

SITING, DESIGN AND OPERATIONAL CONTROLS FOR SNOW DISPOSAL SITES

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ABSTRACT: The Municipality of Anchorage, at 61° north latitude, plows and hauls snow from urban streets throughout the winter, incorporating grit and chloride applied to street surfaces for traffic safety. Hauled snow is stored at snow disposal facilities, where it melts at ambient spring temperatures. Municipal studies performed from 1998 through 2001 show that disposal site melt processes can be manipulated, through site design and operations practices, to control chloride and turbidity in meltwater. An experimental passive ‘V-swale’ pad configuration tested by Anchorage investigators reduced site meltwater turbidity by an order of magnitude (to about 50 NTU from the 500 NTU typical of more conventional planar pad geometries). The Municipality has developed new siting, design and operational criteria for snow disposal facilities to conform to the tested V-swale pad configuration.

KEYWORDS: Urban Snow Control, Snow Storage, Snow Disposal, Snowmelt, Design Criteria

INTRODUCTION

Economical and effective control of pollutants released from snow disposal sites serving high latitude communities presents problems peculiarly reflecting the impact of a subarctic climate. At high latitudes snow plowed from streets accumulates rather than melts due to low solar insolation and daily temperature ranges that generally remain below 0°C throughout the winter. As plowed snow accumulates and exceeds available storage space along streets, it is hauled to central storage areas and placed as a compact snowfill. High fuel costs usually prohibit forced melting, so instead the hauled snow is stored and allowed to melt under ambient spring weather conditions.



Pollutants contained in stored snow also reflect the effects of an arctic climate on street maintenance practices. At high latitudes, deicing often has limited use in improving road traction, and instead grit is widely applied. Salt (granular sodium chloride) is added to grit in amounts necessary to maintain fluidity during application (in Anchorage about 5% by weight of grit). A fraction of the applied grit and salt, as well as fugitive pollutants from vehicles, becomes incorporated into hauled snow. When seasonal melt occurs, the stored snowfill releases these pollutants in a complex fashion. Studies performed by the Municipality of Anchorage (MOA) over the last several years have shown that the manner in which pollutants are released strongly reflects the initial source of hauled snow, the melt processes of stored snowfill, and the geometry of storage areas and the snowfills themselves. Based on findings from these studies, the Municipality has developed effective new snow storage site design and operation practices that address control of a range of pollutants, particularly sediment.

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METHODS

In 1998 MOA implemented a program to assess the environmental impacts of its winter street maintenance practices. As part of this program MOA studied the performance of four Anchorage snow disposal sites through four melt seasons, from 1998 through 2001. In the first year of study, investigators focused on seasonal melt and chloride release patterns. Meltwater sampling at the storage sites was temporally and spatially stratified to assess the effects of different snowfill and pad geometries and meltwater flow regimes (Wheaton, 1998a). Based on initial results, in the summer of 1998 MOA site operators implemented minor modifications to operational practices and drainage infrastructure at all MOA snow disposal sites (Wheaton and Jokela, 1998b). Snow pad changes included snowfill set-back staking and channel armoring. Operational changes emphasized placement of snowfill in steep, compact footprints and at downgradient positions on snow pads.

MOA investigators broadened the scope of meltwater sampling for spring of 1999. Analytical parameters sampled for that year included chloride, basic anions and cations, polynuclear aromatic hydrocarbons (PAHs), metals, particulates, and fecal coliform sampled both in the snowfill and in meltwater (WMS, 1999a; 1999b). However, it became apparent to MOA investigators early that controlling particulates would also treat adsorbed pollutants.

As a result, in spring 2000 MOA focused studies on the melt process and its relationship to changes in turbidity (WMS, 2000a). Investigators were particularly interested in ice layers formed at the base of snowfills, and changes in water quality as meltwater exited from the surface of the basal ice and traveled across the storage pad. Snowfills were cored to establish initial snow quality and to estimate the thickness and position of basal ice. Meltwater samples were collected at seepage and discharge points along the snowfill boundaries, along flow channels on the storage pad, and at offsite discharge points. Samples were tested in the field for electrical conductivity using temperature-compensated meters calibrated daily. Field turbidity data were collected using formazin-standard portable nephelometric turbidimeters calibrated at the beginning of the project. For most of these parameters, Anchorage data was consistent with that reported by others (Novotny et al., 1999; UAF, 1996). All data were documented and related to a time series photographic record of the melt process (WMS, 2000b).

