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Research and Development

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Project Summary

Characterizing and Controlling Urban Runoff Through Street and Sewerage Cleaning

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A study was conducted in Bellevue, Washington, to characterize urban runoff and evaluate its control by street and sewerage cleaning. The project was one of a series conducted in the city from 1978 through 1983 to investigate Bellevue's urban runoff sources, effects, and potential controls.

The project reported here spanned the period 1980-1983, and it completely monitored more than 300 urban runoff events in two residential areas during that time. Flow-weighted composite samples were analyzed for a core list of important constituents. Complete flow monitoring results allowed detailed descriptions of urban runoff quality and quantity, and they permitted estimates concerning the contributions of flows and pollutants from different source areas. Street surface and sewerage particulates were also collected and analyzed to determine the effectiveness of street and sewerage cleaning.

Most of the heavy metals were determined to originate from street dirt, but street cleaning improved the quality of urban runoff by a maximum of only 10 percent. A specially modified street cleaner was then tested and found to be much more effective than the conventional model in removing the small particles of street dirt that are washed off the streets by rains. Catchbasin cleaning twice a year was estimated to improve runoff quality by a maximum of about 25 percent.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

A 2-year monitoring program was conducted to examine the sources of urban runoff flows and pollutants in Bellevue, Washington. The study of these elements enabled a comprehensive investigation of the direct effects of street and sewerage cleaning on runoff quality. A large number of storm events were monitored under two extreme street-cleaning frequencies to investigate possible improvements in urban runoff quality. Urban runoff was studied in two residential areas using automatic, flow-weighted samplers and sonic depth gauges to monitor runoff during storms and dry weather. Street dirt samples were obtained in conjunction with specific street cleaning programs using special vacuum collection procedures. Storm sewer inlet and sewerage particulate samples were also obtained periodically.

Significant decreases in street surface loadings occurred with intensive, three-times-a-week street cleaning, but large improvements in the quailty of urban runoff were not detected. The improvements averaged only about 10 percent, possibly because the light Bellevue rains removed only some 15 percent of the street loadings. The particulates that washed off the streets were of the finer particle sizes that are not effectively removed by conventional street cleaners. These particulates constituted only a small portion of the total urban yields of many pollutants, but street dirt washoff is a major contributor of many heavy metals and organic priority pollutants. In addition, the amounts of rainfall at the two locations differed by more than 20 percent at least half of the time. These rain differences made basin calibrations difficult and tended to mask variations in runoff concentrations or yields that may have been caused by street cleaning.

