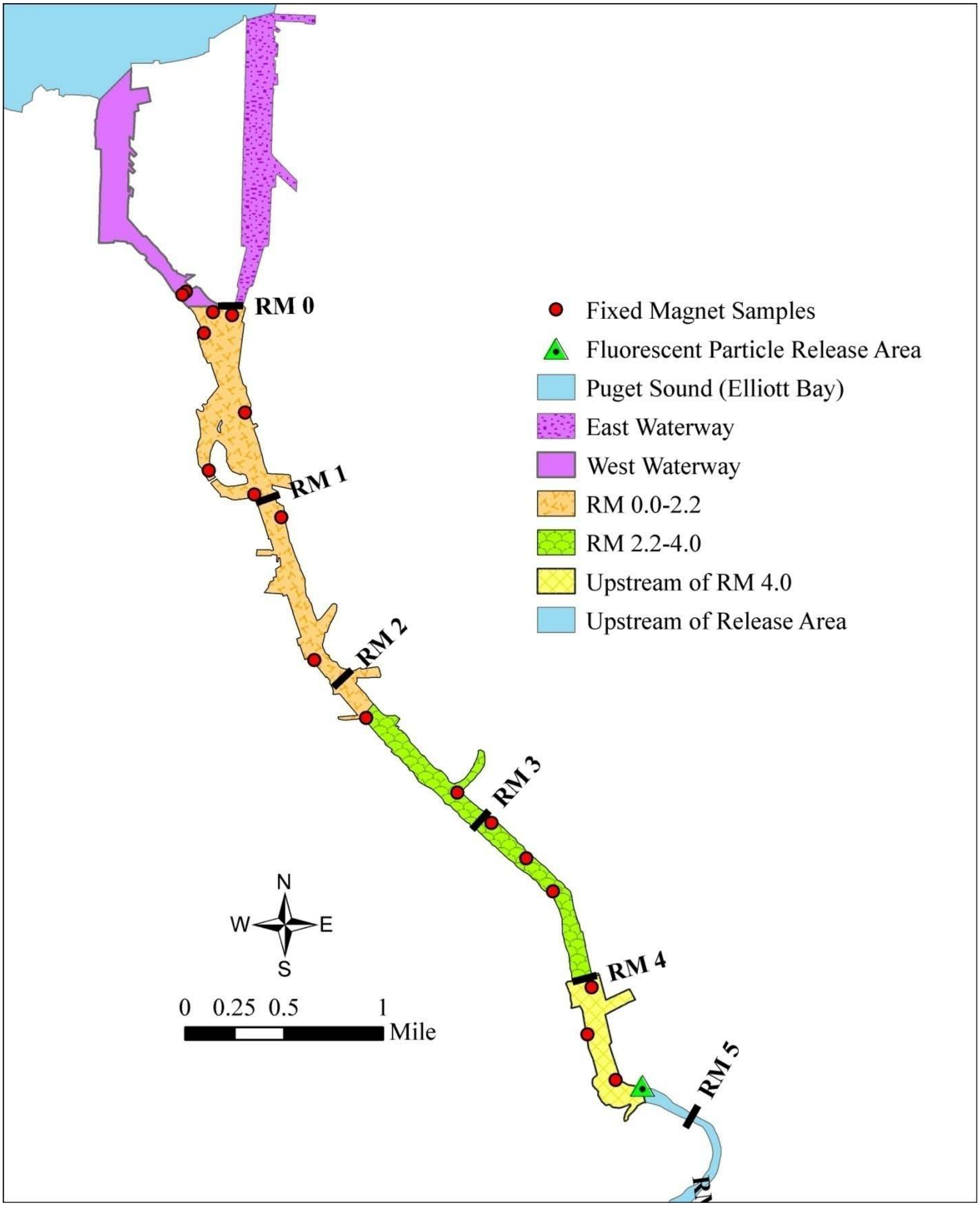

Figure 6. Approximate locations of passive bar magnet samplers.
RM - River mile.

