Anchorage Street Sweeping and Storm Water Controls: 2013 Performance Evaluation

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MUNICIPALITY OF ANCHORAGE  
WATERSHED MANAGEMENT PROGRAM

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Anchorage Street Sweeping and Storm Water Controls: 2013 Performance Evaluation

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EXECUTIVE SUMMARY

The Municipality of Anchorage (MOA) and the Alaska Department of Transportation and Public Facilities (DOT) (the Permittees), under State of Alaska Pollutant Discharge Elimination System (APDES) permit AKS-052558, administered by the Alaska State Department of Environmental Conservation (ADEC), are authorized (Part I.B.) to discharge storm water from their storm drainage systems to waters of the United States. Conditional to this authorization, the Permittees are required to implement various programs and practices. Part II.B.4.d) (vi) (page 21) of permit AKS-052558 requires that:

Not later than four years from the effective date of this permit the permittees must update the document entitled “Anchorage OGS and Street Sweeping as Storm Water Controls: Performance Analysis”, Document #WMP APR 022002, (November 2002). The updated document must be submitted to ADEC with the 4th Year Annual Report.

This report summarizes work performed by the Permittees in compliance with this requirement.

The Permittees understand that evaluation of controls required under this part must be completed in context with the capacity of those controls to reduce the impact of storm water runoff discharged from the Anchorage Municipal Separate Storm Sewer System (MS4) on the quality of waters of the United States. Given this, we have completed the required work using the following criteria:

• Evaluation must be performed from the perspective of potential for reduction of MS4 impacts to receiving water quality.
  o Performance must be evaluated in context with State and Federal water quality standards.
  o Performance must be evaluated in context with APDES/National Pollutant Discharge Elimination System (NPDES) ‘maximum extent practicable’ (MEP) rules for municipalities.

• Evaluation must be performed from an appropriate system perspective.
  o The controls to be evaluated function as parts of a complete storm water ‘treatment train,’ and therefore shall be assessed as parts of the ‘train’ as a whole.
  o The evaluated controls are driven by stochastic (statistically random) precipitation events and therefore shall be assessed at a sum-of-loads (SOL), or seasonal, scale.

With these criteria in mind, we focused performance evaluations on the total seasonal (SOL) removal of fine particulates, a suitable surrogate for a range of water quality pollutants. We also expanded evaluation of the target controls to include catch basins, a critical element in the Anchorage treatment train. Finally, as an MEP basis for evaluation of Anchorage performance, we completed research of national and international technical literature to provide a database of norms of performance for similar nationwide practices and individually applied sweeping equipment and storm water controls.

To provide a means of viewing interactions of controls along the Anchorage treatment train, we prepared a simple model of street pollutant buildup and transport through that treatment train. The model reflects street dirt buildup (from end-of-winter [EOW] and summer loading),
abstractions (from summer street sweeping and rainfall runoff), and transport through drainage system controls (catch basins and hydrodynamic oil/grit separators). Using a mass balance approach, we calibrated the model using street dirt and washoff loading data collected in Anchorage studies completed by the Permittees in 1996, 2012, and 2013. Data collected in 2013 was also used to directly assess performance of Anchorage street sweeping practices by measuring street sweeping ‘residuals’ (the dirt left on the streets following street sweeping). Loading (lbs / per curb mile), along with laboratory analysis of particle size distributions (PSDs) and organic content of the ‘residual’ street dirt, helped qualify the potential for washoff, treatment by other controls, and water quality impact represented by the sediments remaining on the street after sweeping.

Based on our analysis, current Anchorage sweeping practices do not meet national performance norms from a water quality perspective. In addition, storm water controls (catch basins and hydrodynamic oil/grit separators) present along Anchorage’s piped storm drainage system do not sufficiently supplement current sweeping practices to otherwise provide such water quality protection. However, project data also suggests that sweeping performance deficits can be readily corrected by modest changes in practices, including addition of sweeper types to those already used, changes in dust suppression practices, and modest changes in sweeper train patterns and number of passes.

Specifically, this project shows Anchorage to have summer street dirt buildup, particle size distributions, and mineral character generally similar to that of most other U.S. communities. However, sampling results also show that Anchorage post-sweep residuals, at about 4100 and 2300 lbs / curb mile for arterial and residential streets respectively, typically exceed by 2 to 10 times that reported for other U.S. communities (Error! Reference source not found.). In addition, Anchorage residuals include a large fraction (on the order of 10 to 20% by weight for residential streets) of organic fines generated by comminution of vegetable matter (predominantly leaves), a significant vector for other adsorbed contaminants.

However, project data also suggest that the unusually large post-sweep residuals and the high organic content are directly related to the extraordinarily high EOW loadings unique to Anchorage. Unlike winter sanding at any other U.S community, Anchorage’s entire winter sanding load is accumulated, frozen in the gutter, at spring breakup. Under current sweeping practices, the accumulated winter sand generates a very large post-spring sweep residual, forming a primary source of the total summer street sediment load. In addition, the large organic loading observed in Anchorage street dirt is thought to be related to this seasonal accumulation of winter sand. Fallen leaves accumulated along the gutters are comminuted to fine fibrous organics in late fall and over the winter. Current sweeping practices, focused on aesthetic and hydraulic conveyance performance goals, are effective at removing the coarse particulates but miss these organic fines, magnifying the loading of this water quality sensitive pollutant.
These unusual seasonal street dirt conditions in Anchorage may, however, help leverage solutions. Aggressive removal of the large EOW load, including the comminuted organic fines, during the spring sweep would significantly reduce the overall summer street dirt load. Model results indicate such improvement can be achieved with relatively modest changes in seasonal sweeping patterns (Table ES - 1) and practices including:

- implementing restricted parking (alternating sides with ‘no parking’)
- increasing number of sweeping passes along the gutter
o minimizing the amount of flushing/wetting done for dust suppression
o using mechanical sweepers earlier during heavier street dirt loading and vacuum sweepers 24 hours later under dryer street dirt conditions
o using high-intake velocity vacuum sweepers (‘leaf vacuums’) along the gutter as a last ‘polishing’ sweep
o performing early fall sweeping using normal sweeping practices
o late fall (late September/early October) sweeping along residential and landscaped arterial streets using only leaf vacuums along gutters

Figure ES - 1 Current and 2013 modeled sweeping patterns in Anchorage, Alaska

The proposed sweeping practices are synergistic and should be considered as a whole. For example, late fall removal of leaves from gutters will not only reduce the primary source of organic loading, but also protect against suspected increased gutter scouring by fall rainfall.
runoff. Staging mechanical sweepers 24 hours prior to vacuum sweepers applies the mechanical sweepers at their strength (heavy dirt loading, wet tolerant sweeping) and prepares the streets for optimum performance from the vacuums (lighter, finer sediment loading under drier conditions). Project analysis of current and proposed changes in sweeping practices in Anchorage further suggests that these proposed changes can dramatically improve overall performance with little change in current costs (Table ES - 2).

**Table ES - 2 Anchorage Current versus Proposed Sweeping Performance**

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arterial Sweep Residual</strong>¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>4,475</td>
<td>625</td>
</tr>
<tr>
<td>Summer</td>
<td>1,581</td>
<td>350</td>
</tr>
<tr>
<td>Fall</td>
<td>639</td>
<td>350</td>
</tr>
<tr>
<td><strong>Residential Sweep Residual</strong>¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>2,377</td>
<td>503</td>
</tr>
<tr>
<td>Summer</td>
<td>1,849</td>
<td>436</td>
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<tr>
<td>Fall</td>
<td>759</td>
<td>369</td>
</tr>
<tr>
<td><strong>Annual Treatment Load</strong>²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweepers</td>
<td>13,689,000</td>
<td>15,309,000</td>
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<tr>
<td>Catch Basins</td>
<td>520,000</td>
<td>340,000</td>
</tr>
<tr>
<td>OGS</td>
<td>496,000</td>
<td>198,000</td>
</tr>
<tr>
<td><strong>Annual Washoff</strong>²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2,584,000</td>
<td>1,056,000</td>
</tr>
<tr>
<td>+100µm</td>
<td>390,000</td>
<td>355,000</td>
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<tr>
<td>-100µm</td>
<td>2,194,000</td>
<td>701,000</td>
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<tr>
<td>-20µm</td>
<td>1,085,000</td>
<td>312,000</td>
</tr>
<tr>
<td><strong>O&amp;M Unit Costs</strong>³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweepers</td>
<td>-$0.18</td>
<td>-$0.15</td>
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<tr>
<td>Catch Basins</td>
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<td>-$0.46</td>
</tr>
<tr>
<td>OGS</td>
<td>-$0.96</td>
<td>-$0.96</td>
</tr>
<tr>
<td><strong>O&amp;M Street Sweeping Costs</strong>⁴</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual</td>
<td>-$2,515,000</td>
<td>-$2,259,000</td>
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<tr>
<td>5-Year NPV</td>
<td>-$12,700,000</td>
<td>-$12,007,000</td>
</tr>
<tr>
<td>30-Year NPV</td>
<td>-$86,500,000</td>
<td>-$78,800,000</td>
</tr>
</tbody>
</table>

¹Sweep residuals values in lbs / curb mile.  
²Annual values in total lbs.  
³Unit cost values in annual cost / annual treatment load.  
⁴Costs are represented as net present values (NPV). Costs are determined from ARDSA data, and represent relative O&M costs for MOA and DOT. Proposed sweeping costs represent planning level costs. Further analysis is recommended to determine specific savings which should include a pilot test.

Improvements achieved by these changes in sweeping practices can be further leveraged by improved performance in other storm drain controls as a result of Anchorage’s unusual climate. Precipitation in Anchorage is modified by nearby high mountain barriers such that summer rainfall volumes and intensities are quite low compared to that of most communities within the continental United States. Low-energy rainfall characteristics reduce potential for street sediment washoff and enhance potential for removal by these controls, primarily catch basins and oil/grit separators. Treatment by these controls can be further enhanced by modifying design criteria as recommended in this current report and the Permitees’ previous 2012 analyses of OGS and sedimentation basins and adjusting maintenance schedules to match sweeping and seasonal loading conditions.
Finally, we believe these project results provide a useful representation of current performance levels of Anchorage street sweeping practices, and provide a sound planning basis for improvements to them. However, for storm water controls, practicable and cost effective management requires reliable performance information at the overall scale of the system—not just at the scale of one of its parts. Therefore, in addition to changes in sweeping and controls maintenance practices, we also recommend that the Permittees develop and adopt monitoring tools capable of evaluating Anchorage storm water systems at the scale of the individual controls as well as over the whole treatment train at seasonal scales.

Evaluation at these larger scales, however, will require appropriately scaled tools and timelines. Monitoring for sweeping performance, for example, should include vacuum sampling of gutters, statistically-designed to provide confident assessment of sweeping performance at several different scales, i.e., at the scale of individual sweeping events as well as at the scale of the summer seasonal period. These techniques, then, can supplant current inadequate street sweeper hopper counts as methods for performance measurement as well as provide a resolute basis for long-term analyses of controls performance. Careful monitoring design can minimize costs as well by use of sampling and field tests focused on critical parts of the system (e.g., the gutter vs. the entire street width).

