A Department of Ecology Report

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# Stormwater Sediment Trap Literature Review and Design Consideration

## Abstract

This paper presents a review of potential designs for a sediment trap designed to collect suspended particulate matter from stormwater for contaminant analyses. Design criteria for the potential stormwater sediment trap include: inexpensive to build and operate; ability to trap a representative amount of particles 63 μm or less; ability to collect 50-100 grams of material in a reasonable period of time (1-3 months); and constructed of a material which is non-contaminating and durable.

Present sampling technology is discussed for comparative purposes and to support the need for a new design. Pertinent literature was reviewed to find an existing sediment trap that could be easily placed in storm drains to passively collect sediment. This research found no sediment trap specifically designed for this purpose. Two trap designs developed for marine application which could potentially be adapted for use in stormwater sampling were identified. Although both of these traps meet the design criteria, the domed bottle trap appears to be better suited for the task since it can trap with flows from any direction. Recommendations for construction of a prototype and field testing are included to evaluate the traps ability to perform in the high energy environment of a stormwater system.

## Summary

Nearly two thirds of the sediments mass found in stormwater consists of particles in the silt/clay range (BURP, 1984). Since these particles have the highest affinity for toxic substances, it is logical to isolate them for testing. Although our research did not find any current technology that directly meets the criteria, it did find two marine sediment traps that may be adaptable to storm drains. The domed bottle and the slit cylinder traps both show strong potential from the results of Gardner's (1980) experiments.

One of the main questions is how these traps will perform in the high energy environment of a storm drain system. Gardner's testing was with flows that did not exceed 9.5 cm/s. Flow velocity

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in storm drain is on average 90 cm/s to 475 cm/s. However, it is not known what the actual flow velocity will be in a catch basin below the outlet pipe, where it is recommended that the trap should be mounted. Another unknown is how varying the size of the trap opening will affect trapping rates at different velocities.

We recommend proceeding with the development of a prototype for the domed bottle. Since the domed bottle can trap efficiently with flows from any direction, that makes it more versatile and efficient given the current recommended mounting location. The traps must be made out of a material that is durable and non-contaminating. Teflon or heavy weight glass are two materials that meet both of these criteria. Laboratory testing may not prove to be valuable since it would be too difficult to simulate the dynamic and powerful environment of a stormwater catch basin. We recommend field testing over a period of several months to see how efficiently the domed bottle trap works. Then a particle size distribution analyses and sample quality would prove whether or not the trap is ready for actual monitoring applications.

## Conclusions and Recommendations

In order to determine if stormwater particulates are contaminated they need to be collected and analyzed. A potentially economical way to do this is to place a trap in a catch basin and allow it to passively collect sediment. No technology currently exists to accomplish this nor is there any on-going research in the area of storm drain sediment traps.

Two potential designs, the domed bottle and slit cylinder, were identified. They were both tested by Gardner (1980) in the marine environment to trap fine grained sediment in slow moving water. However, these traps have not been tested in velocities of approximately 90 cm/sec to 500 cm/sec which are expected to occur in storm drains (WSDOT Hydraulic Manual). The traps were tested at velocities that did not exceed 9.5 cm/sec (Gardner, 1980). When deployed in a suitable manner it appears likely that they will function well as storm drain sediment traps; however, further research is needed to prove this.

As a next step to developing a stormwater sediment trap, we recommend the development of a prototype of the domed bottle design. The domed bottle can trap from any direction; it is more versatile and efficient given the recommended mounting location. The traps need to be made out of a material that is durable and non-contaminating. Teflon or heavy weight glass are two materials that meet both of these criteria. Field testing over a period of several months will prove how effectively the domed bottle trap works. Then a particle size analyses and sample quality will reveal the usefulness of this trap design for long-term monitoring of sediments. Taking water samples during the test period would be required to evaluate performance and calibration, particularly with respect to total suspended solids. The sample collected in the trap would be analyzed and compared to results from water sampling and would prove whether or not the trap is ready for actual monitoring.

## Acknowledgements

Many individuals made valuable contributions to this research and discussion of the storm drain sediment trap. The authors would like to acknowledge all participants and extend a special thanks to the following individuals:

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## Introduction

The Department of Ecology's Sediment Management Unit, Water Quality Program, Central Programs, and Environmental Investigations and Laboratory Services all have a joint interest in developing stormwater sediment sampling capability. Particulates transported by stormwater are potentially a major source of bottom sediment contamination in receiving waters. The origin and level of contamination of these particulates is difficult to evaluate with existing sampling techniques, which are expensive, high maintenance, and labor intensive. The ability to inexpensively collect stormwater particulates would help achieve the following goals:

- Prioritize investigations and concentrate efforts where the impacts are the greatest.

- Identify sources of contamination. By placing traps at key points in a storm drain the pollution source can be isolated.

- Assess the effectiveness of stormwater Best Management Practices (BMP). Traps above and below water quality control structures would help evaluate the usefulness of the BMP's.

The major objectives of this work were to:

- Retrieve and summarize the relevant scientific and engineering literature on the design and performance of sediment traps and related structures. Focus the theory and design to the kind of high energy environment found in storm drains, e.g. rivers, high velocity currents.