Field and Sampling Procedures

Sampling Native Sediments

Samples used to assess the physical properties of native sediments will be collected using two methods. First, approximately 700 liters (185 gallons) of river water will be pumped from mid-channel and 0.6 times the maximum depth in the Green River at RM 6.7 (Figure 1). The water will be allowed to settle for several days, decanted to <50% of the original volume, and the process repeated until less than 4 liters (< 1 gallon) remains. This will result in a substantial concentration of the suspended sediments. Second, a Ponar grab sampler will be used to collect 20 samples of oxidized surface sediment from locations along various transects within the LDW (also Figure 1). Sampling will follow standard procedures modified from Aasen (2007) to collect only the oxidized layer of surface sediments.

All native sediment samples, together with other existing data, were sent to Partrac for measurement of various physical properties, including assessment of background fluorescence and magnetic properties.

Field Preparations

The following activities will occur prior to releasing the main batch of tracers:

- Each water filtration sampling apparatus will be tested.
- Magnet mounts will be constructed and deployed a week prior to tracer release.
- Tracers will be pre-wet at Ecology facilities.
- A trial release will be conducted.
- Vessels, staff, and equipment will be reserved and assembled.

The bar magnets will be encased in a close-fitting clear plastic sheath and mounted on 12' long 2"x4" boards by means of a metal bracket. The magnet mounts will be unobtrusively attached to pilings in the LDW in a manner minimizing risk of loss. This will occur approximately one week prior to the main release of tracers. Magnets will be mounted at an elevation expected to be in the top four feet of the water column when tracers pass by. Just prior to tracer release, native magnetic particles that have accumulated during the intervening week will be removed from three magnets and the magnets redeployed in the river. These three magnets (one per reach) will serve as field blanks and used to assess the accumulation and characteristics of native suspended sediments with magnetic properties.

Tracers will be shipped to Ecology as a dry material, sealed in air-tight metal drums. The tracer particles will be thoroughly wetted to eliminate surface charges that may cause them to temporarily ‘float’ on the surface (unnatural starting conditions). This will be accomplished by placing the tracers in a large container (100-liter trash barrel) with water and a small amount of surfactant. The tracer mass will then be stirred vigorously and allowed to settle for one-to-two hours. After siphoning off the overlying water, any tracer that remains floating will be removed using a handheld 11,000 gauss magnet. This procedure, designed to rinse the tracer of detergent and fully remove the buoyant fraction, will be repeated several times. The tracers will then settle for 24 hours, after which any obvious suspended tracers will be removed by a final decanting.

Tracer Release

The main release of tracers will occur near the south boundary of the site (approximately RM 4.9). This will occur during an ebb tide on a date between late November 2008 and February 2009. The daily flow entering the waterway at this time is expected to exceed the annual mean (1,350 cfs), and may be as much as 2,000-3,000 cfs. Most transport of suspended sediments is believed to occur during such flows. The release will take place over a short period using a method designed and tested to ensure that tracers will mix into the water column and not substantially alter concentrations of suspended solids a short distance downstream.

Tracers will be released gradually over a relatively short period of time (e.g., 2 kilograms per minute for 50 minutes) below the water surface via a PVC pipe mounted at the stern of the Ecology research vessel, Skookum. This will be accompanied by a large flow of pumped river water (e.g., 250 gallons per minute). The timing and mechanics of the release will increase the likelihood that tracers will mix into the water column and approach ambient concentrations within a short distance downstream.

Various field measurements and water samples will be collected prior to and during release of tracers. To assess whether tracers change in-situ conditions, a laser diffraction instrument (LISST-Streamside, Sequoia Scientific) will measure concentration and PSD of in-situ suspended sediment over time. Periodic water samples will also be collected near the point of release and analyzed for TSS. To inform same-day sampling downstream, the depth of the mixed layer will be assessed by measuring vertical profiles of salinity with a Hydrolab or similar instrument (Swanson, 2007).

Sampling to Recover Tracers

Recovery of tracers will include boat-deployed water column samplers, passive magnetic sampling devices, sediment grabs, and sediment cores. To prevent contamination during the recovery of tracers, all personnel and gear (including boats) involved in releasing tracers into the river will be thoroughly cleaned or not used.