Tools to assess at the larger, whole-system scale are also required. A storm water treatment model scaled to an SOL seasonal level can provide a reliable framework for this type of work. A conventional and utilitarian model can be inexpensively developed using public or proprietary software (e.g., WinSLAMM or SYMPTM) stratified at seasonal timescales. Given the Permittees’ standard permit term length of 5 years, we recommend that schedules for development and implementation of such a monitoring and evaluation program be set as follows:

- **Monitoring implementation, 0 – 2nd year**: develop and implement statistically-designed sweeping performance monitoring and data collection (used as a basis for both event-by-event sweeping performance checks and permit term SOL modeling performance evaluations).
- **Model implementation, 0 – 5th year**: select, develop, and calibrate a storm water controls evaluation model (including first term period model-based program recommendations for performance improvements).
- **Re-evaluation, at each succeeding 5th – 6th year intervals (end of each permit term)**: re-evaluate system performance (through data and model analysis) and recommend and implement modifications.
PART I. PROJECT PURPOSE

The Municipality of Anchorage (MOA) and the Alaska Department of Transportation and Public Facilities (DOT) (the Permittees), under State of Alaska Pollutant Discharge Elimination System permit AKS-052558 as administered by the Alaska State Department of Environmental Conservation (ADEC), are authorized (Part I.B.) to discharge storm water from their storm drainage systems to waters of the United States. Conditional to this authorization, the Permittees are required to develop and implement various programs and practices and periodically assess performance of these practices (Part II through IV) relative to the extent that they prevent violation or the potential for violation of Alaska water quality standards and meet other restrictions (Part I.D.). One such condition requires assessment of street sweeping and oil/grit separators (OGS) as they act to control discharge of pollutants from the Permittees’ storm water drainage systems into receiving waters. Specifically Part II.B.4.d)(vi) (page 21) of permit AKS-052558 requires that:

No later than four years from the effective date of this permit the Permittees must update the document entitled “Anchorage OGS and Street Sweeping as Storm Water Controls: Performance Analysis”, Document #WMP APr 022002, (November 2002). The updated document must be submitted to ADEC with the 4th Year Annual Report.

This requirement is stated in context with additional requirements that the Permittees periodically perform “...assessments of street sweeping effectiveness to minimize pollutant discharges...”, including “...excess leaves and other material...”, “...to storm drains and creeks...”. This report was submitted as fulfillment of these requirements.

Goals and Objectives

The primary goal of work summarized in this report is to comply with the Permittees’ storm water permit requirements as stated at Part II.B.4.d)(vi). These permit requirements explicitly require the Permittees to evaluate performance of street sweeping and OGS controls. They also specifically require that this evaluation be done relative to these controls’ performance in limiting impacts to receiving water quality. Some discussion of these requirements is critical in understanding the project objectives we have set to guide this evaluation.

Recognize that water quality impact is the basis for evaluation of the controls. Street maintenance agencies and water quality scientists use widely different criteria to evaluate street sweeping performance. Historically, and currently, the primary reasons street maintenance agencies give for street sweeping is to remove debris and dirt to improve urban aesthetics and ensure public safety and health. Another important purpose from the maintenance perspective is to remove particulates from streets before they can enter and clog drainage systems. Generally, these purposes can be satisfactorily met by removing coarser particles and leaving behind some minor fraction of finer particles, particularly if this remnant is located along the gutter pan. Frequently meeting these levels of service can be (and commonly is) adequately evaluated by visual inspection alone.

Water quality scientists, on the other hand, are less concerned with the coarser particles and much more concerned with the fines left behind. This is because the fines commonly carry a significant fraction of adsorbed and soluble pollutants, which can be problematic for water body
benthic and water column environments alike. The fines that are left behind after sweeping are more easily mobilized, increasing potential for water quality impact. Finally, because the mass of fine sediments left behind in the gutter after sweeping is relatively small, assessment of improvements in water quality performance as a result of sweeping through visual observation alone may not be adequate.

Nevertheless, this water quality performance perspective is the primary focus of the storm water permit conditions addressed in this project. The difference in ‘performance’ viewpoints, then, clearly sets up a scenario for misunderstanding and conflict between street maintenance groups and water quality scientists. Therefore, we emphasize that to effectively use the results of this project, all groups involved (regulators, managers, planners, street maintenance groups, and scientists) should recognize the criteria upon which this evaluation must be performed and consider responses to it in that context.

**Recognize that storm water controls perform as parts of stochastic systems** and should be evaluated in that context. It has long been recognized that, given the stochastic nature of storm water runoff and pollutant mobilization, measurement of treatment performance (total pollutants treated) may be most accurately evaluated at some seasonal scale, i.e., as the ‘sum of loads’ (SOL) of the total mass of pollutants that is treated or removed over some appropriate annualized time period. Since the MOA’s Watershed Management Section’s (WMS’) performance analysis of street sweeping in Anchorage in 2002, storm water science has attained a much better understanding of street dirt loading and washoff systems and made substantial design advances in controls as well. As a result, it is now much more common to incorporate storm water controls as suites of treatment systems, and to consider controls more as interconnected wholes than as individually performing parts. The approach taken in this project reflects this in that it addresses the suite of controls typical of the Anchorage storm water ‘treatment train,’ including street sweeping; catch basin; OGS; and sedimentation basins, and assesses sweeping and OGS performance as they participate in overall treatment by the entire train.

**Recognize that storm water control is goal-oriented and MEP-evaluated.** Because storm water runoff and pollutant mobilization is driven by precipitation, performance expectations and evaluations must be modified to discount effects of extreme events (very large storms). Federal storm water regulation addresses this through application of ‘maximum extent practicable’ rules (MEP), as balanced against water quality standards. Performing to meet water quality standards then becomes both a goal and a requirement. In this project, we have therefore elected to use national norms of performance as primary evaluation criteria in assessing Anchorage controls and practices.

Given the water quality, treatment systems, and MEP basis of our project approach as described above, we have adjusted our response to the specific permit requirements addressed in this report. Instead of sweeping and OGS alone, we address the whole suite of controls typical of the Anchorage storm water ‘treatment train,’ including street sweeping, catch basins, OGS, and sedimentation basins. We evaluate performance of these systems at local seasonal (SOL) scales to allow more accurate accounting of pollutant mobilization and treatment. Finally, we perform the required evaluation with ultimate reference to water quality (WQ) standards, but also assess Anchorage performance on an MEP basis using national performance norms as reference. In this context, the formal goals and objectives of this project can be summarized as follows:
GOAL: Evaluate performance of Anchorage storm water control practices relative to:

- ‘SOL’ approach – evaluate performance of controls scaled to local seasonal intervals (i.e., a ‘sum of loads’ approach).
- ‘Treatment Train’ systems – evaluate individual controls, including sweeping, as they perform as part of a suite of linearly integrated storm water controls.
- ‘WQ’ goals – evaluate performance related to potential for impact to receiving waters based on water quality standards set by Alaska law.
- ‘MEP’ goals – evaluate practical performance based on standards referenced to nationwide norms and practices.

Four project work objectives reflecting our approach and goal are summarized as follows:

**Objective 1:** Establish Anchorage context for controls evaluation, including:

- Local climate and receiving water characteristics
- ‘Sum of Loads’ (SOL) design and performance context
- Anchorage storm water pollutant sources and characteristics

**Objective 2:** Identify and compare Anchorage and national storm water control practices, including:

- Anchorage street sweeping, catch basin (CB) and oil/grit separator (OGS) practices and performance
- National and international practices and performance

**Objective 3:** Identify Anchorage storm water treatment costs, including:

- Anchorage storm water treatment unit costs
- Anchorage storm water treatment annual costs

**Objective 4:** Identify systematic (‘treatment train’) strategies to improve performance, including:

- Key recommendations to improve system performance
- Alternative strategies to implement key recommendations
- Estimated costs to implement alternative strategies

**Report Structure**

This report consists of four major parts. These include an Executive Summary, the main report body consisting of three main sections, a references and bibliographic listing, and appendices including summaries of data collection and analyses completed for this project. Citations contained in text, tables, or figures may be referenced by author or by a publication identification (‘PubID’) code number used by the Municipality’s WMS to code documents in its storm water bibliographic database.

**PART II. FINDINGS AND ANALYSIS**

This study addresses evaluation of performance of select storm water controls as they operate as part of a whole complex of controls commonly placed in linear fashion (a ‘treatment train’)
along Anchorage storm drainage systems. We also assess that performance over seasonal periods (a ‘sum of loads,’ or SOL, approach) to better account for the random nature of storm water runoff and the precipitation events that drive it. Finally, we use national norms of practices and performance, along with state and federal WQ standards and goals, as the basis of our evaluation. To perform this evaluation we have researched national practices and findings of studies similar to this one. The Permittees have conducted similar studies of Anchorage storm water controls and systems in the past and as a part of this project, and we have reviewed and included findings from these studies here as well. A complete bibliography of the resources we reviewed is included as a reference list in this report, including all cited references. Finally, we also collected and analyzed additional data in Anchorage in 2012 (PubID 018) and 2013 (Appendix B) to fill gaps in our understanding of the functioning of our local systems and to help resolve anomalous information, particularly with regard to sweeping performance and post-sweep street dirt residuals. This section of our report summarizes and describes our findings from all these efforts. In a following section we will summarize inferences we have drawn from these findings and our recommendations for actions that might improve Anchorage performance.

Description of Anchorage’s Storm Water System

Given the ‘treatment train’ approach to our controls performance evaluation, we will begin with a brief description of the overall system in which these controls operate. The effects of pollutants introduced into environmental systems are generally described in terms of pollutant sources and loadings; mobilization, transport, and transport pathways of those pollutants; decay and transformation of the pollutants; and the potential impacts of initial and derivative pollutants that ultimately enter receiving waters. In this report, we will concentrate on pollutant loading that typically occurs along street surfaces, the transport mechanisms that occur across those surfaces, and transport mechanisms located along piped storm drain systems that receive drainage from the streets. This neglects a significant loading to urban storm drain systems that a number of investigators believe comes from non-street pollutant sources (PubID 092, p. 3; PubID 003, p. 24). However, this will help to focus our current investigation on streets and municipally managed controls. Non-street storm water pollutant sources and control is addressed separately under the Permittees’ LID and other programs.

In Anchorage, street surfaces generate and release pollutants in ways typical of streets everywhere. Particulates and debris are lost from vehicles both from wear and tear as well as from accidental releases. Discharge of solids and liquids from vehicle leaks and fugitive loss of fuel, lubricants, and coolants occur chronically. Solid and liquid materials are placed intentionally on streets for maintenance and trafficking purposes, and some of these materials ultimately become part of the street dirt pollutant load as well.

In fact, street dirt pollutant build-up and transport of that build-up in Anchorage has a strong seasonal character due to the city’s geographic position and surface maintenance practices common to this locale. In Anchorage, streets are sanded throughout the winter to maintain traffic safety, similar to practices at many northern communities. However, due to its high latitude, heat from solar insolation received by Anchorage street surfaces is only about a tenth of that received at even the northern tier of the contiguous 48 states. Similarly, though many communities in the continental United States experience winter daily low temperatures as cold (or colder) than Anchorage, the average daily high temperature here during winter rarely rises above freezing. Other communities also experience large end-of-winter buildups (PubID 003, p.
27), but in Anchorage no melt occurs throughout the winter, and sand applied to the streets here becomes embedded in gutter ice (PubID 119). With sediments frozen into the gutters, winter sweeping is typically not feasible for most Anchorage streets and street dirt accumulates to create unusually large street dirt loads in spring (PubID 020). The winter ‘freeze’ also limits mid-winter washoff to rare (and relatively unpredictable) events. Because of these conditions, most storm water runoff control practices in Anchorage are focused on a single prolonged spring snowmelt runoff event and a series of summer rainfall runoff events.

