CHAPTER 7
OPERATIONAL SOLUTIONS

Section I. Vessel Scheduling or Convoying

7-1. Introduction. Frequent vessel passages through ice-covered navigation channels under frigid conditions generates extra ice. In addition, the passage of vessels causes most of the ice grown along tracks opened by previous vessels to be broken into brash ice, which may collect as thick accumulations that eventually impede vessel movements. Field observations, results from ice-tank (laboratory) experiments, and numerical models have shown that navigation tracks opened by transiting vessels become covered with a rather porous layer of brash ice that is approximately 1.5 to 3 times the thickness of the surrounding sheet-ice cover. The greater the number of passages, the thicker the brash-ice layer is likely to become. In addition to hindering vessels, the accumulations of brash ice may form partial or complete ice jams in the navigation channel itself and parallel ridges beneath the ice cover adjacent to the navigation channel. Ice-tank experiments indicate that these ice jams and ice ridges form especially rapidly in shallow river reaches, where they may extend downward to the bottom of the channel. An additional problem that may affect towboats and barges transiting through level or broken ice is their propensity for entrapping and transporting brash ice beneath their flat-bottomed hulls. Ice-tank experiments have shown that the thickness of the ice accumulations on the flat bottoms of towboats and barges increases with decreasing velocity of the vessels, and also increases when lateral confinement (such as provided by ice ridges along the track) does not allow ice pieces to slide off the vessel bottom toward the sides.

7-2. Operational Choices. The problems outlined above suggest two general approaches for their control and mitigation. The first approach entails the use of mechanical methods for controlling brash-ice accumulations at specific channel locations, either by removal or breakup. Icebreakers could be used to loosen and break up such ice accumulations, and to ease transit conditions for commercial vessels, including towboats and barges. However, no icebreakers currently operate on the Ohio and Upper Mississippi Rivers, or on the Illinois Waterway. The second approach involves the optimum scheduling of tow transits, and possibly the convoying or grouping of tows, which will minimize ice growth in navigation channels.

7-3. Transit Scheduling or Convoying. Results from laboratory experiments and numerical modeling indicate that the basic rule for minimizing the volume of ice grown in a navigation channel is to minimize the total number of transits or tow passages per day. However, the demands of navigation do not generally allow this to be done. Assuming that a certain number of transits must take place per day, numerical modeling has shown that varying the time interval between individual transits has no significant effect on the volume of ice grown. But convoying of vessels, i.e., having tows grouped together to transit one after the other, is a specialcase equivalent to a large, single transit. Under a convoying concept, only one icebreaking event per day would take place. Correspondingly, the total volume of ice produced in a waterway each winter would be minimized.

a. Limitations. Ice-prone waterways may have relatively short periods of severe ice conditions. The river reaches between locks and dams in many locations are relatively short, resulting in frequent lockages of the tows. The vessels may have numerous and varied origins and destinations along the waterways, some of which may lack adequate docking and mooring areas where several tows could be assembled for convoying. Finally, upbound and downbound transits usually have equal frequency. Under these conditions, elaborate transit scheduling, requiring close coordination between the Corps of Engineers, the Coast Guard, and the navigation industry, is unlikely to be administratively or economically feasible.

b. Guidelines for Scheduling or Convoying Tow Traffic. For certain river reaches where ice accumulations are particularly severe, or for a given period when cold weather conditions are extreme, partial scheduling or convoying may be chosen as a temporary, expedient measure to help keep the waterway open and expedite traffic. In such a convoy, normally the leading towboat would be the most powerful one. It is the vessel most likely to be able to do the required icebreaking in the difficult areas. It may also involve the widest tow configuration, thereby opening the navigation channel for the rest of the tows in the convoy. Finally, the most powerful boat may be capable of sustaining a speed sufficiently high to avoid ice accumulations underneath its own barge bottoms, as well as those of the following tows. The size of a convoy may be limited by the time required to pass it through a lock, rather than by the time required to move between two successive locks. While transit scheduling or convoying are not common approaches to alleviating winter transit difficulties in the navigable waterways of the northern United States, they should be considered when extraordinary local and short-term ice conditions are forecast or are at hand.

Section II. Operational Techniques at Locks and Dams

7-4. Introduction. Operational techniques to mitigate ice-related problems at locks and dams tend to be site-specific. Factors influencing the success of any operational technique include the geographical location of the project with respect to river features, the river system that the project is on, the location of the dam in relation to the lock, the presence of an auxiliary lock, the kinds of gates at the lock or dam, the presence or absence of an effective high-flow air system at the lock, the availability of a work boat assigned to the lock, the prevailing wind direction, the amount of winter navigation, and so on. The general problems caused by ice at locks and dams are summarized in Chapter 3: ice obstructing the upper lock approach, fragmented ice floes accumulating in miter gate recesses, ice adhering to lock walls and miter gate recess walls, inoperative floating mooring bitts, vertical check pin (line hook) icing, ice accumulating in the lower lock approach, difficult ice passage at dam spillway gates, ice buildup from spray at dam spillway gates, icing from leakage at gate seals, and ice accumulating on intake screens. Several of these problems involve ice adhering to structure surfaces. When methods for the prevention of these ice buildups are not available, it may become necessary to resort to physical removal techniques.

a. Mechanical Contact Tools for Ice Removal. Two hand tools that can reliably be used to remove ice from concrete or steel surfaces are the pike pole and the ice chipper. Both of these tools

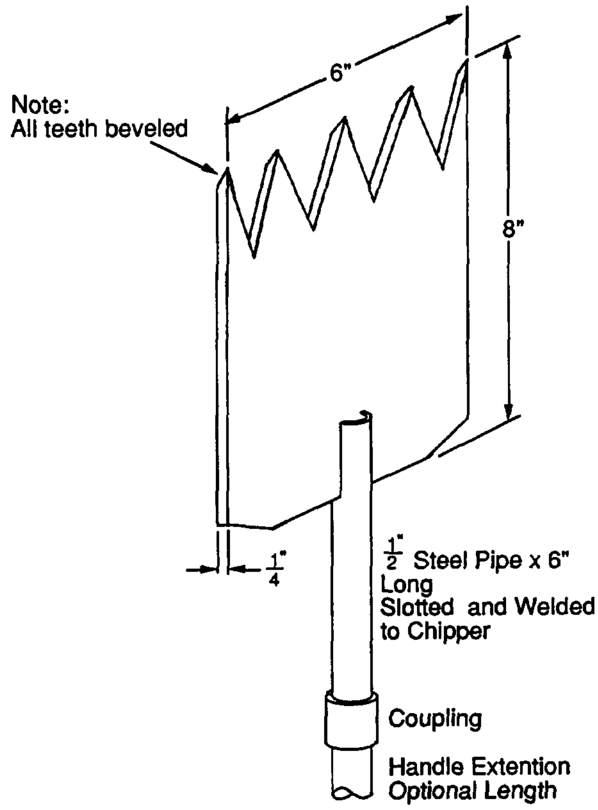


Figure 7-l. Effective design for a manual ice-chipping tool.

are widely used by lock personnel at sites that experience winter icing problems. Figure 7-l is a sketch of an ice chipper that has been refined over many years by its users. Large mechanical equipment used to scrape ice collars from lock walls is limited. Backhoes scrape the wall vertically by drawing the bucket teeth up the face of the concrete. With a light machine, this may require more than one pass to scrape through to the concrete, and frequent repositioning of the machine is necessary. With a heavier track-mounted machine, a single pass is usually sufficient. It is easy to move the machine along and there are no spuds to be set. However, with forceful operation, damage to the lock wall is inevitable, and the concrete on grooved or paneled walls could be seriously spalled.

b. Ice Removal with Noncontact Tools. Two techniques for ice removal using noncontacting tools are steam and water jets. Steam, when available at the desired locations, has always been used, often via lances or pipe probes placed and maneuvered by hand. But using steam is slow and time-consuming. The use of high-pressure water jets is rare because of the high horsepower required and the bulkiness of the typical systems. Advances in the design of such systems could make them more attractive.