Water samples

To assess whether tracer concentrations rapidly approach ambient conditions, levels of TSS and number of fluorescent tracer particles will be measured in approximately 10 surface water samples collected approximately 100 meters downstream. This will be done immediately before, during, and after the tracers are released. A known volume of water will be pumped and filtered through pre-weighed 4.7-cm diameter glass fiber filters (1.6-µm pore size). A laser diffraction instrument (LISST-Streamside, Sequoia Scientific) will also be used to monitor for any changes in concentration and size distribution of suspended sediment found downstream.

To evaluate whether the fine tracers pass out of the LDW and into the West Waterway, a known volume of water will be pumped and filtered through approximately 10 pre-weighed 9.0 cm diameter quantitative paper filters (8-µm pore size). These filters will allow far more volume through than the smaller filters used upstream and thereby increase the likelihood of recovering tracer particles.

To facilitate tracking water movements and recovery sampling, drogues will be released before and during tracer release into the surface waters.

Sediment samples

Samples of the surface oxidized layer of sediment will be collected using a single van Veen or standard Ponar grab sampler. The default sampling depth will be 1-2 centimeters, but this depth may be modified based on field observations. The more important metric – total area sampled – will be measured with a stainless steel ruler. Sampling will occur as soon as possible after release (1-5 days), and then approximately one month and two months later. Each sample will be placed into 8-oz pre-cleaned glass jars for storage and transport.

A small (1” diameter) push core will also be inserted into half of the van Veen or Ponar samples to collect and archive deeper sediments. This will be done to address the potential for tracers to be more deeply buried after one-to-two months. Push cores will not be collected during the initial recovery sampling event.

Magnet samples

Approximately 32 bar magnets (11,000 gauss), encased in a plastic sheath, will be mounted on 2"x4" boards and attached to pilings. The magnets will be recovered approximately one week after tracers are released. This will be done by:

- Removing the magnet mounts from pilings.
- Removing the sheath from magnets.
- Washing the tracers (and native magnetic sediments) off the sheaths into plastic jars.

The sheaths will be replaced and magnets redeployed for an additional one month, after which time the magnets will be sampled a second time.

Sample Storage, Labeling, and Transport

All filters, sediment, and magnet-derived samples will be placed in sealed plastic containers. Approximately 1-2 ml of water will be added to all filter and magnet samples to maintain moistness. Samples stored more than two days in cool, dark conditions will be preserved with glutaraldehyde to prevent growth of bacteria and protists[3]. Samples will be frozen if addition of glutaraldehyde to samples is problematic for shipping. Core samples will be frozen intact. To avoid analytical bias, all sample containers will be labeled using a random numbering system before shipment to the laboratory.

[3] Total concentration approximately 1% (volume/volume).

Measurement Procedures

Tracer Manufacture and Testing

Ecology's contract with Partrac includes a statement of work (Exhibit B) that describes the contractor tasks for manufacturing tracers and measuring them in various samples recovered from the LDW (Ecology, 2008).

Samples of native suspended and deposited sediment provided by Ecology to Partrac were evaluated as follows:

- Settling velocity of sands was measured using a sedimentation tower and balance.
- Settling velocity of silts was calculated from the reduction in concentration over time, as measured by an optical backscatter sensor (silts).
- Particle size distribution was measured using laser diffraction.
- Specific gravity was measured using a standard density bottle volumetric method.
- Incidence and size of fluorescent particles was measured using epifluorescent microscopy.
- Fraction (by mass) and size of native sediment particles with magnetic properties were measured using laser diffraction and a flow-through Magnetic Particle Separator.

Partrac will have an ISO 9001:2000 certified facility manufacture 100 kg of each type of tracer. The manufacturing process will be comparable to what has been used since 2005 for studies conducted by the U.S. South Florida Water Management District using similar tracers. After being manufactured, Partrac will collect two representative samples, test them for the same properties, and compare results to the final specifications. The final tracers will be approved by Ecology for use if they meet the following criteria for acceptability of fluorescent tracers (Black et al., 2007; White, 1998):

- Total mass delivered to Ecology will be within 2% of the amount required by contract (200 kg).
- Mean specific gravity (density) will be no more than ± 6% of the density in the final specifications.
- Settling velocities of tracers (minimum, mode, and maximum) will be within 20% of velocities observed in native sediment samples.
- Particle size minimum, mode, and maximum will be within ± 20% of the specification for the size distribution as a whole.