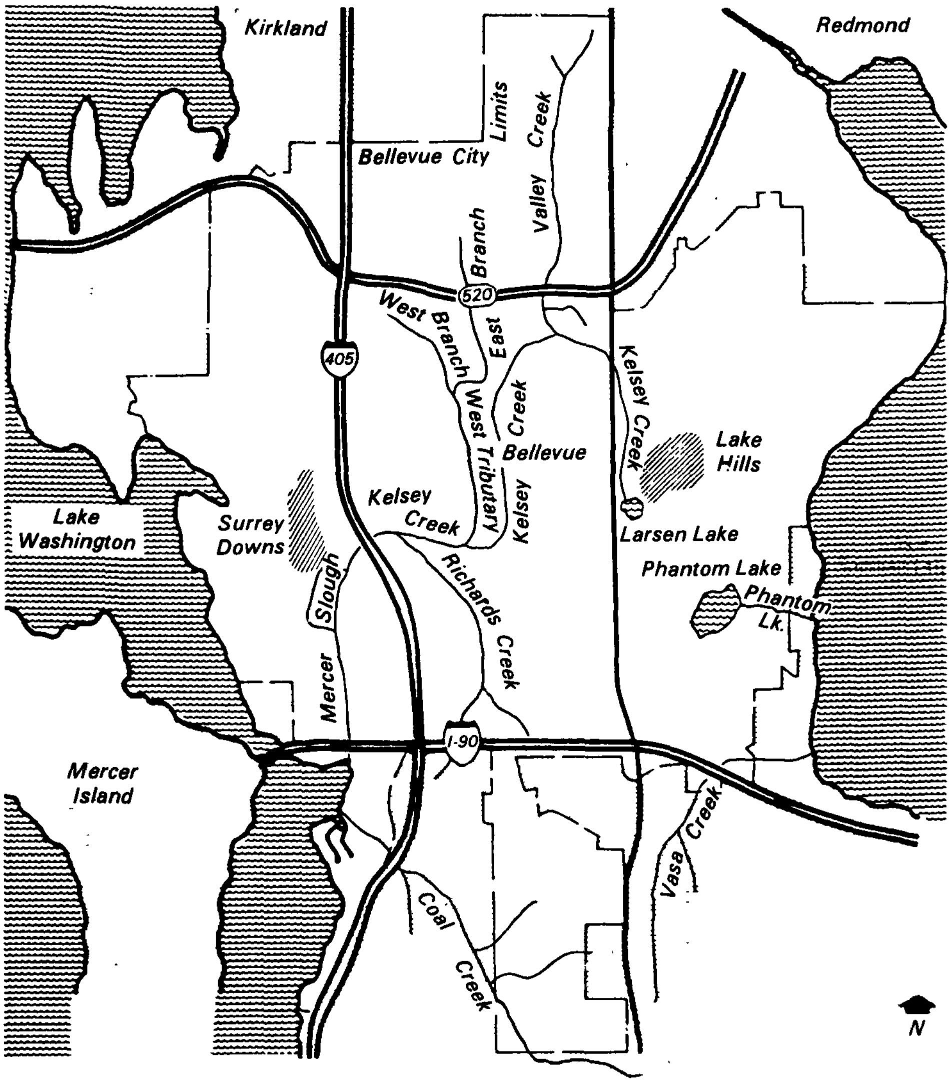

Figure 1. *City of Bellevue, Washington, study sites.*

Study Area Description

Bellevue is a middle to upper middle class suburban community near Seattle, Washington. The city is decentralized, with residential areas served by shopping malls and numerous businesses along arterial streets. No heavy industry exists in Bellevue. The population growth has been rapid in the past decade, and the population was about 74,000 in 1980. Though the growth of Bellevue has mostly been in residential areas, recent development has included construction of additional office buildings and hotels. The area is within commuting distance of Seattle. Bellevue receives about 1 m/yr of rain, but substantially more rain falls on the Olympic Peninsula to the west, and much smaller amounts occur to the east in Washington.

Two residential areas were studied in this project—Surrey Downs and Lake Hills (Figure 1). The communities are about 5 km apart, and each covers an area of about 40 ha. Both are fully developed, mainly as single family residences.

The Surrey Downs basin is about 38 ha in size and includes the Bellevue Senior High School in addition to single family homes that were built in the late 1950's. Most of the slopes in the basin are moderate, with some steeper slopes on the west side. The Surrey Downs basin ranges in elevation from about 3 to 55 m, and about 60 percent of it is pervious. Back and front yards make up most of the land surface area of the basin, and streets make up about 10 percent. The streets are generally in good condition, with smooth to intermediate textures. The curbs need repairing in a few locations. Westwood Homes Road and 108th Street have no curbs. The Surrey Downs basin has little traffic, and the on-street parking density is low. The storm drainage system discharges into an artificial pond located in an adjacent development. This pond discharges into Mercer Slough, which eventually drains to Lake Washington and Puget Sound.

The Lake Hills catchment covers about 41 ha and contains the St. Louise parish church and school in addition to single family homes, also developed in the 1950's. Lake Hills has slightly more pervious area than Surrey Downs, but its lots are typically smaller. With a few exceptions, the slopes in Lake Hills are more moderate than those found in Surrey Downs. The elevation of the Lake Hills study area ranges from 80 to 125 m. The street surfaces and gutter systems are similar to those in Surrey Downs. Most of the streets in Lake Hills also carry low volumes of traffic and have low parking densities, except for two busy roads that cross through the area. The Lake Hills storm drainage system outfalls into a short open channel that joins Kelsey Creek just downstream from Larsen Lake. Kelsey Creek also discharges into Mercer Slough.

Sources of Runoff and Pollutants

Sources and amounts of runoff, flows, and receiving water conditions are all affected by site-specific rain conditions. Bellevue rains are quite different from those in most other U.S. locations. They occurred every 2 or 3 days during the study period and were on the average less than 6 mm each. Fewer than 10 percent had volumes greater than 25 mm, and the largest rain monitored was 100 mm. Dry periods of more than a week are rare, but they did occur. Storms during the wet season generally yield twice the amount of rain and last twice as long as those during the dry season.

This project monitored about 400 rains and all base flow volumes between events that occurred at the two main study locations during 2 years of data collection. Bellevue received about 1 m of rain during each project year. Base flows represented relatively large portions of the total annual urban flows.