7-5. Methods Used at Locks. Operational techniques used to mitigate ice problems at locks are briefly listed below. The list of practices can always be, enlarged by discussing any particular problem with the lock or maintenance personnel at neighboring project sites.

a. Upper Approach. Techniques to reduce upper approach ice problems include using an auxiliary lock with a bulkhead spillway to pass ice, ice lockages in the main chamber or an auxiliary chamber, diagonal high-flow air-screen deflectors, and towboat wheel wash. Other possibilities are the placement of barge traffic awaiting downbound lockage in appropriate configurations to deflect ice, using ice spillways near dams (if present) or using dam gates to pass ice, assuming sufficient flow is available for this purpose.

b. Miter Gate Recesses. To clear fragmented floes from around miter gates and recesses, towboat wheel wash, miter gate fanning, pike poles and ice rakes, or recess air flushers are used. If the techniques used to deflect floating ice away from the upper approach are effective, then the task of dealing with fragmented ice in the lock chamber and gate recesses will be reduced.

c. Lock Walls and Recess Walls. Ice accumulations or ice collars on lock walls and miter gate recess walls cause width restrictions, as noted earlier. To remove ice collars, or to prevent or reduce the ice growth, various techniques can be considered. If the pool elevation in the chamber is kept high except during lockages, the chamber wall temperature will be near the water temperature. On the other hand, if the pool is kept at a low level, more of the lock wall is exposed to the subfreezing air, allowing the wall to reach temperatures below freezing and thus allowing more ice to form. Removal of the ice is critical in the gate recess area. Common practices at many locks are the labor-intensive ones of using chippers, pike poles, and steam lances. Other techniques that may be available include low-flow bubblers, surface-mounted heat mats, embedded circulation loops of warm fluids, and mechanical tools like backhoes.

d. Mooring Bitts. Floating mooring bitts typically freeze in place because of floating ice being pushed into the bitt recess area, as well as because of ice buildup on tracks and related rollers. Currently, personnel at many locks secure the bitts in the top position, not using them during the winter months. This, of course, leaves the bitts unavailable while lock traffic may still be in need of them. The techniques of using a single-point air bubbler or replaceable embedded electric heaters have been developed but are not yet widely adopted. Additional safety systems should be added so that if a floating bitt becomes frozen in the submerged position, it will not be launched skyward when the ice melts.

e. Check Pins. Vertical check pins are typically iced over and are forgotten until spring. Lock personnel rely on mooring points on the top of the lock wall to secure the lines during the winter months. Constant monitoring of the lines by deck hands is required. No operational technique appears feasible, other than steaming or chipping the ice on the check pins.

f. Lower Approach. The final lock ice problem is the accumulation of ice in the lower approach. Typically, this is not a serious problem for lock personnel. It is possible to stage tows waiting to be locked up in such a manner as to block the encroachment of ice. Water discharge when lowering the lock chamber level helps to clear the immediate lower approach area.

7-6. Methods Used at Dams. Operational techniques used to handle the icing problems associated with dams are much the same as those used at locks. Comments on specific practices at dams are given here. Many dams have been equipped with embedded electrical heaters along gate sealing surfaces. Unfortunately, these heaters have a record of frequent failure, and a new technique has been designed for the installation of a removable heater that is easily exchanged if it becomes inoperative (see Para. 6-19a). Steam lances are commonly used in dam deicing. This is a time-consuming operation but it can be effective. Cindering the dam gate seals (i.e., applying coal cinders to the water above the gate, which then flow toward and plug the gaps at the seals to reduce water leakage) helps to prevent the formation of larger ice deposits on the downstream side of the gate. A new method that has been proposed is a heater inserted in the hollow channel of a J-seal to keep the seal material flexible (see Para. 6-19c). The increased flexibility makes a better seal, eliminating or reducing leakage and ice formation on the downstream side of the gate. The types of gates and their lifting devices are largely site-specific, and techniques used to operate them in winter are developed with time and experience. Typically, submergible gates operated in the submerged position have the fewest operational problems from ice during the winter months. Problems experienced with submergible dam gates are identified in *Submergible Gate Use Within the Corps: Case Histories* (U.S. Army 1985). In many instances, operational techniques now used by lock and dam operators are also described in that report.

Section III. Warm Water Use

7-7. Introduction. Most rivers have sources of warm water that either already suppress some ice formation or may be used to cause some ice suppression. The most obvious are power plants that discharge heated water into the river. Typically, there will be a narrow band of open water for some distance downstream of these plants when the river is otherwise ice-covered. In other cases reservoirs, even with ice covers, may contain water above the freezing point of 32°F. When this water is released, it will flow some distance downstream before it begins to freeze. This section describes the effect on ice covers of these sources of warm water and provides approximate means of estimating this effect.

7-8. Sources of Warm Water. Besides the two main sources of warm water in winter mentioned above, there are other sources such as the discharge of treated sewage, warm waste water from industrial plants, and, occasionally, warm springs, but generally all of these release too little heat to cause more than very local effects on the natural ice cover. In seeking to use warm water as an aid to river ice management, it is important to realize under what conditions the warm water may be effective, and the extent of the influence.

a. Power Plants. Both fossil fuel power plants (using coal or oil) and nuclear power plants require cooling in the process of generating electrical power. This cooling generates waste heat that is then discharged into the environment, either directly to the atmosphere by use of cooling towers, or indirectly by first discharging the heat to a water body that then transfers the heat to the atmosphere. If an existing plant already has cooling towers, it is unlikely that the plant will be able to discharge the heat to a water body because of the large capital costs of having two cooling

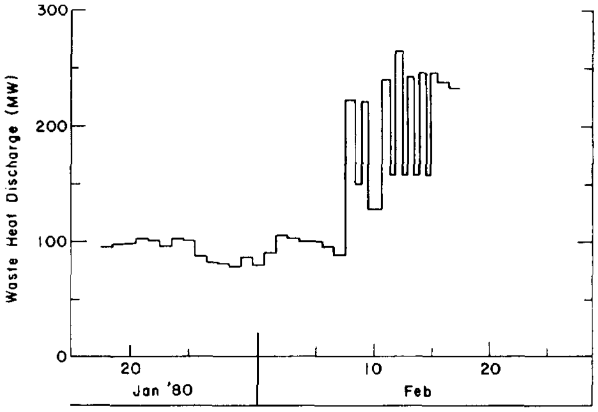


Figure 7-2. Record of waste heat discharge from a power plant that uses Mississippi River water for cooling. Prior to 8 February, much of the plant was down for maintenance; thereafter, it operated alternately between full and partial load.

systems. However, many plants do use rivers as the heat sink. The warm water released results in ice suppression that in some instances can be helpful in managing ice problems. Power plants operate either as base load plants, at a more or less constant capacity, or as peaking power plants to supply power at the time of greatest demand. The actual operating characteristics can only be ascertained from the utility companies directly. In Figure 7-2 the waste heat discharge of a power plant on the Mississippi River, 7 miles upstream of Lock and Dam No. 15, during January and February of 1980 is shown to illustrate the nature of the output that might be expected (Ashton 1979). During January of 1980, a large part of the plant was shut down for maintenance, and even after that the plant was not running continuously at full load. As a consequence, the waste heat discharge was variable. Nearly all plants maintain a record of input and output water temperatures, which, along with the cooling water discharge rates, enables calculation of the waste heat discharge. The waste heat discharge is determined from these data according to

$$Q = \gamma C_p N (T_{out} - T_{in}) \tag{7-1}$$

where

Q = waste heat release rate (Btu/hr)
γ = specific weight of water (62.4 lb/ft^3)
C_p = specific heat of water (1.0 Btu/lb°F)
N = cooling water discharge rate (ft^3/s)
T_{in} = intake cooling water temperature
T_{out} = outfall cooling water temperature.

