

Preliminary Study of Melting Snow and River Ice by Dusting Using Leaf Mulch

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ABSTRACT

Dusting ice with a dark material has been used on northern rivers to weaken river ice, with the objective of preventing ice jams during spring runoff. River sand, coal slag and fly ash have been commonly used to melt ice. However, introduction of these materials to rivers can adversely affect the fish habitat. We explored the use of leaf mulch as an alternative dusting material that can be used in place of sand, etc. This report summarizes the field work that has been carried out by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) during the springs of 1993 of 1994, studying the effectiveness of leaf mulch and other biodegradable dusting materials in comparison to previously used dusting materials. We found that the leaf mulch is effective in lowering the albedo of the white ice surface from 0.5 to 0.2, which is comparable to the albedo of coal slag or sand on ice. During the spring of 1994 leaf mulch was spread on the ice using a hydroseeder. We found we could dust 8000 m² (2 acres) in about 20 minutes using the hydroseeder. Our field tests showed that leaf mulch is effective at melting the snow cover on top of the ice. This allows the sunlight to start melting the dusted ice sooner than the undusted ice. We also found that the leaf mulch was as effective at melting the ice cover as sand and other materials.

Key words: Dusting, Ice weakening, Hydroseeding, Leaf mulch, Snowmelt

INTRODUCTION

Decay of river ice depends not only on the ambient air and water temperature, but also on the absorption of solar radiation into the ice. Ashton (1985, 1986) shows that once the ambient air temperature reaches freezing, the rate of deterioration of the ice cover (i.e., structural weakening of the cover) depends greatly on the absorption of the solar radiation by the ice cover. Thus reduction of the albedo (reflected solar radiation/solar radiation incident to the surface) of the ice sur-

face can contribute to accelerated decay of an ice cover, which can reduce the potential for ice jam formation on a given river reach during ice breakup.

Dusting (the application of a dark material to a snow/ice surface) can be used to hasten ice cover deterioration by reducing the albedo of the snow/ice surface (for a review of dusting applications, see Slaughter 1969). Typical albedo values for "black" or clear ice are about 0.2 (Perovich 1992), while "white" ice—which contains air bubbles, snow ice or frazil—can have albedo values as high as 0.6 to 0.8 (Prowse and Demuth 1992). Albedo values for fresh snow can be as high as 0.9. However, as snow ages the albedo decreases. A typical value for this old snow is around 0.5 (Colbeck 1988). Depending on the type of "dust" used and the amount applied, dusting can reduce the albedo of a snow or ice surface to 0.15 to 0.2 (Williams 1967). Thus, dusting can be used to increase absorption of solar radiation in all but black ice. However, if there is snow on top of this black ice, dusting can be used to accelerate the ablation of the overlying snow, allowing the sunlight to melt the ice faster than would naturally occur.

The dust material is frequently put on ice the using an aircraft. Examples of this include dusting operations on Yukon River in Galena, Alaska (U.S. Army Corps of Engineers 1968) and on the Platte River near Omaha, Nebraska (U.S. Army Corps of Engineers 1979, 1994). The first few years that the Yukon River was dusted, a modified B-25 aircraft was used to spread river sand on the ice. More recently crop dusting aircraft have been used to spread the river sand on the ice. The dusting operations that have been carried out on the Platte River use crop dusting aircraft as well; however, coal slag has been used for the dusting material on the Platte.

Although aircraft are well suited for dusting large rivers, there are many rivers, such as those found in New England, cannot be dusted using aircraft because they are narrow, and have trees and dwellings that line the riverbanks. We found it necessary to develop a new way to apply dusting materials on these small rivers.

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Also, coal dust and slag is considered a threat to the riverine aquatic life due to the contaminants they contain. Additionally, small particles such as sand, coal dust, and slag can also be a problem in many New England rivers, since they can clog the spaces between rocks where fish lay their eggs and thereby inhibit reproduction. The above environmental concerns led us to explore the use of biodegradable dusting materials that might be more environmentally friendly.

This paper details the use of leaf mulch, which was spread on two rivers in Vermont using a hydroseeder. We describe the performance of the leaves as a dusting material, and the usefulness of a hydroseeder in applying the leaves.

EVALUATION OF DUSTING MATERIALS

During the winters of 1993 and 1994, several dusting tests were conducted on an ice-covered pond at CRREL in Hanover, New Hampshire. Figure 1 shows a typical test plot setup on the pond. The purpose of these tests was to evaluate the effectiveness of several organic dusting materials at melting snow and ice. During these tests the snow and ice thickness was measured and compared to a control area that was not dusted. We also measured the albedo of these materials and of the snow.