Based on encouraging findings from 2000 observations, investigators became interested in the possibility of artificially shaping the basal ice beneath snowfill as a means of controlling meltwater discharge and turbidity. To test the concept, operators shaped a portion of one storage pad to have a pronounced 'V' cross section perpendicular to the general pad surface gradient, with the pad section designed to direct flows laterally to a central depressed axis. Over the winter of 2000-2001, site operators placed hauled snow across the full width of this experimental 'V-swale' and the following spring, investigators observed melt processes and collected data to assess its performance.

RESULTS AND DISCUSSION

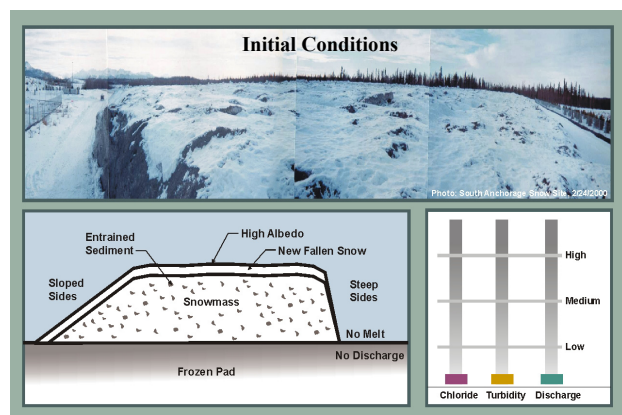
Study of Anchorage snow disposal sites has provided local investigators with a detailed understanding of the processes by which the snowfill at these sites melts and mobilizes pollutants. The potential for manipulation of these processes is central to new management practices developed by MOA and leads to the basic conclusions of MOA's 4-year study:

- Chloride can be controlled passively only through detention and dilution.
- Mobilization of metals and PAHs is related to chloride concentration, but a large fraction can be controlled with particulate capture.
- Particulate loading in meltwater is related to the geometry of the snowfill and the pad on which it is situated, and may be controlled by manipulation of these elements.

The first two principles have been examined in detail by other investigators (Novotny et al., 1999; Oberts et al., 2000) but the potential influence of site and snowfill geometry on pollutant release has not been significantly addressed. Observations at Anchorage suggest the melt processes that occur within and around a snowfill mass, along with the aspect, geometry and physical characteristics of the stored snow, play central roles in how the snowfill melts and the degree to which pollutants are mobilized during melting. MOA site investigators have identified three main stages in the melting of a snowfill: a) ripening, b) main melt and vertical deflation, and c) final melt and disintegration. These melt stages and their relation to pollutant mobilization are summarized below.

RIPENING: THE COLD SNOWFILL UNDERGOES INTERNAL CHANGES

Snowfills hauled from Anchorage streets consist of lightly compacted snow and ice. These masses generally contain a homogenous, dilute distribution of fine mineral particles, and applied and fugitive chemicals. At conventional Anchorage snow disposal sites, heavy equipment operators place hauled snow onto earthen pads in a series of one or more lifts, each 2 to 4 meters thick. By the end of winter, the total mass of snow stored at any one of Anchorage's facilities is on the order of $7 \cdot (10^4)$ cubic meters. Snowfills are steep-faced on several sides but often have one or more low-sloping faces where snow has been pushed into place. The albedo of a snowfill at the beginning of the melt period is typically high as a result of a covering of fallen snow and the snowfill's initial homogenous nature. Though no data has been collected at Anchorage snow disposal sites to confirm this, at the end of winter snowfills likely have low core temperatures relative to ambient spring conditions. Similar spring temperature gradients have been reported for much thinner natural snowpacks (Luce and Tarboton, 2001).



| Initial Snow Conditions | | |
|-------------------------|------------------|--------------|
| Constituent | Range | Median |
| Water Equivalent | 60%-72% | 60% |
| Chloride | 53-140 mg/L | 115 mg/L |
| Total Sediment | 0.6-14.6 kg/cu.m | 3.25 kg/cu.m |