- Contact researchers and field staff who have used these traps and evaluate their strengths and weaknesses in actual application.

- Compare existing designs against these characteristics.

- Identify the strongest candidate traps. Discuss their strengths and weaknesses.

- Recommend next steps in development of prototype, field testing, etc.

## Results

### Storm Sewer Design

A storm sewer is a system of drainage conduits that carries surface drainage or street wash from catch basins, or other surface inlets, through manholes to an outfall. The system may have three or more laterals branches and trunks.

All storm sewer designs are based on an engineering analysis which takes into consideration total drainage areas, runoff rates, pipe capacity, foundation conditions, soil characteristics, pipe strength and any other factors pertinent to the particular situation. The runoff from a drainage area can be computed by one of a number of mathematical runoff models. The "Rational Formula" is one of the least sophisticated models; it simply states that the runoff is directly proportional to the size of the drainage area, a runoff factor, and the rainfall intensity.

Velocities of flow are designed to be 3.0 feet (91cm)/ per second or greater to prevent silting and clogging the pipes. This velocity is calculated under a plug flow condition even if the pipe is only flowing partially full with the design storm (WSDOT, Hydraulics Manual, M23-03).

## Current Sampling Technology

Technology currently exists to collect stormwater particulates by a number of methods. The following is a review of conventional methods to collect particulates stormwater and a discussion of the advantages and disadvantages associated with each one compared to study objectives:

SEDIMENTS

The easiest place to collect stormwater sediment samples is in catch basins. A study of Vactor truck wastes found that catch basin sediments were predominantly coarse grained (Serdar, 1993). The median of 20 samples contained only 12% silt and clay. The Bellevue Urban Runoff Program found, similarly, that "the sediments in the catch basins...were mostly the largest particles that were washed off the street" (BURP, 1984) (see Table 1). Sediments have been collected from catch basins for a tracing study in Bellingham (Cubbage, 1994). In this study it was found that many catch basins did not collect sediments, and those that did trapped only gravel. Sample locations that are important in locating the source of contamination may not have any material to collect, or the material sampled may be course grained.

Finally, stormwater sediments can be collected at the end of the pipe, either with sediment traps or bottom samples. In 1987 potential sources of PCB contamination in the Hylebos Waterway of Commencement Bay were investigated by sampling sediment deposits in or near discharges to the waterway. The objective of the study was to identify potential and ongoing sources of PCBs to the Hylebos Waterway (Stinson, Norton, Johnson). However, there are numerous problems associated with this method. First of all, the sediments in the catch basin are an unrepresentative sample that contains primarily the largest size particles. The exact source of the sediment is difficult to determine in situations where there are a number of outfalls to the water body. In areas of high currents there may not be enough material at the outfall to sample. Receiving water sediments may have different characteristics from those found in the pipe. The fine fraction may be carried an unpredictable distance from the pipe depending on currents. Contaminant concentrations may be diluted or altered upon contact with receiving waters.

**Table. 1** Stormwater Suspended Sediment Size Distributions (BURP 1984)

| Suspended Sediment Sieve Diameter (microns) | Percent in Size Range |
|---|---|
| >1,000 | 0.5% |
| 500-1000 | 3.5% |
| 250-500 | 7.0% |
| 125-250 | 9.3% |
| 63-125 | 15.7% |
| <63 | 64.0% |
| **TOTAL** | **100.0%** |

FLOW-THROUGH CENTRIFUGE

Centrifuging has been used successfully to extract particulates from stormwater (Cubbage, in preparation). In this technique sediment is removed with centrifugal force by continuously spinning a diverted flow sample. Depending on the storm duration and the concentration of suspended particles, a large amount of material can be accumulated. The equipment used is very expensive (approximately $60,000) and must be constantly attended by trained personnel. The high expense comes from time needed to prepare, clean, set up and disassemble the system, collect an adequate amount of sample, and maintain the equipment (Yake, 1993). Equipment and employees must be ready and waiting for storm events. Also, due to the amount of equipment and personal required to operate the flow-through centrifuge, only one or two drains can be monitored simultaneously. These factors add up to a prohibitively expensive monitoring program. The advantage of the flow-through centrifuge is a large sample size. Lower detection limits can be achieved with a large amount of material for the lab to work with.

FILTRATION

Filtration methods use a semipermeable membrane to separate particulates from the water sample. It involves the use of compressed nitrogen, a container capable of being pressurized and a micropore filter bed. Water is taken up into the container and then forced under pressure through the filter medium. This makes it an unlikely candidate for an inexpensive in-line collector because additional pressure would have to be available from some mechanical means, such as a pump or compressed gas chamber. This involves moving components, batteries, gas cylinders; it is an unreliable and costly system. This is a labor intensive operation that must be coordinated with flow in the drain.