Dusting tests

In March of 1993 four, 65-in.- (1.65-m-) square test plots were marked on the pond's surface. In this test we compared the performance of bark, hay and leaves

to sand. Each test square was dusted with 960 mL of material, one material on each square. The control was the ice cover adjacent to the test squares. All the test materials were immersed in water overnight and were applied wet to prevent them from blowing away. A day after this test was started (20 March) 7.5 cm of snow fell. Within two days of the snowfall (22 March) the snow over the test plot with leaves had melted off. The other test materials also melted the overlying snow more quickly than untreated areas, but they did not become uncovered until the 26th of March, 4 days after the leaves were exposed. Due to heavy snowfalls the remainder of the winter no further evaluations could be made.

On 18 February 1994 a test site was again set up on the pond with five test squares. There was 30 cm of ice and between 5 and 10 cm of snow on the test area. Again, hay, sand, bark and leaves were used, but this time both wet and dry leaves were applied.

Figure 2 shows the measured snow and ice thicknesses throughout the test. The ice measurements are shown by the solid lines, while the snow depths are indicated by the dashed lines. During the first day the wet leaves melted further into the snow than did the dry leaves; wetting the leaves decreased their albedo about 5–10%. By the following day the leaves that were applied dry were wetted by their meltwater, and thereafter the two plots of leaves performed similarly. Thus only the results for the wet leaves are plotted.

Figure 2 shows that the sand and leaves performed equally well at melting snow and ice. The bark was not only less effective at melting snow, but there was



Figure 1. Test setup for evaluation of dusting materials on ice covered pond (February 1994).

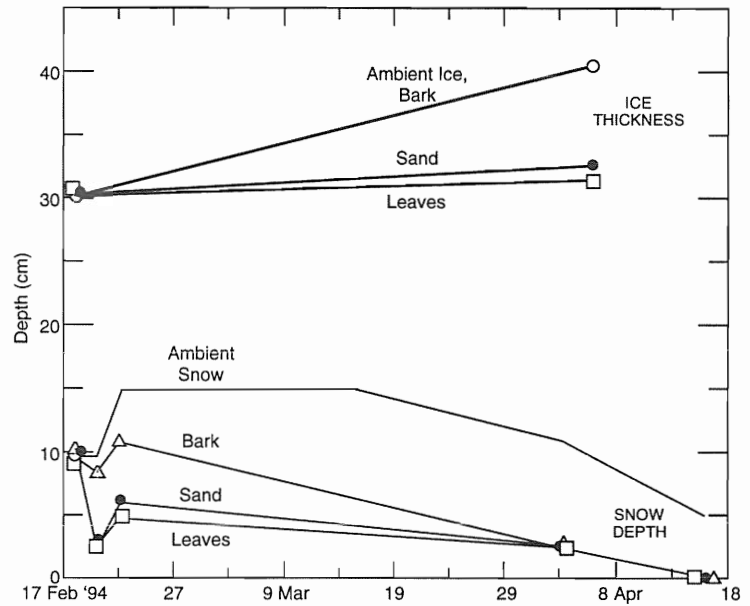


Figure 2. Snow depth and ice thickness in test plots and control on ice-covered pond. Results for hay are not plotted.

no noticeable melting of the ice under the bark. We also note that since both the hay and bark float, they were not effective once the surface was covered with meltwater, as they were easily washed off the surface. Since the leaves and gravel were heavier than water these materials stayed on the surface even with meltwater on the surface of the ice. We also found that wetting of organic materials had the advantage of hastening melting in the early stages of the tests, and prevented the material from being blown around by the wind during and immediately after application.

Albedo measurements

In March of 1994 we also made albedo measurements of snow and dusted snow on the frozen pond. The materials tested were hay, leaves, bark, sand, and

coal dust. All of the measurements were made using a field-portable radiometer. The measurements covered the visible and near-infrared portion of the spectrum (400–1000 nm).

The albedo measurements were made on separate test plots from those described above. No special preparations were made to the snow before application of the materials. The dusted areas were 60 × 60 cm and all the measurements were made 30 cm from the ground. The test areas had 1000 cm³ of material spread on their surfaces (except the coal dust which had only had 750 cm³ of material). The albedo was measured with a hemispherical cosine collector. This gathered radiation from the entire 3600-cm² test area.