Important differences between the two study sites occurred in quantity of rainfall, base flow, and runoff yields. Overall, the base plus stormwater urban flows from Lake Hills were about 18 percent greater than those from Surrey Downs when normalized by area (figured on an equal area basis).

For both study years and test basins, only about 25 percent of the rain that fell left the areas as runoff. Typically, the small rains had the smallest runoff factors (Rv: ratio of runoff volume to rain volume) and the large rains had the largest factors.

Multiple regression analyses were conducted to relate the Rv values to total rain, average and peak intensity, and days since last rain. Results showed that rainfall volumes alone accounted for about 95 percent of the individual Rv values. The season of the year was extremely important in determining actual runoff and rainfall relationships. The winter wet months of November through February had Rv values some 35 percent higher than those for the drier months of March through October for similar rains. Thus, there was no real need to adjust the calculated Rv values for rain intensity or length of preceding dry period. All that needed to be considered was total rainfall and season.

A model was developed to determine the sources of runoff and their proportionate contributions. The model was based on the variations of Rv values for different rain volumes. Source of runoff considered included vacant lots, parks, front and back yards, roof tops, driveways, parking lots, and streets. The amount of runoff contributed by each source depended on its distance from the drainage system, its size, and the type of surface cover.

For all rains greater than about 2.5 mm, impervious surfaces contributed more than 60 percent of the total urban runoff flows. The remainder of the flows were approximately evenly divided between front and back yards. Vacant lots and parks contributed very little flow because of their limited presence in the test areas. Street surfaces contributed about 25 percent of the total urban flows for most rains causing runoff.

Quality of Stormwater Runoff

Collecting data on the quality of stormwater runoff was a major aspect of this project. Most of the analytical effort was associated with a core list of important constituents. The sampling procedures involved collecting total storm flow-weighted composite samples throughout most of the events that occurred during the 2-year sampling period at the Surrey Downs and Lake Hills sites. Variations in stormwater quality with total storm characteristics were analyzed. Very few variations were observed in the total solids concentrations for various storm characteristics, and they were statistically insignificant.

The runoff water quality at Bellevue was much better than that at most other U.S. locations, but the base flow quality was worse than expected. The reason was probably that the study basins were completely urbanized and the base flows consisted of percolated urban sheet flow waters from previous storms that were draining out of the surface soils. In basins with undeveloped upstream areas, the base flow would originate mostly from the nonurbanized upper reaches and would be of much better quality.

The mass yields for annual urban runoff (Table 1) indicated an apparent difference between the runoff in Lake Hills and Surrey Downs when expressed on a unit area basis, but the total annual storm runoff plus base flow discharges from the two basins were quite similar. A much larger fraction of the total urban runoff in Surrey Downs occurred as base flow between rain events. The runoff events in Lake Hills were more sharply defined, and the base flows made up a much smaller fraction of the mass yields for urban runoff.

The relative contributions of pollutants from various source areas (Table 2) differed from the contributions of runoff flows. During very small rains, most of the runoff and pollutant discharges were associated with the directly connected impervious areas. As the rain total increased (to greater than about 2.5 mm), the pervious areas became much more important. These patterns varied significantly, depending on specific rain characteristics and land uses. For most rain events, total solids originated mostly from the back and front yards. Street surfaces, however, were expected to account for most of the lead, zinc, and COD discharges. Phosphates and total Kjeldahl nitrogen were mostly contributed from street surfaces, driveways, and parking lots combined. Front and back yards contributed slightly less than half of these

Table 1. *Annual Mass Yields for Baseflow and Stormwater Runoff (kg/ha)*

	Surrey Downs			*Lake Hills*		
Constituent	*Base Flow*	*Storm Runoff*	*Total*	*Base Flow*	*Storm Runoff*	*Total*
Total solids	*110*	*205*	*315*	*76*	*280*	*360*
COD	*11*	*90*	*100*	*9.9*	*110*	*120*
Total Kjeldahl nitrogen	*0.60*	*1.8*	*2.4*	*0.20*	*2.7*	*2.9*
Total phosphorus	*0.11*	*0.40*	*0.51*	*0.04*	*0.69*	*0.73*
Lead	*0.03*	*0.26*	*0.29*	*0.02*	*0.45*	*0.47*
Zinc	*0.06*	*0.24*	*0.30*	*0.027*	*0.31*	*0.34*

Table 2. *Percentage Distribution of Urban Runoff Pollutants from Various Source Areas**