WHOLE WATER SAMPLING

Whole-water sampling techniques consist of taking a water sample of some specific size. The problem with water samples is that the particulates comprise such a small fraction. The National Urban Runoff Program gives the median TSS for urban stormwater as 100 mg per liter (NURP, 1983). To get an adequate sample size, over 350 liters of water must be collected, depending on the concentration and the rate of extraction. Stream sediment collecting equipment typically holds a pint or a quart containing a very small amount of solids (USGS, 1988). Automatic, ISCO type, samplers hold 20 liters yielding 2 grams of solids under similar conditions. Inexpensive in-line flow-actuated samplers are being developed now (Brian Mar, personal communication). Unfortunately these samplers collect only a small sample containing little sediment.

It is difficult to evaluate stormwater sediment contamination from whole water samples which do not differentiate between dissolved and particulate-bound contaminants. Detection limits in whole water (especially for organic contaminants) are typically not adequate to detect and quantify sediment-bound pollutants (Horner, 1994, personal communication). Additionally, it is difficult to characterize intermittent discharges.

Table 2 summarizes and compares current methods and how they compare. Generally, methods that produce a large enough sample size to give low detection limits are expensive.

**Table 2.** Sediment sampling methods evaluated.

| Type | Labor | Cost | Sample size | Comments |
|---|---|---|---|---|
| Centrifuge | ***high*** | ***very high*** | large | high quality sample, expensive |
| Catch basin | med | low | ***variable*** | unreliable |
| End of pipe, sediment | med | low | large | ***large particle size bias*** |
| Filtration | ***high*** | ***med*** | med | pressurized filter bed |
| Automatic water sampler | med | ***high*** | ***small*** | security problem if unattended |
| In-line, flow actuated | low | low | ***small*** | ***in development*** |
| Depth-Integrating Stream Sampler | ***high*** | low | ***small*** | very small sample |

-high, medium, and low values are estimated based on the research
***-bold, italic text designates the limiting factors***

Table 3 shows the amount of material (dry weight basis) required for some common physical and chemical tests (Magoon, 1994). To perform a suite of tests including metals, semivolatiles, TOC, pesticides/PCB's, Dioxins/Furans, percent solids, specific gravity and grain size would require 68 grams of dry material. This minimum sample size is for one analysis. Duplicates, spikes, and other additional analyses will require more sample material.

**Table 3**. Estimated minimum amounts of dry solids required for analysis (Magoon, 1994).

| Analysis | Minimum sample size (grams, dry weight) |
|---|---|
| Priority Pollutant Metals | 5 |
| Semivolatile Priority Pollutants | 10** |
| Priority Pollutant Pesticides/PCB's | 10** |
| Dioxins/Furans | 10 |
| Total Organic Carbon | 1 |
| Percent Solids | 2* |
| Grain Size | 20 |
| Specific Gravity | 10 |
| **Total** | **68** |

* All tests require % solids determination for conversion to dry weight
** Requires 30 g wet weight; these two analyses can be extracted from the same aliquot.

For all of the stormwater sampling techniques, the time at which the water is collected is of critical importance. Either someone must be present at the drain during a storm event, or the sampler must to have a sampling system proportional to flow. Training and coordination of sampling personnel is difficult and costly. Automatic equipment is expensive, presents a security problem and is not completely reliable.

## Literature Review

A Literature search was conducted for references on stormwater sediment traps. The databases queried were UnCover, Selected Water Resource Abstracts, Current Contents, LaserCat, and Compendex (see Appendix A for description).

The literature indicates that what is needed is a device that can :

- Passively collect storm drain particulates from a high-energy catch basin environment.
- Operate over a relatively long period without maintenance.
- Collect 50-100 ( Betts, Brown, McFarland, 1995) grams solids to analyze with acceptable detection limits.
- Collect a proportionate amount of material in the silt/clay range of <63 μm. The silt/clay fines attract contaminants because of their large surface area, and is the material which stays in suspension and is ultimately deposited in the receiving waters.
- Be adaptable to variable storm drain designs and be easily installed and retrieved.
- Be relatively inexpensive to manufacture and maintain.

With these criteria in mind we reviewed the available literature to determine a suitable design and make a recommendation for further action. No references were found that mentioned a device for in-line sampling of stormwater sediments. We also put out an appeal for designs on an Internet stormwater bulletin board (Sewer-List).

Several individuals involved in stormwater regionally were contacted to see if they were aware of any research on the topic. They commented that, to their knowledge, none was being done (Horner, Mar, Hartigan, personal communication).

The Center for Urban Water Resources at the University of Washington is currently engaged in research on inexpensive flow actuated whole water samplers. However, these will yield inadequate sample sizes (Mar, 1994, personal communication).

It appears that most of the stormwater sampling done now is for whole-water. Water quality standards exist, but applicable sediment quality standards are rare. However, Ecology is presently working on this issue. There have been several studies conducted in Washington that have sampled stormwater sediments. Table 4 shows a brief list of examples where stormwater sediments have been collected.

