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## WINTER SAND RECOLLECTION BY HIGHWAY DRAINAGE

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**Abstract** Roadway sanding is a common practice in cold regions because sand increases the roadway friction when mixing with snow. However, after snow melt, sand imposes potential hazards to the traffic. Recovery of sand from highways has become an increasing concern not only for the reason of traffic safety, but also for being nonpoint pollution sources to nearby wetlands and streams. In this study, a snow storage element is introduced to the renascence project of a mountainous highway which is running through an environmental sensitive forest area in Colorado. Recovery of winter sanding material from the highway is designed to be a joint effort of surface runoff and sweeping machines. As a tradeoff exists between sand recovery and size of snow storage area, this study also presents a maximization methodology by which the size of snow storage area can be determined by the diminishing return of sand recovery.

*Key Words: Snow, Sand, Recovery, Basin*

### INTRODUCTION

The year-round use of highways is expected by the public and essential to the national economy. As indicated by the Transportation Research Board in 1991, removal of snow and ice from highways costs \$1.5 billion every year in the United States. Sanding, deicing, plowing, and sweeping are major elements for highway winter maintenance. In the State of Colorado, the average annual sanding material applied to the traffic lanes of Interstate Highway 70 (I-70) near Eisenhower Tunnel is approximately 4.58 pounds per square foot (Moser 1996). At higher elevations such as the Berthoud Pass corridor on Highway 40 in Colorado, it consumes an annual amount of 7.25 pounds of sand per square foot by the traffic lane surface (Sato 1997). Sanding is important to public mobility and safety because it rapidly provides more drivable and less hazardous road conditions during winter months. However, snow blowing, sweeping, and melting processes result in pollution to surface runoff water and often impact on water quality in wetlands and streams nearby the highway. For instance, on Berthoud Pass over Highway 40 in the State of Colorado, the snow-sand mixture on such a mountainous highway can be either stacked up by sweeping machines along the shoulders or blown away by air blowers to the adjacent mountainous slope areas, depending on the availability of storage space. Over years, piles of highway sanding material have been eroded and washed by surface runoff towards nearby streams. How to effectively control and collect winter sanding material has been one of the major concerns for highway drainage designs and maintenance in cold regions.

In the Berthoud Pass renascence project, a snow storage element was introduced to the roadway drainage system. In the winter, snow mixed with sand can be piled up to the maximum capacity of a storage area. Recovery of sand can be achieved by snowmelt runoff washing at first, and then machine sweeping later. For the purpose of sand recovery, the wider the storage area is, the more snow-sand mixture is captured. However from the cost point of view, "the narrower, the better." This paper presents an approach by which the size of snow storage area can be determined by the diminishing return of sand recovery.

### SAND RECOVERY DRAINAGE SYSTEM

Figure 1 shows a typical roadway cross section which incorporates sand recovery functions into a highway drainage system. The essential elements in the drainage system include

1. *snow storage area* which is the open space on both sides along the highway shoulders. These areas are designated for snow piling in winter or as a bike path in summer.

2. *roadway drainage system* which is a shallow triangular channel running through the centerline of the storage area. It transports the sand-laden water to a downstream collection system.
3. *collection system* which can be a crossing culvert for direct runoff release or a sand basin for extended runoff release, depending on the sensitivity to the local natural streams. When a sand basin is installed, the sedimentation process will separate sand particles from water.