As an example, in early February one unit of the plant whose output is shown in Figure 7-2 had an intake temperature of 32°F, an outfall temperature of 49°F, and a discharge rate of 89 ft^3/s. Thus

$$Q = \left(62.4 \frac{\text{lb}}{\text{ft}^3} \right) \left(1.0 \frac{\text{Btu}}{\text{lb°F}} \right) \left(\frac{89\text{ft}^3}{\text{s}} \right) \left(49°\text{F} - 32°\text{F} \right)$$

= 94,400 Btu/s = 340 x 10^6 Btu/hr or 99,600 kW.

This rate of energy release is greater than the electrical output of the plant, since typically coal and oil plants have 40 percent efficiency, and nuclear plants have even less at about 33 percent. Thus, coal plants discharge as heat energy to the cooling water about 1-1/2 times the amount of electrical energy put out over the transmission lines, and nuclear plants about twice as much. These ratios are useful for quick assessments of ice suppression, as will be discussed below.

b. Reservoirs. In many reservoirs the water beneath the ice cover is above the freezing point. When this water is released during the winter, it takes some time and distance before it is cooled by the atmosphere down to the freezing point, after which further heat loss results in ice formation. If the warm water release encounters ice before it has cooled to the freezing point, it will melt the ice until the water is at the freezing point. The extent of melting or the distance to cool to the freezing point depends on both the release flow rate and the water temperature. This distance depends also on how cold the atmosphere is. Methods to predict the distance or extent of melting are described below. The biggest uncertainty is the temperature of the reservoir water, which is usually below the 39°F temperature of maximum density, and depends on the particular sequence of meteorological conditions at the time of freezeup and the extent of throughflow during the winter. Water released from the bottom of reservoirs will usually be warmer than water released from near the top. Direct measurement of the release water temperature is the most certain way of assessing the flow temperature.

7-9. Warm Water in the Context of Ice Production. In the Pittsburgh District on the Ohio River there are nine power plants that discharge warm water at a total rate of about 5500 MW over a distance of 125 miles. At 14°F the heat loss from open water over this reach is about 15,000 MW, so that the warm water reduces ice production by about 37%. At -4°F the loss from open water is about 30,000 MW, so the warm water reduces ice production by about 18%. If the ice is 2 in. thick, the ice production rate under natural conditions is equivalent to a heat loss rate of about 7500 MW at 14°F and 15,000 MW at -4°F, so the reduced ice production is on the order of 75% at 14°F and 37% at -4°F. In the Huntington District there are four power plants on the Ohio River that discharge a total of 4200 MW over a distance of 310 miles. The heat loss from open water over this reach at 14°F is on the order of 40,000 MW, so the warm water reduces ice production by about 10%. At -4°F the reduction is on the order of 5%.

a. Clearly, the magnitudes of warm water discharge are small when compared with the overall energy exchange rates between the river and the atmosphere, and cannot be expected to mitigate ice problems over the entire reaches. Close to the plants, however, the suppression can be significant in affecting local ice conditions.

b. The fact that large quantities of warm water are discharged into the river does not mean that the water temperatures are excessively high. In fact, in winter the temperatures of the warm water discharges rapidly approach the freezing point. In one observation for example, 3000 ft downstream of the Riverside Power Plant on the Mississippi River, the highest water temperature in a plume from a 200-MW release was only 35°F. However, even small increases in water temperature above the freezing point can stop ice from thickening. As an example, if the air temperature is -4°F and the ice is 6 in. thick, the thickening rate is about 1.9 in. per day, if the water temperature is at the freezing point. If the water velocity is 1.5 ft/s and the temperature is 32.16°F (or 0.16°F above freezing) it will stop the thickening, that is, the heat transferred to the ice from the water exactly equals the heat loss to the atmosphere. Under the same conditions but with 12-in. thick ice, a water temperature of 32.10°F stops further thickening. Thus, one of the effects of warm water discharge into a cold river is to limit the ice production that otherwise might occur.

7-10. Effects on River Ice of Warm Water Release. Warm water effects are discussed below by first evaluating natural conditions, and then discussing various modes of heat introduction to the river.

a. Natural Conditions. To assess the effects on river ice of a warm water discharge, it is important to appreciate the magnitude of temperatures, natural ice conditions in the river, and the heat losses to the atmosphere that cause ice formation. The water temperatures of rivers more or less follow the average air temperatures through the annual cycle until those temperatures go below the freezing point. At that time the water, instead of cooling below the freezing point, forms ice in proportion to the heat loss to the atmosphere, and the ice acts as a buffer preventing further temperature decline. Throughout the period of ice cover, water temperatures remain very close to the freezing point both as a consequence of turbulent mixing, which prevents stratification, and as a consequence of continually flowing past the ice cover, which is a heat sink for the river water. Only in still water or at extremely slow velocities can any significant stratification develop. There is a minor heat gain from energy stored in the bottom sediments during the preceding summer (O'Neill and Ashton 1981), and a minor gain from viscous dissipation or friction in the flow, but these gains are very small relative to the heat losses at the surface. In general, when there are significant amounts of ice present in a river, the assumption that the water temperature is at 32°F is very accurate. This is particularly useful when assessing the effects of adding warm water, since all the energy of the warm water is used either to melt ice or is lost to the atmosphere in open water areas.

(1) Ice conditions in a river vary widely from site to site, depending on many factors. These are discussed in earlier chapters. From the standpoint of the effects of warm water, the ice may be classified as moving or stationary. If the ice is moving, the effect of the warm water is to reduce the volume of ice passed downstream in proportion to the amount of heat discharged. Nearly all the energy discharged into flows with moving ice is used to melt ice. In the case of an intact, stationary ice cover, the waste heat is used to melt the ice or suppress its otherwise natural thickening, as well as being directly lost to the atmosphere in the open water areas formed by the warm water. In a sense the open water areas formed in the ice cover act as a short circuit to the atmosphere for some of the waste heat, at least to the extent that the heat transfer rate is greater at larger values of the water vs. air temperature difference than would be true for an open water surface at 32°F.

(2) This leads directly to the subject of natural heat losses from rivers in winter. Two cases are important - the open water case and the ice-covered case. In the case of open water, the heat losses may be calculated using detailedenergy budget methods, which consider the daily or diurnal variations of long wave radiation gains and losses, short wave radiation gains, sensible heat losses

to the air due to either free convection (when the air is still) or forced convection (when the air is windy), and evaporation losses. The variables involved include time of year, time of day, latitude, air temperature, humidity, wind speed, and cloud cover. For some studies such energy budget methods are necessary, but they involve considerable calculation effort, plus field data as input. For many studies a simpler method is adequate for estimates of the effects of warm water discharge. This method consists of simply combining all the energy budget effects into a single heat transfer coefficient applied to the difference between the water temperature and the air temperature (Ashton 1982). The heat loss per unit area of open water surface q_{wa} is then given by

$$q_{wa} = H_{wa}(T_w - T_a) \tag{7-2}$$

where

H_{wa} = heat transfer coefficient
T_w = water temperature
T_a = air temperature.