Despite the general infeasibility of sweeping street surfaces during the winter and the presence of large accumulations of particulates in spring, several system characteristics tend to reduce mobilization of the street dirt during snowmelt runoff (PubID 018). Spring breakup in Anchorage is usually prolonged resulting in relatively low-energy seasonal snowmelt runoff rates. Low flows, armorring provided by the very large dirt loads present, and the frozen condition of much of the street dirt, limits mobilization by snowmelt runoff. Treatment provided by headwater controls, primarily catch basins (CBs) and oil/grit separators (OGS), is significantly improved under these low flow conditions. With lowered feasibility of winter sweeping in Anchorage, these systems provide primary storm water treatment during snowmelt runoff. This study, therefore, assesses early winter spring sweeping practices (relative to snowmelt runoff) only to the extent that they might enhance the performance of these other headwater controls during spring breakup.

Given the unusual winter buildup conditions described above, we were not surprised to find that, in Anchorage, street dirt loading available for washoff during the summer season is strongly dependent on the large post-spring sweep residuals, i.e., the large seasonal loading from remnant winter street sand left after spring sweeping. Sampling completed in 2012 (PubID 018) and in 2013 for this project (Appendix B) also confirmed a significant fine organics loading in the post-sweep spring street dirt loading. The organics appear to be strongly correlated to presence of trees and lawns (primarily residential land uses) and appear to result from leaf loading and comminution during summer sweeping, with late fall leaf and fibrous organic loads becoming further comminuted during winter weathering and the following spring sweep. Finally, the various street dirt sampling efforts undertaken in Anchorage (including that performed for this project) also reveal that summer street dirt buildup occurs at a similar range of rates and at the same high variability as that observed in studies at other lower-48 communities.

As for winter buildup, climate in Anchorage plays a critical role in determining the degree of mobilization of particulate pollutants during summer rainfall runoff events as well. Anchorage is semi-arid and subject to cyclonic rainfall events (PubID 018). Our storm events, their impact often tempered by intervening mountain ranges, yield low-intensity, low-volume, long-duration rainfalls with low raindrop impact and washoff energy relative to that experienced at many other communities in the continental United States. These climatic conditions, along with relatively large post-sweep residual loadings measured in Anchorage, led us to use of a simple empirical washoff model for this project, focused on erosion along the gutter valley as modified by the ‘available loading’ concept described by Pitt (PubID 002).

Treatment of pollutant loading on, and washed off from, municipal streets includes controls to limit: loading (e.g., winter sanding types and rates); treatment at the surface (sweeping, leaf pickup, snow hauling and melting, and LID practices like sheet flow and filtration and infiltration); washoff (including erosion-enhancing effects from coarse organics loadings); treatment at drainage system entrances (CBs, and entrance LID practices like vegetated ditches
and headwater infiltration controls and detention basins); treatment along the drainage system (predominantly OGS, but including some LID practices like ditch controls and check dams); treatment near or at the end-of-pipe (EOP) (including OGS and/or sedimentation basins); and disconnected discharge to low-sensitivity receiving waters (e.g., discharge to low-sensitivity natural wetlands). The Permittees have addressed all of these treatment elements in a range of studies and programs. However, the primary focus of this project is treatment performance by street sweeping, CBs, and OGS.

As discussed above, this study focuses only on spring and summer performance of the target controls, though we do consider effects from seasonal snowmelt and of maintenance schedules as they reflect loading at these controls. In this study we also focus primarily on control of particulates, with the assumption that particulate control will result in substantial control of many other pollutant types as well. We focus primarily on performance of these street and drainage water quality controls at seasonal scales and within the context of the entire Anchorage drainage system treatment train. We leave detailed consideration of loading rate controls and LID to other studies. We discuss project findings in this order: street dirt loading and sweeping performance, CB performance, and OGS performance. Of course, we recognize that focusing primarily on particulates, though we believe appropriate at this initial stage of system analysis, may miss important effects from those pollutants that are not closely associated with particulates or from transport transformations of those that are. As Anchorage controls and monitoring programs evolve in the future, we will narrow our investigations to address in more detail other critical pollutants that are not addressed in this initial system analysis.

Finally, it is important to note that we believe that the model and data developed under this project are adequate to provide relative mass balance for use in planning-level assessment of performance and in guiding modification of sweeping and other storm water control practices. However, the model is not sufficient for use in quantifying mass transport and flux under site specific conditions. Nevertheless, the large residual (post-sweep) loadings of both mineral and organic particles observed in Anchorage relative to national performance norms suggest that at this point, relatively simple changes in Anchorage sweeping practices will result in significant changes to washoff loadings. We also believe our findings provide a sufficient basis for development of useful and practical guidance for modifications to Anchorage design criteria and to local maintenance inspections and scheduling of the primary controls addressed in this study.

**Anchorage Street Dirt Loading and Sweeping Performance**

Everything else being equal, the character of a pollutant present on the street surface is directly related to the potential for it to be mobilized into and along the municipal storm drainage system, and to the performance of devices intended to control it. For particulates, the primary focus of this project, the most important characteristics are their street loading (the amount of street dirt per some unit of street surface), particle size distribution (PSD), and specific gravity.

The controls we consider in this project are gravity and density separation-types where higher specific gravities are important relative to control performance. Most street dirt is comprised of mineral particles and has a specific gravity of about 2.65, or that of most common rocks. Organic particulates (comminuted leaves and other organics) have specific gravities of about 1.6 to 1.5 and are much less subject to density or gravity separation than mineral particles. In the simple models we used in this project we applied a specific gravity of 2.65 to all particles and accounted for the lower specific gravity of organics by allocation of all organic content to a
smaller particle size range, where specific gravity has reduced effect on removal by gravity separation. We also account for this modeling (and treatment) bias in our recommendations by weighting alternative treatments for organic pollutants towards street surface removal options.

Observations made for every Anchorage street dirt sampling project have revealed a substantial organic fraction, both in dirt on the street as well as in particulates captured by controls along the drainage systems. Similar patterns have been observed by other researchers (Error! Reference source not found.), with fallen leaves a particular problem reported by observers across the nation and Canada (PubID 037; PubID 038; PubID 095, p. 50-51). Anchorage data shows a marked difference in organic loading between arterial roads and residential roads, with organic content appearing to be significantly higher in residential systems. Observations made during 2013 sampling suggest a correlation exists between higher organic loading and adjacent land uses that maintain lawns to the curb edge and have significant tree canopy. Observations also suggest a more comminuted load is present along Anchorage street gutters in spring, with twigs, leaf and seed hulls, and grass clippings contributing to a coarse organic load as the year progresses. Late fall leaf off not removed by sweeping, along with any remaining coarse organic debris from summer loading, is suspected as the primary source of the finely comminuted organics present in street dirt in spring. Observations of washoff also suggest masses of fallen leaves present along gutters in Anchorage may locally increase erosion of underlying mineral sediments along the gutter.

Table 1 Street Sediment Organics Loading

<table>
<thead>
<tr>
<th>WMS PubID</th>
<th>Year</th>
<th>Location</th>
<th>Arterial Organics, %</th>
<th>Residential Organics, %</th>
<th>Controls Organics, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>2000</td>
<td>Anchorage, AK</td>
<td>1.31-5.73</td>
<td>1.91-9.02</td>
<td></td>
</tr>
<tr>
<td>121</td>
<td>2002</td>
<td>Anchorage, AK</td>
<td></td>
<td>40</td>
<td>40 (CBs)</td>
</tr>
<tr>
<td>018</td>
<td>2012</td>
<td>Anchorage, AK</td>
<td>3.9, 4.4</td>
<td>9.0, 20.7</td>
<td>3.9-20.7 (OGS)</td>
</tr>
<tr>
<td>Proj.</td>
<td>2013</td>
<td>Anchorage, AK</td>
<td>2.2</td>
<td>18.1</td>
<td></td>
</tr>
<tr>
<td>025</td>
<td>2007</td>
<td>Oakland, CA</td>
<td></td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>095</td>
<td>2009</td>
<td>Seattle, WA</td>
<td>6.1-26</td>
<td>4.3-38</td>
<td>11-20 (CBs)</td>
</tr>
</tbody>
</table>

Where finely comminuted organics represent such large fractions of the total particulate load present on Anchorage streets, they strongly influence the second major characteristic of street dirt, its particle size distribution (PSD). From a water quality perspective, PSD is important as it influences the potential for a particle to be mobilized, its probability of successful treatment, and its adsorbed chemical contaminant load. The capability of sweepers to ‘pick up’ and remove street dirt is significantly affected by the particle size distribution of the dirt. Similarly, particle size (along with specific gravity and other factors) is directly related to the fraction of street dirt that is subject to washoff by any given storm size, with smaller particles much more likely to be mobilized. Finally, the treatment performance of CBs and OGS (both gravity separation devices) is directly affected by the PSD of that fraction of street sediment that is washed off, with
smaller particles much less likely to be captured. Thus, larger particles are less likely to be mobilized and more likely to be captured by any controls present, reducing risk to drainage systems from a hydraulic conveyance perspective. However, finer particles, less likely to be captured and typically considered to carry a higher proportion of the total pollutant load as adsorbed contaminants, represent a significant potential risk to receiving water quality. Therefore the presence of fines in street dirt, and any improvements that can be made in control practices to capture them, must be carefully assessed in this project.

**Figure 1 Street Sediment Wastes: Typical PSDs**

Particle size distributions typical of Anchorage street sediment waste streams are shown in Figure 1. This figure shows PSDs of the wastes swept up by Anchorage street sweepers (red-tinted dashed lines), of the residual sediments remaining on the streets after sweeping is complete (bold black lines), and of wastes captured by catch basins and OGS from sediments washed off the street (bold white lines). Prominent characteristics of each of these categories are apparent in the figure. First, sediments left on the street after sweeping are clearly finer, and thus more mobile than the initial load. Second, and interestingly, CBs have PSDs quite similar to that of the wastes the sweepers are capable of removing, particularly at the finer fractions. Hydrodynamic-type OGS clearly have capability of removing much finer fractions, particularly at design criteria and flows specified in the Permittees’ 2012 analysis of these devices performing under Anchorage conditions (PubID 018).

This figure also shows an anomaly in sweeping performance revealed by 2013 street sediment sampling. Sweeping normally results in a fining and ‘de-armoring’ of the initial street dirt load,
increasing vulnerability of the remaining sediments to rainfall washoff events. This effect is generally apparent in the residential sampling series of spring residual and summer buildup street sediments as measured by WMS in 2013. For residential stations, where sweeping occurred over a single, relatively brief period at the beginning of summer, the time series sampling data displays an overall coarsening relative to initial spring conditions. This pattern reflects the expected removal of fines with time (and concomitant coarsening of the remaining street sediment) as rainfall washoff occurs. However, the same is not true for the arterial sampling series, where 2013 sweeping was more continuous relative to the sampling events. The summer arterial sampling shows a significant fining relative to the spring residual. These differences become even more apparent when changes in the 15 percentile fractions of each of the sampling events are plotted (Figure 2).

The observed effects are believed to be due to important differences in sweeping practices between the two street types in 2013. In 2013, spring sweeping for all residential streets was performed over a very short interval during which no rainfall events occurred. As a result, a larger percentage of the total number of sweeping passes is believed to have been performed across the full street width relative to the number of passes made along the gutter. No further sweeping was done on residential streets for the remainder of the summer. A significant number of residential gutters at 2013 sampling stations were also ‘depressed’—locations where pavement overlays are not tapered to the gutter pans, resulting in a gutter pan abruptly recessed relative to the road surface. Under these conditions, 1) loads swept into or initially present in the recessed gutters would be more difficult to remove with later sweeping passes made along the gutter, and 2) fines exposed by the spring sweep event were subject to preferential mobilization throughout the series of sampling events. As washoff events occurred throughout the project’s 2013 sampling season and fines were removed, the remaining street dirt load gradually coarsened.
For arterial streets, however, spring sweeping was nearly continuous relative to the project’s arterial sampling series, with later sweeps occurring almost solely along the gutter. A larger percentage of total sweeping passes is also suspected to have been done along the gutter. Depressed gutters were not present at any of the 2013 arterial stations so that gutter sweeping effectiveness would not be reduced as it would at many of the residential stations. As a result, sweeping may have been more effective at arterial stations, particularly along the gutters, and more continuous sweeping would also achieve removal of buildup along with residual loads left by previous partial sweeping efforts. A more continuous sweeping effort made throughout the entire project sampling period may therefore have resulted in an end condition of increased overall fining despite ongoing washoff abstractions.