RADIANT ENERGY BEGINS TO MELT THE SNOWFILL SURFACE

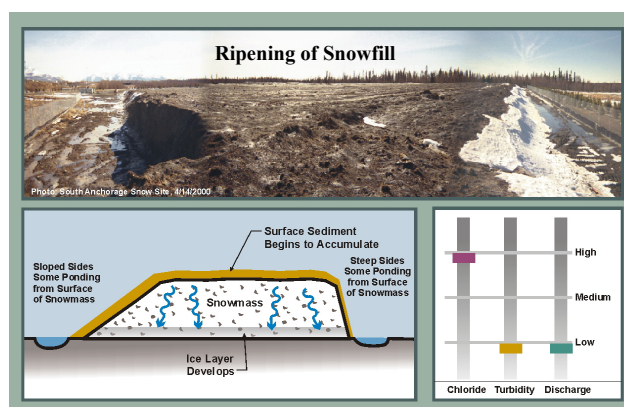
With the rapid rise in solar radiant heat, the top of snowfills begin to melt early in spring (March in Anchorage). However, water formed from this melt infiltrates and does not flow across the surface of the snowfills. 'Moulin'-like features, on the order of 3 to 5 cm across, are common and are thought to result from formation and rapid break-through of small puddles of meltwater at the surface. Also coring showed no continuous horizontal ice layers within snowfills (despite an Anchorage maintenance practice of watering tops of lifts to allow passage of winter truck traffic).

As snow melts at the top of the snowfills during early ripening, movement of the meltwater appears to be generally vertical, with little apparent perching or lateral movement.

THE SNOWFILL RIPENS AND A BASAL ICE LAYER FORMS

The vertically infiltrating meltwater does not carry significant particulate matter with it. As a result, the albedo of a snowfill rapidly changes as snow and ice at the surface melts and infiltrates, leaving behind and concentrating in a thin layer the dark colored mineral particles present in the original hauled snow. Sampling at Anchorage sites shows that the infiltrating meltwater leaches chloride from the surface of ice crystals and solids within snowfills. However, despite a depressed freezing point, relict colder winter temperatures at the core of the snowfills refreeze the initial flow of infiltrating meltwater. Refreezing meltwater forms a thick ice layer, typically a little over a half a meter thick at the base of Anchorage snowfills. Though it is uncertain whether a progression of meltwater freeze and thaw fronts migrate downward or if larger ‘pulses’ of meltwater build the basal ice, the ice layer is commonly observed at the bottom of snowfills in Anchorage. During this stage little or no runoff escapes from the snowfill.

Snow cores and observations at Anchorage snow sites suggest the basal ice layers conform closely to the topography of the underlying ground surface for flat to moderately sloping pads. Sample cores and borings advanced in the snowfill at the V-swale site showed no significant increase in thickness of the basal ice layer, beyond normal variability, either laterally across the V-section or along the V-section trough. A generally uniform basal ice thickness independent of ground slope also seems reasonable, given that saturation and beginning of any lateral flow (that might support a localized increase in ice thickness) will not occur until the core snowfill temperatures have risen above those that will support refreezing and formation of basal ice.



MIDDLE MELT: MELTWATER FLOW FROM A SNOWFILL BEGINS

The middle stage of snowmelt occurs as meltwater begins to flow from a snowfill. Flow begins as soon as snowfill temperatures have equilibrated, the snow is saturated above the basal ice layer, and hydraulic head is sufficient to promote flow through the snowfill. The number and location of discharge points depends upon the quality of the snow and geometry of the pad on which it has been placed. Hydraulic head determined from measurements of saturated thickness in an Anchorage snowfill suggests a relatively low gradient (about 0.001 meters/meter) is required to move the meltwater through the snowfill during the early part of this stage. Others (Fox et al., 1997) report that tortuous, saturated flow in natural snowpacks is rapidly replaced by integrated flow along open conduits, but investigators observed no indication of this during the middle melt stage for snowfills placed on flat sites at Anchorage. However integrated flow along surface and subsurface conduits is an important process in later stages of melt for these sites.