H_{wa} depends on all the variables that determine the energy budget, but is typically between 2.7 and 4.5 Btu/hr ft^2°F, with the higher values associated with higher wind speeds. As an example, if the air temperature is 10°F and the water temperature is 33°F and H_{wa} = 3.5 Btu/hr ft^2°F, the heat loss is

$$q_{wa} = 3.5 \frac{\text{Btu}}{\text{hr ft}^2\ °\text{F}} \times (33 - 10\ °\text{F}) = 80.5 \frac{\text{Btu}}{\text{hr ft}^2}\ . \tag{7-3}$$

(3) Once an ice cover is on top of the water, it acts to insulate the water, with the insulation effect increasing as the ice thickens. A snow layer increases the insulation effect even more. And, since the water below is at 32°F, the heat losses are directly transformed into ice production. A simple layer analysis enables estimates of the heat loss through the ice (and snow) cover. As shown in Figure 7-3, the air temperature is denoted by T_a, the top surface ice temperature by T_s, the bottom surface ice temperature by T_m, which is always at the melting-freezing temperature of 32°F. The thermal conductivity of the ice is denoted by k_i and the ice thickness by *h*. It is important to note, particularly for thin ice covers, that the top surface temperature is not the same as the air temperature; if it were there would be negligible heat loss to the atmosphere and no ice thickening.

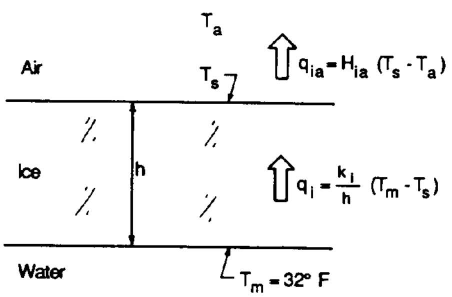


Figure 7-3. Schematic diagram showing notation and heat transfer equations governing the heat flow from a water body through an ice cover to the atmosphere.

As a first approximation, which is very good for most purposes, the heat flow may be analyzed as a quasi-steady state process such that the temperature profile in the ice varies linearly from T_m to T_s over the thickness of the ice. The heat flow through the ice is then given by

$$q_i = \frac{k_i}{h}(T_m - T_s) \cdot \tag{7-4}$$

The heat loss to the atmosphere from the ice q_{ia} can be written similar to that from an open water surface with T_s substituted for T_w in Equation 7-2 to give

$$q_{ia} = H_{ia}(T_s - T_a) \,. \tag{7-5}$$

The heat flow through the ice equals the heat loss at the surface, so that $q_{ia} = q_i$, which allows T_s to be eliminated between Equations 7-4 and 7-5 and gives

$$q_i = q_{ia} = \frac{T_m - T_a}{\frac{h}{k_i} + \frac{1}{H_{ia}}} \tag{7-6}$$

This result may be compared to the heat losses from an open water surface to show the insulating effect of the ice cover. In Figure 7-4 the ratios of heat losses (q_i) through the cover to the open water losses (q_{wa}) are shown as functions of ice thickness, for the range of heat transfer coefficients usually found; 6 in. of ice reduces the heat loss by 50% or more.

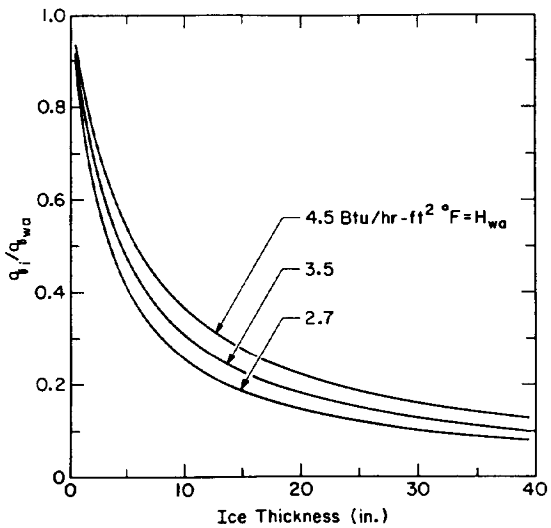


Figure 7-4. Ratio of heat loss through an ice cover (q_i) to heat loss from an open water surface (q_{wa}) versus ice thickness, for three values of the heat transfer coefficient, H_{wa} (or the equivalent H_{ia} for heat transfer from ice to air).

(4) This heat flux through the ice is also the heat flux upward from the bottom surface, which causes the ice to thicken at the bottom. The thickening rate is inversely proportional to the heat of fusion ***(L)*** times the specific weight of ice, so that the thickening rate is given by

$$\frac{dh}{dt} = \frac{1}{\gamma_i L}\left[\frac{T_m - T_a}{\frac{h}{k_i} + \frac{1}{H_{ia}}}\right] \tag{7-7}$$

For most practical river ice problems, the specific weight γ_i, the heat of fusion ***L,*** and the thermal conductivity k_i may be treated as constants with values for pure ice as follows:

γ_i = 57.2 lb/ft^3
L = 144 Btu/lb
k_i = 1.30 Btu/hr ft °F.

Using these values the thickening rate is given by

$$\frac{dh}{dt} = 0.0029\left[\frac{T_m - T_a}{0.769h + \frac{1}{H_{ia}}}\right] \text{ (ft/day).} \tag{7-8}$$

As an example, for T_m = 32°F, T_a = -5°F (very cold), h = 0.5 ft, and H_{ia} = 3.5 Btu/hr ft^2°F, the thickening rate is 0.16 ft/day or about 2 in. per day. When the ice is 1-ft thick, for the same conditions the thickening rate drops to 1.2 in. per day. Figure 7-5 shows thickening rates to be expected as functions of average daily air temperature and ice thickness, assuming H_{ia} = 3.5 Btu/hr ft^2 °F.

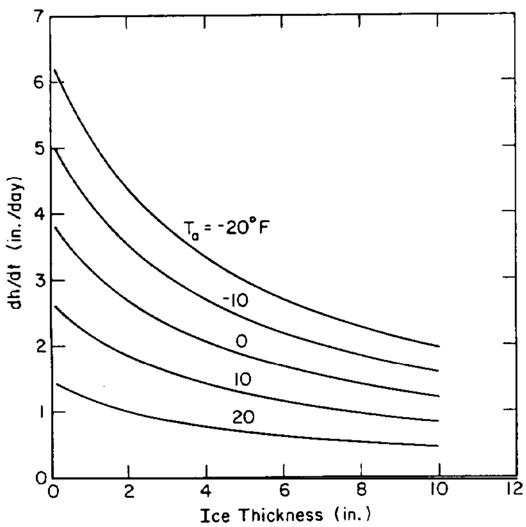


Figure 7-5. Rate of ice thickening versus ice thickness, for five values of average daily air temperature. H_{ia} = 3.5 Btu/hr ft^2°F is assumed.

(5) The above calculations overestimate the thickening rate, or rate of ice production, if there is a snow cover on the ice. Typically, the thermal conductivity of the snow cover is about one-tenth that of the ice cover, so it has the insulating effect of ten times its thickness of solid ice.

(6) There are several purposes to the above calculations. First, they may be used to estimate rates of ice production as a function of air temperature and ice thickness. Second, the results of the calculations show that the ice production is greatly reduced as the ice thickens, which, in turn, suggests that the effectiveness of warm water discharged into a river is greatest when the ice is thicker, since a smaller amount of heat is required to stop the growth of the ice cover. Thus, while warm water discharge may not have a great effect in preventing initial ice formation, it may have a significant effect in limiting ice production over significant reaches of the river.