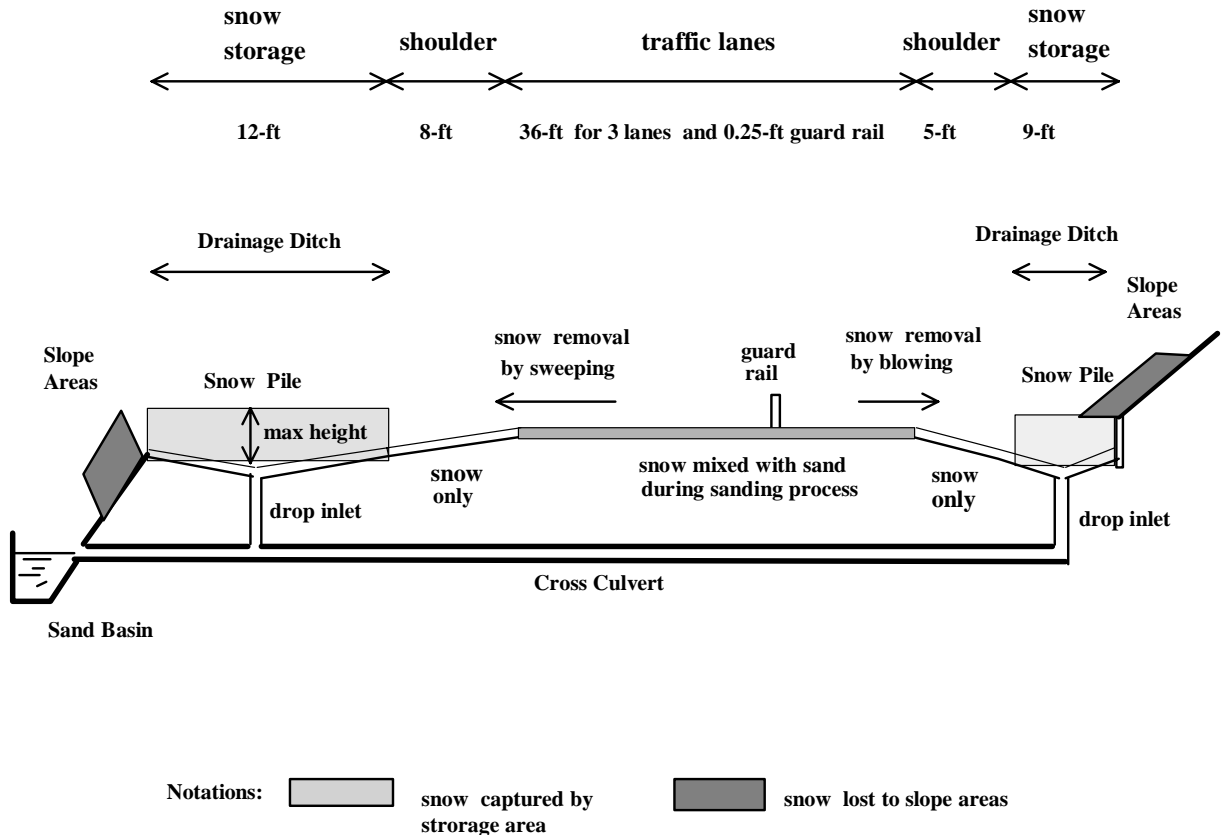


Figure 1 Illustration of Snow Storage Element in a Roadway Section

Of course, additional facilities such as trash racks at inlets, outlet protections from erosion, and esthetic designs are also necessary to maintain the functional integrity of the systems.

## SAND RECOVERY RATE

In this study, the sand recovery rate is defined by the ratio of the annual sand amount collected by the highway drainage system to the annual sand amount applied to the highway. During a snow plowing operation, sand is only applied to traffic lanes. Between two adjacent cross culverts under the highway, the annual sand amount can be estimated as:

$$W_s = w_s B_t L \quad (1)$$

in which  $W_s$  = sand amount in pounds or kilograms,  $w_s$  = annual unit sand amount such as 7.25 pounds/square foot used for Berthoud Pass (Sato 1977),  $B_t$  = width of traffic lanes in meter or feet, and  $L$  = distance of the highway between two adjacent culverts in meters or feet. Snow plowing and blowing process is to remove the snow from the

traffic lanes and shoulders to the storage area for compacting and piling. The compacted snow volume between two adjacent culverts can be estimated as

$$V_s = nmP_sBL \quad (2)$$

in which  $V_s$ = compacted snow volume in cubic meters or feet,  $P_s$ = equivalent water depth to annual fresh snowfall depth,  $n$  = snow compact ratio defined as one-ft fresh snowfall equivalent to  $n$ -ft compacted snow,  $m$  = snow-to-water depth ratio defined as  $m$ -ft fresh snowfall to produce one foot of water, and  $B$  = total width of the paved highway area including traffic lanes, shoulder areas, and storage areas. Snow plowing and piling along a highway can be a joint effort of shoveling and blowing. Tabler in 1994 conducted a study on the stability of compacted snow piles and suggested that snow be stacked up to a maximum height of 7.5 feet during highway snow removal operations. In this study, the capacity of a storage area is defined using the maximum snowpile height as:

$$V_c = H_m B_s L \quad (3)$$

in which  $H_m$ = maximum height of snow pile,  $B_s$ = width of storage area,  $V_c$ =snow capture volume. As illustrated in Figure 1, the excess snow will be lost to and spread over the hilly areas adjacent to the highway. Therefore, the capture rate of the snow volume from the highway paved surface by the storage area is defined as:

$$r = \frac{V_c}{V_s} \quad (4)$$

in which  $r$  = snow capture rate by storage area. Since snow and sand will be well mixed during the plowing process, the corresponding sand amount in weight,  $W_c$ , captured by the snow storage area is:

$$W_c = rW_s \quad (5)$$

In this study, a shallow and wide drainage ditch with a side slope of 1:10 is built through the storage area. This ditch collects and delivers sand-laden snowmelt runoff to a downstream drainage facility. The sand amount transported through the ditch can be estimated by the event mean concentration (EMC) method as (Urbonas et al. 1996, and Mosier 1996):

$$W_b = \gamma_s E_w V_o \quad (6)$$

in which  $W_b$  = sand amount in weight transported,  $E_w$  = empirical value of EMC,  $\gamma_s$  = specific weight of sand such as 110 to 150 pounds/cubic foot, depending on the sand consolidation in a sand basin, and  $V_o$  = total annual runoff volume. In the early summer, the total runoff volume from the paved area consists of the snowmelt runoff from the storage areas and storm runoff generated by rainfall events. Therefore, the total runoff volume is

$$V_o = C(rP_s + P)BL \quad (7)$$

in which  $C$  = runoff coefficient, and  $P$  = total rainfall depth during the snowmelt season. The ditch through a snow storage area is designed to be intercepted by a cross culvert which may or may not drain in a sand basin. Obviously, without a sand basin, the sand-laden water will be directly released to the slope areas. As a result, the amount of sand transported through the ditch becomes a loss to the effort of sand recovery. On the contrary, with a basin, the sedimentation process in the basin shall be designed to provide sufficient sand capture. After the snow has melt, the sand remained in the storage area needs to be collected by sweeping machines. The recovery of sand by machine is estimated as

$$W_m = R_m(W_c - W_b) \quad (8)$$

in which  $R_m$ = efficiency of sand collection by machine such as 0.80 to 0.90, depending on field operations. Therefore, the sand recovery,  $W_t$ , between two adjacent culverts is the sum of Eq's 6 and 8 as

$$W_t = W_m + eW_b \quad (9)$$

in which  $e = 1$  for sand collection with a basin, or  $e = 0$  for direct release through a culvert to the environment.

## CASE STUDY

Berthoud Pass over Highway 40 is located in north-central Colorado approximately 50 miles west of Denver. Berthoud Pass is an important route to the central area of Colorado. It was opened in 1884 and paved in 1938. The average elevation is 10,500 feet above the mean sea level. Over years, the annual average sanding material applied to the roadway surface is approximately 7.25 pounds per square foot of traffic lanes. Winter maintenance operations have resulted in increasing concerns about pollution to the local wetland areas and streams. During the 1997 renaissance project, the typical roadway cross section was developed for this 6.2-mile mountainous highway as shown in Figure 1. The total width of three traffic lanes is 36 feet. The widths of left and right shoulders are 5 and 8 feet. Therefore, the following design variables are defined as:

$$B_t = 36 \text{ feet and } w_s = 7.25 \text{ pounds/sq ft}$$

Table 1 is the summary of the monthly rainfall and snowfall distributions recorded at the Berthoud Summit station operated by the Soil Conservation Service from 1951 to 1996. Based on the 46-year records, the snow compact ratio was found to be 0.43 and the snow-to-water ratio is 3.50. At the project site, the annual snowmelt runoff is approximately 20.30 inches which only occurs from May through July. In addition, the total rainfall depth from May through October, before the first snow, is approximately 13.8 inch. As a result, on an annual basis, the following variables can be determined as:

$$m = 3.5, n = 0.43, P_s = 20.30 \text{ inch, } P = 13.8 \text{ inch, and } C = 0.95 \text{ for highway pavement.}$$