**Table 4**. Example of stormwater sediment studies

| Location | Reference | Project | Type of Sampling |
|---|---|---|---|
| City of Bellingham | Cubbage, 1991 | Bellingham Bay | catch basin grab samples |
| City of Tacoma | Tacoma Surface Water, 1990 | Commencement Bay | centrifuge, catch basin grab samples, pressure filter |
| Seattle (METRO) | Tim Hubbard, Tim Sample, 1982-1984 | S.W. Lander St., S.W. Florida St. (Duwamish River) | catch basin grab samples |
| Bellevue | Robert Pitt, Pam Bissonette, 1984 | Bellevue Urban Runoff Program | catch basin grab samples |
| Commencement Bay | Stinson, Norton, Johnson, 1987 | PCB investigation in Hylebos Waterway | outfall sediment samples |

## Potential Sediment Trap Designs

Based on our review of available literature, the following criteria were required:

- Inexpensive to build and maintain.
- Ability to collect an adequate sample in a reasonable length of time.
- Durable and constructed of non-contaminating materials.
- Ability to collect a representative grain size.
- Adaptable to a variety of storm drain configurations.

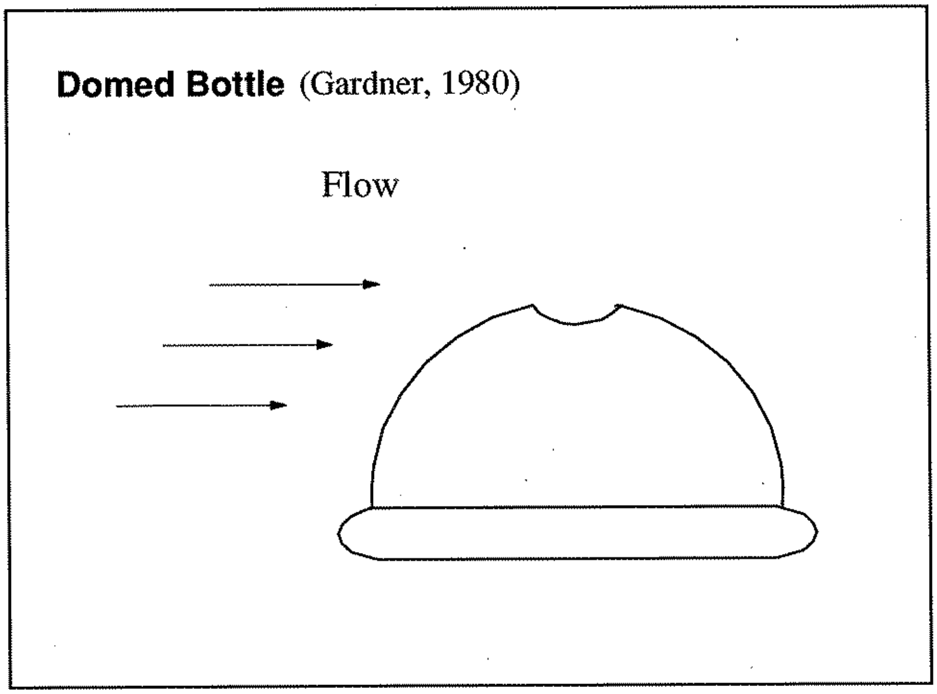
The mechanism by which particles are collected in any trap in flowing water is by fluid exchange of particle-laden water with particle-deficient water. Particles settle out of the water inside the trap. At varying rates the water is replaced by incoming eddies, and particles in the "new" water can settle out. Therefore, the trapping efficiency of a container is a balance between particle settling velocity, angular velocity of eddies, rate of fluid exchange of "stagnant water" in the trap, and hydrodynamic factors influencing the way fluid enters the trap, all of which may possibly be parameterized by the "residence time". For example, an open container placed in a moving fluid produces a flow pattern that induces eddies at the leading edge which plunge into the container at the downstream edge. Particle laden eddies that enter the container form an area of rapid circulation at the mouth that shares a boundary with more stagnant water further inside. Particles are exchanged across this boundary and then settle out in the relatively calm area below. (Gardner, 1980)

There are several sediment traps that use settling to determine vertical flux in marine environments, including: cylinders, flat plates, domed bottles, narrow-necked wide-bodied traps, and the horizontal slit cylinder traps. Of these the domed bottle and the horizontal slit cylinder traps appear to be best suited for use as a stormwater sediment trap. Both use a similar mechanism to trap particles carried by a moving fluid.

To make a container work as a sediment trap in a storm drain, the stormwater sediments must have a long residence time in the trap while immersed in rapidly flowing water, in order for the sediments to settle out. In 1980 Gardner did experiments that were designed to evaluate sediment traps for their ability to measure the vertical flux of marine sediments. Various shapes were placed in a test flume, and sediment laden seawater was passed over them. He found that a domed bottle with a small hole in its top was a particularly good collector. A horizontal cylinder placed perpendicular to the flow, with a narrow slit along the top on the longitudinal axis, also performed exceptionally well. These designs are shown in Figure 1.

The domed bottle was 4.5 cm high and 4.5 cm in diameter with a 1.8 cm hole in the top (see Figure 1). In his experiment the particles were ocean sediments sieved to exclude particles >63 μm with a median grain size of 2.6 μm. Concentrations in the flume water ranged from 11.5 mg/l at the beginning of the 42.7 hour run to 2.3 mg/l at the end. The flow velocity in the flume was 9 cm/s. The domed bottle trapped at the average rate of 0.3 g/hr. The grain size distribution of the material in the trap was identical to that present in the flume. The advantage of this trap is that it will collect from any flow direction. It is possible that by altering the hole diameter, higher fluid velocity ranges could be accommodated. This would have to be determined by testing different size holes with varying flow velocities and comparing the results.