Field Sample Analysis

Approximately 10-20 water samples, collected downstream on the day of tracer release, will be analyzed for TSS using EPA Method 2540D (APHA et al, 1998; MEL, 2008).

Analysis of Recovered Tracers

Tracer analysis will consist of measuring or estimating the following parameters in each water, sediment, and magnet and sample:

- Dry mass of tracers.
- Fluorescence (color) of tracers.
- Abundance (number) of tracer particles of each color.
- Size distribution of tracers.

These parameters will be measured for all water samples collected on pre-weighed filters or rinsed and concentrated from magnet samplers. However, sediment samples will be thoroughly suspended in distilled water and flushed through a magnetic particle separator that consists of two powerful magnets separated by a wire mesh. As the sample of suspended sediment passes through the mesh, the magnetic fraction will be retained on the mesh and the non-magnetic fraction will not. The dry mass of the magnetic fraction will then be determined to 3 decimal places.

Measuring dry mass

The dry mass of the magnetic fraction will be measured in each water, sediment, and magnet sample, as well as QC samples (blanks, replicates, and matrix spikes). Dry mass will be determined by weighing samples on a certified 4-decimal-place (0.1 mg) balance after drying at 70^{o} C to constant weight. Image analysis will be used to estimate the proportion of the total dry mass of sample represented by each batch of different colored tracer.

Image analysis

The objective of this analysis is to measure the number and size distribution of different colored fluorescent particles in each sample.

Counting native fluorescent particles

A minimum of 300 native particles will be counted in each sample using a Zeiss fluorescent microscope fitted with an excitation filter set. If more than 1% of all native sediment particles are found to be naturally fluorescent, a correction factor will be applied to future counts made using the same filter.

Counting tracers in recovery samples

Tracers in sediment and magnet-derived samples will be passed wet through a 63-µm sieve for a preliminary separation by size. This will increase the accuracy of the subsequent measurements for each batch of tracer. Material passing through, and material collected on, the sieve will be suspended in water and sub-sampled. The number of tracer particles of each color present in each sample will be determined by counting fluorescent particles under a Zeiss fluorescent microscope (with appropriate excitation filters) or a Zeiss light microscope. For each tracer, the proportion of the total number of particles (minimum 300 particles counted) will be determined.

Tracers less than 63 µm will be resuspended, and an aliquot will be placed on a specialized microscopic slide (improved Neubauer counting chamber). The density of tracer particles will be adjusted by concentrating or diluting the sample, if necessary, to meet QC requirements for Neubauer counts (approximately 15-20 tracer particles/square). If a tracer density of greater than 15 particles/counting square cannot be achieved, then tracers will be counted using a modified Utermöhl method [4]. Procedures will be repeated for particles greater than 63 µm in diameter.

Particle size analysis

PSD of tracers in recovery samples will be measured by laser diffraction if sufficient mass is present. This analysis will use a Coulter LS230 that can measure 0.4 – 2000-µm-diameter particles. A small amount of material will be mixed with water and added to the instrument through a 2-mm sieve until it is 8-12% obscured. The sample runs will then be analyzed for five minutes.

[4] A standard minimum number of tracer particles is counted in a sub-area of a Palmer-type depression counting slide. The total number of tracer particles in the original sample is calculated using the sub-area count, the fraction of the total area counted, and the fraction of the total sample in the aliquot.

Quality Control Procedures

Field Measurements

The project manager and field lead will take a copy of the final QA Project Plan to the sampling site for all sampling events. The same staff will be responsible for decisions about deviating from the QA Project Plan, as well as documenting those decisions.

Field replicate results for water and sediment samples will be reviewed as an indication of field variability, but there are no field MQOs. There will be no field replicates for tracers collected using passive magnet samplers.