(7) In summary, there are two main effects of warm water released into ice-covered rivers. First, the heat locally suppresses the ice completely and creates open water areas near the point of release. Second, the heat acts to limit the ice thickness at regions downstream and beneath the ice cover. Both effects may be calculated using methods described below. The effectiveness of the warm water depends a great deal on specific site conditions and the nature of the ice formation that would occur otherwise.

b. Fully Mixed Releases. The water release from a reservoir is generally above freezing and results in complete suppression of ice for a certain distance downstream, and partial suppression of the ice further downstream beneath the ice cover. There are methods available (Ashton 1979) to simulate these effects that take into account the unsteady nature of the air temperature and release rates, but they are too detailed for full treatment here. Instead, some steady-state example calculations are presented as well as some results from unsteady simulations, so as to give an appreciation of whether or not a warm water release causes a significant effect. Occasionally, the effluent from a power plant is diffused uniformly across the receiving river flow, but this is more the exception than the rule. In general this form of release on larger rivers results in insignificant lengths of open water, but a definite suppression of the ice growth (thickness) downstream.

(1) Introduction. Three example cases are considered: a reservoir discharging 1000 ft^3/s at 36°F into a river 400 ft wide, a reservoir discharging 5000 ft^3/s at 36°F into a river 500 ft wide, and a very large power plant of nominal capacity of 2400 MW discharging 4800 MW of waste heat through a diffusing system into a river 2000 ft wide. As a first approximation, the area of open water, and hence the distance to the upstream edge of the ice cover, can be determined for low air temperatures by estimating the heat transfer coefficient and applying it to the average temperature difference between the water and the air.

(2) Example 1.

(a) Conditions.

—Reservoir discharge: 1000 ft^3/s at T_w = 36°F

—Available heat discharge:

$Q = \gamma C_p N (T_w - T_m) = 62.4 \times 1.0 \times 1000 \times 3600 \text{ s/hr} \times (36 - 32)$

$Q = 899 \times 10^6$ Btu/hr

—Open water area: $A = Q/q_{wa} = \dfrac{Q}{H_{wa}(T_w - T_a)}$

—Width of open water : W = 400 ft

—Length of open water : $L = A/W$

—For H_{wa} = 3.5 Btu/hr ft²°F:

T_a (°F)	$T_w - T_a$ (°F)	A (ft^2)	L (ft)
20	12	21.4×10^6	53,500
10	22	11.7×10^6	29,200
0	32	8.0×10^6	20,100
–10	42	6.1×10^6	15,300

(b) Discussion. This reservoir release maintains open water in the river downstream a distance up to 10 miles when the weather is mild in winter, and the distance shortens to a little less than 3 miles when the weather is very cold (-10°F is the average daily temperature and not the extreme overnight low). The heat release is equivalent to 240 MW, which is about the rate of heat released from a fossil-fueled power plant of nominal capacity of 160 MW. The discharge over two months adds up to 120,000 acre-ft, and requires a significant reservoir if it is to have that capacity of warm water at the beginning of the ice-covered period.

(3) Example 2.

(a) Conditions.

-Reservoir discharge: 5000 ft^3/s at T_w = 36°F

-Available heat discharge:

$Q = \gamma C_p N (T_w - T_m) = 62.4 \times 1.0 \times 5000 \times 3600 \text{ s/hr} \times (36 - 32)$

$Q = 4490 \times 10^6$ Btu/hr

-Open water area: $A = Q/q_{wa} = \dfrac{Q}{H_{wa}(T_w - T_a)}$

-Width of open water: W = 500 ft

-Length of open water: $L = A/W$

-For H_{wa} = 3.5 Btu/hr ft2 °F:

T_a (°F)	$T_w - T_a$ (°F)	A (ft^2)	L (ft)
20	12	107×10^6	214,000
10	22	58×10^6	117,000
0	32	40×10^6	80,000

(b) Discussion. This is a large reservoir release with open water about 11.6 miles downstream even at -10°F air temperature. The heat release is equivalent to 1200 MW, which is about the heat released from a fossil-fueled power plant of 800 MW capacity. The discharge over two months is 600,000 acre-ft.

(4) Example 3.

(a) Conditions. A large power plant of nominal capacity 2400 MW is discharging 4800 MW through a diffusing system into a river 2000 ft wide, Temperature rise in the river depends on the river flow, but under the simplified assumptions used here, the open water area can be calculated approximately without that knowledge since it is based on the required water surface area to remove the heat content. This surface area depends on the temperature difference between the water and the air, and the water temperature will be very near 32°F.

—Available heat discharge:

$$Q = 4800 \text{ MW} \times \frac{10^6 \text{ Btu/hr}}{0.293 \text{ MW}}$$

$$Q = 16{,}400 \times 10^6 \text{ Btu/hr}$$

—Open water area: $A = Q/q_{wa} = \dfrac{Q}{H_{wa}(T_w - T_a)}$

—Width of open water: W = 2000 ft
—Length of open water: $L = A/W$
—For H_{wa} = 3.5 Btu/hr ft^2°F, and $T_w - T_a$ = 32°F - T_a:

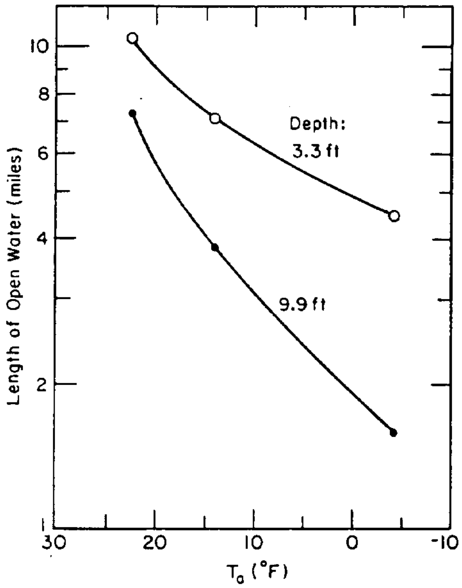
T_a (°F)	$T_w - T_a$ (°F)	A (ft^2)	L (ft)	L (mi)
20	12	390×10^6	195,000	37
10	22	213×10^6	106,000	20
0	32	146×10^6	73,000	14
–10	42	111×10^6	56,000	11

(b) Discussion. This is a very large power plant and a very large river. The effect on the ice is open water for many miles downstream when the air is mildly cool, but only 10 to 15 miles when the air temperatures are around 0°F. The simplified assumption, namely that the open water area is based only on the area required to remove the heat added, is probably not very accurate here, since the complete mixing by the diffuser probably results in water temperatures sufficiently close to freezing that ice will form on top of the slightly warm water if the flow is not too fast. For such a case a more detailed analysis would be needed. If skim ice forms, however, the warm water still prevents the ice from thickening as much as it would without the addition of heat. Note also that we did not need to know the velocity of the flow or the depth, but merely needed to assume that the flow was fast enough to mix the warm water, and carry it downstream.

