Chapter 3

Water supply

Although the subject of water supply is well covered in many emergency manuals, there are additional factors which will affect the provision of fresh water for domestic supplies in conditions where the ambient temperature is close to or below 0°C. Chemical reactions are slower at low temperatures and biological processes also take more time. The physical properties of water, in the form of water, ice or snow, are temperature dependent, therefore affect processes involved in supplying water and the range of technology that can be used.

The provision of water supply and sanitation is always closely related to the type of shelter in which the affected population is living. This is more so in cold regions where the provision of shelter is obviously a high priority. Specific shelter options are discussed at greater length in Section 5.4.

3.1 Properties of water, ice and snow

Water density

As liquid water cools its density gradually increases, a behaviour that is typical of most liquids. However water maximum density reaches its 4°C, below which the density decreases slightly: the water expands, until ice begins to form at 0°C. As it congeals into ice it gains approximately 9% of its liquid volume, consequently ice is less dense than water, and floats.[5]

The fact that water is most dense at 4°C causes a quality fluctuation in the water in lakes in cold regions. During the autumn, as the water slowly cools, the warmer and colder layers 'turn over' causing a sudden, temporary, increase in Total Dissolved Solids (TDS).[6] Sediments, containing suspended solids and soluble materials, will be disturbed as the warmer and colder water layers mix. As the temperature of the top layer of water falls below 4°C, it sinks and disturbs water at greater depth. Also, in winter the warmest water in lakes is at the bottom whereas it is at the surface during the summertime.

[5] Davis and Day (1964)
[6] Smith (1996)

Water viscosity
As water temperature decreases, its viscosity increases. This increase in viscosity reduces the settling velocity of suspended particles (affecting the design of sedimentation tanks) as well as increasing the energy requirements for mixing and pumping operations.

Ice formation
When water freezes and becomes ice the effect of its expansion can exert pressures as high as 2500kg/cm^2. To put this into perspective, it is the same as a static head of water approximately 25km high. These high pressures inevitably cause problems if water freezes in pipes, pumps or other containers which cannot withstand such large forces.

Snow
Properties of snow vary greatly according to how old it is. New snow is less dense than old, more compacted snow, and has better insulating properties. Surprisingly, perhaps, all snow is a relatively good insulator: its thermal conductivity, even when dense, is much less than that of ice. This affects not only how much heat is lost from buildings, but also the rate of formation of lake and river ice.[7] In Canada and Alaska, settlers used to pile snow against their wooden buildings in order to increase the insulating properties of the walls.

A snow covering of 1 to 10cm in depth raises the temperature of the surface of the ground by 1.1°C above air temperature for each centimetre of snow depth (although the ground temperature cannot be greater than 0°C). Even at pipe-burial depths (e.g. 0.6m to 2m) a covering of snow will raise the temperature of the soil by at least 0.1°C per cm of snow cover, compared to the temperature at the same depth of uncovered or cleared ground.[8]

3.2 Sources
If there is no 'urban' water supply, or if it is temporarily unusable, water source options for abstracting water for drinking, cooking and washing obviously depend on what sources exist in the local area. Snow or other winter weather which makes trucked water deliveries impossible may also mean that the development of local water sources is a priority.

Appendix A contains flowcharts that can be used to aid the selection of appropriate water sources for emergency use in cold regions. Whilst these flowcharts concentrate on technical issues, it must be stressed that social, religious, environmental, and financial (cost) implications are also important factors to be considered when selecting appropriate water sources. *Emergency Water Sources* offers a comprehensive description of many issues connected with this subject.[9] This section describes some of the factors that will affect the choice of supply in a cold region, and which are additional to the normal factors of proximity, water quality, adequate volume and cost that will always affect source selection decisions.

7 Langham (1981)
8 Steppuhn (1981)
9 House and Reed (1997)

Groundwater

Being warmer than surface water, and with temperatures and quality that are generally constant throughout the year, groundwater offers several advantages over surface water as a potential water source in cold regions.

These advantages include:

- The higher temperature makes it less likely that water will freeze in storage tanks or distribution pipes.
- The reliability of temperature and quality means that the same water treatment regime can be used all year round. Seasonal quality and temperature variations of surface water sources can make its treatment options more complicated.

One potential problem associated with using groundwater is that above-ground pumps are liable to maintenance problems or damage from frost although submerged ones will be protected (insulated) by the water. (See section 5.3 *Mechanics*.)

Positive and negative factors should also be weighed up against factors that are common to warm or cold climates, such as:

- Properly protected wells and boreholes can have extremely low levels of faecal pollution, minimising health risks and treatment costs.
- Water quality varies depending on local hydrogeological conditions. The water may have a high mineral content, including dissolved metals and salts, which could make the water unpotable, or minerals such as arsenic and fluoride which have associated health problems. In any case, a full physical and chemical analysis of the water should always be carried out.
- Location and development of groundwater sources can be very expensive.

Wells and boreholes

When constructing wells and boreholes in areas where the ground is liable to freeze, bentonite (clay) should be used, instead of concrete for grouting the annular space around the casing (to prevent the flow of surface water, containing pollutants, into the hole). Concrete, can bond tightly to steel well casings, whereupon frost heave, caused by the annual freezing of the ground, then pulls the casing apart, ruining the well or borehole.[10]

In permafrost areas, the frozen ground acts as an impermeable layer above groundwater aquifers. Surface water features such as rivers and lakes cause the permanently frozen ground to thaw below them, so that it is possible to locate groundwater closer to the surface near to surface water features. Figure 3.1 shows how boreholes located on the inside of river bends can access groundwater at a depth where the ground of the surrounding area is permanently frozen.

Springs

It is easy to assume that the water inside a spring box is unlikely to freeze, because the water is continually flowing and because the water, having originated underground, would nor-

[10] Smith (1996)

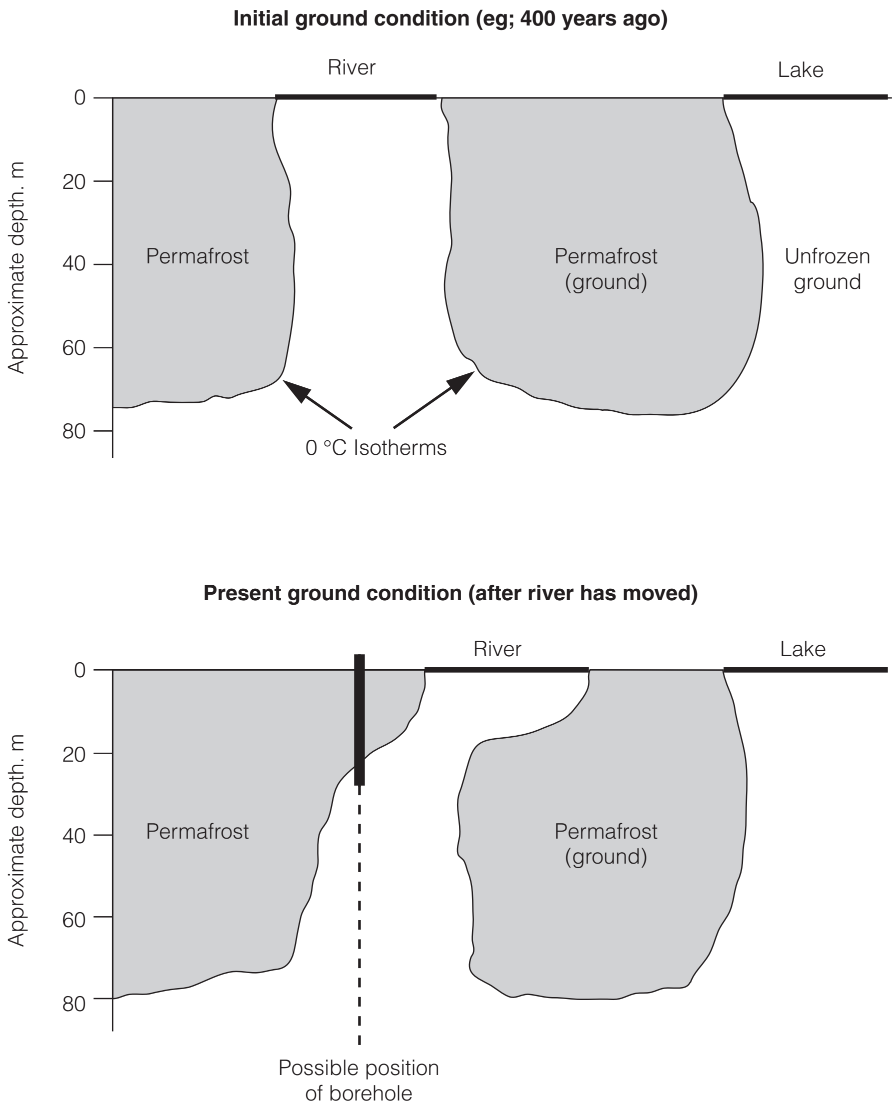


Figure 3.1. The effect of a shifting river, in a permafrost area, on groundwater depth and on the location of boreholes[11]

[11] adapted from Smith (1996)

mally be slightly warmer than surface water. However in mountainous areas freeze-ups and other problems are possible.

First, in mountainous areas, water emerging from springs is likely to be quite cold already, having originated higher up the slope. This increases the likelihood of the water freezing during a cold spell. If outlets from a spring boxe do freeze up, the resulting back-pressure may cause subterranean water flow channels to alter their course, causing the spring to emerge at a different place! It is essential to guard against freeze-ups by covering spring boxes with an insulating layer of soil, of a depth equivalent to the depth of maximum winter frost penetration in the ground, so that water in the spring box is never cooled to below 0°C. A thickness of 0.75m to 1m of soil cover provides adequate insulation for most situations.