In this study, the two-year field data collected from the project: *Efficiency of Sediment Basins*, sponsored by Colorado Department of Transportation, was analyzed. There were 11 sediment basins constructed at outfall points from Interstate Highway 70 to Straight Creek in 1994. These basins were located within six miles west of Eisenhower Tunnel and designed to capture the sand applied to Interstate Highway 70 and sediment from cut slope areas along the highway. Among these 11 basins, there are four basins tested for collections of winter sanding materials from paved roadway areas only. The annual precipitation for these basin sites is approximately 40 inches. Table 2 presents the results derived from field data observed from 1994 to 1996. The mean concentration of sand in snow/rainfall runoff from Interstate Highway 70 ranged from 5036.10 to 13370.19 mg/liter. In this study, the sand recovery rates for Berthoud Pass are investigated using these two values as the upper and lower limits for the EMC method.

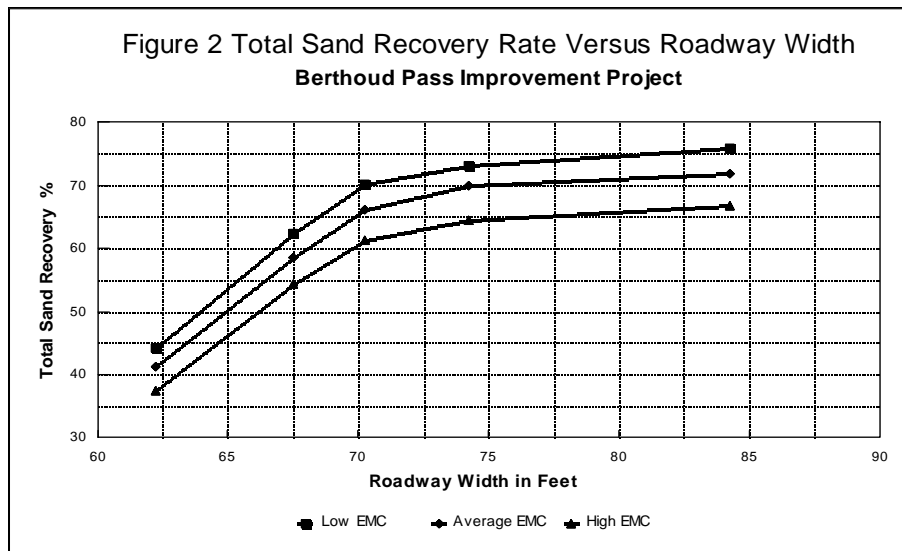
Berthoud pass runs through an environmental sensitive forest area. In order not to change the drainage patterns, the 21 existing culverts at the project site are upgraded in size and remain at the same locations. Among these 21 culverts, there are 13 culverts which drain to slope areas, and another 8 culverts directly drain towards streams or wetland areas. The decision was made for this project that a total of eight sand basins shall be constructed at the direct outfall points to natural streams or wetland areas.

Eq's 1 through 9 are derived for the sand recovery rate between two adjacent culverts. For this project, the total sand recovery rate,  $R$ , for the 13 culverts without a sand basin ( $e = 0$  in Eq 9), and 8 culverts with a sand basin ( $e=1$  in Eq 9) can be integrated as:

$$R = \frac{\sum_{i=1}^{i=N} (W_m + eW_b)_i}{\sum_{i=1}^{i=N} (W_s)_i} \quad (10)$$

in which  $i = i$ -th culvert and  $N =$  total number of culverts; for this case,  $N=21$ . As illustrated in Figure1, the widths for traffic lanes and shoulders have already determined by the traffic needs and safety. Therefore, the width of snow

storage becomes a design variable. For instance, considering 9 and 12-foot snow storage widths as shown in Figure 1, Table 3 summarizes the total sand recovery calculations for a roadway width of 70.25-ft. Applying the average EMC value to sand transport through ditches, the total sand recovery rate for 21 culverts with 8 basins is estimated to be 67% which includes 29% of the annual sand amount captured by sand basins and 38% of the annual sand amount collected by sweeping machines. Repeat the same procedure for the high and low EMC values. As shown in Figure 2, the sand recovery rate does not seem to be sensitive to the value of EMC for this case. The high value of EMC is approximately 2.5 times the low value, but the total sand recovery rate only varies between 70.22% and 61.24% for a roadway width of 70.25 feet for Berthoud Pass. This fact can be explained by the complimentary effort of sweeping machines.