Like PSD, pollutant loading, which is the last critical characteristic, also strongly affects potential for particle mobilization. As discussed earlier, particulates—‘street dirt’—are a good surrogate measure of most storm water pollutants, and we use it in this project as our primary measure of pollutant loading. Pollutant loading for this project, then, is the total mass of street dirt present at any time per unit street area. Generally, the larger the street dirt load, the greater the mass washed off for a given storm size, with the more-difficult-to-treat finer fraction the most readily mobilized. Thus, a larger street dirt loading presents an increased potential for water quality impact. Conversely, reducing the street dirt load at the source (and particularly the fines and organic fraction of that load) represents a reduction in that potential.

As it is our intent in this project to evaluate performance of Anchorage’s storm water runoff controls in context with national norms, it is important to use common terminology for units of street dirt loading. Common practice includes normalizing loading as mass per unit area of street surface or as mass per unit length of street. Generally, expressing loading as a linear measurement in the form ‘pounds per curb mile’ is preferred when addressing storm water control practices, as this measure is more useful in applying loading results to analysis of total pollutant load mobilization through linear storm drain systems to single point ‘outfall’ discharges. The common definition of ‘pounds per curb mile’ is the dirt loading present across the entire curb-to-curb width of a roadway over the length of 1 mile (see e.g. PubID 115, p. 42; PubID 014, p. 156; PubID 006, p. 14). Readers should be particularly aware that the term ‘pounds per curb mile’ does not reflect loading along a single curb, but rather the loading across the full width of the street and both curbs for a length of 1 mile along the centerline of the street. We have adopted this definition and use this measure as the preferred form for expressing street dirt loading in this report. However, where use of units of mass per surface area (e.g., grams per meter$^2$ or pounds per foot$^2$) eases understanding or comparison of local conditions and performance, we show these terms as well.

Street dirt sampling efforts have been conducted over the years at communities across the nation, with many of the earlier efforts conducted under the Environmental Protection Agency-sponsored National Urban Runoff Pollutant Program implemented in the late 1970s and early 1980s. With the onset of National Pollutant Discharge Elimination System (NPDES) regulation in the mid 1990s, there has been a resurgence in these types of studies in the last decade. Results from a number of studies have been compiled in Table 2 to allow direct comparison with Anchorage loading characteristics. Studies included in the table can be linked to citations tabulated in the project references through their WMS bibliographic code, ‘PubID’.

A number of similar studies have been conducted in Anchorage, including several designed sampling efforts conducted in 1996 (PubID 021) and in 2013 for this project (see Appendix B).
Additional designed sampling was also conducted in Anchorage in 2000 and 2002 (PubID 120; PubID 121), and exploratory volumetric sampling was conducted in 2010 and 2011 (PubID 125; PubID 126). Street sediment loading in Anchorage was also inferred (PubID 018) from annual street sweeping load counts reported by the Permittees’ street maintenance groups in Permit annual reports. However, these latter data have proven to be erroneous due to poor measurement practices and are not used in this project. Excluding the street maintenance inventory data, however, all Anchorage studies have yielded generally concurring results. Results for the 1996 and 2013 Anchorage sampling studies, believed to be generally representative of local conditions, are summarized in Table 2.

The table lists Anchorage estimates of street dirt loadings for unswept end-of-winter (EOW) conditions; post-sweep conditions (i.e., amount of dirt left on the street immediately after sweeping, or sweeping ‘residuals’); and maximum summer loading conditions (the highest street dirt load measured at a station at any time during the summer period). Reports of similar estimates are shown for other national communities for comparative purposes. Where available, results are shown in units of both mass per curb mile (lbs/curb mile) and mass per unit area (gm/m$^2$). The table also includes estimates of street dirt buildup rates for summer periods. Estimates are broken into those for arterial and residential road types (generally higher average daily traffic counts (ADT) streets versus lower ADT streets). Most values in the table are reported as medians, though some estimates were only available as averages. Where the information was available, ranges are included (in parentheses adjacent to median values). Tabulated values are as reported by the cited study or as derived by this project from inspection of reported values, as necessary to allow comparisons between studies.

Values reported for Anchorage are reasonably consistent between the 1996 and 2013 studies (see particularly loading values reported by unit area). However, 1996 values are somewhat higher than comparable values reported in 2013. Some of this difference is likely due to a focus in the 1996 study to sampling near-intersection areas where winter street sand is primarily applied and loading is higher, and to a finer stratification of street types in the 1996 sampling design (four classes in 1996 and two classes in 2013).
Inspection of Table 2 shows that end-of-winter (EOW) street dirt loads are very large for Anchorage compared to other communities. This is not surprising given the unusual climatic conditions in Anchorage. The EOW values estimated in the 1996 study for arterial streets may also be biased upward by as much as 30% due to road type stratification used in that study. EOW loading estimated for 'minor arterial' road types in the 1996 study more closely matches the arterial station types sampled in 2013, and yielded a median EOW load of about 33,000 lbs / curb mile. This EOW is still 2 to 8 times the EOW load reported for other communities. The Anchorage EOW estimate for residential streets is substantially less at about 10,000 lbs/curb mile but still remains about times the norm for most other lower-48
communities. These end-of-winter values are used as initial conditions for the mass balance and performance model analyses applied in the current study.

We also used the spring sweeping residuals measured in 2013 to evaluate current performance of Anchorage sweeping practices. These residuals reflect an Anchorage EOW removal rate of about 95% for arterial roads and about 75% for residential roads. This is remarkable in terms of total waste load removed but the large removal efficiencies are not necessarily a good measure of sweeping performance from a water quality control perspective. Sweeping is very effective at high street dirt loads, with removal rates as high as 90% or more achieved even with lower performing sweepers. However, for all sweeper types sweeping performance drops off rapidly as street dirt loads decrease and/or PSDs become finer. For sweepers other than specialty designs (e.g., so-called ‘regenerative air’ sweepers), performance is asymptotic as the street dirt load decreases with the ‘base residual’—the street load at which a sweeper can no longer collect sediment—dependent upon a range of factors including remaining dirt load.

Post-sweep street dirt loads were also estimated from sample data collected in 1996 and 2013. These street dirt loads represent the unit amount of dirt left on the street after sweeping is completed and provide a much better measure of sweeping performance than does amount of EOW removed. Median values for 2013 post-sweep loadings were about 2300 lbs/curb mile and 4100 lbs/curb mile for residential and arterial streets respectively. These 2013 values conform closely to sweeping residuals reported in the 1996 work, especially when compared to ‘non-intersection’ values. Good agreement between results of these designed sampling efforts suggest that the much larger loadings (on the order of 30,000 lbs/curb mile) inferred from sweeping inventory values provided by Anchorage street maintenance groups (as part of required annual permit reports) are in error. Further investigation of this error suggests it is due to visual overestimation of the fraction of street dirt solids in the slurries typically delivered by street sweepers to waste transfer sites.

However, the sweeping residuals (dirt left on the street after sweeping) estimated for Anchorage in 1996 and 2013 are well above the sweeping residuals reported for all other studies reviewed for this project. Median values of sweeping residuals at other communities ranged from 167 to 790 lbs/curb mile for residential streets and 141 to 475 for arterial streets (Table 2). Sweep residuals estimated from 1996 and 2013 Anchorage data (2300 and 4100 lbs/curb mile for residential and arterial streets respectively) were more than double those of the worst performers for all continental United States communities reviewed. The Anchorage residuals are also well above most researchers’ estimates of best possible performance, or ‘base residuals’, for mechanical sweepers and vacuum assist sweepers, about 1000 and 500 lbs/curb mile respectively.

Observations of sweeping activities and road conditions in Anchorage studies suggest a number of reasons for the underperformance of Anchorage street sweeping. Chief among them certainly could simply be too few passes during spring sweeps. However such a shortfall may be easier to understand when one considers the dramatic visual difference between 30,000 lbs/curb mile and 4100 lbs/curb mile.

Second may be an overemphasis on full width sweeping. Though at least one full-width sweep is likely necessary, particularly in the spring when street dirt loads are largest, it has long been known that traffic rapidly mobilizes most street dirt to the gutter (PubID 115). However, in the face of limited resources and rigid application of regulatory rules for sweeping practices in
Anchorage, excessive sweeps may be completed across traffic lanes while leaving gutters underswept.

Third, there is some evidence that operators may overwater Anchorage streets in efforts to control dust during sweeping. Many street maintenance crews believe that flushing is the most effective means of cleaning streets (which it is) but are not aware of the impact it can have on water quality (through fines washoff) and reduced sweeper efficiency at removing the now too-wet fines. Anchorage streets are heavily flushed with water trucks immediately ahead of sweepers. This practice in Anchorage is evident in the common delivery by street sweepers of sand/water slurries to waste transfer sites (and as noted earlier is also the probable reason for the large overestimation of sweeping wastes inventories). Such heavy wetting significantly reduces the efficiency of sweepers, particularly vacuum types. Heavy wetting may also mobilize fine fractions into the drainage system during sweeping.

Road condition also appears to play a role in poor sweeping performance in Anchorage. ‘Depressed’ gutters reduce efficiency of all sweepers but particularly of vacuum types due to the vacuum break represented by the abrupt drop from pavement surface to gutter pan. These conditions may also require use of articulated brooms—which may not always be available—to adequately break up sediments that accumulate and compact in these constricted gutter pans.

Trackout and unrestricted parking along residential streets had an obvious local effect, as both a source of street dirt and as an impact on sweeping performance during sampling for all Anchorage studies. Unpaved alleys intersecting curb and gutter streets significantly increase local loading through trackout from exiting traffic (quantified in the 1996 study and observed and sampled randomly during 2013 sampling). Parking had singular effects as well. Though restricted parking is a relatively common practice at other communities, parking is not restricted in Anchorage during sweeping. Effects of parking are magnified beyond the footprint of the parked vehicle alone. Because of the limited turning radius of sweepers, in addition to the area occupied by the vehicle itself, the area in front of and behind the parked vehicle cannot be swept. As a result, the gutter along the entire length of the parked vehicle as well as its ‘shadow’ is left untouched by the sweeper.

**Buildup and Washoff Modeling**

Sweeping is a source control in that it removes source pollutants prior to their mobilization in storm water. The resultant sweeping residual plus any pollutant buildup occurring after sweeping and before a storm occurs represents the mass of street dirt that is available for mobilization in rainfall runoff events. The character and amount of the available street dirt along with the character of the rain event are primary factors in the amount of dirt that is in fact washed into the storm drain system. Therefore, we must have some understanding of these characteristics before we can evaluate performance of the storm water controls present along the storm drain system itself. Similarly, before we can propose any modifications to sweeping ‘practices’ (i.e., the combination of equipment and patterns of application of equipment to a sweeping task), we must begin with some understanding of the intrinsic performance capabilities of the individual pieces of equipment that make up a sweeping practice. Following are brief descriptions of these factors specific or relevant to Anchorage.
Identification of base performance of individual sweeper types is essential to assessing performance of overall current and alternative sweeping practices for Anchorage. Substantial effort has been directed towards this goal by others over the years (PubID 014; PubID 041; PubID 092; PubID 115). In general, sweeper types addressed in this report (and their performance levels) can be categorized as mechanical broom sweepers (‘mech’), mechanical broom sweepers with vacuum assist (‘vac’), and vacuum sweepers (‘regenerative air’ and ‘leaf vac’). The particulate capture estimates used in this project (by particle size and specific street conditions) are summarized in Appendix C. General applicability and performance limitations are also summarized below.