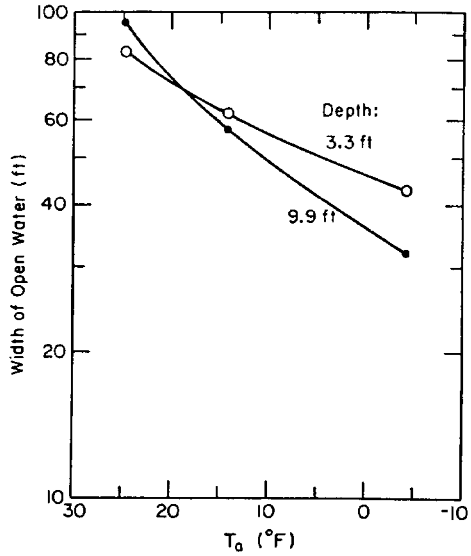
c. Side Channel Releases. The most usual method of disposing of a power plant's waste heat to a river is to release it directly at the side of the river. This case is more difficult to analyze because now the rate of transverse mixing of the warm water plume across the river must be considered. As a general rule the open water area resulting from a side channel release is quite narrow, on the order of 50 to 100 ft, but very long, on the order of miles. While some of the heat is transferred directly to the atmosphere through the open water area, a significant amount of the heat is transferred to the bottom of the adjacent ice cover and to the bottom of the ice cover downstream of the end of the open water. From the standpoint of maximum decrease of the volume of ice that would be produced in the river without waste heat, this is the most effective use of the waste heat since, once under the ice cover, nearly all of the heat is used to retard ice thickening or to melt it. Simulations are available that enable estimates of the lengths and widths of open water and the amount of ice suppression that results beyond the open water, but they depend on the amount of heat released, the flow velocity, air temperature, depth of river, and the mixing characteristics of the river. For straight reaches of river, the simulations seem to yield reasonable estimates of open water extents.

(1) In Figure 7-6 are presented parametric plots of the lengths and widths of open water that may be expected from a side channel release of warm water into rivers of 3.3 and 9.9 ft depths with flow velocities of 1.6 ft/s, as functions of air temperature and rates of heat release. These figures are useful to gain an appreciation of the nature of the ice suppression. Figure 7-6a shows that as the air gets colder, the length of open water decreases significantly. The length of open water is also much shorter for the deeper river than for the shallower river. Figure 7-6b shows that the width of open water is little affected by the depth, but of course is narrower at lower air temperatures. Figures 7-6c and 7-6d show the effect of different rates of heat release on the lengths and widths of open water. As expected, both the length and width increase with increasing warm water discharge.

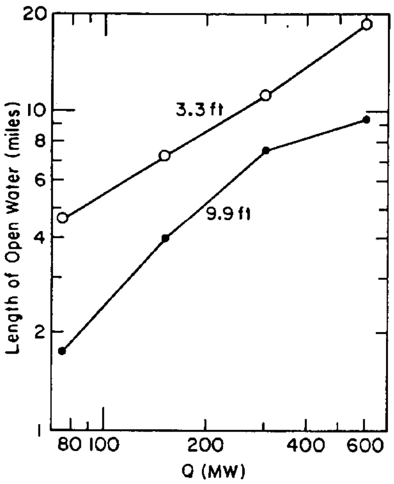
(2) Not apparent from the various plots of Figure 7-6 are the relative amounts of heat from the warm water that are transferred directly to the atmosphere through the open water or are transferred to the underside of the ice. Less than 30 percent of the heat is transferred through the open water to the air in all cases. This means that 70 percent of the heat is transferred to the ice cover, and either retards thickening or causes thinning of the ice. This effect of the waste heat may extend for many miles further downstream, beyond the end of the open water reach. These effects



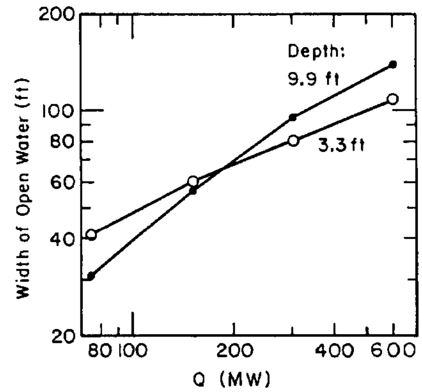
a. Length versus air temperature, heat discharge fixed at 150 MW.



b. Width versus air temperature, heat discharge fixed at 150 MW.



c. Length versus heat discharge rate, air temperature fixed at 14°F.



d. Width versus heat discharge rate, air temperature fixed at 14°F.

Figure 7-6. Length and width of open water resulting from side channel release of warm water into a river of either 3.3-ft or 9.9-ft depth, as functions of air temperature and heat discharge rate. In all cases the flow velocity is 1.6 ft/s.

have been simulated by numerical analysis but are too complex to be described quantitatively here, since the effects vary from site to site. Some general statements can be made, however. The rate of heat transfer to the bottom of the ice cover is more or less proportional to the product of the velocity and the amount by which the water temperature is above freezing. Even temperature differences as small as 0.1°F have effects that are important, so that any field measurements must use accurate thermometers. The deeper the water, the further downstream the waste heat will affect the ice. For depths on the order of 3 ft, the warm water will have cooled to very near freezing in about 3 miles, while for depths of about 12 ft the effect will extend for as far as 10 miles.

d. Mid-Channel Releases. Rarely is waste heat from a power plant discharged in the middle of a river. If it were, the effects would be similar to a side channel release and result in a long, narrow open water stretch. The open water would be wider than a side channel release but shorter because the warm water now mixes and spreads on both sides of the thermal plume, rather than only on one side. There may be cases where it would be desirable from an ice management viewpoint to release an existing source of warm water other than at the side. Before doing this, a simulation of the effects should be made to estimate whether the ice suppression would be effective at the particular site.

Section IV. Unconventional Energy Use

7-11. Introduction. Conventional energy sources, such as electricity from public utilities, or the burning of hydrocarbon fuels for heating (either direct heating, or indirect heating such as for generating steam), can be viewed as comparatively expensive sources of energy for ice control at lock and dam installations. Therefore, consideration might be given to unconventional energy sources, such as sensible heat from groundwater, heating of a transfer medium by solar energy, or electricity generated from wind energy, as possible ways to more economically control ice at navigation projects. A study was conducted to evaluate the feasibility of using energy from either groundwater, sunlight, or wind to achieve typical ice removal or ice prevention tasks at lock and dam projects (Nakato et al. 1988). The conclusions from that study are briefly summarized here.

7-12. Baseline Power Requirements. The study focused on the process of maintaining lock walls and miter-gate recess walls free of ice collars as the typical ice control task at navigation facilities. As a baseline for comparison of ice control techniques (whether they are conventional or unconventional techniques), the power levels needed to keep the collar formation areas of lock walls at or above 32°F were calculated after making certain assumptions for purposes of illustration.

a. Assumptions. Let the ice collar area along the two walls of a 600-ft-long lock chamber be defined as 6 ft high, for a total of 3600 ft^2 on each wall or 7200 ft^2 for the entire lock. A heat loss coefficient describing the heat transfer from the surface of the lock wall to the atmosphere is taken to be 3.5 Btu/hr ft^2°F.

b. Power Levels. For selected values of air temperature, the amount of power needed to keep the walls at 32°F in the example lock is as follows:

Air temperature (°F)	*Heat loss rate (Btu/hr ft²)*	*Theoretical maximum power required (kW)*
23	32	66
5	94	199
-13	158	332

c. General. The sample power requirements shown above are for *net* heat rates *at* the lock wall surfaces. Consequently, actual power delivery would have to be higher to allow for inefficiencies and extraneous losses in delivering the energy to the walls. On the other hand, the power levels shown are for *continuous* delivery of energy to the wall surfaces, whether ice is present or not. In practical terms, intermittent delivery of heat to the lock walls may be all that is needed to control ice collar buildup. If supplying heat only half the time is sufficient (as is more than likely), the power requirement is reduced by half. Similarly, it is commonly found that only one wall needs attention because of ice adhering only to the wall that receives little or no direct sunlight; thus, the power needed is cut in half again. And further, it is probable that supplying heat to a band of wall 6 ft high is excessive, and the same result can be achieved by heating a band only 3 ft high; the power is halved still one more time, becoming only one-eighth the amount shown in the table above. Thus, for practical purposes, the following power levels should be kept in mind when studying the remainder of this section.