For the experimental V-swale pad configuration, seepage at the pad perimeter was almost absent. Almost all meltwater discharge from the snowfill was confined to a single point at the downgradient end of the V-swale. Meltwater also exited the V-swale snowfill as an integrated flow—not as seepage—with this flow beginning at approximately the same time as more distributed seepages were first observed at adjacent, conventionally configured snowfills.

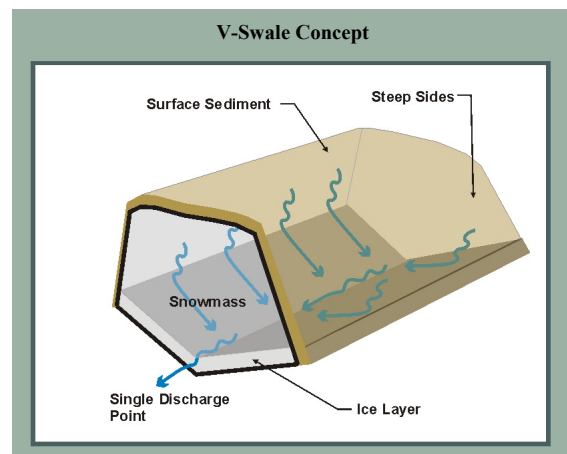
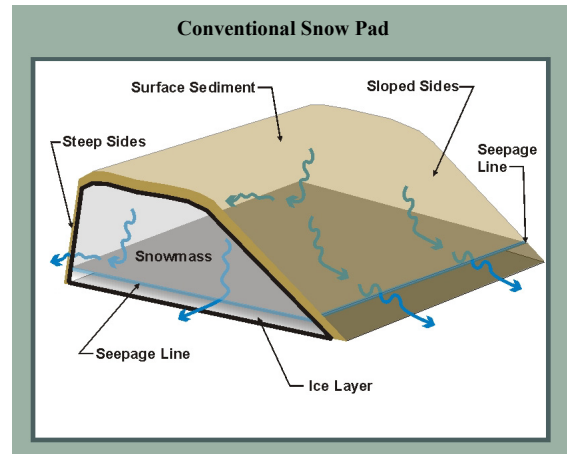
THE BASAL ICE CONTROLS SEEPAGE

During the middle meltwater stage, discharge observed at relatively flat, conventionally-configured Anchorage sites tends to occur as a continuous seepage along the top surface of the basal ice layer and around the entire perimeter of snowfills. Little or no early flow occurs under the basal ice, though pad geometry can work to encourage development of sub-basal ice meltwater conduits as the melt season progresses. At this stage, flows across the pad surface are directed along the perimeter of the basal ice (not under or through it). Though the seepages themselves have very low kinetic energy as they exit from the snowfill, erosive power as these flows integrate can become greatly enhanced by the configuration of both the snowfill and the pad on which it is placed.

For meltwater discharge from the experimental V-swale, the flow exit point remained confined to the downslope end of the pad throughout this stage of the melt season. Concentrated internal flows along the axis of the V-swale tended to slowly erode the basal ice headward along the trough of the swale. As removal of the basal ice progressed up the trough, snow pad soils became exposed to erosion and are believed to have contributed to turbidity measured in meltwater at this site. However, exposed trough soils rapidly self-armored, limiting these effects.