	Percent of Pollutant Contributed from Source Area$^+$					
Source Area	*Total Solids*	*COD*	*Phosphates*	*Total Kjeldahl Nitrogen*	*Lead*	*Zinc*
Streets	*9*	*45*	*32*	*31*	*60*	*44*
Driveways and parking lots	*6*	*27*	*21*	*20*	*37*	*28*
Rooftops	*<1*	*3*	*5*	*10*	*<1*	*24*
Front yards	*44*	*13*	*22*	*19*	*<1*	*2*
Back yards	*39*	*12*	*20*	*20*	*<1*	*2*
Vacant lots and parks	*2*	*<1*	*<1*	*<1*	*<1*	*<1*

**For 2.5- to 65-mm rains.*

$^+$*Approximate.*

nutrients. Zinc contributions from rooftops (galvanized gutters) made up about a fourth of the total zinc discharges.

Contributions of Street Dirt to Urban Runoff Discharges

About 600 samples of street surface accumulations were collected from the test areas during the 2-year project. The particulate loads for each sample were plotted to observe changes in street surface loadings with time and to determine the initial rates of deposition and long-term accumulation. The deposition rate is the amount of dirt that accumulates over the first several days after a significant rain or street cleaning. This rate is a function of various characteristics of the area; especially climate, land use, traffic and street surface texture. The accumulation rate equals the amount of dirt deposited minus the amount removed by rain, street cleaning, traffic-induced turbulence or wind. Material blown from the street can remain suspended in the air, but most of it settles to the ground within about 10 m of the roadway.

Each of the street surface samples was separated into eight different particle sizes. These size distributions showed that the smallest particle sizes account for only a small fraction of the total material, especially during the wet season when the rains were most effective in removing the smallest particles. During the dry season, the larger particle sizes also accounted for relatively small fractions of the total solids weight. Most of the street surface particulates were associated with particles in the middle size ranges of 0.125 to 1.0 mm.

The initial accumulation rates (assumed to be equal to the deposition rates) in the test areas were estimated to vary between 1 and 6 g/curb-meter per day, with an average rate of about 3 g. This rate compares with accumulation rates observed in other locations for smooth streets in good condition. The frequent rains do not remove all of this material from the streets. The texture of the street traps and protects particulates so that typical street cleaning equipment and rains cannot remove them. About 50 to 100 g/curb-meter of street surface particulates remain on the streets after storms of about 6 mm or greater. Infrequent large rains may remove much more of the street surface particulates than the smaller rains common in Bellevue.

Chemical characteristics of street dirt in the different study areas varied most with respect to lead, especially when comparing streets with varying traffic levels. Particle size also had a significant effect on concentrations of chemical pollutants in street dirt. Chemical oxygen demand, Kjeldahl nitrogen, and phosphorus concentrations all showed high concentrations associated with the smallest particle sizes, small concentrations with the intermediate sizes, and high concentrations with the large sizes. Lead and zinc concentrations were the highest with the smallest particle sizes which is typical (based on other studies for heavy metals).

The contribution of the street surface particulates to runoff water depends on the ability of the rain to loosen and wash these particulates from the street surface. During the 2-year project about 25 pairs of street surface loading values were obtained within 2 days of rain. Figure 2 shows the percent and size distribution of surface particulates washed from the street in Lake Hills during both the dry and wet seasons. The initial loadings were significantly greater than the residual loadings for particle sizes smaller than about 500 microns. The smallest particle sizes had the greatest significant washoffs, whereas particles greater than about 500 microns had lower significant washoff values. With the smallest particle sizes, the washoffs varied from about 40 to 50 percent, whereas increases were found in street loadings for the larger particle sizes. The overall reduction in net loading averaged about 16 percent. Even more material may have been removed during the rains and replaced at the same time by erosion material.

Most of the material washed from the street surfaces had particle sizes of less than about 125 microns. Only about 10 percent of the washoff material was greater than about 500 microns. The largest particle sizes were notably absent from the washoff material. A total of about 8.5 to 10 g/curb-meter was removed from the street surfaces during the rains, with about 4 to 6 g/curb-meter having particle sizes smaller than 125 microns.

Table 3 summarizes the approximate annual street dirt accumulations, washoff values, and fugitive losses to air for the Surrey Downs and Lake Hills sites. In many cases, the amounts involved were substantially greater for Lake Hills than for Surrey Downs. About 15 percent of the annual street dirt accumulation was washed from the streets and either discharged or accumulated in the sewerage systems. About 10 percent of the annual accumulation was lost to the air, with much of this material settling out near the roadway. The remaining street dirt would build up over time on the street surface or be removed by street cleaning operations.