Secondly, building spring boxes in scree is very likely to cause problems. In scree subterranean flows can alter course periodically, causing the spring to emerge at a different place. The spring protection then has to be moved to the new location where the water emerges from the ground, or new protection facilities built. Scree movements are also likely to damage spring boxes, necessitating continual maintenance. If it is impossible to avoid scree, use local materials, as it is very likely that the spring box will have to be replaced periodically.

Handpumps

Soil will provide some thermal insulation, so underground water may remain unfrozen even when air temperatures above ground are below freezing. Whether groundwater freezes or not depends on the depth to the groundwater, the air temperature and the insulating properties of materials separating the water from the air above ground. In addition, groundwater will freeze from the top down, so water below the water table may remain unfrozen even if water close to the top of the water table freezes. Whatever type of handpump is used, some damage due to freezing is possible. Features useful for all types of handpump installed where temperatures can fall below freezing include:

- Locate pumps in a pump house to help prevent water freezing inside.
- Ice is likely to form on concrete aprons around boreholes and wells. Care should be taken to provide good drainage, and to encourage people not to splash water around if at all possible.

Lift pumps

These are distinguished from suction pumps by the location of the pumping cylinder, which is submerged below the water level in the borehole. Lift pumps are normally used when the dynamic water level is more than 7-8m below ground, making suction impossible. Lift pumps make sense in cold areas precisely because the working parts of the cylinder will always be underground, where they will be insulated from the cold.

Above-ground pump parts can be protected by making a small diameter ‘weephole’ in the riser pipe just above the cylinder (either below groundwater level or above the water table at a depth where freezing will not occur). Water slowly drains out of the above-ground section when the pump is not being used, reducing the likelihood of water freezing in the above-ground pump sections. This causes a small loss in the pumping efficiency, although being below water level the cylinder needs no priming.

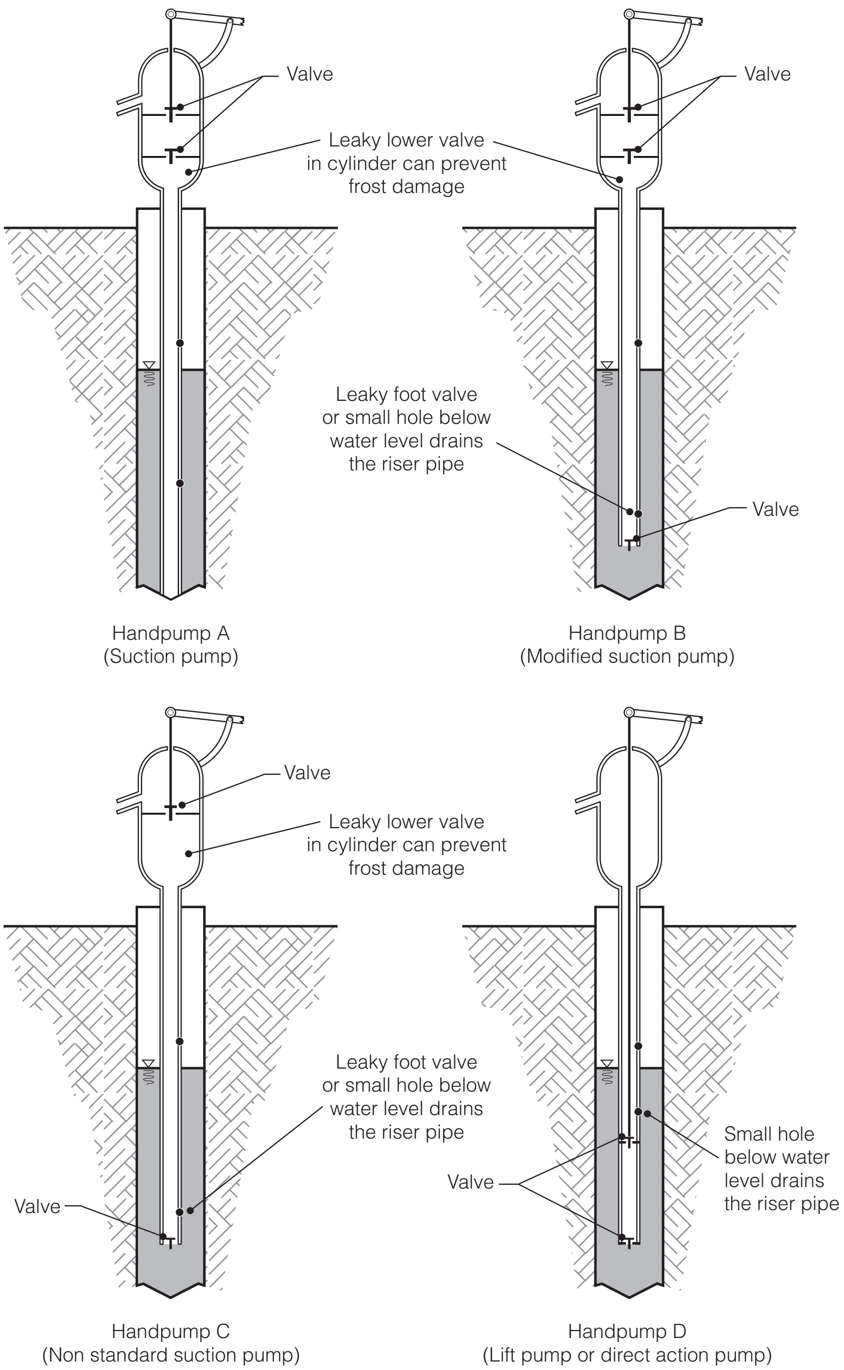


Figure 3.2. Handpumps with features to prevent freezing

Suction pumps

Because the pumping cylinder is above ground, it is prone to damage when the water remaining inside the pump freezes after pumping ceases. One way to protect it is to use a lower valve (in the cylinder) that leaks slightly into the rising main. That way the cylinder drains when the pump is not in use. If there is, instead, a foot valve at the bottom of the riser pipe (a one-way valve), either it can be made to leak slightly, or a small hole can be drilled in the riser pipe just above the foot valve. Note that such a hole must be below the water level or the pump will not function at all.

The above measures for suction pumps imply that the pumps will, automatically and slowly, drain themselves of water. There is a loss of pumping efficiency since the water has to be pumped again, and this, obviously, should be minimised. The self-draining nature of the above-ground pump parts, may also make it necessary to have water available, close to the pump, for priming the pump. In this case the water needs to be kept indoors, but close to the pumping area, to prevent it freezing at night. Also, it is important that the priming water is kept in a sealed container and protected from pathogenic organisms, which would lead to contamination of the pump and possibly the borehole itself.

Surface water

Quality

Surface water is always liable to be contaminated by faecal pollution, particularly during a disaster, when normal excreta disposal facilities may not be functioning properly. However, incorrect assumptions are often made about the quality of surface water in cold regions.

One myth is that bacteria cannot survive in very cold water. This is not true; bacteria actually survive longer in cold water, although their rate of metabolism is greatly reduced. If consumed by humans their rate of development will increase once more, possibly leading to disease. Living coliforms have been detected in military camps in the Arctic that had been abandoned years earlier.[12] The presence of faecal coliforms in water is an indicator that it has recently been polluted with faecal matter, and that dangerous bacteria and other pathogens could also be present. The possibility of faecal organisms surviving a winter in a refugee camp, only to cause health problems by entering the water supply in the summer, should not be discounted.

There are certain bacteria which are adapted to live in colder conditions (psychrophilic bacteria). If present in drinking water, certain of these could cause health problems. Therefore no assumptions should be made about the water quality of mountain streams, and proper water supplies must be established, with frequent and thorough water testing for quality.

Rivers and streams

Many cold-region countries have high concentrations of industry and use modern farming methods. In addition to pollution caused by broken sewerage systems, the destruction or running down of industry and farms during a time of disaster makes it highly likely that rivers and lakes will be polluted by chemicals and livestock wastes. Laboratory testing of water

[12] DiGiovanni et al. (1962)

samples is the only reliable way to determine pollution levels. If pollution is detected then this will obviously affect the decision whether or not to use rivers and streams as water sources.

In winter the flow volumes in rivers and streams either increase or decrease depending on whether precipitation falls as rain or snow. In the case of an increased winter flow, this reflects the increased winter rainfall, leading to increased turbidity, and the likelihood of various pollutants being washed into the rivers.

If precipitation upstream falls as snow a reduced river flow will be the result. If it is cold enough the snow stays on the ground instead of melting and flowing into water courses. In addition small streams and minor surface flows are liable to freeze solid instead of joining larger water courses. Some small streams are likely to become completely frozen, with no flow. Quality implications include:

- The reduction in flow originating from surface water runoff implies that in winter a greater proportion of river water will originate from groundwater sources such as springs. If the concentration of minerals in the groundwater is higher than that in surface water runoff (and it is likely to be) then the concentration of dissolved minerals in the river will be higher in winter than in summer.
- River water quality deteriorates significantly in the spring because of the seasonal thaw. Ice and snow that accumulated on the surface of the land in winter melts, washing pollutants into the river. The result is a sudden temporary increase in Total Dissolved Solids (TDS) and turbidity.
- Quality monitoring is necessary at all times of the year to ensure that water treatment processes are able to deal with seasonal variations in water quality.

In extreme cases, during the spring large blocks of ice that are released from areas where the river had been frozen over will float downstream. These blocks can wreak havoc if they collide with structures. They are capable of damaging water intake structures and bridges unless very substantial protection structures are built.

Lakes and ponds

As with rivers and streams, the quality of water in lakes and ponds varies seasonally. One cause of these quality variations is the seasonal change of the water temperature:

- In the autumn it is common for the layers of water to invert, disturbing sediments from the bottom of the lake and causing a sudden temporary increase in turbidity and total dissolved solids.
- In winter impurities are slowly rejected from surface ice as it forms, which increases the concentration of suspended and dissolved solids in the water below the ice.

Seasonal variations of water quality are shown more clearly in Figure 3.3.