- **‘Mech’** - A mechanical broom sweeper (no vacuum assist). Dirt is collected by one or more brooms that direct the swept dirt onto conveyors that then deposit the collected dirt into hoppers. This sweeper type is most suited to sweeping streets having very heavy dirt loads and/or sweeping rough road surfaces and is well suited (particularly with application of accessory ‘articulated’ brooms) to loosening compacted dirt along gutter lines. This sweeper type is not effective at lower dirt loads (<1000 lbs/curb mile) or at removing fine particles (<67.5 µm). Under optimum conditions it has a best post-sweep residual (‘base residual’) of about 1000 lbs/curb mile. At its load limitations it can perform well under damp to slightly wet (less than saturated) conditions.

- **‘Vac’** – A vacuum-assisted broom sweeper. Similar to the mechanical sweeper, this sweeper uses brooms to direct dirt towards conveyors but also includes air intake plenums where negative pressure generated by a central fan creates a vacuum to assist collection of the dirt. This type of sweeper is a higher performing sweeper than the ‘mech’ type, particularly at removing fine particles. Under good conditions it can achieve residuals of 500 #/curb mile or better. However it does not perform as well under heavy loading conditions, or over rough road surfaces or along ‘depressed’ gutters (which can create vacuum breaks). It also is most effective under dry to damp conditions. When street dirt is wetter than this, effectiveness in fines removal is substantially reduced.
**‘Regen air’** - a regenerative air or other dry sweep vacuum sweeper designed for high performance fine-particle pickup without use of dust suppressants (usually water). Regenerative air sweepers typically recycle exhaust air through the sweeper’s intake plenum thereby reducing dust and the need for application of dust suppressing water. This sweeper can be highly effective at removing fine particles but does not perform well in wet conditions, under heavy street dirt loading, over rough road surfaces or along ‘depressed’ gutters. Regenerative air sweepers also have higher capital costs and are typically more expensive to maintain than mechs and vacs. This sweeper type is severely limited in its use by road conditions and is best considered for application only in critical areas (areas with high-density land uses and sensitive receiving waters).

**‘leaf vac’** – a vacuum that applies a relatively small-cross sectional area nozzle (about 140 to 200 in\(^2\)) yielding higher intake velocities (8,000 to 24,000 feet/minute) to increase lift forces on street dirt. For street cleaning purposes, these devices will optimally include a hydraulically articulated boom to allow placement of the nozzle closely along the gutter pan by the driver while driving the vehicle. This type of street vacuum is typically used to collect bulk fallen leaves and larger debris from curbs and curbside areas. However because of its small nozzle area we also believe it could be highly effective at removing, loosened mineral fines, comminuted organic fines (leaves, grass and other organic debris), and fallen leaves from along gutter lines, including depressed gutters.

In addition to intrinsic sweeper performance capabilities, some understanding of the rate at which sediments build up on street surfaces is also necessary to evaluate performances of overall sweeper practices. Sampling performed in 2013 provides some opportunity for a data-based approximation of summer buildup rates for residential streets in Anchorage. Researchers have long known that street dirt buildup occurs at a higher rate initially (PubID 115, PubID 002), dropping off rapidly as the system equilibrates to abstractions (sweeping, washoff, wind erosion). If the system is upset by a large abstraction event (e.g. sweeping or a large rainfall), the initial buildup rate will recur, then drop off again as an equilibrium load is re-obtained. The 2013 Anchorage buildup estimates are based on differences in street dirt loading measured over a
single 21-day interval in early spring. Thus these Anchorage estimates are measures of higher linear rates of early buildup and do not represent the overall (curvilinear) accumulation rate (buildup as it occurs over longer periods). However, inspection of the measured maximum buildup rates along with the maximum summer loads measured during the same 2013 sampling period do provide a means of approximating equilibrium conditions.

Based on the 2013 sampling data, the median initial linear buildup rate in Anchorage is estimated at 42 lbs/curb mile for residential streets (Figure 3). Estimation of this peak linear rate may be biased low by 5 to 10% due to a rainfall occurring early in the period between sampling events. Inspection of individual buildup rates for each station also suggests that important strata are present that influence buildup for residential streets that may be masked by our small (n=12) sample set. Specifically, the data display a sharp break in buildup rates between two groups of stations, with one group showing much larger initial buildup. We cannot exclude the possibility that some of the observed difference between the two groups may be due in part to inadequate composite sample size (i.e., larger than planned variability in street dirt distribution within a station not accounted for in sample design), particularly for the sites displaying larger buildup rates. However the latter were also the sites where street parking, trackout from unpaved alley and off-site parking, and organic loading from adjacent landscaping was prominent, so sources to drive the observed higher buildup rates were certainly available.

Figure 3 Anchorage 2013 Residential Buildup Rates

Though based on problematic data, the 2013 estimates of summer buildup rates for Anchorage residential streets fall well within the range of buildup rates reported for other communities (Table 2). Though there are some reports of very high buildup rates at other communities, the data collected in Anchorage in 2013 further suggests the estimates of street dirt buildup (488 lbs/curb mile) implied by Anchorage street maintenance sweeping inventory reports (PubID 018) are in error. We therefore excluded these data from further consideration and used the 2013 estimates of summer buildup rates along with measured maximum summer loads to calibrate our washoff model.
Estimating street sediment washoff is problematic for most storm water studies, but is particularly so in Anchorage. Washoff is primarily a function of rain volume and intensity and the loading and PSD characteristics of the residual sediment present on the street. Most washoff models assume relatively small residual loads (relative to current Anchorage conditions) distributed in an asymptotic pattern across the full width of the street surface and the gutter pan. Most models also assume rainfall impact plays a significant role in mobilization of particulates and fit observed washoff data to an exponential function (PubID 115; PubID 122). However analysis by Pitt (PubID 002) of data from a range of communities from across the nation suggests that the fraction of an ‘available’ load that is washed off is strongly related to rainfall intensity and street roughness. Pitt defines the ‘available’ load as that fraction of the total street dirt load, typically about 90%, that is removed at a rainfall volume of about 0.39 inches occurring over a period of several hours. For smaller storms the fraction mobilized is related to the ‘available’ load, rain intensity, and street condition and ranges from about 4.5 to 10% of the total load for low intensity rainfalls (similar to those typical of Anchorage).

For this project, where resources and data were limited, we used a simple algorithm based on this empirical analysis, weighted by particle size to recognize lower mobility of larger particles, to estimate washoff quantities in Anchorage (Appendix C). As our sum-of-loads strategy was to calibrate our model against the total seasonal washoff mass measured at a basin outfall instrumented in Permittees’ 2012 study of Anchorage sedimentation basins and OGS (PubID 018), we used our precipitation data deck for the summer of 2012 to time washoff events and assumed a mean 2012 storm size for all events. Initial (spring) post-sweep street dirt loading and buildup rates were set at median values as measured in 2013. To set up and calibrate our model we used sweeping events as performed in 2013 (spring, summer, and fall for arterials, and spring and fall for residential units) and street characteristics (arterial, residential) of the 2012 measured basin. Unit performance of OGS controls was known from experiments performed in the 2012 study and CB performance was assumed from known geometry of Anchorage devices and performance algorithms published in the literature (e.g., PubID 058; PubID 081; PubID 115). Washoff was then calibrated to achieve seasonal mass balance through minor adjustments to the percent mobilized by PSD. With the washoff model calibrated, we could then assess relative sum-of-loads performance of each of our treatment train controls (sweeping, CBs, OGS) as alternative sweeping practices were applied.

Once calibrated, we set model parameters to assess the effects of changes to ‘current’ sweeping practices on the particulate load discharged to the model ‘outfall’ (i.e., the total seasonal particulate effluent load estimated following OGS treatment). Sweeping ‘practices’ assessed included selection, timing and application of sweeper types in specific patterns along ‘arterial’ and ‘residential’ street classes. At optimized performance (minimum total and fines load discharged at the model outfall), total loads captured by CBs and OGS were noted and the required sump storage/maintenance schedules for these devices identified. Optimized street sweeping practices were identified as those that resulted in a) maximum seasonal total particulates removal and b) maximum seasonal total fines removal.

Though this washoff model had the benefits of simplicity, it did not allow us to incorporate other system factors that are well known or reflect local conditions observed during 2013 field work. For example, preferential mobilization of fines by rainfall intensities less than 0.1 inches per hour (PubID 002, p. 32) is not likely to be adequately represented by this model. This is an
important consideration given the large loading of comminuted fine organics and the common occurrence of these types of rainfall in Anchorage. Similarly, effects of large unswept leaf load on gutter scour observed by Anchorage samplers in the fall of 2013 can not readily be represented by this simple model. The latter is of some import as it reflects significant potential for increased late season mobilization of mineral sediment and loss of storm water control capacity needed for treatment of snow melt runoff. The conditions for this arise when fallen leaves become segregated from the mineral street sediments present beneath them and mobilize under moderate gutter flows to form larger surface accumulations. The leaf masses tend to become interlocked and weighted with pore water, forming surface masses relatively stable against even larger gutter flows. Runoff flows along the gutter are diverted by the stabilized leaf masses into more sinuous flow, promoting local increases in gradient, depth, and flow velocity, and concomitantly increasing scour of the now-exposed underlying mineral sediments.

**Storm Water Controls Performance**

The storm water controls considered in this project include catch basins (CBs) and hydrodynamic oil/grit separators (OGS). Their performance has been well established, by early studies for catch basins (PubID 081) and by Anchorage investigations of OGS (PubID 018). Assuming proper hydraulic sizing, the performance of both depends primarily upon the particle size distribution of the sediment load delivered to the device, device geometry, and proper maintenance scheduling. Particle sizes influent to catch basins are immediately determined by street dirt loading (in turn dependent upon street sweeping performance) and by washoff effects. In turn, particle size influent to OGS is dependent upon performance of the catch basins, i.e., the PSD of catch basin effluent. Optimum device geometry for both control types depends primarily on flow rate and the goals set for removal of each particle size expected to be received as influent to the device. Finally, optimum maintenance scheduling is dependent primarily on (scour-free) storage capacity (and so the total load expected to be captured by the device in some unit time versus protected sump capacity) and acceptable risk for occurrence of undesirable or unacceptable waste transformations with time. These factors along with critical design elements are briefly summarized in the following discussion.

Detailed studies of catch basins (PubID 081; PubID 031) show that a few simple rules will optimize performance of these devices. First, all CBs must be offline. An offline device is not located along a main storm water trunk line pipe, but rather is isolated from the main storm water pipe by a service pipe. Second, sump storage volume should exceed the seasonal or annual total influent load to a device (dependent on cleaning frequency and schedules). This volume is directly related to the contributing area to each CB and to the seasonal street dirt loading present (and therefore the street sweeping practices that are in place). Third, entrance to the CB should be rectangular rather than circular or v-shaped (to reduce scour from concentrated plunging flows from the street). Fourth, available (scour-protected) sump storage should be calculated as that volume 0.9 feet below the outlet pipe invert. However, designs providing for a surface pool about 2 feet deep below the invert can capture particles as small as about 40 µm at flow less than 32 gallons per minute (PubID 080). Finally, maintenance must occur before available sump storage is reduced below about 75% of the total (to provide minimum storage for sediments mobilized by snow melt runoff). However, waste removal at sediment depths greater than about 50% of capacity (or depths greater than about 1 foot) or at intervals exceeding about 3 years does risk increased potential for deleterious pollutants in sediment pore water as a result of chemical transformations in an increasingly reducing environment (PubID 042). These pollutants
represent increased risk to receiving waters in the case of scour, or increased costs for treatment during waste removal and disposal. CBs meeting these criteria perform well in capturing sediments as small as about 40 µm (PubID 115). Typical particle size distribution of sediments captured by Anchorage CBs (and other communities) is shown in Figure 4. The range of treatment expected for well designed CBs are reported by a number of investigators (PubID 004; PubID 011; PubID 024; PubID 031; PubID 036; PubID 041; PubID 063; PubID 079; PubID 081; PubID 095); the treatment curve used in this project is described in Appendix C.