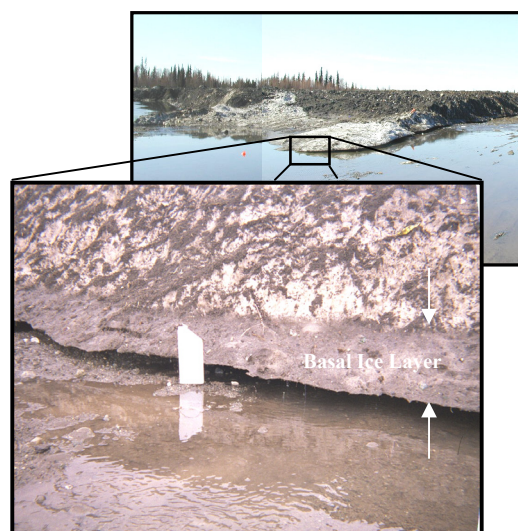
INITIAL POLLUTANT RELEASE BEGINS

Initial pollutant release begins with the first meltwater discharge from a snowfill. At Anchorage sites, because of early leaching and low meltwater volumes (3 to 5 liters/second [L/sec]), chloride concentrations from the initial discharge can be extremely high (10^3 to 10^4 milligrams per liter [mg/L]), dependent apparently upon deicing and snow hauling practices as they reflect year-to-year climate variability. At Anchorage, peak chloride releases wane within several weeks of first snowmelt discharge and fall rapidly as melting progresses. By the end of the middle stage of melt, flow is at a peak (10 to 30 L/sec) but chloride concentrations have typically fallen to concentrations of 10^2 mg/L or less.



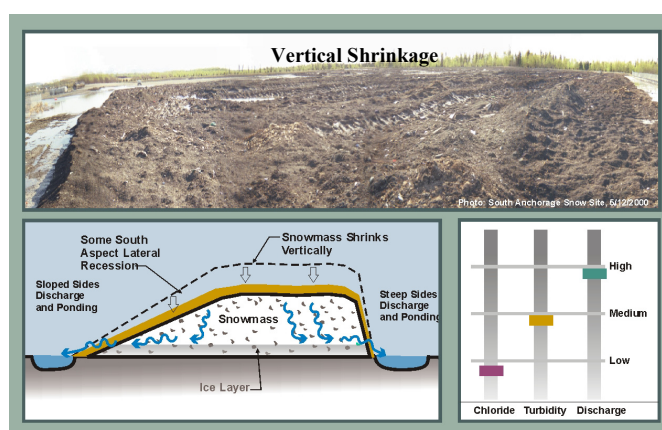
At this stage, particulates that have accumulated on snowfill or pad surfaces also become subject to erosion and transport by meltwater flow. As seepages exit from basal ice surfaces, they saturate the fine sediments accumulated on the surface of the snowfills. These sediments are then readily mobilized in gravity flows or entrained in meltwater as seepages become integrated. Mobilization of sediments on a snowfill surface is significantly greater where the snowfill is gently sloped. This is principally because a gently sloped surface represents a greater initial snowfill surface area and therefore exposes a larger pollutant load to erosion. On the other hand, near-vertical surfaces, besides representing smaller surface areas, tend to become self-armored as they build thick sediment accumulations away from the seepage face.

At Anchorage, where meltwater cascading from snowfills flowed across pad surfaces, turbidity was measured at 150 to over 1,000 nephelometric turbidity units (NTU), though a typical range was 350 to 500 NTU. Very shallow ponding (2 to 10 cm deep) occurring serendipitously on pad surfaces reduced the initial turbidity of meltwater accumulating on a pad to a range closer to 150 to 300 NTU. Throughout the early and middle stages of melt, flow discharging from the V-swale site showed notably lower turbidity values than all other locations, typically ranging from 10 to 50 NTU.



THE SNOWFILL SHRINKS VERTICALLY

As the middle melt stage progresses, a snowfill shrinks significantly in height over its entire area. Some perimeter recession also occurs, mostly along exposed south aspects and along strongly sloping faces. During this stage of vertical deflation, flow and ponding over the surface of a conventional snowfill still has not developed, and discharge occurs predominantly along the perimeter of the mass, initially as seepage at the edge of the basal ice and then as integrated flows across the pad surface. Conversely, flow from the experimental V-swale site remained confined principally to a single outlet point at the end of the V trough, with perimeter seepage and flow small compared to the trough discharge.