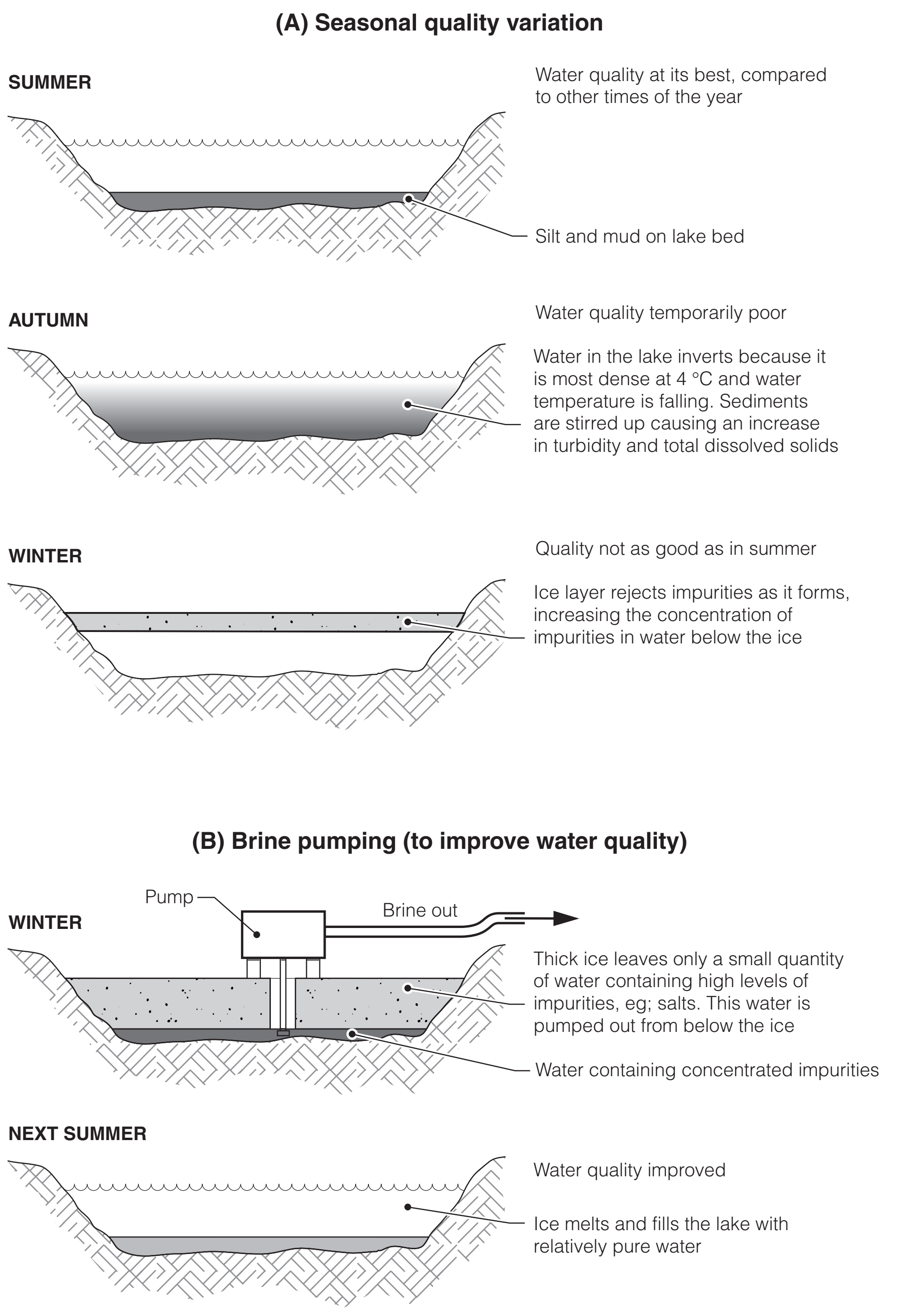


Figure 3.3. Seasonal quality variation of water in lakes and quality improvement by brine pumping

Purification of lakes or ponds by brine pumping
In very cold areas it is possible to purify a shallow lake or pond and prepare it for use as a water source the following year by a process known as brine pumping. Dissolved solids lower the freezing point of water, so ice will only form in solutions at temperatures below 0^oC. As the surface of water containing dissolved salts begins to freeze, crystals of pure ice form, and the dissolved salts become concentrated in the remaining solution below and around the ice. As the concentration of salts in the remaining solution increases, the freezing point of the water in the remaining solution is lowered further.

As ice forms on the surface of a lake or pond, impurities are slowly rejected by the freezing water and are therefore concentrated in the remaining water. If most of the water freezes, which is more likely in shallow lakes than in deep ones, then the small amount remaining as a liquid can become highly saline and contain high concentrations of dissolved solids. This water is very unlikely to be suitable for use as a source for domestic supply, however if that liquid portion of the lake water is pumped out and discarded, the majority of soluble pollutants will be removed from the entire lake in one action. When the ice melts in the spring, the water in the lake will contain substantially less Total Dissolved Solids (TDS) than the year before, and may therefore be more suitable as a source of drinking water. Purification of lakes by brine pumping is illustrated in Figure 3.3.

Ice cutting from lakes

Since impurities are rejected from ice forming on the surface of lakes, the ice remains fairly pure. Provided it is handled and stored carefully, cut ice is a valid source of water. Cut ice has been used as a source of water in remote villages in Alaska for many years. Key factors are:

- The fuel and stoves necessary to melt the ice will require some organisation.
- Unless cutting is well organised, people moving around will pollute the frozen lake surface.
- The ice may not be thick enough to support people moving around on it, and falling through could be fatal, so great caution is necessary when investigating this option.

Intakes

Intakes for extracting water from lakes that are liable to freeze over need to incorporate various design features to prevent damage of equipment. To pump from an ice-covered lake or river one temporary solution is to pump intermittently using a portable pump which is located on either the ice or the shore. The pump needs either to be protected from the elements or to be removed in between pumping times. The pipe over the ice should be propped at a continual gradient, using wood blocks, so that water drains back into the lake after the pump has been removed. Possible intake arrangements for winter and summer pumping are shown in Figure 3.4.

Infiltration galleries

In wide gravelly rivers, the winter flow may be under a thick layer of ice and its path through river gravels can shift frequently. Smaller rivers and streams may appear to have frozen completely, but a sub-surface flow may continue throughout the winter. In these conditions water abstraction is difficult: a shifting flow means that it may be difficult to locate running water and the point of abstraction may have to be moved frequently. Utility providers in

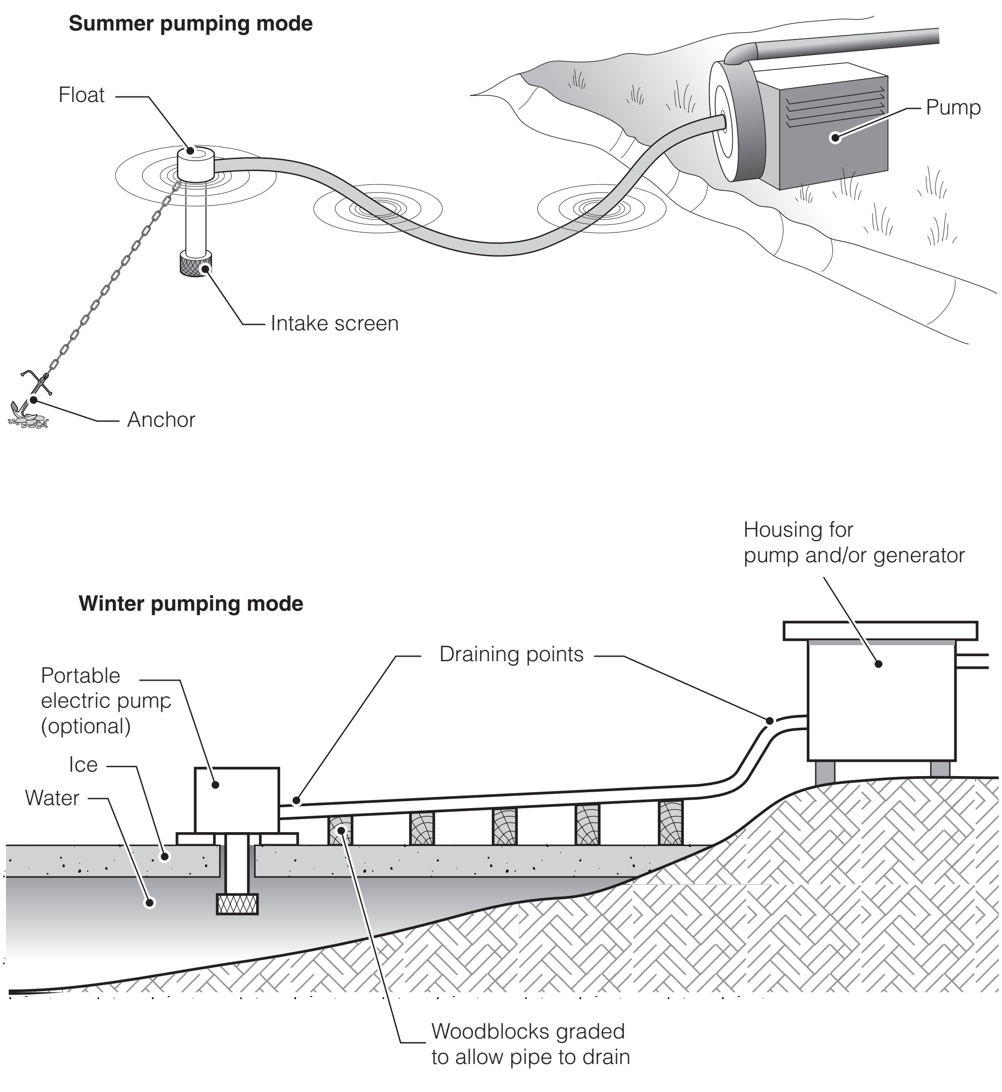


Figure 3.4. Temporary water intakes showing arrangements for summer and winter pumping[13]

[13] adapted from Smith (1996)

Alaska overcome these problems by using infiltration galleries that span the width of the riverbed. Infiltration galleries are effective because they avoid the necessity to locate the flow under the ice and, even when surface flow has ceased altogether, a subsurface flow of water may continue.