Figure 4 PSDs of Wastes Captured by CBs in Anchorage and Other Communities

In Anchorage OGS are typically installed near or at outfalls on storm drain systems. They typically receive storm water that has already been treated by catch basins and therefore receive finer particle size distributions than that washed off the streets. Like catch basins, relatively simple rules can guide selection and design of these devices. First, type of device is critical for effective removal of the fine particulates that are the target pollutants for treatment by these devices. Only hydrodynamic-type separators should be used. Baffle box-type OGS were analyzed by the Permittees’ in a study completed in 1997 and were determined to be ineffective (PubID 022). A recent national study (PubID 063) confirmed these early Anchorage findings, concluding that these type separators are commonly subject to scour and typically no more effective than catch basins. Second, like catch basins, these devices should be installed only in an off-line position and should include momentum type bypasses with shutoff gates (where base flows exist) to allow cost effective maintenance access. Third, design should incorporate guidance summarized in the Permittees’ 2012 analysis of these types of devices (performance curves used in this project are described at Appendix C). Sump storage capacity should also match that necessary to meet 125% of total load accumulated over the planned maintenance
schedule (see e.g. Figure 5) with cleanout scheduled every three years or more frequently (as necessary to prevent exceedance of designed sump capacity). Finally, any OGS incorporating screens in their design must include annual screen removal and cleaning in the maintenance schedule. Under current (high organic) loadings, these screens are readily clogged by fine fibrous organics.

Figure 5 3 year OGS Sediment Load versus Range of Vortechs® OGS Storage Capacity

Model Results

Once we established estimates of street particulate loading, buildup and PSD characterizations, and sweeping and controls performance, we applied our empirical model to estimate timing and transport of these loads and relate treatment by the different controls over the summer season. The model we developed for this project incorporates street loading and characterization data collected in earlier studies and under the current project. Sweeping abstractions and timing were estimated using Permit-required sweeping schedules (spring, summer and fall sweeping events) and performance data developed by this project, along with estimates of the range of ‘base residual’ performance of individual sweeper types under specified surface conditions. We estimated mobilization of dirt from the street surfaces using the model’s simple washoff algorithm based on research empirically relating washoff to ‘available’ loads, rainfall intensity, and street condition (PubID 002). We used outfall discharge loading data and precipitation patterns for a basin sampled in WMS’ 2012 study of OGS and sedimentation basins (PubID 018).
along with Project street dirt loading data and estimates of street sweeper practices and storm water controls performance to calibrate the model for (summer) seasonal loading under ‘current’ conditions. Current sweeper practices performance values were as estimated for this project. Current storm water controls performance were fixed on the basis of an estimated percent of sump capacity remaining and on estimated base ranges of performance made by others for CBs and by the Permittees’ for OGS (ibid).

Using data and information compiled under this project we developed alternative sweeping practices and then ran the sweeping abstraction element of our model to estimate effects on Anchorage sweeping performance (Appendix C). Using an assumed error of 50% in sampling (a common standard used by investigators for sweeping studies) and a suitable range in sweeper performance (based on street conditions and loading) we established a ‘best’ measurable street dirt load performance threshold of 500 lbs/curb mile. Using this threshold we iterated the model, applying a range of sweeping configurations and passes, to estimate sweeping performance under the proposed modifications until an optimized pattern was identified. The optimized configuration of the sweeper train, including the number of passes and sequence for each sweeper type required to near or achieve the best threshold performance (500 lbs/curb mile), for the three seasonal events are shown in Figure 6. Performance results, including changes in total load and fines load, are tabulated in Table 3. The optimized sweeping patterns and practices applied to resolve the observed current problems are also briefly described below.

Current and optimized sweeping practices based on model results are shown diagrammatically in Figure 6. Post-sweep street dirt loading (lbs per curb mile) and seasonal total loading (lbs per summer) based on current and optimized sweeping patterns are tabulated in Table 3. Total particulates and total fines treated by the entire treatment train (i.e., including CB and OGS treatment) relative to current and optimized street sweeping practices are shown in Table 4. Estimates of unit costs ($/lbs captured, $/sweeper pass) and total costs ($/summer) under current and optimized sweeping practices conditions are summarized in Table 5.
Figure 6 Sweeping Practices, Spring Summer and Fall Sweep

**Spring Sweeping Practice**
- Mechancial Sweeper
- Vacuum Sweeper
- Leaf Vacuum Sweeper

**Summer Sweeping Practice**

**Fall Sweeping Practice**
Table 3 Sweeping Performance Results: Current and Proposed

<table>
<thead>
<tr>
<th>Arterial Sweep Residual$^1$</th>
<th>Current</th>
<th>Proposed</th>
<th>Change in Sediment Capture$^5$</th>
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<tbody>
<tr>
<td>Spring</td>
<td>4,475</td>
<td>625</td>
<td>3,849</td>
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<tr>
<td>Summer</td>
<td>1,581</td>
<td>350</td>
<td>1,231</td>
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<td>Fall</td>
<td>639</td>
<td>350</td>
<td>289</td>
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<table>
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<th>Residential Sweep Residual$^1$</th>
<th>Current</th>
<th>Proposed</th>
<th>Change in Sediment Capture$^5$</th>
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<td>Spring</td>
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<td>Summer</td>
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<td>436</td>
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<td>Fall</td>
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<tr>
<th>Annual Sweeper Load$^2$</th>
<th>Current</th>
<th>Proposed</th>
<th>Change in Sediment Capture</th>
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<tr>
<td>Total</td>
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<td>15,309,000</td>
<td>1,620,000</td>
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<table>
<thead>
<tr>
<th>Coarse Sediment</th>
<th>Total</th>
<th>Current</th>
<th>Proposed</th>
<th>Change in Sediment Capture</th>
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<td>2000 µm</td>
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<td>840 µm</td>
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<td>420 µm</td>
<td>2,833,000</td>
<td>2,838,000</td>
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<tr>
<td>250 µm</td>
<td>2,548,000</td>
<td>2,559,000</td>
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<tr>
<td>149 µm</td>
<td>1,997,000</td>
<td>2,028,000</td>
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<table>
<thead>
<tr>
<th>Fine Sediment</th>
<th>Total</th>
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<th>Proposed</th>
<th>Change in Sediment Capture</th>
</tr>
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<tr>
<td>105 µm</td>
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<td>1,358,000</td>
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<td>75 µm</td>
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<td>35.2 µm</td>
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<tr>
<td>13.1 µm</td>
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<td>6.6 µm</td>
<td>33,000</td>
<td>117,000</td>
<td>84,000</td>
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<tr>
<td>4.6 µm</td>
<td>12,000</td>
<td>58,000</td>
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</tr>
<tr>
<td>1.3 µm</td>
<td>33,000</td>
<td>117,000</td>
<td>84,000</td>
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<tr>
<td>pan</td>
<td>43,000</td>
<td>176,000</td>
<td>133,000</td>
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</tbody>
</table>

$^1$sweep residuals values in lbs / curb mile.

$^2$annual values in total lbs.

$^5$a (+) value is a proposed increase, and a (-) value is a proposed decrease.
Table 4 Treatment Train Performance Results: Current and Proposed

<table>
<thead>
<tr>
<th>Treatment Train</th>
<th>Current</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual Treatment Load</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Street Load</em></td>
<td>17,428,000</td>
<td>17,428,000</td>
</tr>
<tr>
<td><em>Sweeper Treatment</em></td>
<td>13,689,000</td>
<td>15,309,000</td>
</tr>
<tr>
<td><em>Washoff</em></td>
<td>2,584,000</td>
<td>1,056,000</td>
</tr>
<tr>
<td><em>Catch Basins Treatment</em></td>
<td>520,000</td>
<td>340,000</td>
</tr>
<tr>
<td><em>OGS Treatment</em></td>
<td>496,000</td>
<td>198,000</td>
</tr>
<tr>
<td><em>Sed. Pond or Water Body</em></td>
<td>1,569,000</td>
<td>517,000</td>
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</table>

<table>
<thead>
<tr>
<th><strong>Annual Coarse (+105 µm) Load</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Street Load</em></td>
<td>12,432,000</td>
<td>12,432,000</td>
</tr>
<tr>
<td><em>Sweeper Treatment</em></td>
<td>11,423,000</td>
<td>11,471,000</td>
</tr>
<tr>
<td><em>Washoff</em></td>
<td>390,000</td>
<td>355,000</td>
</tr>
<tr>
<td><em>Catch Basins Treatment</em></td>
<td>260,000</td>
<td>236,000</td>
</tr>
<tr>
<td><em>OGS Treatment</em></td>
<td>62,000</td>
<td>56,000</td>
</tr>
<tr>
<td><em>Sed. Pond or Water Body</em></td>
<td>70,000</td>
<td>62,000</td>
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<table>
<thead>
<tr>
<th><strong>Annual Fine (-105 µm) Load</strong></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td><em>Street Load</em></td>
<td>4,996,000</td>
<td>4,996,000</td>
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<tr>
<td><em>Sweeper Treatment</em></td>
<td>2,266,000</td>
<td>3,838,000</td>
</tr>
<tr>
<td><em>Washoff</em></td>
<td>2,194,000</td>
<td>701,000</td>
</tr>
<tr>
<td><em>Catch Basins Treatment</em></td>
<td>260,000</td>
<td>104,000</td>
</tr>
<tr>
<td><em>OGS Treatment</em></td>
<td>434,000</td>
<td>142,000</td>
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<tr>
<td><em>Sed. Pond or Water Body</em></td>
<td>1,499,000</td>
<td>455,000</td>
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*annual values in total lbs.*
### Table 5 Treatment Cost Estimates: Current and Proposed

<table>
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<tr>
<th>O&amp;M Unit Costs</th>
<th>Current</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sweeper Pass</strong></td>
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<td>-$42,622</td>
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<tr>
<td><strong>Sweepers</strong></td>
<td>-$0.18</td>
<td>-$0.15</td>
</tr>
<tr>
<td><strong>Catch Basins</strong></td>
<td>-$0.46</td>
<td>-$0.46</td>
</tr>
<tr>
<td><strong>OGS</strong></td>
<td>-$0.96</td>
<td>-$0.96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>O&amp;M Annual Costs</th>
<th>Current</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sweepers</strong></td>
<td>-$2,515,000</td>
<td>-$2,259,000</td>
</tr>
<tr>
<td><strong>Catch Basins</strong></td>
<td>-$238,000</td>
<td>-$156,000</td>
</tr>
<tr>
<td><strong>OGS</strong></td>
<td>-$477,000</td>
<td>-$477,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>O&amp;M 5-year NPV Costs</th>
<th>Current</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sweepers</strong></td>
<td>-$12,701,000</td>
<td>-$12,007,000</td>
</tr>
<tr>
<td><strong>Catch Basins</strong></td>
<td>-$1,203,000</td>
<td>-$787,000</td>
</tr>
<tr>
<td><strong>OGS</strong></td>
<td>-$2,407,000</td>
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</table>

<table>
<thead>
<tr>
<th>O&amp;M 30-year NPV Costs</th>
<th>Current</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sweepers</strong></td>
<td>-$86,500,000</td>
<td>-$78,800,000</td>
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<tr>
<td><strong>Catch Basins</strong></td>
<td>-$8,200,000</td>
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<tr>
<td><strong>OGS</strong></td>
<td>-$16,400,000</td>
<td>-$16,400,000</td>
</tr>
</tbody>
</table>

1. Cost represents annual costs / annual sweeping passes. There are 59 current passes and 53 proposed passes.
2. Unit cost values in annual $ / annual treatment load
3. Costs are represented as net present values (NPV). Costs are determined from ARDSA data, and represent relative O&M costs for MOA and DOT. Costs represent operations cost and overhead cost. Proposed sweeping costs represent planning level estimates. Further analysis is recommended to determine specific savings which should include a pilot test(s).
PART III. CONCLUSIONS AND RECOMMENDATIONS

Under State of Alaska and Federal APDES (NPDES) storm water permit requirements, Anchorage MS4 Permittees must complete and report in 2014 evaluation of the performance of street sweeping and oil/grit separators (OGS). The Permittees have elected to meet this requirement through assessment of these storm water controls in context with performance of the entire storm water ‘treatment train’ over mean summer seasonal periods using a sum-of-loads (SOL) approach.