The slit cylinder was 10.4 cm long, 4.8 cm in diameter, and with a 0.11 cm wide slit long the top. Under similar conditions to the dome bottle test, the slit cylinder trapped at an average rate of 2 g/hr. The collected particles were slightly larger than those in the flume with a median size of 3.7 μm.



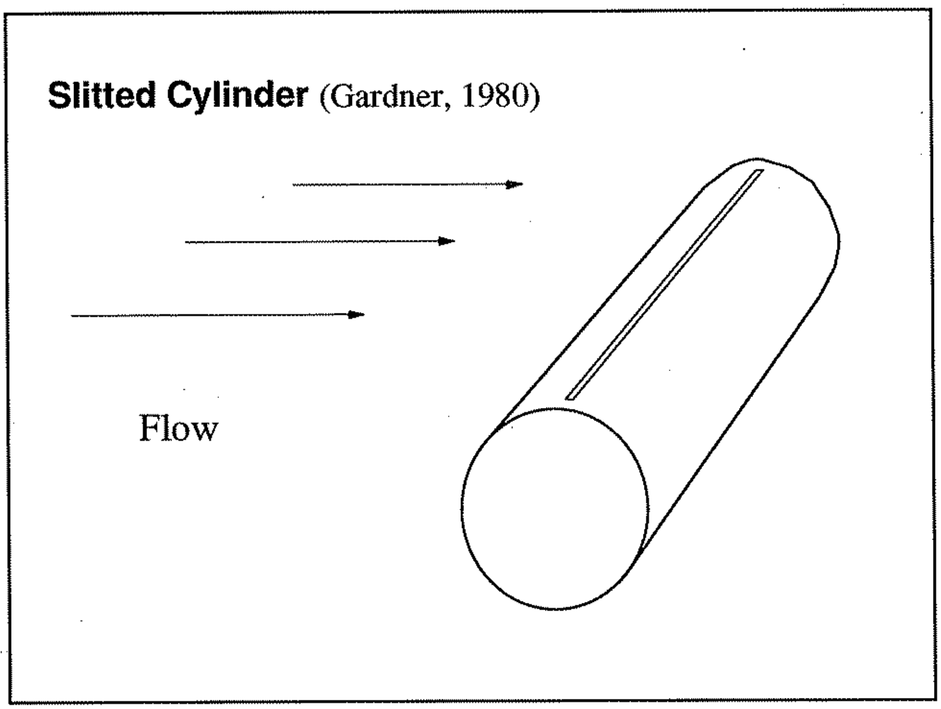




Figure 1. Potential Storm Water Particulate Trap

**Table 5** - Particle size classes used in analyses of street dirt

| Range of sizes, in microns | Class names [1] |
|---|---|
| less than 63 | silt and clay |
| 63-125 | very fine sand |
| 125-250 | fine sand |
| 250-500 | medium sand |
| 500-1,000 | coarse sand |
| 1,000-2,000 | very coarse sand |
| 2,000-6,400 | very fine gravel |
| greater than 6,400 | fine gravel and larger |

(Gardner, 1980)

These devices appear to collect efficiently in the silt/clay range, one of our basic requirements. Although these trapping rates were achieved under ideal laboratory conditions, it is remarkable that such fine material could be accumulated at this rate. Even with only half that recovery rate, a trap in-situ could collect a substantial amount of sediment over a 3-month interval, completely unattended. The suite of tests mentioned above requiring 68 grams of material could be performed routinely, providing flow was present in the drain with sufficient particulate concentrations. (see Table 5)

Flows in catch basins, the most frequent point of access to stormwater systems, are going to be much greater than those in the lab tests. Velocities in storm drain pipes are typically 90 to 475 cm/s (DOT, M23-02), far above 9 cm/s. In addition, fluid dynamics in these basins could be very complex because inlets may enter from various directions and heights. A big problem in the design of this trap is finding an appropriate place to put it and determine what flows it will experience. The bottom of the catch basin will have varying depths of sediment present, so a trap cannot be anchored there. The water level changes with the change of input flow. But when there is flow through the catch basin, the water level will at least be above the outlet invert.