Generally infiltration galleries are expensive and take considerable effort to construct, and therefore cannot be classified a low technology, emergency solution to water source problems. Repair or renovation requires experienced engineering skill. However it may be viable to construct collector wells with either a horizontal infiltration gallery parallel to the water's edge or with a gravel-filled channel connecting the well to the main body of surface water. Figure 3.5 shows possible arrangements for infiltration galleries and collector wells.

Construction of infiltration galleries requires that:

- the ground in which the gallery is to be placed is not frozen or, in a permafrost area, the ground is in the thaw bulb area where the ground is kept at above 0°C by the heat of the water in the main water body; and
- the ground is permeable. (A coarse-grained medium, such as sand or gravel, is better than a fine-grained one, such as silt.)

Infiltration galleries beside small streams may continue to yield water even when the stream is completely frozen, if there is some subsurface flow.

Snow

For a while snow was the main source of water for Kurdish refugees who were surviving in the mountains of northern Iraq in 1991, and was also used in some rural parts of Bosnia in the wintertime.[14] Therefore it is worth considering snow as a water source even if only as a temporary or seasonal option. Factors include:

- The logistical requirements to distribute materials to melt snow are considerable: cooking vessels, fuel and, possibly, heavy duty plastic bags so that teams can collect large volumes of snow more easily.
- After melting, the water must be treated to kill pathogens. Either the water should be boiled to kill pathogens (an extra fuel requirement, but a convenient option), or small batches should be treated with chlorine tablets (see also the water treatment section, 3.4).

It is also important to note:

- Snow is easily contaminated, therefore it is essential to define and rope off suitable areas/snowfields for use only as a water source.
- Snow should never be eaten, as it greatly lowers the body temperature, causing risk of hypothermia. Snow must be melted before drinking because snow may be much colder than 0°C.
- Potential hazards exist in mountainous areas, such as loose snowfields where there may be a risk from avalanches, or where people collecting snow may be exposed to risk of injury from exposure or falling.

[14] Potts (1993)

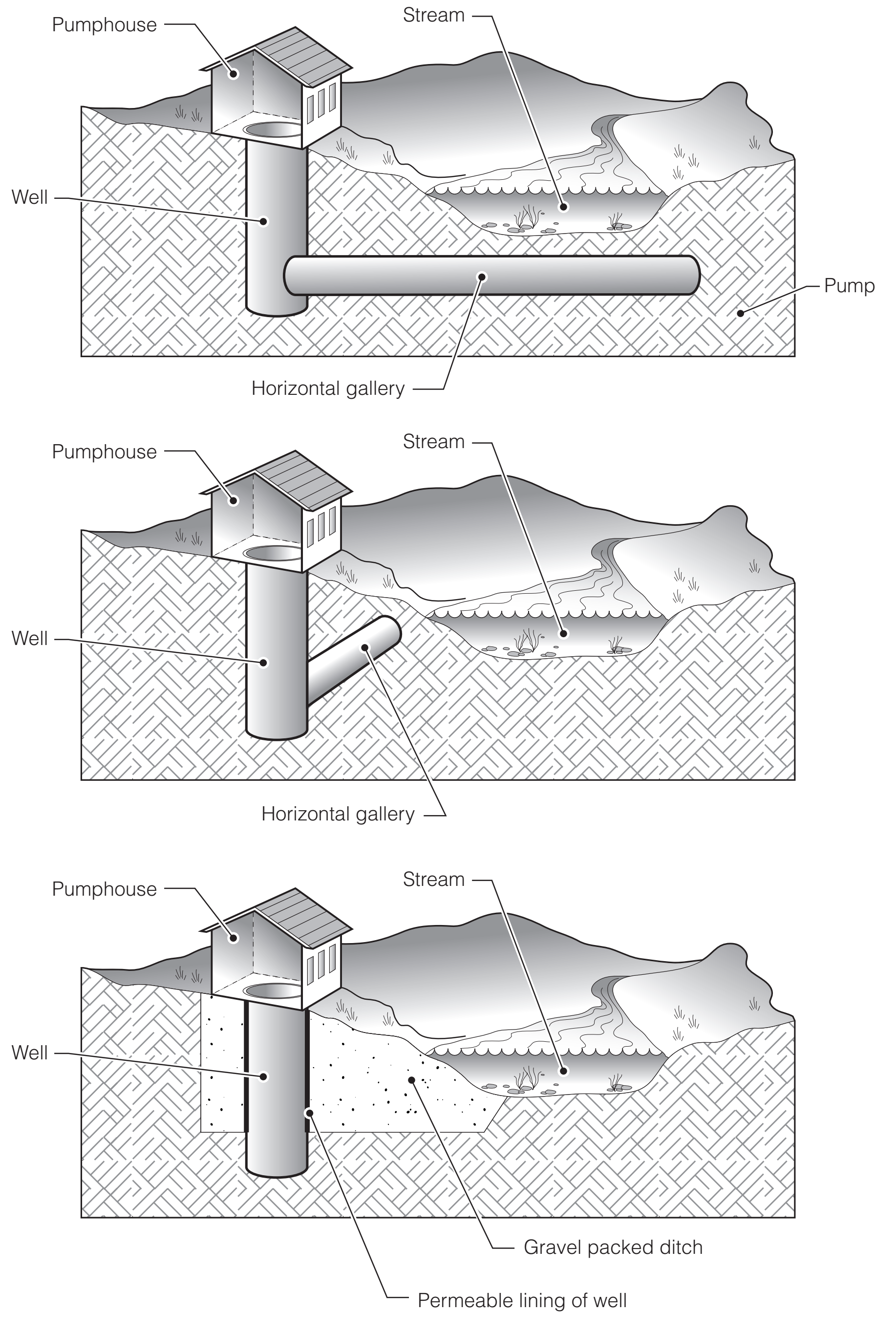


Figure 3.5. Possible arrangements of infiltration galleries and collector wells[15]

[15] adapted from Smith (1996)

- Snow is not very compact. The volume of water collected by melting snow will range from 10% to 40% depending on the age of the snow (old snow is more compact than fresh snow).

Snow has been used as an emergency water source in the past and, as such, should be considered seriously for future use.

Hauled water

The use of tanker trucks and water trailer tanks pulled by tractors to bring water into a disaster area is an established practice where it is difficult or impossible to do anything else. The practice is logistically complicated, very expensive, and other arrangements should be made if at all possible. In cold regions there are some additional factors to consider:

- In winter vehicles may not be able to reach certain areas, especially mountain regions. In these circumstances very local water sources must be used, or the entire population will have to move away from the area.
- Trucks and tractors should be equipped with snow chains and shovels, and should not be forced to make dangerous journeys (e.g. along icy mountain roads) unless it is absolutely unavoidable.
- Maintenance issues are more complicated. Possible difficulties include: diesel gelling, drinking water freezing in tanks and pipes, antifreeze being necessary in coolant water and screenwash, and the need for indoor parking (see also section 5.3).

The logistics and the mechanics sections (5.5 and 5.3) are also relevant to hauled water.

3.3 Water storage

Tanks

Storage tanks donated by international aid organisations have had problems with water freezing inside and causing damage to liners, valves freezing up, and snow breaking flimsy canvas roofs. ‘Onion’ or ‘bladder’ tanks are especially unsuitable if there is any risk of water freezing inside them. Short of redesigning or adapting both rigid tanks and bladder tanks, the only way to overcome these problems is to locate the tanks inside heated buildings (e.g. warehouses, other industrial buildings or barns).

Figure 3.6 shows some of the possible features that are useful for temporary storage tanks cold regions.

New tank designs or modifications should take into account the factors below which will help to reduce the probability of the water freezing inside, and minimise damage to the tank if it does so.

Factors that affect all tanks when water freezes inside

- Tank outlet valves should be protected by insulating them. A ‘valve-box’ lined with insulating foam will help to prevent damage from frost.
- Attachments protruding on the inside of a tank (e.g. ladders) will be ripped off if surface ice forms and then the water level goes up or down. This could rupture the tank walls. Avoid designing any fixtures on the inside of tanks.