To complete evaluation, this project has assessed and summarized Anchorage street dirt loading, character, and distribution, and particulate removal performance of local sweeping practices and storm drainage controls, including catch basins (CBs) and hydrodynamic oil/grit separators (OGS). Work has included designed sampling and testing of Anchorage street dirt; review of existing Anchorage, national, and international technical studies; development of a simple buildup, abstractions and washoff model; and application of that model along with project and national data to estimate performance of the Anchorage storm water treatment train, including street sweeping, CBs and OGS.

Based on these data and analyses, this section summarizes conclusions and key recommendations specifically for sweeping and storm water controls performance, and describes alternative strategies that could be applied to implement the key recommendations.

Conclusions

Based on work completed by this project, the Permittees’ current sweeping practices do not meet national performance norms relative to water quality protection. In addition, storm water controls (CBs and OGS) present along Anchorage’s piped storm drainage system do not sufficiently supplement current sweeping practices to otherwise provide such water quality protection. However, we also believe that current sweeping performance deficits can be readily corrected by modest changes in practices, including addition of sweeper types, changes in dust suppression practices, and modest changes in sweeper train patterns and number of passes.

In general project results demonstrate that Anchorage has summer street dirt buildup, particle size distributions, and mineral character similar to that of most other U.S communities. However, sampling performed by this project and other Anchorage studies also showed that Anchorage post-sweep residuals (street dirt left on streets after sweeping is complete) exceed by 2 to 10 times that reported for other U.S. communities. In addition, Anchorage residuals include a large fraction (on the order of 10 to 20% by weight for residential streets) of organic fines generated through comminution of vegetable matter (predominantly leaves), a significant vector for other adsorbed contaminants. Project data suggests that the unusually large post-sweep residuals and the high organic content are directly related to the extraordinarily high end-of-winter loadings unique to Anchorage.

However, project results suggest that some of the unusual sources of the sweeping problems in Anchorage may also provide unique opportunities to manage and treat street dirt here that are not available at other communities. The most unusual problem includes the very large remnant street dirt loads present at the end of Anchorage’s winters. Unlike winter sanding at any other U.S community, Anchorage’s entire winter sanding load is accumulated, frozen in the gutter at spring breakup. Under current sweeping practices, the accumulated winter sand generates a very large post-spring sweep residual, forming a primary source of the total summer street sediment.
load. In addition, the large organic loading observed in Anchorage street dirt is thought to be related to this seasonal accumulation of winter sand. Fallen leaves accumulated along the gutters are comminuted to fine fibrous organics in late fall and over the winter. Current sweeping practices, focused on aesthetic and hydraulic conveyance performance goals, remove the coarse particulates but miss these organic fines, magnifying the loading of this water quality-sensitive pollutant.

However, unusual street dirt conditions in Anchorage may also serve to leverage solutions. Analysis of current sweeping practices in Anchorage suggests that relatively simple modifications to them can dramatically improve overall winter sand removal performance relative to water quality protection. Aggressive removal of the prominent seasonal winter load, including the comminuted organic fines, during the spring sweep will dramatically reduce the overall summer street dirt load. Removal of fall leaves will also reduce the primary source of this organic loading as well as protect against suspected increased gutter scouring by fall rainfall runoff. These improvements in sweeping performance relative to water quality are also likely to be leveraged by Anchorage’s unusual climate. Anchorage enjoys a climate modified by nearby high mountain barriers such that summer rainfall volumes and intensities are quite low compared to most communities within the continental United States. These rainfall characteristics reduce potential for street sediment washoff and enhance potential for removal by simple gravity separation controls like catch basins and oil/grit separators.

In this latter regard, storm water controls (catch basins and OGS) are expected to perform at high levels in Anchorage, particularly under optimized sweeping practices. Local design criteria for these devices currently conform to recommendations described in the technical literature (PubID 115). Mean low storm volumes and intensities experienced in Anchorage also optimize for a sum-of-load performance of these devices. This will be particularly so where maintenance practices match criteria recommended in this project for device pool freeboard and sediment removal schedules.

Finally, we think it is important to note at this point that many of the sweeping problems discussed in this report (and others that are not) are not unique to Anchorage. Surveys of communities across the United States reveal similar street maintenance perspectives and street sweeping issues. Inspection of Error! Reference source not found. summarizing a number of recent surveys shows that maintenance groups commonly focus on aesthetics, public safety and maintenance of hydraulic conveyance capability as the primary criteria for sweeping performance. Given this, a focus, like that of this report, on sweeping practices that more effectively address water quality protection can easily seem extreme to the very groups that must implement them.

The high organics loading in Anchorage shown by this and other local studies is just one example of the importance of adjusting our perspective so that water quality-related performance issues can be recognized and addressed. The fact is organics (mostly fallen leaves) are a problem that plagues all communities. For many of these communities, the primary problem that the leaves present is pipe conveyance (clogging). However in Anchorage, the unique overwintering and comminution of these same leaves presents a potentially much more severe water quality problem. Of course this particular issue in Anchorage can be resolved, but solution of this, and other problems like it, are even further exacerbated given obstacles that street maintenance agencies of many other communities report, including parking, aging and inadequate equipment, and most of all limited budget. Thus, though we think that the sweeping
problems in Anchorage can be fixed, an even more important message may be that it will clearly require commitment on the part of the community to provide the resources, both monetary and political, to do so.

Table 6 Community Street Maintenance Operations Comparison

<table>
<thead>
<tr>
<th>WMS PubID</th>
<th>Pub Date</th>
<th>Source</th>
<th>Problem</th>
<th>Equipment</th>
<th>Frequent</th>
<th>Summer</th>
<th>Problems</th>
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<td>Cntr. Wshed Protect</td>
<td>Chesapeake Bay (US, n=6)</td>
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<td>51</td>
<td>56</td>
<td>8</td>
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<td>2005</td>
<td>Schilling</td>
<td>MN</td>
<td>57</td>
<td>32</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>38</td>
<td>2005</td>
<td>Schilling</td>
<td>US/Canada</td>
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<tr>
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<td>US</td>
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<td>9</td>
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<td>18</td>
<td>82</td>
<td>50</td>
<td>25</td>
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</tr>
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</table>

Recommendations

Project results and modeled performance estimates identify both weaknesses in the Permittees’ current storm water treatment systems as well as opportunities for practicable improvements. Key amongst our recommendations for system modifications include:

1. Modify street sweeping practices to improve particulate (mineral and organic) pollutant removal performance from a water quality perspective.
2. Adopt and implement optimum design criteria for catch basins and OGS
3. Develop and implement monitoring and modeling tools to support seasonal street sweeping performance assessment and long-term (5-year interval) performance evaluation of storm water systems.
4. Based on seasonal sweeping performance monitoring and long-term modeling evaluations, identify and implement modifications to sweeping practices and storm water controls maintenance schedules

Development and implementation of plans for these key recommendations should reflect best current understanding of the Anchorage storm water system and maintenance practices, and the priority needs reflected in that current understanding. Seasonal sweeping performance monitoring should be done so as to support evaluation of short-term (immediate) sweeping activities as well as to provide statistically sound data for use in long-term evaluations. Long-term characterization and evaluation of performance should be done at a system level, with performance and needs addressed from an overall treatment train and sum-of-loads perspective. At this scale of assessment, evaluation and modification to controls and practices must cover sufficient seasonal periods to be sufficiently resolute and practicable. Therefore, long-term evaluations should be completed at intervals of about 5 years or longer (to provide adequate trial periods and sufficient sampling and monitoring resolution while still approximately fitting permit regulatory review periods).

Evaluation under this current project has identified a number of practices and programs alternative to those currently employed that we believe will improve performance of Anchorage
sweeping and storm water controls performance from a water quality perspective. These are each briefly discussed below in context with the four key recommendations outlined previously.

Anchorage Alternative Street Sweeping Practices

We believe that street dirt mobilized through Anchorage storm drain systems can be dramatically reduced by relatively simple modifications to sweeping equipment, practices, and patterns. Optimum practices developed in modeling performed for this project assume three sweeping events will be performed on an annual basis in spring, mid-summer, and mid- to late fall. Spring sweeping should begin about the time gutters first become frost free, street sediments are no longer saturated, and the traffic surface is generally dry (usually mid-April to early-May depending upon the road type). Initial traffic lane passes and sufficient gutter passes using mechanical sweepers to remove the bulk of EOW loading should be completed as soon as possible after these conditions are met. The remainder of the spring sweep passes should be completed no later than the middle of June. Summer sweeping should be scheduled to begin sometime in early to mid July and be completed by sometime in early August. Fall street sweeping should be scheduled to begin in early September, with late fall leaf removal (using high velocity leaf vacuums) scheduled to be performed separate from the earlier street sweeping and no earlier than late September.

Operations under relatively wet (but not saturated) conditions are acceptable for mechanical sweeper operations. Sweeping using vacuum sweeper-types under street dirt load conditions of less than 1000 lbs/curb mile should only be done under dry to damp conditions (no flushing and minimal sprinkling). Sweeping using vacuum sweepers should not be performed on the same day that flushing or heavy sprinkling is done.

On-street parking should be restricted on the day of any sweeping. Common practice at many communities is to post permanent signs prohibiting on-street parking on one side of the street or the other on alternate days during periods of scheduled sweeping. This not only dramatically improves street dirt removal but also sweeper operational efficiency, particularly in residential areas.

Street dirt removal targets in terms of lbs/curb mile should be set for seasonal sweeper performance. Current sweeping inventory methods (hopper counts) used to assess sweeper performance do not work in Anchorage. These methods have resulted in systematic (and gross) overestimation of sweeping wastes removed (PubID 018). Preferable method would include statistically-designed collection of composite gutter samples using portable hand vacuums. Such a technique could provide immediate feedback (to sweeper operators) as well as resolute data of known confidence that would be useful in modeled long-term evaluation of overall system performance. Such sampling could also be assessed at relatively low costs (through use of seasonal compositing) for carbon content as a surrogate measure of organic fines content.

Alternative sweeping practices and patterns that are anticipated to achieve acceptable sweeping goals in Anchorage from a water quality perspective are briefly described below.