Air temperature (°F)	*Practical total power required (kW)*
23	8
5	25
-13	42

7-13. Groundwater Heat. Heat energy in groundwater appears to be an attractive energy source. Groundwater is readily available in the vicinity of most rivers. Its temperature is generally near the average annual air temperature for any particular site, meaning that it is well above 32°F for nearly all of the inland waterways of the conterminous United States. But the appeal of groundwater is diminished by practical problems involved in extracting and applying its heat, and by the fact that in the colder areas where heat energy is needed most, the groundwater temperatures are lower.

a. Application Modes. Three ways of applying the heat contained in groundwater were investigated for preventing or relieving ice buildup on the walls, recesses, or gates of a lock chamber-heating the entire mass of water in the lock chamber (which in turn would keep the lock walls ice-free), heating the water adjacent to the lock walls, and passing groundwater through pipes embedded in lock walls to raise the wall temperatures.

b. Whole-Lock Heating. This process amounts to continuously supplying groundwater to a lock chamber to replace the river water it contains, at a sufficiently large flow rate that the water does not cool below the freezing point before it is replaced by the continuous subsequent flow of groundwater. One of the practical problems of this approach is the tendency for thermal stratification in the water. Groundwater that is introduced at the water surface with a temperature greater than 39°F, the maximum density temperature, will spread out on the surface and cool to 39°F. Then it will sink to the bottom, permitting cooler water from below to rise to the surface. Consequently, this process *does not* protect the surface from freezing, and makes it necessary to expend energy to diffuse the introduced groundwater, and to keep the resulting blend of water well-mixed in the chamber.

(1) For illustration, consider a lock measuring 600 ft long, 110 ft wide, and 30 ft deep at high-pool level, or 15 ft deep at low-pool level. Assume the river water is not yet frozen, but that it is at the freezing temperature, 32°F. For two example values of groundwater temperature, 43 and 54°F, we want to know how much groundwater is needed to prevent freezing in the lock chamber, and what the power requirement for delivering it would be. Obviously, air temperatures are going to affect the answers, so for illustration three air temperatures (23, 5, and -13°F) will be used.

(2) Assuming that sufficient mixing is achieved to avoid the thermal stratification problem, the amounts of power lost from the water surface to the air and the corresponding amounts of warm groundwater needed to replace those losses are:

Air temperature (°F)	*Power loss (kW)*	*Flow (gal./min) at groundwater temperatures of:*	
		43°F	*54°F*
23	609	378	189
5	1830	1130	567
-13	3050	1890	944

(3) If sufficient mixing is not achieved, these groundwater flow rates would need to be multiplied by a factor of 3.5 to ensure that the surface temperature never went below 32°F. Thus, under the unmixed condition, and in the particular case of 5°F air and 43°F groundwater, a flow of 3960 gal./min would be needed. In the example of a 600 x 110-ft lock, at low pool, groundwater flow at this rate would be needed for over 31 hours to fill the chamber and replace the river water.

(4) Any of the above values represent potentially large amounts of groundwater withdrawal. Again, selecting the example in which air is at 5°F and groundwater is at 43°F, the flow rate for the *well-mixed* condition (1130 gal./min) is equivalent to the entire water demand of a community of 9000 people (at 180 gal./day per capita). For the unmixed condition, the equivalent community has about 31,600 persons. If large amounts of groundwater are withdrawn from wells close to a river, the temperature of the well water in winter may become lower than expected, because

recharge of the withdrawn groundwater by the cooler river water may take place. If wells are located farther from the river, or if recharge by river water does not occur, there could be problems arising from a decline of the water-table elevation.

(5) What is well-mixed? If the example flow of 1130 gal./min were introduced into a lock chamber through two 7.6-in. diameter nozzles at a mean velocity of 4 ft/s, each jet would penetrate about 67 ft before the mean jet velocity dropped to 0.5 ft/s. Assessing the mixing by means of a densimetric Froude Number leads to a value on the order of 0.001, and thus to the conclusion that the water is not well-mixed. Additional mixing would be required to ensure that the heat of the introduced groundwater would be dispersed adequately to keep the water surface above 32°F.

(6) The power requirements for the extraction and mixing of groundwater should be estimated to compare with the power needed to achieve ice control by other means. In using groundwater, it is reasonable to consider, for example, that the groundwater withdrawal could require two 1000-gal./min, 100-ft head pumps, which when used together would call for about 60 kW. Mixing the water in an efficient manner in the lock chamber could call for two more pumps (1000-gal./min, 50-ft head), having a power requirement of about 38 kW. The total requirement of 98 kW is a significant power expenditure compared to other means of lock ice control, and compared to the baseline power values given earlier in Paragraph 7-12. On this basis, the whole-lock heating approach has limited attractiveness.

c. Near-Wall Heating. If the flow of groundwater were to be directed only along the lock walls, where the formation of ice collars is to be prevented, it should be possible to keep the wall surfaces at a high enough temperature, and use a lesser amount of groundwater, than in the whole-lock heating scheme. (It would still be necessary, however, for the heat introduced by the groundwater to balance the heat lost to the atmosphere.) A way of doing this would be to use a manifold along each lock wall below the ice collar area, and to discharge the warmer groundwater through orifices in such a way as to develop flow circulations that would bathe the walls with a blend of water above 32°F.

(1) Assume that the walls will be kept free of ice if strips of the water surface that are 3 ft wide along each wall and extend the length of the 600-ft lock are kept free of ice by balancing the heat loss to the atmosphere with groundwater flow. As in the whole-lock heating example, two values of groundwater temperature (43 and 54°F) and three values of air temperature (23, 5, and -13°F) are used below to illustrate the groundwater flow requirement:

Air temperature (°F)	*Power loss (kW)*	*Flow (gal./min) at groundwater temperatures of:*	
		43°F	*54°F*
23	33	21	10
5	100	62	31
-13	166	103	52

These groundwater flows are quite modest. Note that these values are related to those for the whole-lock heating approach by a factor relating the two different water-surface areas to be kept unfrozen in each approach:

(2 x 3 x 600) / (110 x 600) = 0.055.

(2) The groundwater flows identified above are too small to develop sufficient circulation to mix water along the lock walls, and so the actual amount of groundwater required is determined by the flows needed for achieving sufficient mixing, rather than by the amount of heat in the groundwater. The question now becomes: What are the flow requirements for a water-jet manifold to achieve sufficient mixing while delivering warm groundwater to the area adjacent to the lock walls? To answer this, assume the following criteria: For each wall, the induced velocity at the water surface should be 1 ft/s, the manifold (minimum 9-in. diameter) is at a depth of 10 ft and has 100 nozzles that are each 0.5 in. in diameter and spaced 6 ft apart along the 600-ft length of the lock. Under these conditions, the discharge through each manifold would be 2330 gal./min, or 4660 gal./min if both walls are equipped with manifolds. By use of a densimetric Froude Number criterion, the water would be considered marginally well-mixed. It is clear that the discharge needed for mixing is much greater than that needed for heating, and even exceeds the groundwater discharges under the whole-lock heating concept when the latter uses pumps to achieve mixing.