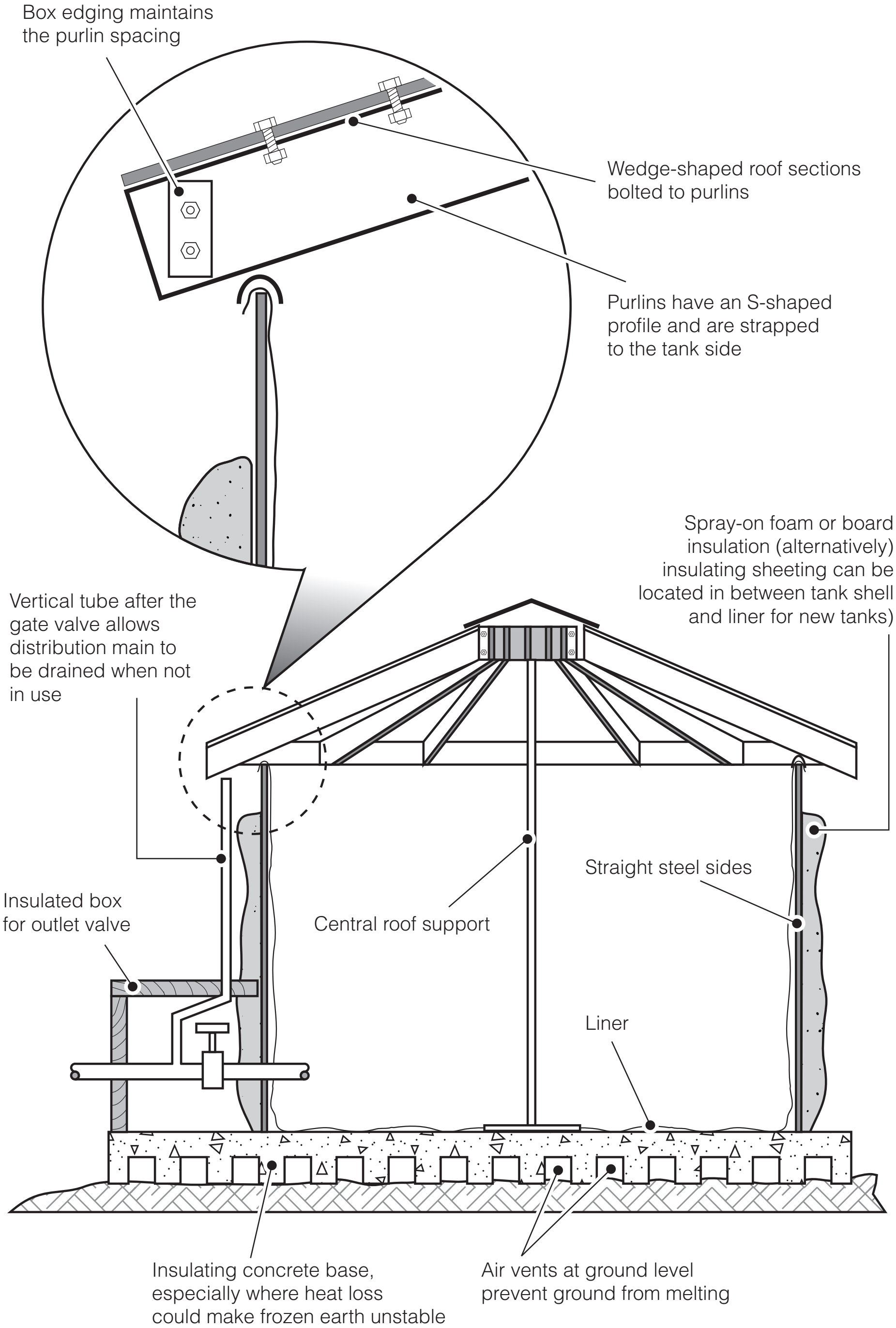


Figure 3.6. Temporary storage tank, showing design features appropriate for cold regions

- If the distribution network needs to be drained at night then a vertical air inlet pipe (higher than the maximum water level in the tank) should be added directly after the gate valve at the tank outlet. This will allow the distribution network to be drained without draining the tank, or subjecting the pipes to negative pressure, which could damage them.
- If there is a continuous flow into the tank (no matter how small) it will help to prevent freezing.
- It has been suggested that some heating of water in tanks would also help to prevent freezing. Raising the water temperature by just one or two degrees could be enough to stop damage due to water freezing. Suggested heating methods include installing a submerged length of high-resistance heating wire (protected from tank liners) connected to a suitable electrical supply; bubbling steam through the water; and heating batches of water separately on a stove. However, the value of using power to do this is debatable, and would need considerable organisation in terms of operation and maintenance.
- Locally made tanks can overcome some of the problems usually associated with outdoor tanks in a cold area, since the local engineers will know designs that are appropriate. In some ex-communist countries the local water authorities have standard designs for water tanks that contractors can build surprisingly quickly.

Insulating existing or new temporary storage tanks

There are several ways to insulate an outside, temporary tank from the surrounding cold air:

- Spray-on polyurethane foam insulation. This minimises the volume of materials to be transported, but application requires dry weather; minimal wind conditions; the tank surface to be dry and clean; surface temperature above 15°C; and air temperature above 10°C.
- Insulating boards can be glued or strapped to the outside of the tank. Boards should be less than 75mm thick to allow installation on curved surfaces. For moist locations a closed cell material that will not absorb water should be used, since wet insulation is much less effective than dry insulation (e.g. closed cell polystyrene or polyurethane). If possible protect boards from getting wet, weathering, birds, and animals by covering them with a cladding material such as plastic sheeting.
- For a new tank, fit insulating boards between the rubber liner and the outer wall of the tank. Boards should be chamfered around outlets, so that the liner fits snugly around flanged fittings.[16]
- Pile earth around the tank. This is a simple and effective solution that also increases tank stability. Wet earth loses its insulating properties, however, and piled-up earth will make the tank roof and inlets accessible to more people, risking roof damage or contamination of the water.
- Tanks can be insulated from the ground by mounting them on insulating concrete or wooden bases. Tanks may be mounted on bases for two reasons:

    1. The water is kept as warm as possible, minimising the risk of it freezing from contact with frozen ground.

    2. If frozen ground is allowed to defrost it can become structurally unstable. Insulating tanks from the ground avoids this problem by reducing the likelihood of the water thawing out the ground. Air vents incorporated in the underside of a concrete base also

[16] Gould (2001)

help to maintain the low ground temperature.[17] At the very least a 10cm layer of gravel will help. Meanwhile the concrete base itself helps to spread the load on potentially unstable ground. Aggregates used to make insulating concrete are listed in section 5.1.

- If ground conditions permit, a tank located underground is less likely to freeze due to the insulating effect of the earth surrounding it. Extreme caution should be exercised, however, since the rubber liner of the tank will float if the groundwater level rises above floor level. Do not construct tanks underground if insufficient information about winter groundwater levels is available. In addition, the ground must be stable and able to be excavated, i.e. not already frozen.
- Tank roofs need to be designed to carry snow loads, however the rope and canvas roofs of most temporary tanks will sag and may tear. Snow is actually a good insulator, so avoid brushing it off if you can! Galvanised steel roofs for 'Oxfam' type tanks are available from Evenproducts Ltd in the UK (address and website in section 7.4).

Otherwise a simple roof can be fabricated locally. The section *Construction* in Chapter 6 gives details of how to calculate snow loading.

Tank size and shape

The outer area of a tank (including surface, sides, and base) can be minimised to reduce heat loss:

- A single tank with a large capacity will lose heat less quickly than several smaller ones with the same total storage capacity. This is because its surface area to volume ratio will be smaller in comparison.
- Round tanks have a lower surface area to volume ratio than rectangular ones. Therefore they lose heat less quickly.
- Using straight (non-corrugated) steel sides also reduces the surface area of the tank sides, limiting the rate at which heat is lost.

Ground storage lakes

The issue of the surface area to volume ratio applies to lakes as well as tanks, although the surface through which most of the heat will be lost is the top surface of the water. Therefore an artificial lake should be deep, rather than shallow, to minimise the probability of freezing. Caution is necessary before deepening an existing lake, however; as well as stirring up pollution from the bottom of the lake it is possible to dig through the waterproof layer whereupon the lake may drain. Consultation with qualified engineers is essential if excavation of an artificial lake or modification of an existing lake is to be properly considered as an option for water storage.

[17] Alter and Cohen (1969)

3.4 Water treatment

Cold water is more viscous than warm water, and rates of chemical and biological reactions are slower at lower temperatures. Awareness of the effect of these factors will contribute to the implementation of an efficient water treatment regime.

Mixing and pumping requirements

The increased viscosity of water, when cold, affects the energy requirements for mixing water with coagulants and for the power required for pumping operations. Figure 3.7 is a graph showing the correction factor for the effect of temperature on viscosity-dominated processes. This should be used to calculate the extra energy required for pumping or mixing operations involving cold water.

Note that viscosity is often quoted at 20°C, so the correction factor shown for 20°C is 1.0 . If water temperature is reduced from 20°C to just above 0°C then the rate of viscosity-dominated processes will be reduced to about 0.57 (= 1/1.75) times that at 20°C and the extra energy required rises accordingly.

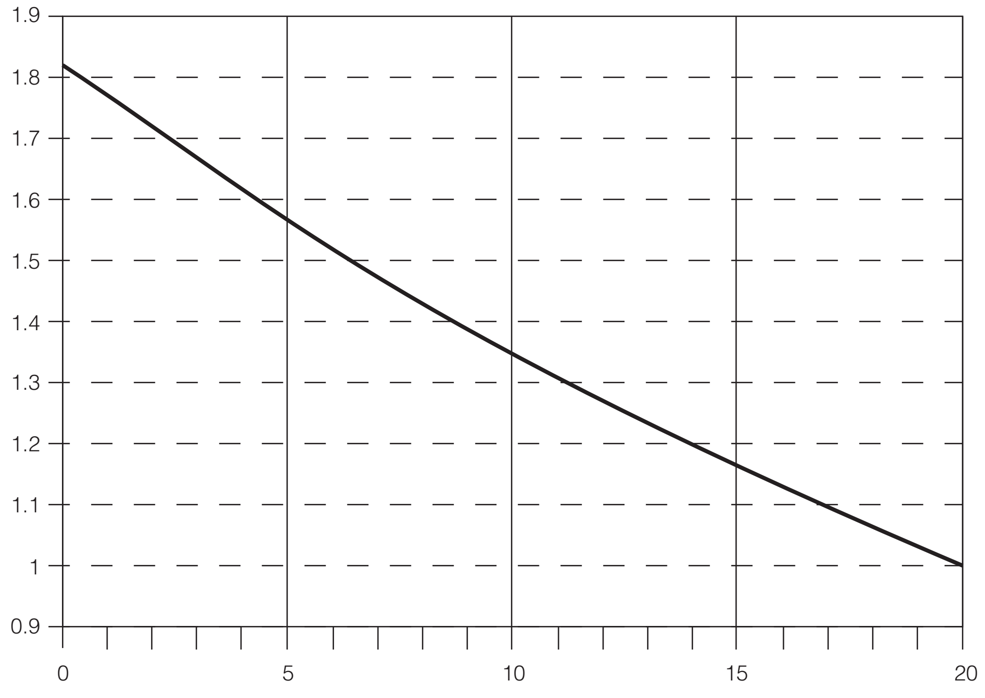


Figure 3.7. Graph of correction factors for the effect of temperature on viscosity-dominated processes[18]

[18] adapted from Smith (1996)

Sedimentation tanks

The function of a sedimentation tank is to reduce the turbidity of water by allowing it to deposit suspended solids in the still water of the tank. In emergencies the aim is to produce a water supply with a turbidity of less than 5 NTU in order to maximise the efficiency of the chlorination process, although chlorination will function relatively effectively at turbidities of up to 20 NTU. The design of sedimentation tanks is well explained in *Engineering in Emergencies*[19] and other emergency manuals.