**SPRING SWEEP**

- **Problem:**
  - Very large end-of-winter load (EOW)
  - Rough roads/depressed gutters
High organic content (leaves comminuted by fall sweep/winter weathering)
Post sweep residual substantially greater than national norms
Heavy wetting (flushing) during sweeping to suppress dust on large EOW

Solution:
Sweep full width only as necessary to mobilize load to gutter (if done at late winter/early spring while gutter pan still frozen, apply brine as wetting only to agglomerate fines and provide single full width sweep) and sweep only to edge of frozen gutter
Focus all other sweeps on gutter
Stage mechanical sweepers for all initial (heavy loading) passes (no flushing but heavy wetting for dust suppression is acceptable) until load reduced to below about 1000 to 2000 lbs/curb mile
Below 1000 to 2000 lbs/curb mile threshold, dry gutter for approximately 12 to 24 hours then stage passes with vacuum assist sweepers (dry to damp acceptable)
Polish with final sweep using high entrance velocity leaf vacuum sweeper along gutter only to remove fines

Spring sweep schedule:
Arterial
Post parking restrictions at all arterial streets
At first seasonal bare streets (after March 15), perform one sweep along the trafficking surface only w/mech/vac w/brine application to collect street dirt from trafficking surface and to move bulk EOW street dirt into gutter pack (frozen, not swept, brine may help agglomerate fines and improve sweeping performance later in the spring. This trafficking surface sweep could also be performed as a final spring sweeping pass (without the brine) if early spring sweeping is found to be infeasible.)
At full gutter thaw, perform sweeps w/mechanical sweepers along gutter only until loading at gutter zone (10 feet from the gutter face) is less than a selected effectiveness threshold (less than 2000 lbs/curb mile to about 1000 lbs/curb mile). Sweeping under wet (not saturated) conditions is acceptable using mechanical sweepers to a threshold of about 2000 lbs/curb mile. At lower street dirt loadings all sweeping must be performed under dry to damp conditions (dry to very light sprinkling just sufficient to suppress dust).
Dry gutter for 12 to 24 hours and perform additional sweeps with a vacuum assist sweeper along gutter only until loading at gutter zone is less than a selected effectiveness threshold (about 500 lbs/curb mile). Sweeping may only be done under dry to damp street dirt conditions.
Perform one sweep with high entrance velocity leaf vacuum along gutter only.

Residential
Post parking restrictions at all residential streets
After full gutter thaw, perform one or more full road width sweeps w/mechanical sweeper to collect street dirt from trafficking surface and to move bulk EOW street dirt to gutter.
• Perform additional sweeps with mechanical sweeper along gutter only until loading at gutter zone is about 1000 lbs/curb mile
• Dry gutter for 12 to 24 hours and perform additional sweeps with vacuum assisted sweeper along gutter only until loading at gutter zone is about 500 lbs/curb mile.
• Perform one sweep with high entrance velocity leaf vacuum along gutter only at all residential streets.

SUMMER SWEEP

Problem:
• large residual street dirt load from spring sweeping along gutters
• large gutter buildup at commercial/light industrial routes
• high organic buildup along roads with extensive landscaping and trees (grass clippings, seeds and hulls, leaves)
• rough roads/depressed gutters
• parking blocking sweeper access to curbs
• unpaved alley and on-site parking trackout
• post sweep residual 4-5x national norms

Solution:
• sufficient spring sweep passes to reduce spring residual loading
• installation of unpaved alley and parking trackout breaks
• sweeping focused on gutter where street dirt collects
• polish with high entrance velocity vacuum (leaf vacuum) at gutter only

Summer sweep schedule:

Arterial
• Perform one or more sweeps with mechanical and vacuum assist sweepers along gutter only until loading at gutter zone is about 500 lbs/curb mile).
• Perform one sweep with high entrance velocity leaf vacuum along gutter only at all arterial streets.

Residential
• Perform one sweep with mechanical and vacuum assist sweepers along gutter only until loading at gutter zone is about 500 lbs/curb mile).
• Perform one sweep with high entrance velocity leaf vacuum along gutter only at all residential streets.

FALL SWEEP

Problem:
• large residual street dirt load from spring sweeping along gutters
• large gutter buildup at commercial/light industrial routes
• large late-fall leaf buildup along gutter at landscaped streets
• rough roads/depressed gutters
• parking blocking sweeper access to curbs
• unpaved alley and on-site parking trackout
• post sweep residual 4-5x national norms

Solution:
• more spring sweep passes to reduce spring residual loading
• restricted parking during street sweeping
• installation of unpaved alley and parking trackout breaks
• sweeping focused at gutter where street dirt collects
• late-fall sweep with high entrance velocity vacuum at gutter only

Fall sweep schedule:

*Arterial*
• Perform one or more sweeps with mechanical or vacuum sweeper *along gutter only* until loading at gutter zone is about 1000 lbs/curb mile.
• Perform one or more sweeps with vacuum *along gutter only* until loading at gutter zone is about 500 lbs/curb mile.
• At post leaf-off (late September), perform one sweep with high entrance velocity vacuum (leaf vacuum) *along gutter only along landscaped* arterial streets only.

*Residential*
• Post parking restrictions at all residential streets
• At pre-leaf off, perform sweeps w/vacuum *along gutter only* until loading at gutter zone is about 500 lbs/curb mile.
• At post-leaf off (late September), perform one sweep using a high entrance velocity vacuum (leaf vacuum) *along gutter only* at all residential streets.

**Anchorage Alternative Storm Water Controls Practices**

Catch basin storm water controls are designed to standard specifications that generally match optimum geometry suggested in the technical literature (PubID 115). Hydrodynamic OGS were experimentally evaluated for Anchorage-specific conditions and design criteria recommended for these devices in work done by the Permittees in 2012 (PubID 018). Recommendations of the latter document should be implemented in the Permittees’ design standards. Sump design and maintenance (cleaning) scheduling for these devices should also be established that match loading and washoff estimates made in this (and future evaluation) study. Until more detailed analysis of snowmelt washoff loading can be obtained, Sump capacities should be designed at 125% of the capacity estimated by this project.

**Anchorage Alternative Monitoring and Evaluation Practices**

Finally, we do not, and readers should not, consider this project to be a final word on performance for the Anchorage storm water systems addressed in this project. Resources were limited in completion of this study. Assumptions had to supplant data in many instances and our analyses, including our particulate abstraction and transport model, must be considered exploratory. Although we do believe that the results of this project are useful representations at a
planning level of current conditions for Anchorage systems (including street sweeping performance), they should be expanded and refined and our methods supplanted with more robust and conventional techniques to ensure not only that improvements take place but also that those improvements are practicable and effective.

Though these current findings are believed to be generally representative of conditions in Anchorage, the information presented here of current sweeping and treatment train performance (with respect to water quality) remains limited as a basis for making detailed management decisions. Practicable and cost effective management requires reliable performance information at the overall scale of the system—and not at the scale of just one of its parts. Similarly, given the complexity and stochastic (precipitation-driven) nature of storm water systems, systems information is reliable only when developed at a seasonal (sum-of-loads) scale. Of course, at these scales, system interactions become more complex and timelines for resolution of effects of management implementations become longer. Nevertheless, in our opinion analysis at this scale remains the only viable approach for confidently identifying, resolving and correcting overall performance problems. Therefore, we recommend that the Permittees undertake monitoring and system modeling at this scale. Important elements to such a program include system monitoring, development of systems models to assess ongoing performance and alternative management options, and periodic implementation of management improvements reflecting monitoring and assessment results.

Assessments at this scale require appropriately scaled tools and timelines. Monitoring for sweeping performance, for example, should include statistically-designed, but simple, vacuum sampling of gutters. Costs for such monitoring can be minimized by use of sampling and field tests focused on critical parts of the system (e.g., the gutter vs. the entire street width). Nevertheless, this low-cost data is useful both at the moment (to provide immediate tests of sweeping performance for example) but, obtained over the years, provides invaluable system-scale information as well.

However, to be useful at the larger scales (of both system and time), such data requires a means of placing it in a larger context as well. A storm water treatment model scaled to an SOL seasonal level provides such a framework. A utilitarian storm water model inclusive of street sweeping can be inexpensively developed using public or proprietary software (e.g., WinSLAMM or SYMPTM). However, a long-term model will only generate useful predictions to the extent it is calibrated and validated using data collected over the longer term. For this reason, we recommend that model development be explicitly set to an appropriate timescale as well. Given the Permittees’ standard permit term length of 5 years, we recommend that schedules for development and implementation of such a monitoring and evaluation program be set as follows:

- **Monitoring implementation, 0 – 2nd year**: develop and implement statistically-designed sweeping performance monitoring and data collection (used as a basis for both event-by-event sweeping performance checks and permit term SOL modeling performance evaluations);
- **Model implementation, 0 – 5th year**: select, develop, and calibrate a storm water controls evaluation model (including first term period model-based program recommendations for performance improvements);
- **Controls modifications, 5th – 6th year**: implement selected controls improvements, and
• Re-evaluation, at each succeeding 5th – 6th year intervals (end of each permit term): re-evaluate system performance (through data and model analysis) and recommend and implement modifications.
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Municipality of Anchorage

Anchorage Street Sweeping and Storm Water Controls: 2013 Performance Evaluation


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TECHNICAL APPENDICES
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A. PROJECT TECHNICAL SUMMARY
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A.1 Project History (performance of project summary)

In 2013 the Municipality of Anchorage (MOA) Watershed Management Services (WMS) evaluated the street sediment concentration of residential and arterial streets. This study and sample data was used in conjunction with an economic and performance evaluation of the municipal separate storm sewer systems (MS4) as required under permit AK52558.

The street sampling and evaluation was intended to determine: 1) the street sediment loads and characteristics relative to street sweeping activities; 2) a current and proposed planning level performance / benefit of storm water treatment structures and practices, and 3) assess economic cost of different storm water treatment structures and practices (storm water controls).

A.1.1 2013 Street Sediment Sampling

The Watershed Management Services (WMS), Municipality of Anchorage Public Works Department completed sampling of street sediments in the spring and summer of 2013. Samples of street particulates were collected from both arterial and residential street surfaces to estimate loading and character of particulates on these street surfaces relative to street sweeping activities. Appendix B of the study details the procedures and findings of this sampling effort.

A.1.2 Storm Water Controls Performance Evaluation

The storm water controls performance evaluation looks at the three primary treatment controls utilized by the MOA: street sweeping, catch basins, and oil and grit separators (OGS). Secondary consideration is given to the impacts of these controls on downstream treatment by sedimentation basins and/or impacts of receiving waters. The performance evaluation analyzes the separate storm water controls in a connected systems model to describe the degree of impact one practice has on the others. The systems model determines the most probable distribution of sediment capture within the MS4 controls during a typical summer. Further, the systems model also evaluates storm water treatment performance for two separate scenarios: 1) MOA’s current Operation and Maintenance (O&M) procedure, and 2) MOA’s proposed O&M procedures. The results from this analysis include:

- The quantity of sediment collected by street sweepers
- The quantity of washed off street sediment
- The quantity of washoff sediment collected by catch basins
- The quantity of washoff sediment collected by OGS
- The quantity of sediment transported to sedimentation ponds and receiving waters
- The expected change in sediment distribution between current and proposed O&M procedures

These results are intended to show the relative water quality impacts of MOA’s primary storm water controls and how the altered O&M procedures could benefit MOA and water quality at the end of the system.

A.1.3 Storm Water Controls Economic Evaluation
The storm water controls economic evaluation analyzes the cost of the three primary treatment controls for ARDSA. This analysis utilized only ARDSA 2012 economic data, but approximately reflects Alaska Department of Transportation and Public Facility (ADOT&PF) annual O&M costs for similar practices. Results from this analysis look at two parameters for the current and proposed ARDSA O&M procedures:

1. Unit costs for each control normalized to the quantity of sediment captured
2. Several Net Present Values (NPV) calculations that determine the costs of the current and proposed ARDSA O&M procedures

The results of this analysis identify the differences between current and proposed ARDSA procedures and serve as guidance for O&M procedural modifications.