(3) A remaining possibility for near-wall heating would be to blend river water and groundwater before putting it through the manifold, so that the resulting temperature is still effective in keeping the wall ice-free, while the more readily available river water reduces the need for extraordinary amounts of groundwater. For example, 50 gal./min of groundwater at 43°F blended with 2300 gal./min of river water at 32°F would yield 2350 gal./min issuing from the manifold, having a temperature of 32.23°F. However, such an arrangement would need careful design to avoid heat loss that would allow the blend to cool to 32°F before reaching the lock walls.

(4) Any near-wall heating scheme has the drawback of placing a large manifold pipe at or near the base of the wall or walls. This protrusion generally would be regarded as unacceptable. In a new lock or a major rehabilitation, such a manifold could be incorporated into the wall, with only the nozzles exposed. Another drawback is that greater flows than cited above would be needed if the manifold were more than 10 ft below the water surface.

d. Embedded-Pipe Heating. Circulating warm groundwater through pipes embedded in the lock walls would seem to be an efficient way to use the heat energy in the groundwater, as the heating of the mass of the walls precedes loss of the heat energy to the air. The study shows that the mass of the walls absorbs so much heat as to make this approach unattractive.

(1) Assume that groundwater at 57°F is flowing through an embedded pipe, and the *pipe-wall* temperature is constant at 32°F throughout its length. This simulates the pipe being embedded in a lock wall that is massive compared to the pipe, and in the vicinity of 32°F throughout its mass. Two sizes of pipe and two flow amounts for each size were analyzed. The following table shows how much energy is transferred from the groundwater to the surroundings of the pipe (i.e., the lock

wall mass) in a pipe length of 200 ft. Also shown is the temperature of the groundwater at the end of the 200-ft run.

Pipe size (in.)	*Flow per pipe (gal./min)*	*Energy transferred in 200-ft pipe run (kW)*	*Water temperature at end of 200-ft pipe run (°F)*
1	10	37	32.2
1	15	57	32.4
2	40	136	34.2
2	60	200	34.5

(2) Note that the values above are to keep the *pipe-wall* temperature at 32°F. The real case would be to keep the *lock-wall* temperature at or above 32°F; consequently, even larger flows and energy transfers would be needed. Depth of pipe embedment and pipe spacing would be important factors in determining how much larger the flows would have to be. Also, note that if the groundwater was at a lower temperature or moving at lower flow rates, or both, there could be danger of freezing near the end of a 200-ft pipe run. This would indicate the need for shorter pipe-run lengths.

(3) An operational application of embedded pipes would call for several parallel pipes running horizontally at the ice-collar location on the wall, each pipe run having a length of, say, 200 ft, and with the pipes being placed end-to-end with other pipes to cover the entire lock length. The example values above indicate that unless the groundwater temperature is very high, water temperatures decrease toward 32°F too quickly, i.e., in too short a distance in the pipes, for this technique to be practical. It appears that other heat sources, such as steam or electric heating, may be more attractive for embedded wall heating systems.

7-14. Solar Energy. In general, the study found that the use of solar energy to assist in keeping lock and dam installations ice-free in winter was not practical. From assumptions based on using standard types of liquid-heating solar collectors, and three values of incoming solar radiation typical of clear-sky daily averages during winter in the Upper Mississippi and Ohio River basins, efficiencies and temperature increases in the heat-transfer liquid were calculated.

a. The heat-transfer medium chosen for the illustration was groundwater at an initial temperature of 50°F. The specific flow rate selected was 1 gal./min per 50 ft^2 of collector area. (Higher specific flow rates would yield lower temperature increases in the fluid, and vice versa, but essentially identical heat gains would result in either case.) The results of the illustration are as follows:

Air temperature (°F)	*Efficiencies (%) at solar radiation values (Btu/hr ft²) of:*			*Temperature increases (°F) at solar radiation values (Btu/hr ft²) of:*		
	95	*127*	*159*	*95*	*127*	*159*
23	50	56	60	4.9	7.1	9.6
14	43	51	55	4.2	6.4	8.9
-4	28	39	46	2.7	5.1	7.5

b. Efficiency drops markedly as air temperature decreases. This is because heat loss from a collector is proportional to the temperature difference between the heat-transfer liquid (50°F in this case) and the air. Also note in the table that the temperature increase never exceeds 10°F. For 1 gal./min, this amounts to a power gain of only 1.4 kW, and in the worst case (i.e., lower air temperature and less solar radiation), it is as little as 0.4 kW.

c. Cloudy days, lower air temperatures, requirements for storage of heat (to make it available when needed, such as at night), and the capital costs of very large collectors and associated equipment all combine to discourage extensive consideration of solar energy for lock ice control, in view of the performance levels that can be anticipated.

7-15. Wind Energy. For most locations, normal fluctuations in wind make extraction of its energy unreliable unless some means of energy storage is available. Theoretically, the immediate power output (without storage) from a wind turbine is proportional to the third power of wind speed. Practically speaking, wind turbines often are subject to system controls to minimize the difficulties of extreme variability of power output. In any case, sample calculations illustrate the amounts of power potentially available from wind.

a. For many locations on the inland waterways, an average winter wind speed may be represented by 9 mph. A wind turbine having 20-ft diameter blades and operating at 50 percent efficiency in this wind condition can generate an average power output of about 0.6 kW, according to commonly used formulas. This means, for example, that five or six such wind turbines would be needed to provide power for continuous operation of the comparatively small (32 ft²) lock-wall heating panels discussed in Paragraph 6-17b and shown in Figure 6-24.

b. As with solar energy, the variability of the energy source and the capital costs of the installations and equipment combine to make wind energy utilization for ice control at locks appear to be unattractive.

7-16. Conclusions. The study concluded that none of the unconventional energy sources that were examined (sensible heat from groundwater, heating of a transfer medium by solar energy, or electricity generated from wind energy) offered great promise over other more conventional means of ice control at locks and dams.

a. Recommended Alternative. The study endorsed electrical heating as a reasonably attractive method for controlling ice, and urged consideration of using an as-yet unconventional means of generating electricity on-site: prefabricated, portable, packaged power plants. The study described a concept then (1988) in the development and demonstration stage for low-head micro-hydroelectric power plants. These packaged plants were of two sizes: one producing 500 kW at a net head of 18 ft and a discharge of 400 ft^3/s, and the other a 1250-kW unit operating with a 12-ft head and 1500 ft^3/s. These plants gain their portability by being barge-mounted. There is an anchored upstream barge providing the water intake, a siphon penstock, and a downstream barge that carries a submergible horizontal turbine. Trunnion-type joints accommodate variations in upper and lower pool stages. There is no major construction involved for these devices to be installed; they can be placed in a variety of dam configurations, for example, in a gate bay of a navigation dam.

b. Hydropower Potentials. To place all of the values of power mentioned in Section IV in a context that can be related to micro-hydroelectric power-plant potentials, combinations of discharge, net head, and resulting power output are listed as follows:

Discharge	*Power output (kW) (at 80% efficiency) at net heads of:*			
(ft^3/s)	*5 ft*	*10 ft*	*l5 ft*	*20 ft*
250	85	170	255	340
500	170	340	510	680
1000	340	680	1015	1355
1500	510	1015	1525	2035
2000	680	1355	2035	2710

c. General. It is the policy of the Corps of Engineers to cooperate with the Federal Energy Regulatory Commission in encouraging private interests to develop hydropower potentials at Corps navigation or flood-control dams. In these cases, the Corps usually has rights to certain portions of the power generated at no cost, as long as it is used for the benefit of navigation. In planning for use of this power, it is recommended that the power needs for ice control be considered. And in those cases where private power development is not likely, the use of dedicated, portable, packaged hydropower units as described above (if they are commercially available) should be investigated and compared to purchased power for meeting the needs of ice control at navigation locks and dams.