The albedo measurements are shown in Figure 3. The snow in the control area was coarse grained and

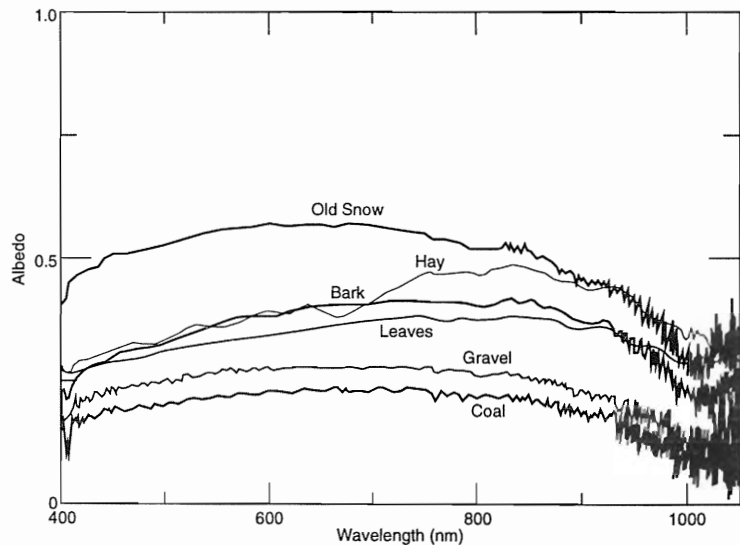


Figure 3. Albedo measurements of the dusted surfaces (March 1994).

dirty which accounts for the low albedo of 50% for the snow surface (Fig. 3). This is a typical value for late winter "corn" snow. The dusting materials decreased the albedo of the snow by varying amounts with hay being the least effective and coal dust being the most effective. Of the organic materials leaves were the most effective at reducing the albedo of the surface.

The fact that leaves are deposited in rivers during the fall suggests that this may be an environmentally acceptable dusting material as well, provided the amount of leaves added to the river by dusting does not overwhelm the aerobic capacity of the river (i.e., the decaying leaves do not use up the available dissolved oxygen in the river). We will revisit these environmental concerns more fully later in this paper.

FIELD TESTS OF LEAF MULCH

Having determined from the tests on the pond that leaves might be an effective alternative to dusting with coal dust, we conducted two field trials during the spring of 1994. The purpose of these trials was to test using a hydroseeder to apply biodegradable dusting materials to river ice. Additionally we measured the depth of the snow and ice in the test reaches during the test to further document the performance of the leaves as a dusting material. The field trials were conducted on the Winooski River in Montpelier, Vermont, and on the White River in Hartford, Vermont. The sites were chosen because they are locations where ice jams have historically formed, resulting in flooding and damages.

In addition to measuring ice thickness, snow depths, and air temperature during the melt period we estimated the incident solar radiation. Estimates were obtained by decreasing the expected solar radiation (computed from the time of day, latitude, and Julian day) using hourly cloud cover data and the procedure outlined by Haehnel et al. (in prep.). We also documented the aerial coverage (fraction of the ice covered by the leaves) by photographing the dusted area and then using an image analysis program to determine the relative fractions of the snow and leaves. This process is described in Haehnel et al. (in prep.).

The leaves used for this study were mulched by the town of Montpelier. The objective in mulching the leaves was to reduce the leaves to mulched particles that were approximately the size of a postage stamp. Mulched to this size, about four bags of leaves yielded one bag of leaf mulch.

The hydroseeder used for this operation was a Bowie model 2500 hydroseeder. We found that 18 to 20 fifty-gallon bags of leaf mulch added to the 2,500 gal. (9,500 L) of water produced a slurry that could be

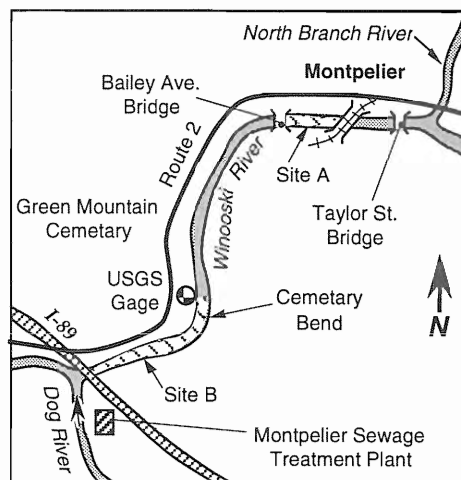


Figure 4. Location of the test sites on the Winooski River in Montpelier, Vermont.

easily sprayed. By volume that is roughly 2.7 m³ of leaf mulch. By weight it was an estimated 540 kg of leaf mulch.

Montpelier, Vermont

The Winooski River has repeatedly had ice jams which caused flooding in Montpelier, Vermont (Fig. 4), the most recent of which occurred on 11 March 1992. From the historical record we find that jams frequently formed at or near cemetery bend (indicated in Fig. 4). The annual formation of a stable ice cover that extends from the I-89 bridge to the Bailey Avenue Bridge appears to be the cause for the broken ice from upstream to arrest and jam at this location (USA CRREL 1994). It was hypothesized that thinning or weakening the ice through this reach may allow the broken ice to be carried out of the city rather than jamming in the city. We selected two locations along this problem area for testing the hydroseeder and leaf mulch on the Winooski River. The locations are indicated by the cross-hatched sections in Figure 4. The area labeled A was located between the railroad trestle and Bailey Avenue Bridge. Businesses were located on both sides of the river at this site; thus it provided a good test of the flexibility of the hydroseeder to work in tight confines. The area labeled B extended upstream from the I-89 bridge to Cemetery Bend. This site had easy access from Route 2, which allowed us to evaluate deployment of the mulch using the hydroseeder's cannon. Both of these sites were dusted on 9 March 1994.