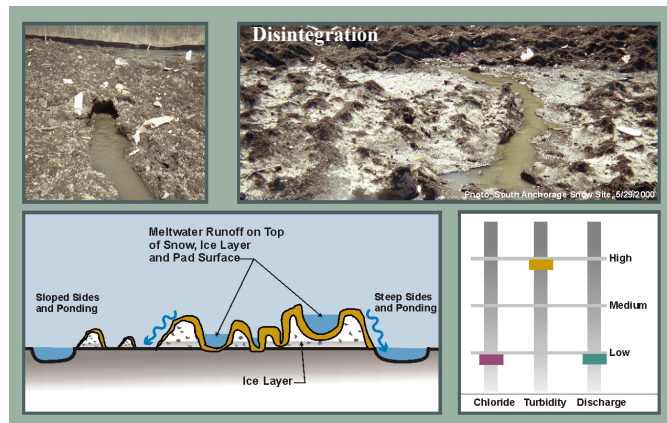


FINAL MELT: THE SNOWFILL DISINTEGRATES

In the beginning of the last stage of melt, a basal ice layer underlying a snowfill becomes exposed locally. At this point, the direction of meltwater flow from a snowfill becomes less influenced by the transmissive characteristics of the snow mass and subsurface conduits, and more influenced by the underlying ground topography as reflected in the surface of the basal ice layer. Sediment collapses onto the basal ice layer and becomes subject to erosion and mobilization by relatively high meltwater flows. The underlying ground surface may also become exposed to erosion as the basal ice is melted or eroded.

Though chloride concentrations are relatively low at this final stage of melt, the erosive power of the meltwater flows and the collapse of the accumulating surface sediment onto flow surfaces greatly increases potential for the mobilization of particulates. The increasing isolation of snowfill remnants raises the potential for erosion as flows from

upgradient snowmelt sources are directed across increasingly bare pad surfaces and against sediment collapsing from downgradient snowfills. Thawing of the pad surface may also reduce the mechanical resistance of surface soils to erosion. This may be particularly true where the pad soils have been weakened by ice segregation during winter freezing and are not protected by vegetation. All in all, as the snowfill at a site disintegrates into isolated snow masses, the basal ice layer erodes, and the pad soils become exposed to flows, the potential for mobilization of particulate pollutants rises dramatically. At this point, concentrations of particulates in meltwater can remain markedly high until most of the remaining snowfill is gone and flows subside.



CONCLUSIONS

Observation of the melting process at Anchorage snow disposal sites suggests a number of control opportunities. Control opportunities can be generally grouped as they address chloride (and soluble pollutants), or particulates (and adsorbed pollutants).

CHLORIDE CONTROL

Chloride and other soluble pollutants are not readily treated by simple technologies. Passive (non-chemical) treatment of chloride is best addressed through: control of street treatment processes, dilution of early meltwater discharges, and application of snow disposal site location criteria. Analysis of Anchorage salt application practices suggests total chloride loading could be reduced by as much as 60% through use of heated sand sheds. Because of leaching, however, detention and dilution of early snowmelt remains a critical element in snow disposal site design and operations criteria. Dilution with shallow ground water has been shown to be a viable option in Anchorage, but implementation requires knowledge of area hydrogeology (Wheaton, et al., 1998a) and acceptance of some changes in the structure of local vegetation communities (Hansen, 2001). On the other hand

design for dilution taking place wholly within surface detention basins must consider a wide year-to-year variability in peak chloride concentrations in meltwater. Four years of record in Anchorage show a range in peak seasonal chloride concentration of greater than an order of magnitude (from 10^3 to 10^4 mg/L). This variability appears to be a function of climate and not of application amount, with larger peaks associated with years having more numerous and larger snowfall events. In any event, given the necessity for dilution, the potential for impacts to other local resources from elevated chloride requires careful consideration be given to facility siting.

| Performance Observations | | | |
|--------------------------|--------------|----------|----------------|
| <u>No Practices</u> | Early Melt | Mid-Melt | Disintegration |
| Turbidity (NTU) | 150-350 | 350-500 | >1,000 |
| Chloride (mg/L) | 1,000-10,000 | 100-500 | <100 |
| <u>Shallow Ponding</u> | | | |
| Turbidity (NTU) | 70-150 | 150-300 | >500 |
| <u>V-Swale</u> | | | |
| Turbidity (NTU) | 10-50 | 10-50 | <200 |

PARTICULATE CONTROL

Where site selection to optimize opportunities for snowmelt dilution is critical in chloride control, designing and operating a snow disposal facility to take advantage of the inherently low energy environment of a melting snowfill is key in particulate control. Turbidity in snow disposal site flows is generated as meltwater exits and cascades off a snowfill, entraining sediment from the surface of the deflating mass. Turbidity may be further increased as meltwater crosses a pad surface, particularly if pad surface soils are unprotected, waste soils are exposed, or flow velocities are increased. Conversely, particulate matter is not significantly present in meltwater flowing in the saturated medium of the snowfill mass itself, as evidenced by turbidity that is an order of magnitude lower in flow from the experimental V-swale site than flow from conventional sites.