Tracer release

The overall acceptability of the method of release will be evaluated by:

- Evaluating conditions in the water column at time of release.
- Comparing concentrations of tracers to ambient suspended sediments at time of release.
- Comparing the concentration and PSD of tracers in the water column approximately 100 meters downstream of the release site to TSS and PSD measured prior to release of tracers.

Tracer recovery

Tracers will be recovered using water and sediment sampling devices and procedures comparable to ones used throughout the region. Other sampling methods developed to maximize probability of recovering such tracers (submerged magnets) will be comparable to ones used in previous studies. Acceptability of sampling will be evaluated by comparing final sampling methods with Puget Sound Estuary Program protocols (PSEP, 1986), Ecology standard operating procedures (Aasen, 2007; Meredith, 2008; Swanson, 2007), and peer-reviewed articles on similar tracer studies.

Laboratory Measurements

QC samples for tracers, water, and sediment samples are listed in Table 3. Method blanks and laboratory duplicates will be analyzed for tracer numbers and mass. A matrix spike sample will be prepared using source tracers and used to assess bias. Sensitivity will be assessed using reporting limits.

If sample results exceed control limits, then Partrac will take reasonable corrective actions. If such actions do not yield acceptable results, Partrac will discuss the need for additional corrective actions with the project manager. Potential corrective actions for the conventional parameters listed are reanalysis or assignment of appropriate data qualifiers.

Measurements of dry mass

Acceptability of results will be judged by review of QC sample results relative to MQOs. Replicate samples will provide data to evaluate precision that will not exceed ± 5% relative percent difference or relative standard deviation. Analytical bias and accuracy will be assessed using matrix spike samples prepared using native sediments and a known quantity of archived tracers. Periodic checks on experimental repeatability for both dry mass and image analysis will be conducted.

Image analysis

Tracers of each color present in each sample will be counted by an experienced microscopist. Standard laboratory equipment and counting procedures will be used. There are no performance standards or acceptance limits for precision, bias, or accuracy of counts, but blind duplicates and matrix spikes will be prepared to assess these quality measures. PSD will also be measured if too few particles are present to measure using laser diffractions (see below). Accuracy of size measurements will be to within 1 µm.

Measurement of particle size distribution (PSD)

QC guidelines will be followed for particle size analysis using laser diffraction. International reference materials will be used to calibrate the instruments before each batch of samples is analyzed. The same operator will measure PSD in all samples. Past results for certified reference materials have shown this reduces operator errors (Partrac, 2009). To ensure that samples are representative, five sub-samples will be collected from a homogenized parent sample and pooled into a single sample that is homogenized and sub-sampled again (Kramer et al., 1994). This will be done for all samples having adequate volume. PSD of most samples will be measured three times, but every tenth sample will be analyzed 10 times (following ISO 13320) to periodically check on experimental precision. Accuracy of particle size measurements made using laser diffraction is ± 1% of the mean particle diameter (Syvitski, 2007).

Data management procedures

Field notes will be taken during all sampling activities. Notes will include date, time, meteorological observations, position at time of sampling, and water depth. These will be recorded using a form similar to the one provided in Appendix A.

Results for all water, sediment, and QC samples will be submitted to the project manager as follows:

- Contract deliverables will include test and QA sample results for the presence, number, concentration, and mass of tracers in each sample.
- Printed deliverables will include case narratives, tables of analytical results for environmental samples and QC samples, and bench sheets. All analytical results will also be provided as an electronic deliverable. The format of electronic data will be provided to Partrac by the project manager.

All tracer data generated for this project will be evaluated relative to the MQOs listed in Table 3. Acceptable results will be used to prepare the final report and will be made available to the public upon request.

Audits and Reports

The project manager will:

- Assess field sampling procedures to ensure consistency with this plan and note any procedural modifications.
- Review field notes for quality of the field data.
- Discuss any apparent problems with the contractor.
- Prepare a report that will undergo internal and external review and will be completed no later than September 2009. It will describe:
    - The study area showing sampling areas.
    - Field and laboratory methods.
    - Data quality, significant analytical problems, and data usability.
    - Field and laboratory results, including number, mass, concentration, and PSD of tracers in each sample.
    - Transport pathways and areas of net deposition, evident from results, for the period of the study (by size class of tracers, if possible).
    - Results in comparison to water quality model predictions.
    - Sources of uncertainty.