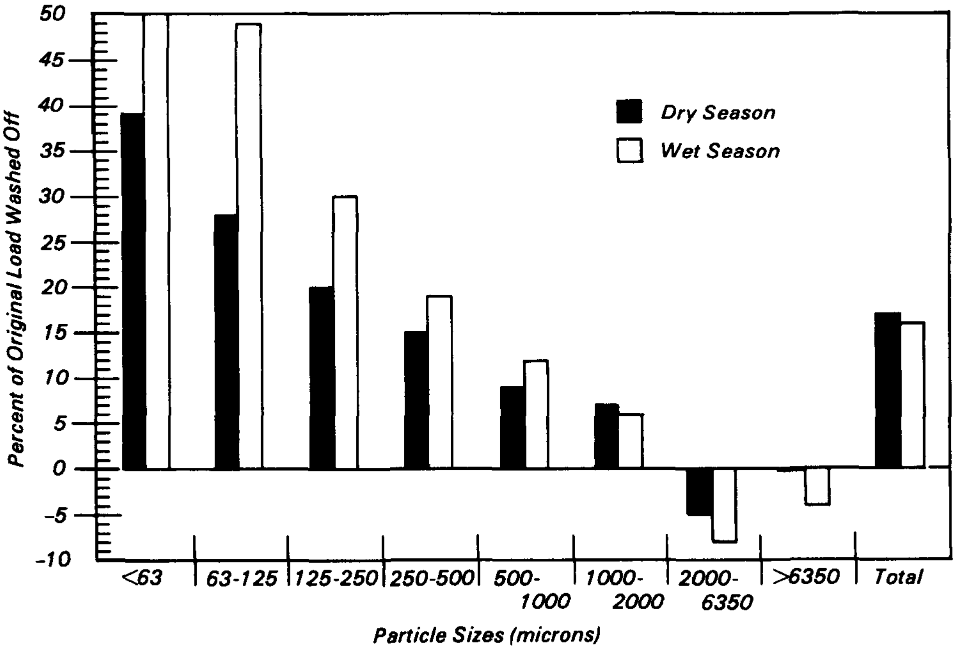

Figure 2. *Percent and size distribution of surface particulates washed from the street in Lake Hills during the wet and dry seasons.*

Table 3. Approximate Annual Street Dirt Accumulation, Washoff, and Fugitive Losses to Air (kg/ha)

	Surrey Downs			Lake Hills		
Constituent	*Accumulation**	*Washoff*	*Loss to Air+*	*Accumulation**	*Washoff*	*Loss to Air+*
Total solids	200	30	20	350	60	20
COD	25	3	2	70	10	3
Total Kjeldahl nitrogen	0.2	0.04	0.02	0.8	0.16	0.05
Total phosphorus	0.1	0.02	0.01	0.2	0.05	0.01
Lead	0.1	0.02	0.01	0.4	0.1	0.02
Zinc	0.03	0.006	0.003	0.08	0.02	0.005

**Using an average 2- to 5-day accumulation period.*

+Calculated based on the deposition minus the accumulation rates times the average interevent time period.

Sediment Accumulations in Sewerage Systems and Catchbasins

Sewerage system sediment loadings were periodically observed in the Surrey Downs and Lake Hills study areas. The drainage systems were cleaned before the project began, and the sediment volumes in inlets and catchbasins were observed nine times during 2 years. The first observations in December 1979 showed light accumulations. The next observations were made in August 1980. Beginning in January 1981, observations were made every 1 or 2 months until the end of the project. The first year of observations indicated steady accumulations of sediment, but the loading remained about the same during the second year. Typically, about twice as much polluted sediment was observed in the storm drainage systems at any given time as was noted on the streets. The flushing of the sewerage sediments out of the drainage systems and into the receiving waters was not analyzed, but such an event would probably not occur except during large storms. The smaller storms probably removed a small fraction of the sewerage sediments.

The stable sediment volumes that occurred during the second year were about 60 percent of the available sump volumes of the catchbasins and inlets. Only about 12 mm of sediment was found in the manholes with outlets on the structure bottoms, whereas about 150 mm of sediment accumulated in the inlets and catchbasin sumps. When analyses were conducted for individual structures, wide variations were observed. The depth below the outlet appeared to be the most important factor, but the larger-capacity sumps did not always contain the largest amount of sediment. Large sump capacity would allow less frequent cleaning before the stable volume was obtained and smaller outlet-to-sump bottom distances would be associated with greater scouring during storms.