Anchorage observations suggest a number of simple options that may reduce turbidity by as much as 50% in snow disposal site meltwater. Perhaps the simplest option is changing practices to place snow in high, compact masses with steep sides all around to minimize the exposure of accumulating sediment on the snowfill surface to seepage and flow. Placing snowfill in a single mass rather than several isolated masses will also reduce exposure of sediment to upgradient meltwater sources. Sites can also be operated to take advantage of aspect, with snow placed as compact masses at northernmost downgradient locations so that a snowfill will preferentially recede from uphill to downhill. This practice will reduce exposure of downgradient sediment to meltwater flows as the sediment settles to the pad surface in the final stages of melt (and becomes most vulnerable to erosion). Placing snow to create shallow impoundments immediately against the melting snowfill may also be beneficial. Even very shallow impoundments can reduce pad erosion and turbidity by effectively 'transporting' meltwater over significant horizontal distances in a low-turbulence (pooled) environment. Use of setback staking and armored channels (oversized to provide room for icing) to direct and contain pad meltwater flows will also limit turbidity. Finally, off-season pad use should be restricted to minimize disturbance of pad soils and to allow re-vegetation.

Adjusting basic pad geometry, in conjunction with operational practices, promises even greater reductions in turbidity. The experimental V-swale pad tested at Anchorage may provide as much as an order of magnitude improvement in particulate control over more conventional (planar sloping) pad configurations. The V-swale configuration promotes meltwater movement as saturated flow within a snowfill so that particulates are not mobilized during the early and middle stages of melt. Flow directed along the trough of the V-swale ensures a single predictable discharge point so that flows can be further managed and directed to minimize erosion of pad and waste soils. The design

also limits late-stage sediment mobilization by helping to short-circuit flows to armored channels. Note that because of variability in the thickness of the basal ice layer, controlled side slopes and swale widths are important to ensure that internal flows are directed to the swale trough. Based on observations of variability in basal ice thickness, MOA has established design parameters that are expected to successfully contain meltwater within the V-swale.

MOA SNOW DISPOSAL SITE DESIGN CRITERIA

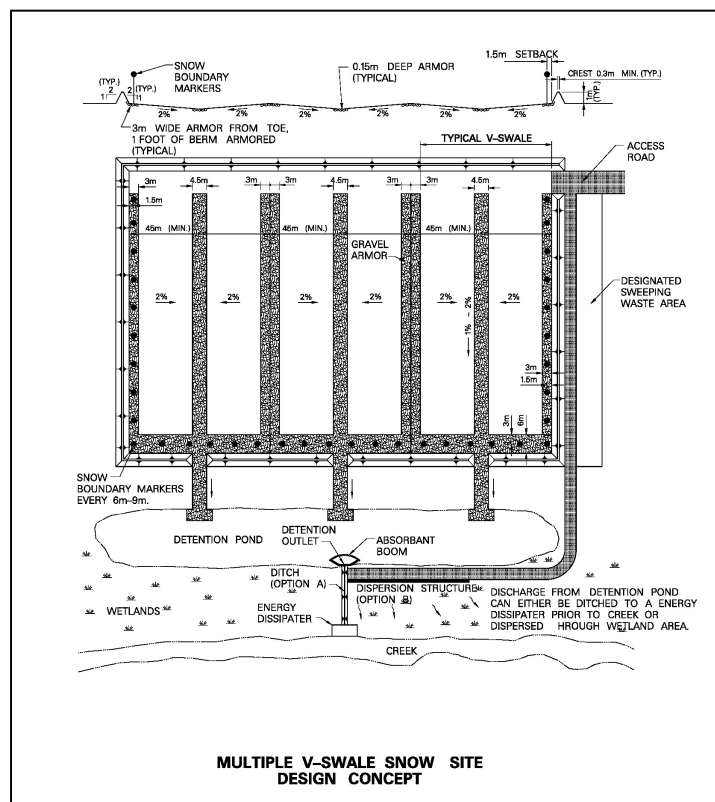
Based on the results of its studies, MOA has developed a set of snow disposal site criteria for Anchorage. MOA criteria particularly emphasize an essential synergy between siting, design and operations. Though the criteria are specific to the typical scale of Anchorage snow storage facilities, they should be adaptable to other northern latitude communities as well. The criteria are generalized here—full text of the recommended criteria can be obtained from MOA upon request.