Appendices will include major field notes, laboratory case narratives, and detailed results.

Data verification

Partrac will review results for all field and QC samples that they analyze. Reviews will be sent to the project manager as case narratives. The narrative will include comparisons of QC sample results to method acceptance criteria for blanks, laboratory replicates, laboratory control samples, or matrix spike samples, as appropriate.

QC sample results will be reviewed for precision, bias, and accuracy. Precision will be assessed by calculating or confirming the relative percent differences or relative standard deviations associated with laboratory replicates. Analytical bias will be revealed by the recoveries associated with laboratory control or matrix spike samples. Matrix spike recoveries will indicate bias due to matrix effects.

Completeness will be determined by the following comparisons:

- Number of samples collected versus number listed in this QA Project Plan.
- Number of samples accepted by Partrac in good condition.

- Ability of Partrac to produce usable results for each sample.
- Fraction of sample results found by Partrac and the project manager to be acceptable for the uses intended.

Data Quality (Usability) Assessment

The project manager will:

- Review records of field sampling and sample handling procedures to identify potential sources of bias.
- Evaluate data quality to determine if project objectives have been satisfied.

The latter will be done by means of thorough review, using this QA Project Plan, of all field sample and QC sample results. Ecology and other experts may also be consulted. All field and laboratory data will also be reviewed to identify and record all sources of bias.

Estimated costs associated with the tracer study are listed in Table 5. The majority of costs are associated with the manufacture of tracers and analysis of tracers found in recovery samples. The table does not capture costs in terms of staff full time equivalents (FTE) or travel. Neither does it include costs associated with the contaminant loading elements of the study.

Table 4. Estimated costs associated with the tracer study contract.

Task	Entity Responsible	Quantity	Cost per sample	Total
Review QA Project Plan	Ecology and Partrac	na	na	$6,000
Collect samples of native sediments	Ecology	na	na	na
Analyze native sediment samples	Partrac	20	$92	$20,500
Manufacture trial fluorescent tracer batches	Partrac	--	--	
Compare trial batch to agreed specifications	Partrac	--	--	
Manufacture final fluorescent tracer batches	Partrac	200 kg	--	
Release tracers into river	Ecology and Partrac	--	--	$500
Conduct recovery samplings	Ecology and Partrac	na	na	na
Analyze recovery samples	Partrac	250	$92	$23,000
Report findings of tracer study	Partrac and Ecology (separate reports)	--	--	$10,000
			Total	$60,000

na – not applicable.

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Appendix. Glossary, Acronyms, and Abbreviations

Ambient: Surrounding environmental condition.

Drogue: A device that floats on the surface of a water body used to investigate a flow regime.

Parameter: Water quality constituent being measured (analyte).

Reach: A specific portion or segment of a stream.

Scour: In this study, erosion of bottom sediments due to high current velocity or local turbulence.

Total Suspended Solids: Portion of solids retained on a filter.

Tracer: Any substance that when added to a fluid allows movements of the fluid to be followed or traced. In this study, fluorescent-magnetic particles are used to trace movements of suspended solids in river water.

Acronyms and Abbreviations

cfs	Cubic feet per second
cm^3	Cubic centimeter (= milliliter)
CRM	Certified reference material
DL	Detection limit
Ecology	Washington State Department of Ecology
EAP	Environmental Assessment Program (Ecology)
g	Gram
kg	Kilogram
LDW	Lower Duwamish Waterway (River Mile 0.0-4.8)
LDWG	Lower Duwamish Work Group
m^2	Square meter
mg	Milligram
mm	Millimeter
MQO	Measurement quality objective
PSD	Particle size distribution
QA	Quality assurance
QC	Quality control
RL	Reporting limit
RM	River mile
RPD	Relative percent difference

RSD	Relative standard deviation
SOP	Standard operating procedure
SPM	Suspended particulate matter
STM	Sediment transport model
TSS	Total suspended solids
USGS	U.S. Geological Survey
ww	Wet weight
µm	Micrometer (= micron)