The footprint (area in plan) of a sedimentation tank is often calculated using:

$$\text{Area (m}^2\text{)} = \text{design flow rate (m}^3\text{/s)} \div \text{settlement velocity (m/s)}$$

If the settlement velocity is miscalculated, the wrong size of tank will be built. Therefore to obtain accurate results it is imperative in cold regions that jar tests to determine settlement velocity of suspended solids should be done at the correct (outside) temperature. Similar jar tests, which determine how much alum (or other coagulant) to add to a water system before chemically assisted sedimentation, should also be carried out at the correct (outside) temperature.

Chemical disinfection

Chemical processes are slower in cold water, a prime example being the reaction when water is chlorinated. Some text books on the subject look at the 'CT' value (Concentration of residual disinfectant × contact Time). Authors differ in explaining how the CT value is affected by temperature. Patwardhan[20] states that for every 6°C drop in water temperature the CT value needs to be increased by a factor of between 1.5 to 3.5, while the US Environmental Protection Agency states that to achieve a consistent inactivation of *Giardia Lamblia* the CT values for chlorine need to be approximately doubled for each 10°C drop in water temperature.[21]

In practice, the chlorine quantity and contact time required should be tested at the correct temperature. If not, tank design may allow insufficient contact time, or insufficient doses of chlorine could be added. Proper disinfection of the water would then not be assured.

Filtration

Two factors affect the use of filter beds to treat water in cold regions: the increase in water viscosity causes greater headloss in water flowing through filters, and the reduced rate of bacterial activity at low temperatures affects the operation of slow sand filters.

[19] Davis and Lambert (1996)
[20] Patwardhan (1989)
[21] USEPA (1990)

Slow sand filters
Slow sand filtration is usually effective when the biological action of the schmutzdecke (a thin bacterial layer at the top of the sand) efficiently breaks down organic matter. The factor by which the number of *E.Coli* in the water is reduced is normally in the range 100 to 1000, however the factor can be as low as 2 if water temperature is less than 2°C.[22] Chlorination is sometimes used as a further treatment method to disinfect water following slow sand filtration. Depending on how effectively a filter removes faecal coliforms, at low temperatures further treatment by chlorination will almost certainly be necessary.

In conditions where the ambient temperatures are sub-zero there are two approaches to coping with ice forming in filter units:

- Cover filters with a roof and an insulating soil layer to help prevent the formation of ice on the surface of the water to be filtered.
- Design the structure, around the filter, to withstand the expansion forces of the ice. This method has been used successfully in the US, using filter sidewalls of 15cm-thick reinforced concrete, covering earth embankment walls sloped at 1:2.[23] Slow sand filters have been kept running with a floating ice block. Although the rate of removal of *E.Coli* is small, this is effective so long as the ice does not touch the schmutzdecke, the temperature of which should not be allowed to cool below 0°C.

Rapid gravity (roughing) filters
Rapid gravity filtration, or roughing filtration, is effective in cold regions, although head losses through the filter will be increased due to the increased viscosity of the water. Relative head loss increases by 2.5 to 3.5 per cent for each °C that the water temperature is reduced.[24]

Removing glacial flour
One use of roughing filtration is to remove glacial flour from a water supply. Glacial flour is created by the abrasive action of glacial ice rubbing rocks against the bedrock, creating very fine particles that appear as reflective specks in the water. These can be very difficult to remove from the water, however one method is to treat the water with between 10 and 30mg/litre of ferric chloride followed by settling, roughing filtration, or both.[25]

Other factors affecting the removal of glacial flour are:

- Ferric chloride is often more difficult to obtain, and more expensive, than alum, which is the most common coagulant. Other coagulants may also be effective, and it is worth doing jar tests using alum, for example.
- People may already be accustomed to drinking water containing glacial flour. If the water quality is satisfactory in terms of bacterial content, removal of glacial flour may not be necessary.

[22] Huisman and Wood (1974)
[23] Hendricks (1991)
[24] Smith (1996)
[25] Ryan (1990)

Boiling water

In cold areas, heaters are obviously necessary for survival and personal comfort, irrespective of water supply or treatment options. If suitable heaters or stoves are widely used or readily available, boiling water may be an effective way to kill disease-causing organisms present in the water. As a disinfection method, boiling is suited to the treatment of small quantities, with each household treating its own drinking water.

For disinfection purposes water should be brought to a rolling (vigorous) boil, and boiling continued for one extra minute for every 1000 metres of altitude above sea level.[26] Alternatively, boil water for between five and ten minutes.[27]

Key factors affecting the suitability of boiling as a method of water disinfection are:

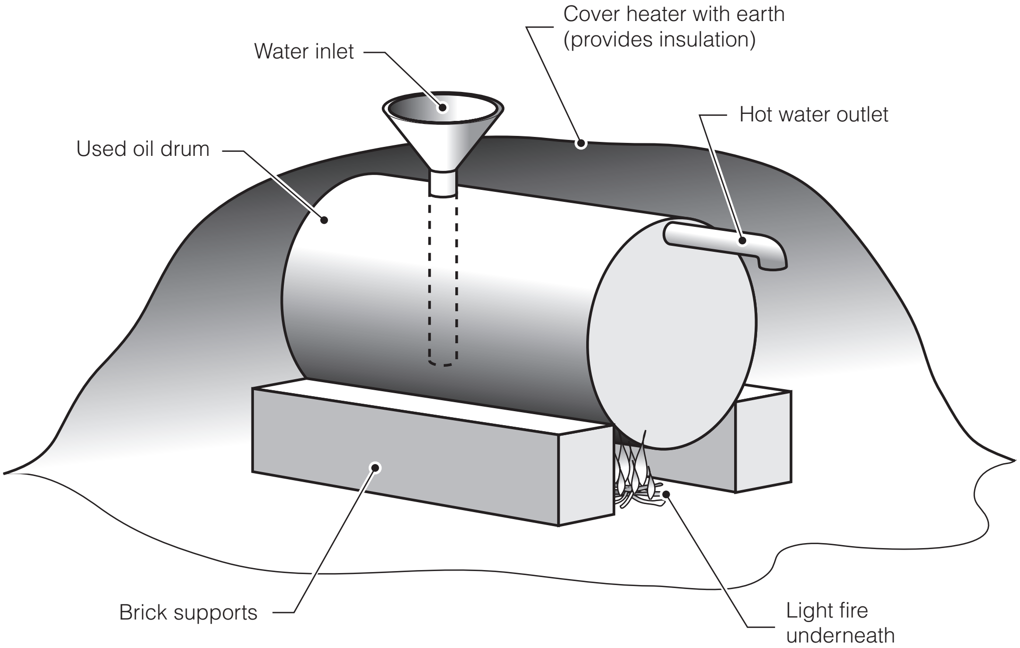
- The amount of fuel available: it takes about 1kg of wood to sufficiently boil each litre of water, depending on altitude.[28] This fuel requirement will be greater still if ambient temperatures are cold. Fuel may be too scarce, and consequently too expensive, to use for water disinfection purposes.
- Local people must be aware both of the required boiling time for effective disinfection, and of hygenic water storage practices.

Table 3.1 shows the effect of altitude on the boiling point of water. Note that the boiling point of water is actually dependent on the air pressure, which is why the estimated air pressure is also shown. These figures are a conservative estimate and if the air pressure at sea level is higher the boiling point of water will also increase.

Table 3.1. The effect of altitude on the boiling point of water[29]

Altitude (m)	*Pressure (mm of Hg)*	*Boiling point (^{0}C)*
0	760.0	100.0
500	715.4	98.4
1,000	673.7	96.6
1,500	634.9	95.0
2,000	595.8	93.3
2,500	560.0	91.7
3,000	526.2	90.0
4,000	464.3	86.4

26 UNHCR (1982) and Ockwell (1986)
27 Davis and Lambert (1995)
28 Davis and Lambert (1995)
29 Adapted from pump.net (2002)



Note 1: Users put in cold water and immediately receive the same volume of hot.

Note 2: The outlet should be as close to the top of the oil drum as possible. This prevents people from pouring in more water than they wish to collect.

Figure 3.8. Put and take water heater

Heating water for washing

When people wash regularly the incidence of contact-related diseases is reduced. Children, especially, will wash more often if hot water is available; washing clothes in hot water is an effective way to kill the eggs of lice (see the section 6.1 *Health*). The provision of hot water facilities for washing, will make a positive contribution to the overall health of refugees in cold areas.

In some areas it is appropriate to provide communal washing and bathing areas. Known as ‘hamams’ in central Asia, these are usually segregated by sex or have male-only and female-only bathing times. Not only do they allow people to stay clean, in many cultures they are also important as social centres.

For small-scale production of hot water, simple ‘put and take’ water heaters can be constructed from oil drums, as shown in Figure 3.8.

3.5 Distribution systems

In cold regions distribution systems and pumps are two of the most vulnerable components of a water supply system. Water in pipes is likely to freeze solid, expanding as it does so damaging pipes and causing leakage of water after the pipes have thawed. Pumps are liable to frost damage and may have fuel or electrical power problems.