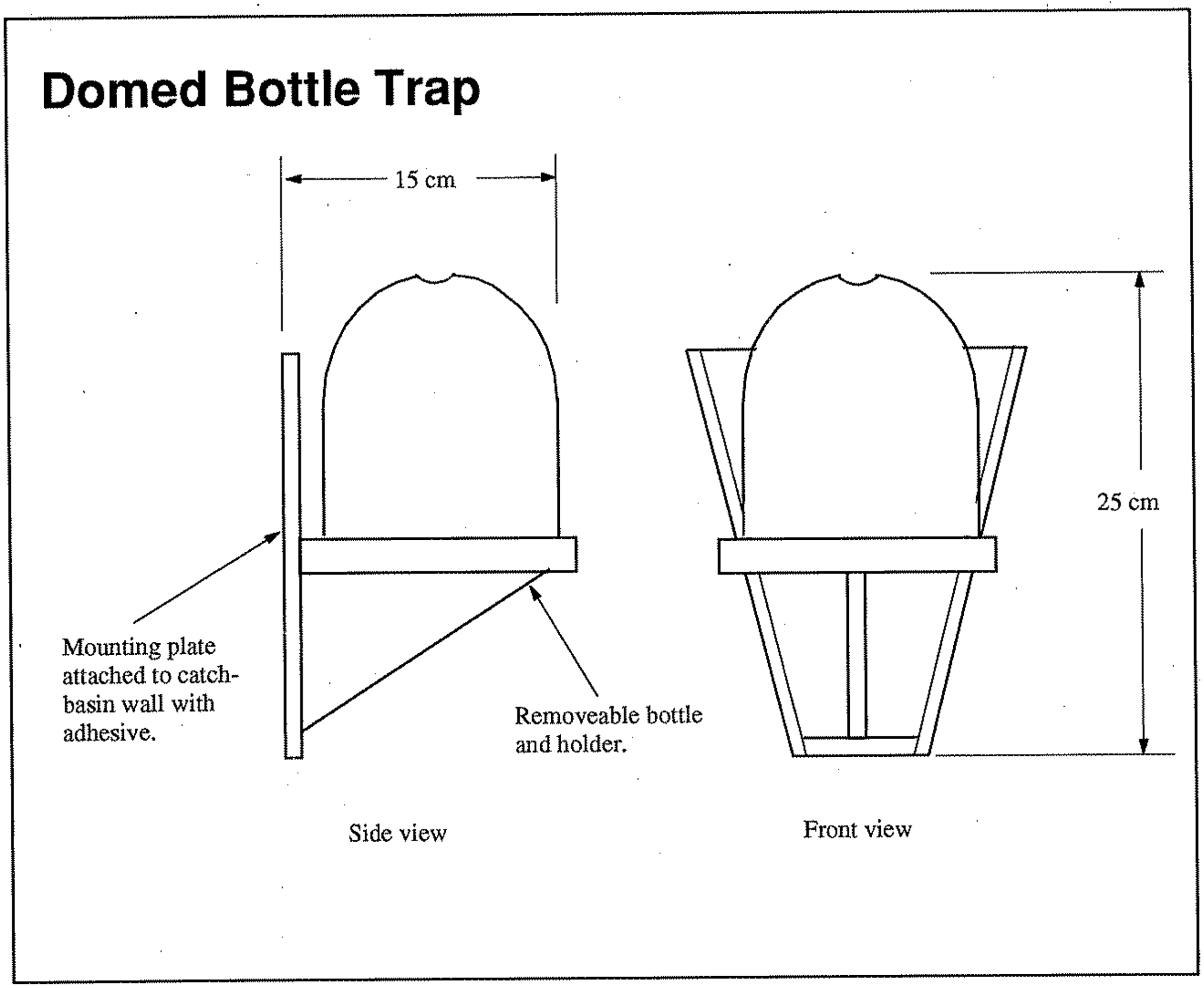
The most logical choice of a mounting location is on the wall below the level of the outlet. There are several reasons for placing the trap directly below the outlet. First, it is the ideal place to select silt/clay particles since the large particles will have already settled out into the catch basin. Second, it is the only spot within all catch basins that has consistent flow characteristics. Therefore mounting the trap just below the outlet provides a convenient, logical location that should prove to be consistent from site to site, and will allow for calibration. The trap would be mounted at some depth below the outlet level where the velocity is determined to be at an acceptable rate (Lindgren, Reaves and Hobbins 1994). There is sufficient depth in the catch basins to deploy either the domed bottle or the slit cylinder traps two feet of sump or greater, depending on the type of catch basin. At least two feet of sump is typical in catch basins and this is adequate for the proposed traps.

Figures 2 and 3 show a domed bottle trap that could be mounted to the side of a catch basin with an adhesive. The mounting allows the trap to be removed and replaced with a minimum of effort. It slides down into a tapered tack locking it into position. It could be retrieved with a telescoping tool from above ground, keeping the technician out of the drain. If an adhesive does not prove to be successful then the next alternative would be to bolt the trap to the wall of the catch basin. This would be more difficult and time consuming and would require the technician to enter the catch basin or manhole to drill holes for the bolts.