Bailey Avenue (Site A)

For the test section at the Bailey Avenue Bridge (site A), wood markers were placed on the ice to indi-



Figure 5. Site A after it was dusted (Montpelier, Vermont).

cate the location to be dusted and the amount of thinning of the ice that occurred in the test section. Holes were drilled in the ice, and one end of the wood cross was put into the hole with the cross-piece laying on the ice. As the ice thinned the bottom of the cross-piece indicated the elevation of the top of the original ice surface. If snow fell on the leaves the markers indicated where the leaves were located under the snow.

The leaf mulch was put on the ice using a 200-ft (60-m) length of fire hose with a $\frac{3}{4}$ -in. nozzle (the hydroseeder is capable of operating with up to 400 feet [120 m] of hose). The area covered using the hose shown in Figure 5 and was approximately 4,000 m² (about 1 acre). It took about 1 hour to do this. The remainder of the 9,500-L slurry was spread using the hydroseeder's cannon aimed upstream from the Bailey Avenue Bridge, and cross river at the railroad



Figure 6. Hydroseeder being used to put leaves on the White River in Hartford, Vermont.

bridge. Figure 6 is a photograph of the hydroseeder cannon being used. At both of these locations the hydroseeder sat about 4.5 m above the ice surface. The spray from the hydroseeder projected out about 40 m across the ice. The area covered using the cannon was about 3,200 m². It took about 10 minutes to cover this area. Thus the total area covered using both the hose and cannon was almost 8000 m² (the total river area in this reach was 13,200 m²). The aerial coverage was about 30 percent. The coverage by weight was about 70 g/m².

The dusting pattern shown in Figure 5 was chosen in an attempt to weakening the ice cover with a minimal amount of mulch. Rather than melt all of the ice, the rationale was to melt break lines into the ice for it to fail along. Then these smaller pieces would easily wash out with the spring runoff. The chevrons (Fig. 5) were oriented to try to channel surface runoff from the adjacent parking lots out to the middle of the ice cover thereby accelerating the ice decay.

Interstate 89 (Site B)

We spread another 9,500 L of slurry at this site from Route 2 using the hydroseeder's cannon. We covered 0.5 km of the river between I-89 and cemetery bend in about 20 minutes. The total area of coverage was again about 8,000 m². The density of coverage was about the same as at the Bailey Avenue Bridge.

History of the ice decay

The initial thickness of the ice at site A and B was about 50 cm, and was covered by 5 to 15 cm of snow. The leaves were applied on top of the snow. The estimated solar radiation and air temperature for Montpelier* and snow depth at the site A during the test period is plotted in Figure 7. The dashed line indicates the location of the leaves in the snow cover during the test.

The day after the leaves were put on the ice 6.5 cm

* The met data were obtained from the Barre-Montpelier Airport which is located about 4 miles from the test sites.

of snow fell, burying the leaves. By 18 March the leaves at site A were covered by about 15 to 20 cm of snow. Nevertheless, on the 23rd the snow was completely melted off the ice in the dusted area at both sites, while the undusted area was covered by an estimated 10–15 cm of snow. When the ice washed out of both test sections on the 27th, there was still snow on the undusted ice, but the dusted ice was free of snow.

Although no snow measurements were taken at site B, observations indicated that the melting in this area was similar to that at site A. This section of the river was less shaded than site A so we expect the melting may have been accelerated in this reach compared to site A.

White River Junction, Vermont

The reach of the White River from the confluence with the Connecticut to the Hartford Village Bridge (Fig. 8) has a history of ice jams with no fewer than 9 jams forming in this reach since the turn of the century.

The most recent of which occurred in the spring of 1990 and resulted in the collapse two piers and loss of a span on the Bridge Street bridge. The two sites we chose to dust (sites C and D in Fig. 8) are historical ice jam locations. The dusting was accomplished on 17 March 1994. We placed 6 stakes in the ice at each test section so we could measure the amount of thinning in this region. The configuration of the stakes is shown in Figure 9.

Bridge Street Bridge (Site C)

Due to a dwindling supply of mulched leaves, only 11 bags were added to the 9,500 L of water in preparation for-

spreading the leaves at the Bridge Street Bridge. Stakes were placed on the ice at regular intervals perpendicular to the north bank of the river so we could measure the distance the hydroseeder could spray the leaves using the cannon. We found using the 1-in. (25-mm) nozzle the hydroseeder had a range of 40 m. Using the flared nozzle the range was cut down to 30 m.