The chemical quality of the sediment material in the catchbasins was also analyzed. The chemical quality of this catchbasin and inlet sump material was very similar to that of the same sized particles of street dirt. Thus most of the catchbasin sediments were probably street surface particulates that had washed off the streets during rains but were not discharged to the outfall.

About 100 liters/ha per year accumulated in the Surrey Downs storm sewer inlet structures, whereas only about two-thirds of this amount accumulated in Lake Hills. About 50 percent more inlet structures per hectare exist in Lake Hills as opposed to Surrey Downs, where the accumulation rate per inlet structure was generally more than double that of Surrey Downs. Nine of the ten most heavily loaded catchbasins in the first summer inventory for Surrey Downs were located on or just downstream from the two streets in the study area that did not have curbs and had extensive off-street sediment sources.

Very few pipes in either Surrey Downs or Lake Hills had slopes of less than 1 percent. Since both study areas were drained by steeply sloping pipe systems, the accumulation of sediments in the storm drainage systems was not great.

Urban Runoff Controls

The last phase in developing an urban runoff control program is to examine measures that can be used to reduce the identified problem pollutants or flows originating from the various source areas that discharge to the receiving water. To meet water quality objectives, a combination of several control measures may be necessary. Complex procedures for analyzing decisions may also be necessary if multiple objectives are important. This part of the study evaluated the effectiveness of street cleaning in controlling the urban runoff problems in Bellevue.

Street cleaning tests were conducted using two different cleaning frequencies: No cleaning, and intensive 3-day-a-week cleaning. For several months, one cleaning frequency was used in the Surrey Downs main basin, and the other was used in the Lake Hills basin. The frequencies were then rotated. During another period of several months, no street cleaning was conducted in either basin.

Street loadings ranged from about 40 to 300 g/curb-meter (with an average value of about 115) during the period of no street cleaning. The loadings were reduced to about 20 to 200 g/curb-meter (with an average of about 60) after street cleaning (from about 650 to 400 microns) because of the selective removal of the largest particles by the street cleaners. Rains, on the other hand, increased the median particles sizes because they were most effective in removing the finer material.

This study collected more than 400 street dirt samples in the two test basins immediately before and after the streets were cleaned. Figure 3 compares the initial and residual street dirt loads for a wide range of loading conditions. Street cleaning equipment cannot remove particulates from the street surface unless the loadings are above a certain level. This value was about 85 g/curb-meter in the test basins. If the initial street surface loading values were smaller than this value, then the residual loadings typically were about equal to the initial loadings. Statistical analysis showed that the frequent rains in Bellevue were probably more effective than the street cleaning in keeping the streets cleaned. The street surface loadings after rains were usually 50 to 100 g/curb-meter. Typical mechanical street cleaning equipment was quite ineffective in removing small particles.

Particle sizes smaller than about 350 microns were not substantially affected by street cleaning, and there was no effective removal of street dirt particles smaller than about 125 microns. Very subtantial removals were observed in the large particles, however. A decrease occurred in median particle sizes as the street cleaners preferentially removed larger particles. These decreases were especially important when the initial median particle sizes were large.

A series of special tests were conducted during September and October of 1982 to compare the effectiveness of a modified street cleaner with that of a standard mechanical street cleaner. Many modifications were made to a standard Tymco* regenerative air street cleaner. The purpose of these modifications was to reduce respirable fugitive dust emissions during street cleaning. The modifications included partial hoods around the gutter brooms, a pressure controller to better regulate the air flows, and a venturi scrubber with a settling chamber in the street cleaner hopper. The water spray bar was also disconnected. This modified street cleaner was compared with both a standard street cleaner that was used in the previous full-scale tests and with an unmodified version of itself. The results of these special tests are also shown in Figure 3. Both the modified and unmodified regenerative air street cleaners showed substantially better performance than the regular mechanical street cleaner, especially for finer particle sizes. The poor performance of the mechanical street cleaners was aggravated by the low loadings of these small particles. The regenerative air cleaners were much more suited to the low loadings of small particles.

Bellevue street cleaning costs were about $13/curb-kilometer. About 73 percent of this cost was associated with labor and labor overhead, about 18 percent was associated with all of the maintenance costs, and 18 percent was associated with the disposal costs. Street cleaner operating costs (including labor, depreciation, tires, oil, and gasoline) were about 64 percent of the total costs.