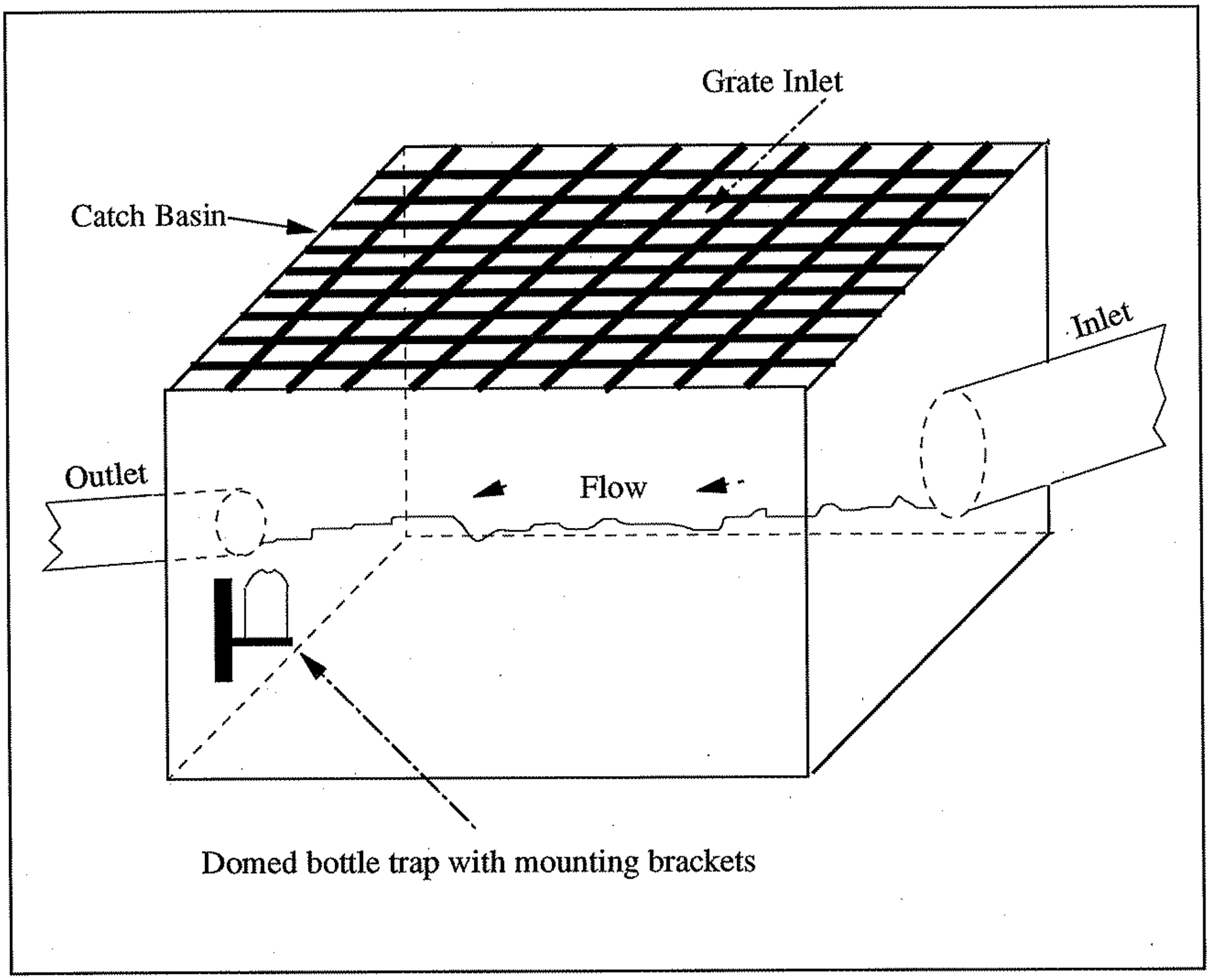
The bottle could be made of either teflon or heavy weight glass to maintain sample purity. Sediments could be removed by decanting most of the liquid portion and then agitating the remaining liquid and sediment to form a slurry that could be poured through the hole. If breakage becomes a common problem then strategically armoring the trap would become necessary. This could be accomplished with a wire screen, placed in a position that would not alter the flow dynamics of the trap.

The slit cylinder could be adapted for use in a larger size catch basin. By mounting it crosswise in a short length of square tubing, flow would be directed for efficient operation and the cylinder would be protected from damage. This technique would require brackets to be mounted on two sides of the catch basin with the trap suspended between. This option lends itself to the possibility of obstructing the flow through the catch basin. The cylinder would be made of standard teflon pipe with teflon ends pressed or threaded in. This trap would make sample removal simple with the removable end caps.

One of the main criteria for a suitable trapping device is that it be able to stay deployed with minimum maintenance for a long enough period of time to collect at least the minimum amount of sample (50-100g). The National Urban Runoff Program (NURP, 1983) gives the median TSS as 100 mg per liter. Given the trapping efficiency rates from Gardner's experiments it seems likely that neither the domed bottle nor the slit cylinder would have any trouble collecting an adequate amount of sample in three months or less. There are numerous variables that factor into the equation of how long it will take to collect 50-100 grams of material, including: size of the catchment basin, runoff coefficient of the catchment basin, total suspended solids in the stormwater, flow velocity over the trap, and the major unknown variable which is the actual rate at which the trap will collect sediments.




# Figure 2. Domed Bottle Trap




# Figure 3. Recommended Trap Mounting Position

There are many variables that affect trapping efficiency which include: concentration of suspended particles, size and density of particles, trap geometry, and current velocity. The number of variables and combination of variables is far greater than the number of experiments made, so trapping effects cannot always be conclusively attributed to a given variable (Gardner, 1980). How these traps will perform under varying conditions is unknown. It would be useful to know if the trap preferentially selected larger particles at higher velocities, or if it collected more efficiently at lower velocities.