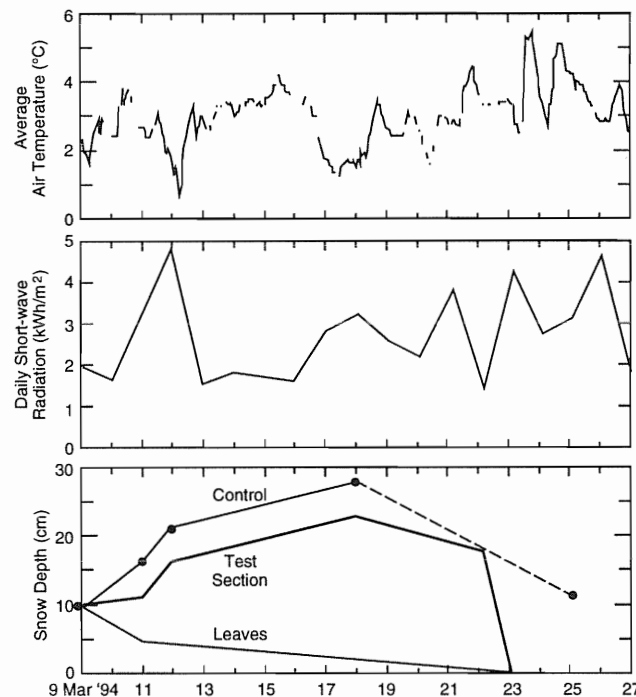


Figure 7. Meteorological conditions and snow cover depth during the field tests on the Winooski River in Montpelier, Vermont.

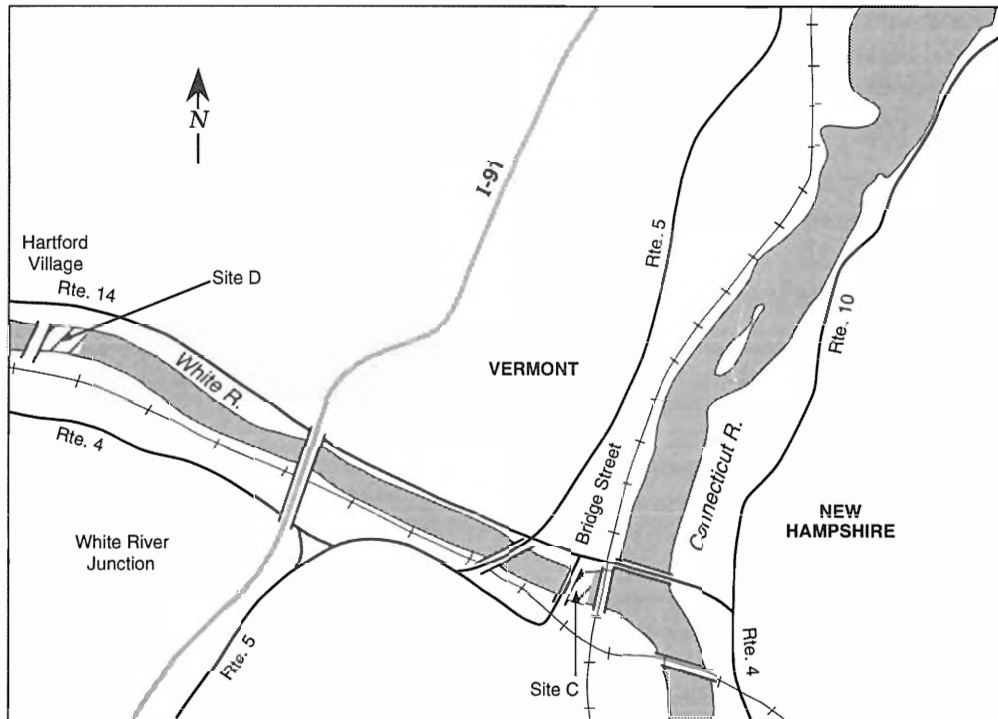


Figure 8. Location of the test sites on the White River in White River Jct., Vermont.