Since a tradeoff exists between the width of snow storage area and the total sand recovery, a sensitivity study was conducted for the range of roadway width between 63.25 feet (with 9- and 5-ft snow storage widths) to 84.25 feet (with 15- and 20-ft snow storage widths). Figure 2 presents the variations of total sand recovery rate versus width of roadway. As expected, the wider the snow storage area, the higher the total sand recovery rate. However, a clear diminishing return on the sand recovery rate is observed in Figure 2 (Guo and Urbonas 1996, Guo 1998). The increasing sand recovery rate for a roadway width of 70.25 feet is close to the average sand recovery rate for the range of case study. Figure 2 indicates that a roadway width exceeding 70.25 feet is discouraged because of the diminishing return on sand recovery. It implies that a roadway width wider than 70.25 feet will result in an increasing sand recovery rate less than the average rate. On the contrary, a roadway width less than 70.25 feet is encouraged to be widened up because an increasing roadway width produces an increasing sand recovery rate greater than the average rate. Therefore, the roadway width of 70.25 feet is considered as a break even point as far as the sand recovery rate is concerned, and recommended for Berthoud Pass improvements.

## CONCLUSION

Recovery of winter sanding materials from highways in a cold region has been an increasing concern not only for the reason of traffic safety, but also for being a non-point pollution source to nearby streams. In this study, an innovative concept of snow storage area was developed for the purpose of sand recovery from highways. With a snow storage area as part of highway drainage system, the recovery of sand can be a joint effort of surface runoff and sweeping machines.

The methodology developed in this paper has been applied to the Berthoud Pass improvement project in the State of Colorado. Field data collected and analyzed for the Berthoud Pass project site provide an example to illustrate how the design procedures can be integrated using the local hydrologic data, drainage patterns, and empirical EMC values for a pre-selected roadway section. In practice, to select a roadway section can be challenging because

a tradeoff exists between sand recovery rates and construction costs of highway. In this study, the concept of diminishing return using the sand recovery rate as a basis was further developed and applied to the determination of the width of snow storage area. Using the Berthoud Pass project as an example, the most efficient roadway width was found to be 70.25 feet which includes snow storage areas of 9 and 12 feet wide along the roadway. For such a roadway section, this method predicts that a total of 29% of the sand amount applied in winter can be recovered by runoff washing and 38% of the sand amount can be recovered by sweeping machines.

This paper presents a design methodology for estimating the sand recovery rate from highways. The optimal values derived for Berthoud Pass may not be transferable to other locations, but the design procedures shall be legitimate when the local hydrologic parameters and EMC values are available.

## APPENDIX I

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## APPENDIX II

B = width of the paved highway area

$B_t$  = width of traffic lanes

$B_s$  = width of storage area

C = runoff coefficient

$E_w$  = the empirical value of EMC

e = one for sand collection in a basin or zero for sand release through a culvert

$H_m$  = maximum height of snow pile

L = length of the highway section.

m = water-to-snow depth ratio defined as m-ft fresh snowfall to produce one foot of water

n = snow compact ratio defined as one-ft fresh snowfall equivalent to n-ft compacted snow

P = rainfall depth

$P_s$  = equivalent water depth to annual fresh snowfall depth

r = snow capture rate by storage area

R = total sand recovery rate

$R_m$  = efficiency of sand collection machine such as 0.85.

$V_c$  = captured snow volume

$V_s$  = compacted snow volume

$V_o$  = total runoff volume

$W_s$  = sand amount in weight applied

$w_s$  = annual unit sand amount

$W_b$  = sand amount in weight transported by runoff

$W_t$  = the total sand recovery

$\gamma_s$  = specific weight of sand

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