Leaks

A common problem is detecting leaks. Pipes contracting in the cold make winter the most likely time for tension forces to open poor joints or other weaknesses in the pipe. Locating leaks under frozen ground is difficult for two reasons:[30]

- The cap of frozen ground above the leak can force leaking water sideways rather than upwards. Normally leaks surface via the relatively loose backfill of the trench, and so water flows to the surface close to the problem in the pipe. However in frozen ground the noticeable problem of water on the ground could be many metres from the actual problem in the pipe, leading to false assumptions about where the problem is and, perhaps, missing the problem altogether.
- A thick frost cap can cause sound distortion that makes the use of aquaphones and geophones (leak detection equipment) more difficult.

Leaking pipes will cause a slipping hazard when water comes to the ground surface and freezes.

Preventing pipes freezing

Water freezing in pipes can be avoided by burial, insulation, draining pipes or by maintaining a continuous flow. Selecting the correct pipe material reduces the probability of damage, should water freeze inside.

Draining distribution pipes and tapstands

If pipes have to be laid quickly, for possible burial at a later date, the best way to prevent them from freezing up is to arrange for the pipes to be drained when not in use. Pipes leading from a water source to raw water bulk storage tanks can be drained when water is not being pumped, and arrangements made to drain water out of temporary distribution systems at night.

Where ambient temperatures are at or below –10°C it is worth draining temporary distribution networks at night, even if buried at shallow depth. Two design features will help:

1. Install a vertical air inlet pipe after the outlet gate valve of the water storage tanks or break pressure tanks (see Figure 3.6).
2. Fit washout valves and drainage facilities at low points in the distribution system.

By opening taps at tapstands, all water can be drained from the pipes. In the event of tapstands becoming frozen, people have been observed lighting fires underneath them, causing damage to both the pipes and the wooden posts.

[30] Gros (1980)

Maintaining a continuous flow
One alternative to draining the pipes is to keep water continuously moving inside them.

Either:
- Leave some taps running at distribution points. Adequate drainage facilities will be needed. Note that this is obviously wasteful of water, and would only be used as a temporary solution.

  Or

- For a pumped system the water can be recirculated, although it requires that at least two parallel pipes are laid along the entire length through which water is to be pumped, and for several valves and joints to be used (see Figure 3.9).

For both these options, draining the pipes when not in use seems a better long-term option.

Surface-laid pipes
Uninsulated surface-laid pipes are most at risk from freezing. By measuring the air temperature and the temperature of the water entering the pipe it is possible to calculate the approximate values of:

- how long water will take to cool down to the freezing point; and
- the maximum acceptable length for an unprotected surface-laid pipe, for a given flow rate, so that the water in it does not cool to 0°C.

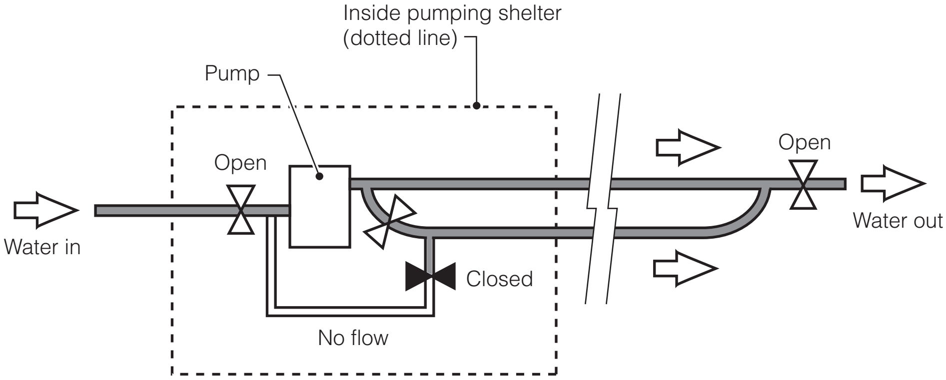
Appendix C shows one method of calculating these values.

Pipe burial
In areas where the ground is not permanently frozen, effective protection against seasonal freezing can be provided by burying most major pipework in the ground. The depth of burial is critical and should, ideally, be greater than the maximum depth of frost penetration. The penetration of frost increases throughout the winter, reaching a maximum sometime after the coldest period of the winter. The maximum depth of frost penetration may be a few weeks, or possibly months after the coldest period.

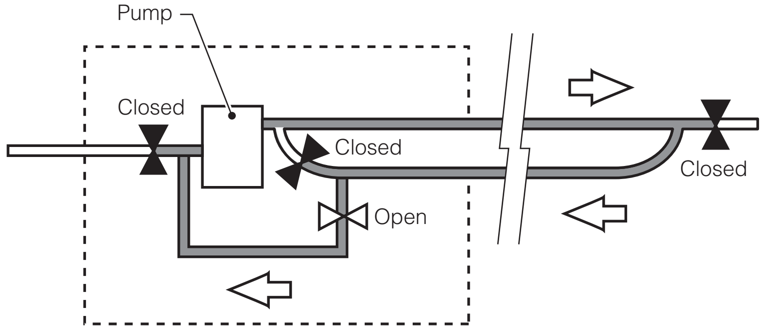
Deep trenching requires more work than shallow, because when trenches are more than about 80cm deep they can no longer be just one spade-width wide: they must be both wide enough for someone to stand in to dig deeper, and built with sloping sides (for safety reasons). Local workers can be encouraged to ensure the necessary depth of trenching by asking them to use a ‘former’ frame (made simply of wood) the same dimensions as the required trench cross-section. This way it will be obvious when the trench profile is correct. Substantially more time should be allowed to excavate trenches, of more than 80cm depth.

Local engineers should have some knowledge of the depth of maximum frost penetration. Otherwise it can be determined by digging trial holes, after the coldest part of the winter, and determining at what depth the soil is not frozen by analysing its texture and/or temperature.

CASE A
Water transferred



CASE B
Water not transferred (recirculated through main pipes)



Note 1: Represents a gate which can be opened or closed.

Note 2: When water is not being transferred the pump is run either continually or periodically (severy half hour or so).

Note 3: This system is suitable for short periods where water is not transferred. For longer periods, the pipes and pump should both be drained.

Figure 3.9. Recirculating pumped system

Pipe insulation
Pipe insulation is effective on its own or in combination with pipe burial. If both methods are employed then the minimum desirable depth is still at least 0.5 to 1.0m, which means that daily air temperature fluctuations will have an insignificant effect, and protection is provided from loads on the ground's surface. In terms of reducing frost penetration a 1.2m wide, 50mm-thick polystyrene-foam insulating board laid directly above a buried pipe is roughly equivalent to 1.2m of sand or silt cover or 1.0m of clay cover.[31] More excavation will be needed for the trench to accommodate the width of the polystyrene boards. Although expensive, pre-insulated HDPE pipes (discussed below) are also suitable for burial.

A North American solution to above-ground pipe insulation is that of a 'utilidor'. Commonly several services, including water supply, sewerage and electricity supply share an elongated wooden or plastic box structure which is filled with insulating foam. A simplified version of this technology is suitable for emergency water supply. The advantage over pipe burial is that pipes are easily accessible for repair. The advantage over simple pipe lagging is that insulation can be thicker and more effective, being protected from rain water.

Disadvantages of utilidors include that in desperate circumstances people will be tempted to use any available wood (such as a utilidor wall) for fuel. Also when a utilidor is required to cross a road it will either have to raised above the level of the traffic or buried.

Pipe materials
Damage to pipes from water freezing inside can be avoided or mitigated by selecting of a suitable pipe material. Appendix B shows the thermal properties of some construction materials, including those used to make pipes.

Medium and high-density polyethylene (MDPE and HDPE)
- Polyethylene remains ductile, even at -60°C, so if water does freeze in the pipes they are unlikely to crack. HDPE pipes have been known to survive several freeze–thaw cycles. Heat-welded joints are also strong enough to resist the pressures of water expansion on freezing.
- MDPE and HDPE have low thermal conductivity, so the insulating effect can mean that water is less likely to freeze in them than in pipes made from other materials, especially metal.
- MDPE or HDPE pipes flexible and sometimes available on long rolls, which also makes them relatively easy to install.

Polyvinylchloride (UPVC)
- UPVC is ductile at 20°C, but can become brittle at very low temperatures (e.g. lower than -10°C) or with prolonged exposure to sunlight.
- UPVC generally having thinner walls than MDPE or HDPE pipes, and so offer less insulation and are more prone to accidental breakage.
- PVC pipes require thrust blocks at changes in pipe direction to prevent ice expansion from pulling the slotted joints apart.[32]

[31] Smith (1996)
[32] Davis and Lambert (1995)

- Many different grades of PVC are available, with quality and material properties being highly variable, depending on the quality of the manufacturing process. Therefore imported PVC may be much stronger than locally made pipes.
- Polyethylene pipes are not flexible when cold, especially when outside temperatures are below freezing. If butt-welded joints are to be used in situations where it is necessary to manhandle pipes into position fairly accurately, storage of pipes indoors or in a heated tent should be considered so that the pipes are more manageable and flexible.

Metal

- Ductile iron pipes are very resilient but will also be very expensive since it is likely they will need to be imported.
- Pipes made from iron or steel are prone to corrosion, although various coatings can be applied to minimise the effects.
- Although metal pipes are strong, they can still be damaged by ice forces.
- Small diameter (up to 50mm) metal pipes can be defrosted electrically.

Pre-insulated HDPE pipes

- Pre-insulated HDPE pipes have a factory-fitted polyurethane foam insulation layer, which is usually well protected by a waterproof layer of UPVC on the outside.
- Pre-insulated HDPE pipes are the most effective solution for pipes that must be completely exposed to the air. Common applications are when water or sewage pipelines cross bridges (and therefore cannot be buried).
- Although HDPE pipes are an expensive option, they are also suitable for burial, and can be buried more shallowly than uninsulated pipes as long as there is enough cover to ensure protection from vehicle traffic.

Thermal properties of bare and pre-insulated HDPE pipe are compared in Table 3.2.