A large part of the data analysis done during this project attempted to identify differences in runoff concentrations and yields caused by different street cleaning operations. No significant differences were observed in runoff yields or concentrations during periods of intensive street cleaning. A very few exceptions occurred, but they were probably due to other factors.

The poor street cleaning effectiveness is probably the result of the specific Bellevue rain conditions. The rainfall and resulting runoff volumes varies greatly between the two test areas—by at least 25 percent for about half of the rain pairs. These differences could have shielded the effects of the different street cleaning operations.

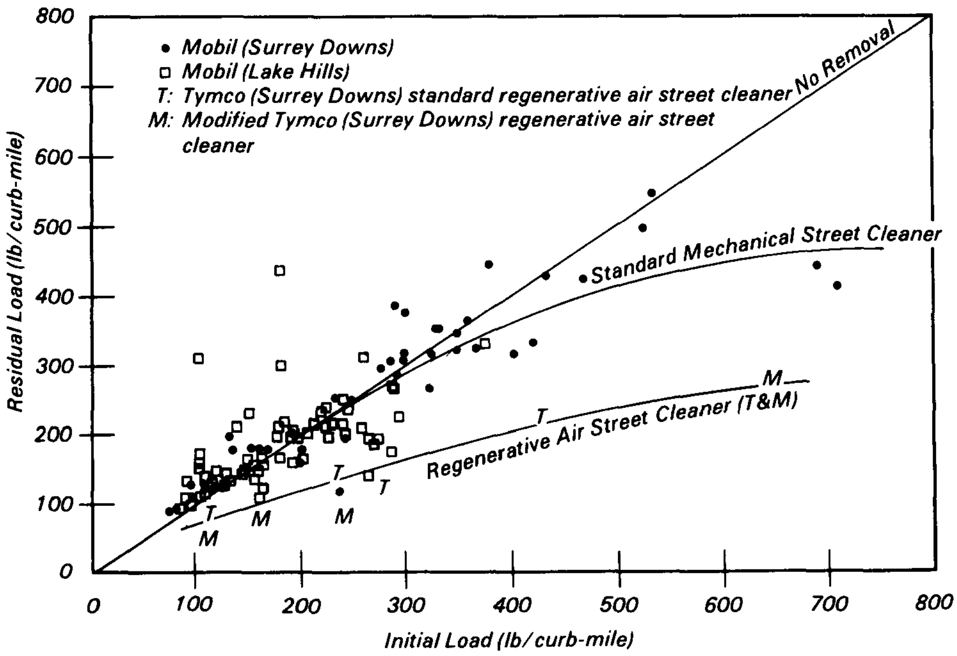

Figure 3. *Street dirt loads before and after street cleaning.*

Though street surface particulates contributed less than 25 percent to runoff yields in nearly all cases, they contributed about 50 percent of the total runoff lead yield. If the street cleaning operations could control a substantial fraction of the street surface particulates, then reducing runoff particulates by street cleaning might be important. Rains were most effective in removing particles smaller than several hundred microns in size. These particle sizes are not abundant, but they do contain the largest concentrations of heavy metals and relatively large concentrations of many nutrients. As noted, however, mechanical street cleaning equipment is not very effective in removing small particles. The regenerative air street cleaners were more effective in this area.

The coordination of street surface sampling, street cleaning operations, and runoff monitoring during this project allowed many data analysis procedures to be used to investigate possible effects of street cleaning on runoff water quality. The use of two test basins and the rotation of the street cleaning operations also allowed one basin to be compared with the other, along with internal basin comparisons. No significant differences were noted in the runoff concentrations over the ranges of data that were common to the various data sets.

Intensive street cleaning resulted in about a 25- to 50-percent reduction in street surface loadings. If the street surface contributes about half of the total runoff yield for a specific pollutant, then intensive street cleaning may remove 10 to 20 percent of the pollutant discharge. Precise runoff measurements and consistent rainfalls over the test and control basins would therefore be required to detect these relatively small improvements. Intensive street cleaning significantly reduced only the large particle sizes, and those particle sizes most subject to washoff by rains were not effectively reduced. This may result in less than a 6 percent improvement in runoff water quality for intensive street cleaning. The regenerative air street cleaner is expected to be about 1.25 times more effective in reducing runoff yields.