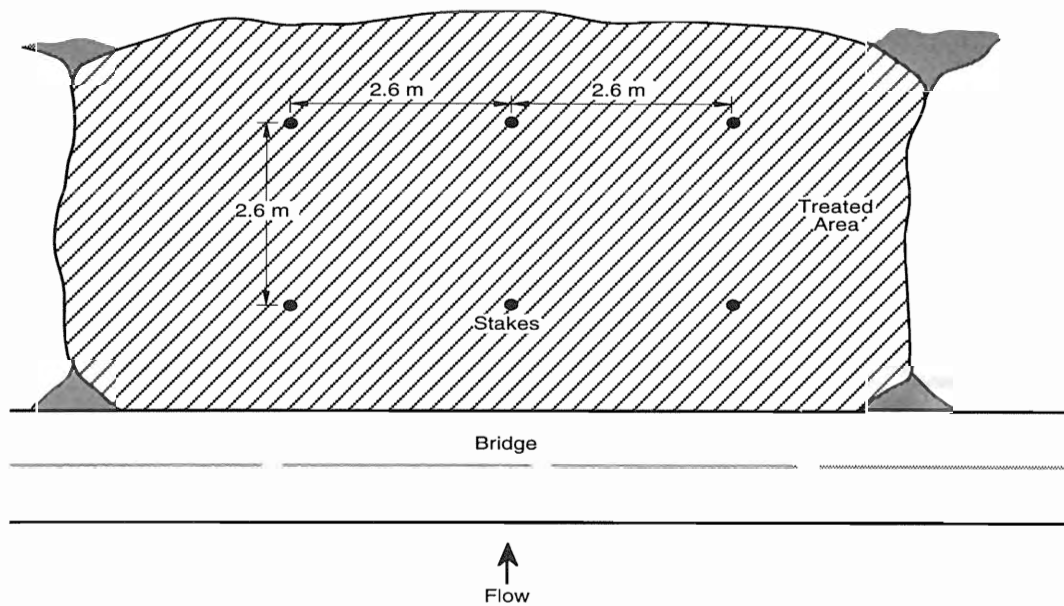


Figure 9. Layout of stakes on the ice for both the Bridge St. and Hartford Village bridge test sites.

From the bridge, shooting with the wind, the range increased to about 43 m. In every instance the cannon was located about 4 to 5 m above the ice.

Only half of the 9,500 slurry was used at this site. The aerial coverage was around 50-80 percent, or about 190 g/m² by weight. The total area of coverage was about 800 m².

Hartford Village Bridge (Site D)

At this site 11 bags of leaves were added to the 4,800 L of slurry left over from the Bridge Street Bridge. The hydroseeder was also refilled to its 9,500-L capacity, so for this site we had a mixture of approximately 18 bags of leaves in the 9,500-L slurry.

This bridge is about 15 m above the ice; thus we were able to get far better range with the 1-in. nozzle previously used. As a result we used this nozzle to spread the leaves farther away from the bridge and the flared nozzle to deliver the leaves closer to the bridge. The aerial coverage here was in the 80% range, or about 190 g/m² by weight. The area of coverage was about 2,800 m².

History of the ice decay

The air temperature and estimated incident solar radiation during the test period is shown in Figure 10. This data comes from the Lebanon Regional Airport, which was about 2 miles from the test sites. Also Figure 10 gives a plot of the ice thickness for site C and snow cover depth for both sites during the tests.

From Figure 10 we can see that leaves were effective in melting the snow and ice in the test sections. The average ice thickness in the test reach is about 3–5 cm thinner than in the control after 13 days. This represents a loss in ice thickness of about 0.3–0.4 cm/day. We note that the 6 cm of snow that was deposited on the ice on the 22nd was melted off the test section the following day. However, in the control section the snow lingered on the ice for another week before melting off. This insulating snow can be very effective at shielding the ice from solar radiation, as well as protecting the ice from warmer air temperatures. Both of

these factors can combine to delay ice melt and deterioration.

Cost estimates

The costs for dusting using the hydroseeder are enumerated below. The base costs listed below are the costs per day of the equipment and labor used in this project. Since we were not charged for the labor or front loader (both were supplied by the City of Montpelier) we provide estimates of these base costs. There was no cost for the leaves since the City of Montpelier annually collected and disposed of them. Thus, the only additional costs to the city for the leaves was mulching them.

Base Costs:

Hydroseeder	\$1600/day
Mulching leaves	
Leaf mulcher	\$50/day
Labor (2 laborers @ \$25.00 /hr each)	\$400/day
Loader and operator	\$300/day

Since it took about an hour to fill the hydroseeder with leaves and water and to dust 8,000 m² of ice using the cannon, we estimated that using the hydroseeder for a full day (8 hours) we could dust 64,000 m². A front-end loader was used to load the leaves into the hydroseeder, so that we have included one day's service for a loader and operator. From our experience we required 18 bags of mulch to cover 8,000 m². It takes 8 hours for two workers to produce 20 bags of mulch; thus to mulch enough leaves to cover 64,000 m² (144 bags) would take 7.2 days. The rent for the leaf mulcher would then be for 8 days, since we could not rent the mulcher for a fraction of a day.

Based on the above discussion the cost per covered hectare (10,000 m²) is listed below.