SITING CRITERIA

- Avoid meltwater discharge to potable water aquifers.
- Avoid meltwater discharge to ‘closed’ lakes and wetlands.
- Avoid reduction of functionality of receiving wetlands.
- Avoid meltwater discharge to streams having winter base flows less than 85 L/sec.
- Optimize opportunities for infiltration to shallow non-potable ground water systems.
- Optimize opportunities for a site orientation sloping down from south to north.

DESIGN CRITERIA

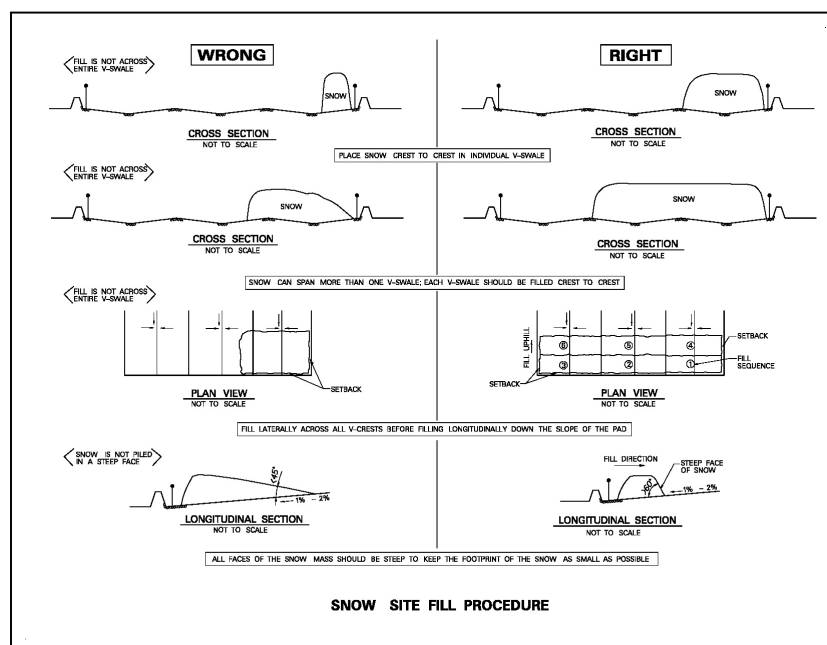
- Map local and site hydrogeology within 300-meter (m) of site.
- Construct pad with a single or multiple V-swale configuration (minimum 45m crest-to-crest swale width, 2% side slope to central trough, and 1-2% longitudinal slope).
- Orient V-swale longitudinal axes downhill from south to north.
- Establish and flag setbacks from swale crests and facility perimeter.
- Armor swale troughs and crests and all facility drainage channels and containment berms.
- ‘Trackwalk’ (imprint with crawler tractor treads trafficking directly upslope and downslope) and vegetate all non-armored pad surfaces with a mix resistant to an annual 2-5cm sediment burial.



- Construct dry detention ponds or other treatment to control chloride and sediment releases (mean chloride release per:
1day=<3600mg/L,
30day=<1200mg/L, and
season=<300mg/L;
sediment removal at ≥95%
of +100µm particles).
- Install flow dispersion and energy dissipation controls at all outfalls to receiving waters.

OPERATIONAL CRITERIA

- Place hauled snow over the full width of each V-swale.
- Sequence placement of snow starting at the downslope side and working upslope.
- Maintain snow in a compact mass with steep sides (1h:1½v or steeper).
- Maintain setback from all containment berms and from the discharge end of V-swales.
- Maintain pad vegetative cover and re-grade only to ensure V-swale functionality.
- Restrict access and prohibit off-season traffic and non-snow storage uses.



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