Conclusions

Direct receiving water effects from urban runoff pollutants were not significant for most storms, but potential long-term problems associated with urban runoff may be associated with settleable solids, lead, and zinc. These settled materials may have silted up spawning beds and introduced high concentrations of potentially toxic materials directly to the stream sediments. The oxygen depletion observed in the interstitial waters was probably caused by organic sediment buildup from runoff events.

Flooding in the receiving waters has increased significantly with urbanization.

**Mention of trade names or commercial products does not constitute endorsement or recommendation for use.*

This flooding has affected several beneficial uses of these waters (aquatic life habitat and water conveyance, for example).

For all rains greater than about 2.5 mm, the impervious surfaces (streets, sidewalks, driveways, parking lots, and rooftops) contributed more than 60 percent of the total urban runoff flows. The remainder of the flows were approximately evenly divided between front and back yards. Vacant lots and parks contributed very little to the flows because of their limited presence in the test areas. For most of the rain events monitored, the street surfaces contributed about 25 percent of the total urban runoff flows.

Most of the total solids in the urban runoff originated from front and back yards in the test areas; the street surfaces contributed only a small fraction. Lead, zinc, and COD, however, were mostly contributed from street surfaces. Nutrients (phosphorus and total Kjeldahl nitrogen) originated mostly from street surfaces, driveways, and parking lots.

Motor vehicle activity was expected to be the primary contributor of most of the toxic pollutants. Gasoline and diesel fuel combustion products, lubricant and fuel leakages, and wear of the vehicles affected the street dirt material most significantly.

The maximum observed runoff event discharged about 25 percent of all pollutants that were on the street surfaces, the catchbasins, and sewerage combined. Thus most urban runoff pollutants were not source-limited. However, those particulates that were most available for washoff (the smallest particles) might be source-limited. About half of the total particulates from annual urban runoff discharge might be residing on the street surfaces and tied up on catchbasins and storm drainage sediments at any given time. If the Bellevue rain events could remove more of this material, the urban runoff discharges would be much greater than observed.

Rains removed only a small fraction of the total particulate loadings on the impervious surfaces (about 15 percent). Large particles were not effectively removed, and only about half of the smallest particles (less than 50 microns) were washed off during rains. These small particles were not very abundant, but they had very high concentration of heavy metals and nutrients. Most of the settled particulates in the storm drainage inlets and sewerage pipes also remained after the observed storms.

Intensive street cleaning three times a week produced significant decreases in street surface loadings—from about 115 g/curb-meter down to about 60 g/curb-meter. The median particle sizes also decreased significantly with intensive street cleaning. A regenerative air street cleaner performed substantially better in removing the finer street surface materials than did the regular mechanical street cleaner.

Extensive data analysis showed no significant improvements in runoff water quality during periods of intensive street cleaning. The street cleaning operations tested are expected to improve runoff quality by a maximum of only 10 percent. The street cleaning equipment preferentially removed the larger particles, and the rain events removed the finer materials. Street cleaning did not very effectively remove the available particulates. Mechanical-broom street cleaning effectively removed the larger litter from the streets. Infrequent street cleaning may result in significant increases in fugitive dust losses to the atmosphere.

After an initial cleaning, nearly a full year was needed for sediment to reach a stable volume in the inlet structures. Only about 60 percent of the total available sump volumes in inlets and catchbasins were used to detain particulates at the stable volume. At any larger storage levels, the rains effectively controlled the volumes. Cleaning the inlets and catchbasin sumps about twice a year is expected to reduce the lead and total solids concentrations in urban runoff by 10 to 25 percent. COD, the nutrients, and zinc might be reduced by 5 to 10 percent.

Based on this project, many recommendations can be made about public works practices in the Bellevue area, but their effects on improving the urban runoff quality would probably be quite small. If intensive street cleaning were implemented along with semiannual catchbasin sediment cleaning, most pollutants in urban runoff discharges would be reduced by about 10 percent. Some of the heavy metal discharges might be reduced by as much as 25 percent. Even though these reductions are quite small, they could contribute significantly to reducing the accumulation of these highly polluted sediments in the smaller creek systems, especially if the receiving water flows were reduced.

Peak runoff flows could be reduced by requiring the use of more pervious areas in developed areas, or by the use of appropriately sized and located detention basins.

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The complete report, entitled "Characterizing and Controlling Urban Runoff Through Street and Sewerage Cleaning," (Order No. PB 85-186 500/AS; Cost: $35.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

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