Estimated costs for covering one hectare using the hydroseeder cannon:

Hydroseeder	\$247
Leaf mulcher	62
Labor	450
Loader and operator	47
Total	\$806/hectare

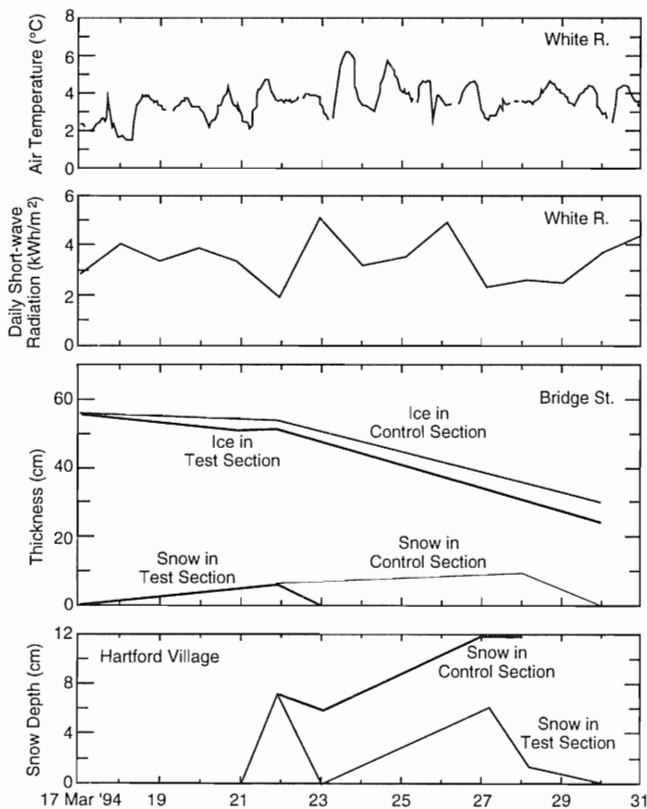


Figure 10. Meteorological conditions, snow cover depth, and ice thickness during the field tests on the White River in Hartford, Vermont.

If we were to recalculate that based on the rate of application using the hose instead of the cannon, we would need to effectively double the cost per hectare for the hydroseeder and loader. This would total about \$1,100 per hectare.

We compare these costs to the costs incurred for the dusting operations in Galena, Alaska, and on the Platte river in Nebraska. The best estimate of costs for the dusting in Alaska come from the records of the Alaska Division of Emergency Services that has coordinated the dusting operation for the last nine years. Here we present the costs for the most recent dusting operation at Galena, which was done in 1993. In this application 92 m² of sand were used. The application rate was about 0.27 kg/m² and that sand weighs about 1300 kg/m³ (U.S. Army Corps of Engineers 1968). The total cost for the operation was \$33,000. The cost estimate per covered hectare was about \$754 (in 1993 dollars).

In the spring of 1994 the Omaha District initiated a dusting operation on the Platte River. Here they used 27,200 kg of coal slag. This operation cost \$20,000 to dust 8 ha with coal slag (US Army Corps of Engineers 1994). This cost included \$4,500 for use of a National Guard helicopter to document the operation and the ice decay. The cost per hectare for this operation was \$2,470. If we remove the cost for the helicopter the cost for the operation drops to \$1,938 per hectare. Even at this, the cost is more than double the cost of the operation at Galena, Alaska. We attribute the lower cost for the operation at Galena to the 25 years experience in dusting and the attendant cost optimization that can occur with such experience.

Environmental considerations

Before using the leaves in a field trial we had the leaves chemically analyzed using X-ray fluorescence (see Hewitt 1994) to check for the presence of heavy metals, as these could be harmful to the stream habitat if present in high concentrations. For comparison we present the chemical composition of the coal slag used on the Platte River in Table 1.

X-ray fluorescence analysis of the leaf mulch

Table 1. Chemical analysis of coal slag (or bottom slag) (U.S. Army Corps of Engineers 1979).

<i>Ingredient</i>	<i>Amount (%)</i>	<i>Ingredient</i>	<i>Amount (%)</i>
Silicon	23.3	Potassium	0.93
Aluminum	11.3	Titanium	0.64
Calcium	5.4	Undetermined	0.54
Iron	5.2	Sodium	0.20
Sulfur	3.1	Phosphorus	0.11
Magnesium	1.4		

shows that the leaves did not contain any heavy metals. The only metal constituent found in the leaves was iron, with a concentration of 0.05% by weight. We note that the coal slag (Table 1) has an iron concentration over 100 times greater than the leaves. The coal slag also contains other metals that the leaves do not, namely aluminum, magnesium, titanium and sodium, all of which occur at high levels. From these chemical analyses we conclude that the use the leaf mulch is more environmentally acceptable than the use of coal slag.

Minshall et al. (1983) indicates that the leaf concentration that falls into Northeastern rivers of the size of the Winooski and White is around 100 to 200 g/m². The estimated leaf coverages from these dusting tests on the Winooski and White Rivers were 60 and 190 g/m², respectively. The amount of leaves spread on the ice in both Montpelier and Hartford is about the same as what falls naturally on the river in the fall; thus, an extensive dusting operation of this kind could effectively double the annual amount of leaves going into rivers of this size.