## References

Betts, Brett; Brown R., Sharon; McFarland, Brenden, Jan 20, 1995. Personal communication, Washington State Department of Ecology, Sediment Management Unit, Olympia, WA.

BURP, 1984. Bellevue Urban Runoff Program, Summary Report.

Cubbage, J., 1993. In Preparation. A Survey of Bremerton Stormwater Quality. Washington State Department of Ecology, Olympia, WA..

Cubbage, J., 1994. Drainage Basin Tracing Study: Phase II, Chemicals Found in Storm Drains, Whatcom Creek and Squalicum Harbor in Bellingham, WA. Washington State Department of Ecology, Olympia, WA..

Gardner, W. D., 1980. "Sediment Trap Dynamics and Calibration: A Laboratory Evaluation, Journal of Marine Research, 38:1, pp. 17-39.

Hartigan, Pat, July 18, 1994. Personal communication, formerly with Washington State Department of Ecology, Stormwater Unit, Olympia, WA.

Hobbins, Mike, December 6, 1994. Personal communication, Washington State Department of Transportation, Stormwater Quality, District 3, Olympia, WA.

Horner, Rich, July 14, 1994. Personal communication, Environmental Engineer, University of Washington, Engineering Department, Seattle, WA.

Lindgren , Brad, December 12, 1994. Personal communication, Stormwater Hydrologist, Washington State Department of Transportation, Environmental Division, District 3, Olympia, WA

Mar, Brian, July 8, 1994. Personal communication, Center for Urban Water Resources, Seattle, WA.

Magoon, S., October 4, 1993. Response to Estimated Minimum Sample Amounts for Centrifuged Solids. Memorandum to Bob Barnard, 3 pp.

NURP, 1983. National Urban Runoff Program, Final Report, vol 1, U.S. Environmental Protection Agency.

Reaves, A., November 28, 1994. Personal communication, Snohomish County, Stormwater Engineer, Everett, WA.

Serdar, D, 1993. Contamination in Vactor Truck Wastes. Washington State Department of Ecology, Olympia, WA.

Stinson, M., Norton, D., Johnson, A. 1987. An Investigation into Potential Sources of PCB Contamination in Hylebos Waterway. Washington State Department of Ecology, Olympia, WA.

U. S. Geological Survey, 1988. Field Methods for Measurement of Fluvial Sediment, USGS Report 86-531

WSDOT, 1989. Hydraulics Manual. M 23-02, Washington State Department of Transportation, Olympia, WA..

Yake, Bill, 1993. Evaluation of Effluent Centrifugation, Washington State Department of Ecology, Olympia, WA.

**Appendix A:** Databases used in literature search (provided by Ecology Library).

LaserCat, Western Library Network, Lacey, WA. (Catalog of many of the libraries in the region. Lists over 3 million references.)

UnCover, Carl Corporation, Denver, Colorado (Periodical database listing 200,000 periodicals).

Ei Compendex Plus, Engineering Information Inc, Hoboken, NJ (Electronic version of The Engineering Index, listing 4,500 journals relating to engineering and technology).

Water Resource Abstracts, USGS Water Resources Division (Database of several thousand publications of the Water Resource Scientific Information Center).

Current Contents, Institute for Scientific Information. (Database of more than 7,000 scientific and engineering journals, issued monthly. The most recent 12 months were searched.)

**Appendix B:** Background materials used in this report.

Bloesch, J. and Burns, N.M., 1980. A Critical Review of Sedimentation Trap Technique, Schweizelishche Zeitscherift fuer Hydrologie, 42/1. Birkhauser Verlag Basel.

Blomqvist, Sven and Hakanson, Lars, 1981. A Review on Sediment Traps in Aquatic Environments, Arch. Hydrobiol. 91, 1, 101-132.

Butman, Cheryl Ann, et al, 1986. "Predictions of Sediment Trap Biases in Turbulent Flows," Journal of Marine Research, 44, 601-644.

Butman, Cheryl Ann, 1986. "Sediment Trap Biases in Turbulent Flows: Results from a Laboratory Flume Study," Journal of Marine Research, 44, 645-693.

Corbitt, Robert A., 1990. Standard Handbook of Environmental Engineering, McGraw-Hill, Inc, NY.

Gardner, W. D., 1980. "Field Assessment of Sediment Traps," Journal of Marine Research, 38:1, pp. 41-52.

Knauer, George et al, August 1989. Sediment Trap Technology and Sampling, U.S. GOFS Planning Report No. 10.

Marino, Robert P., Sept 1, 1991. Survival of Fecal Coliforms and Fecal Streptococci in Storm Drain Sediment, Water Research, vol 25 n 9.

Robertson, John A, et al, 1988. Hydraulic Engineering, Houghton Mifflin Co, Boston.

Sinclair, Charles, Oct 1, 1993. The How-to of Stormwater Sampling, Public Works, vol 124 n 1.

Wei, Chen, Nov 1,1993. Effect of Stormwater runoff on Metal Distribution in the sediment and Interstitial Waters of an Urban River, Environmental Technology, vol 14 n 11.

Welton, J.S. and Ladle, M., 1979. Two Sediment Trap Designs for Use in Small Rivers, Limnology and Oceanography, vol 24.

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