Discussion of field test results

From the tests both at Montpelier and Hartford we demonstrated the effectiveness of spreading leaves on the ice using a hydroseeder. We found that a considerable area can be covered in a short time using this method. Taking into consideration time for refilling the seeder's tank and travel time from the filling station to the river, a modest estimate of 6.4 ha/day could be covered using this method. At this rate of application we estimate the cost per dusted hectare to be about \$806. This compares favorably with dusting using aircraft, which we estimate could cost as low as \$754 per hectare. Accessibility to the river is necessary for using a hydroseeder. A location where a road runs parallel to the river is ideal for using a hydroseeder. Even using the 120-m hose that is available for the hydroseeder, there needs to be good access to the river if the hydroseeder is to be used for dusting. Rates of coverage using the hydroseeder are cut in half if the hose is used instead of the cannon. Consequently we could expect the cost per hectare using the hose to be around \$1,100.

The leaves proved to be effective for melting snow even when covered by up to 33 cm of snow. They may be effective for snow depths greater than this, but that was the deepest snow we observed during our test period. From Dozier et al. (1989) we find that incident solar radiation can penetrate snow depths of 10 to 20 cm, but the fraction of transmitted radiation decreases exponentially with snow depth. Thus, we expect that snow depths much greater than 18 cm

may effectively block any radiation from reaching the leaves. Although the ice may not deteriorate while the snow is on the leaves, the accelerated melting of the snow due to the presence of the leaves removes the insulating snow from the ice surface sooner. Thus, the ice surface will be exposed to solar radiation, thereby hastening ice decay.

The conditions under which this evaluation was performed were less than ideal. Only 7 days of cloudless weather occurred during the 21-day evaluation at Montpelier and 5 cloudless days during the 13 days at Hartford. Nevertheless, at Montpelier we observed the snow deteriorated faster in the test section over the 16-day period from 9 March to 25 March. We saw similar results at the test sites in Hartford. Additionally, at the one Hartford site we saw a noticeable decrease in the ice cover thickness in the test section of about 0.3 to 0.4 cm/day as compared to the control. Since this is a modest amount of ice loss we hesitate to say that the leaves were effective in melting the ice cover since variability in the river hydraulics throughout the test reach could confound these results. Nevertheless, the trend shows promise, and requires further work to confirm the effectiveness of leaves for melting an ice cover.

We cannot say that we promoted premature release of the ice due to our efforts. Nonetheless, it is clear that the leaf mulch was effective in reducing the thickness of ice in the Bridge Street test area, which would result a reduced volume of ice in that area than otherwise would have existing naturally.

CONCLUSIONS AND RECOMMENDATIONS

From the tests conducted on the ice-covered pond we found that dusting can reduce the albedo of the snow and ice from 0.5–0.9 to 0.1–0.2. This reduction in surface albedo was shown to accelerate the melting of the snow cover and the thinning of the ice cover on the pond. Of the materials tested we found sand, coal dust and leaves were the most effective at reducing the albedo of snow and ice surfaces. We found that the leaves and sand were about equal in their ability to accelerate the melting of snow and ice. Leaves naturally occur in New England rivers and are biodegradable. Thus, if leaves are used in moderate amounts to dust ice, they should not adversely affect the stream habitat.

From the field trial conducted on two Vermont rivers we found the leaves were effective at melting the snow cover, even when covered with up to 13 cm of snow. It is less clear how effective the leaves were at melting the ice cover, although the results show a trend toward reduced ice cover thickness in the test

section as compared to the control. The use of a hydroseeder for spreading the dusting material is effective and is comparable in cost to aerial dusting. However, there must be good access to the river bank to use the hydroseeder to spread the leaves. The ideal situation would be where a road runs along the side of a river.

More work is required to find the extent to which dusting can reduce the ice volume and strength. This will require measurements of the ice thickness and strength in the dusted and undusted reaches during the spring melt period leading up to breakup. Concurrent measurements of solar radiation, ice temperature, water temperature, air temperature and other standard meteorological data will also be required to document the decay process and all the pertinent heat and mass transfer occurring at the ice surface. Also a greater understanding of when and where to dust to achieve maximum benefit needs to be established. To do this, a relationship linking ice volume and ice strength to ice jam potential needs to be developed. Finally, further work is required to determine the environmental impact of dusting with leaves on the riverine habitat.

ACKNOWLEDGMENTS

We thank the City of Montpelier, Vermont, for their assistance in gathering leaves and mulching them for the field trials. We acknowledge the efforts of Susan Taylor, James Lever, Janet Hardy, Alan Hewitt, Peter Stark, and Leonard Zabilansky for their technical assistance in these tests. This work was done with funding through the U.S. Army River Confluence Ice Program work unit 32972.

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