Table 3.2. Thermal properties of HDPE pipe, bare and insulated[33]

Pipe diameter (mm)	Ambient temperature = –18°C			Ambient temperature = –34°C		
	No insulation	With 50mm polyurethane foam		No insulation	With 50mm polyurethane foam	
	Time to freeze (hrs)	Time to freeze (hrs)	Heat loss (w/m)	Time to freeze (hrs)	Time to freeze (hrs)	Heat loss (w/m)
50	1	57	2.7	<1	29	5.0
75	3	107	3.4	1	55	6.5
100	4	149	4.1	2	77	7.7
150	9	241	5.4	5	125	10.2
200	16	333	6.6	8	172	12.4
300	34	530	8.9	17	274	16.8
400	53	692	10.6	27	357	20.0

[33] Figures from Urecon Ltd., Quebec, Canada

Other pipe materials

- Asbestos cement pipes become particularly brittle at low temperatures and should not be used unless permanently and properly buried.
- Acrylonitrile butadiene styrene (ABS) pipes have similar properties to PVC although they require a thicker wall section for the same pressure rating, and are more vulnerable to damage by sunlight.

Defrosting pipes blocked by ice

There are two primary options for defrosting water service pipes to houses that have become blocked by ice. Either a large electric current is passed down metal pipes, warming them up, or hot water is fed into blocked metal or plastic pipes. This subject is discussed comprehensively in 'The Cold Regions Utilities Monograph'.[34] Once some flow has been restored, water passing through the pipes will quickly melt any remaining ice.

Defrosting using electric current

Small-diameter metal pipes, such as those used for connections from water mains to individual houses, can be defrosted by passing a large electric current through them. Welding machines, generators or heavy service transformers may be used to provide the current. Electrical connections should be made to the pipe on each side of the length of pipe to be thawed, so that this length of pipe forms part of the electrical circuit.

Note that this method is potentially dangerous, and adequate safety precautions must be taken, especially to keep people away from live electric cables.

Electrical thawing is only suitable for use with relatively small pipes, from ½-inch (13mm internally) to 2 inches (50mm internally). A typical house connection can be thawed using 300 amps for 4 to 6 minutes. More specific times are given in Table 3.3 while cable sizes suitable for making connections are shown in Table 3.4.

Note that if the current is halved, the time taken will be multiplied by four, since the time taken to defrost is proportional to the heat produced, which is proportional to the amount of electrical power used:

Electrical power used is given by the equation $P = I^2 R$

where I = electrical current (Amps) and R = electrical resistance of the circuit (Ohms). Larger pipes will have lower electrical resistance, so will take longer to heat up.

The following are also important factors that need to be considered carefully before attempting to use electrical current to defrost water pipes:

[34] Smith (1996)

Table 3.3. Approximate current and time for thawing steel pipe[35]

Pipe sizes (in inches)						*Approximate time (minutes)*
½	¾	1	1¼	1½	2	
200	270	400				3-4
150	200	300	400			6-8
125	170	250	340	440		8-12
100	135	200	270	320	440	12-16
75	100	150	200	240	330	25-30
50	67	100	135	160	220	60

Table 3.4. Recommended cable sizes[36]

Amps	*Distance from welding machine to pipe connections*						
	17	*25*	*33*	*50*	*75*	*100*	*130*
100	2	2	2	1	2/0	3/0	4/0
150	2	2	1	2/0	4/0	4/0	2 of 3/0
200	2	1	1/0	3/0	4/0	2 of 3/0	2 of 4/0
250	2	1/0	2/0	4/0	2 of 2/0	2 of 3/0	
300	1/0	2/0	3/0	4/0	2 of 3/0		
350	1/0	2/0	4/0	2 of 2/0			
400	2/0	3/0	4/0	2 of 3/0			

- Welding machines can only operate at their maximum current rating for about five minutes. If longer times are required the current taken should be no more than 75 per cent of the maximum rating.
- Welding machines generally operate at low voltage (less than 20 Volts). It is the high current, not the voltage, that will heat up the pipes.
- Wide-diameter wire is needed to connect welding machines to pipes. In principle the cross-sectional area of the wire should be greater than that of the metal of the pipe, so that the wire has less resistance and does not get hot.

[35] Nelson (1980)
[36] Nelson (1980)

- Make good electrical connections to pipes and check them before turning on the current.
- This method is suitable for underground pipes only, not indoor plumbing, which can be thawed simply by warming up the house.
- Before operation, disconnect earth connections to household plumbing, or disconnect the service pipe altogether, otherwise there is a risk of fire. Remove water meters from the pipe section to be defrosted.
- Current can jump from water pipes to nearby gas pipes, which will reduce the effectiveness of this technique.
- In an emergency, welding machines are likely to be needed for vehicle and building repairs, not just defrosting water pipes. Think carefully before removing them from their normal activities.

Defrosting using hot water
This is suitable for both metal and plastic pipes. A flexible pipe is fed into sections of frozen underground pipe: hot water is continually pumped through the flexible pipe so that it melts the ice that is blocking the pipe.

The main advantage of this method is its simplicity. A 20- to 100-litre water container fitted with a hand-pumping mechanism can be used as a hot water reservoir and refilled from stoves and kettles. Alternatively consider using water directly from the outlet of a domestic water heater somewhere in the building. Another advantage of using hot water is that the method is suitable for any diameter of pipe, whereas using electrical current is only practical for defrosting small diameter metal pipes.

The most common problem with using hot water arises because pipes often have internal obstructions from bends, mineral deposits, valves, and so on. The hot water method is reported to be about 50 per cent successful, on average.

Plumbing of hospitals and collective centres

Figure 3.10 shows a simple and effective way to plumb a several-storey building into a distribution system that supplies water intermittently. This system was used for a hospital in Pristina (Kosovo) in 1999. The simplicity of the system shown in Figure 3.10 means that, once installed, there is very little that cound go wrong provided there is sufficient pressure in the water main at some time during the day.[37]

Important features:
1. The lower check (one-way) valve and the ball-cock valve at the tank will ensure that water is taken from the system whenever it is available.
2. Temporary water tanks should be located in the uppermost intact rooms of the building, rather than on the roof where they may be liable to freezing.
3. Almost any point of an existing cold-water supply system will suffice for the connection from the main water supply.
4. Due to the upper check (one-way) valve, water will flow in different directions at different times in different pipes, but as long as there are no leaks, pressure will be maintained by the temporary storage tank.

[37] Reinbold (2000)

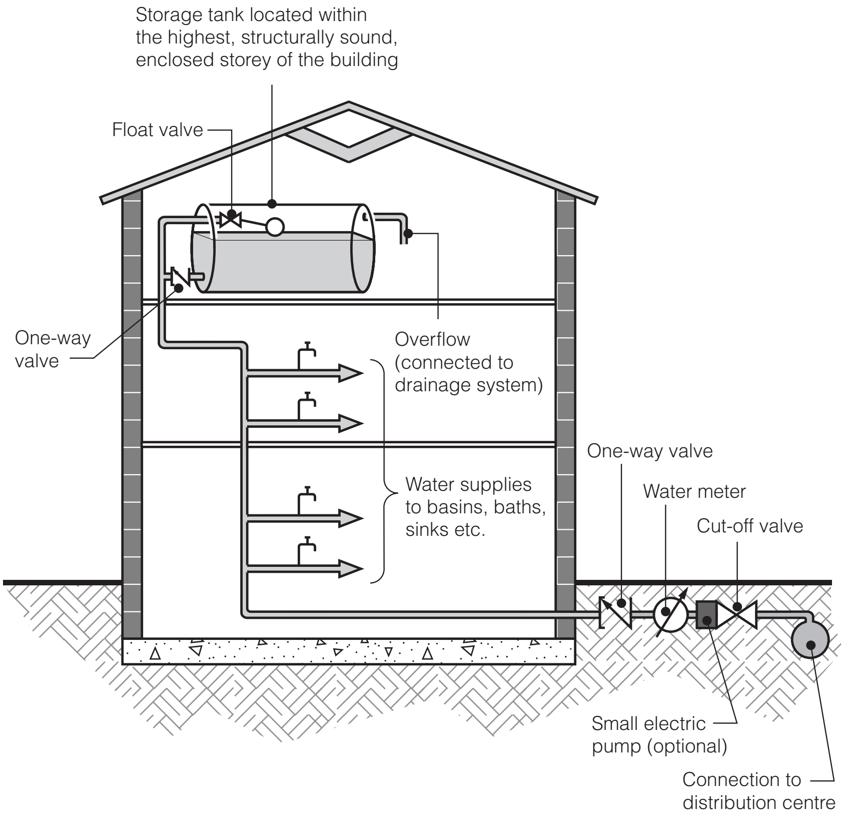


Figure 3.10. Plumbing a large building into an intermittent supply

5. An obvious addition when a water supply has little, or no, pressure for much of the day is a small electric pump, switched on either automatically or manually. Either way, any pump will need some operation and maintenance.

Warning: Structural checks must be made to ensure that the building (floor and walls) can support the weight of the temporary tank or tanks when filled with water.

Protecting distribution points

It is preferable to locate water distribution points inside a shelter for two reasons. First, shelter prevents the problem of water freezing inside standposts or handpumps, and secondly it will provide a more comfortable and safer environment in which people can wait while queuing for water or filling containers.

The location of distribution points in relation to accommodation will obviously affect the length of time that people will have to walk (in cold weather) in order to fetch water. Even a trip of five minute’s duration may constitute a serious risk of exposure to old or sick people.

Drainage of water distribution areas
An important consideration for water distribution points, in any climatic region, is how to provide drainage away from the immediate area. In the summertime standing water provides a potential breeding site for insects that transmit disease. In the winter poor drainage will cause a slipping hazard or mud and water will make using the tap very unpleasant.

The construction of a properly drained area, for example a concrete slab draining to a soakaway, will both prevent the health problems associated with puddles of standing water, which can contaminate wells and boreholes, and help to prevent a build-up of ice that poses the immediate hazard of slipping and falling for people using water distribution points.

Protection of simple stand pipes
Simple standpipes can be protected from the cold by using basic insulation, for example by wrapping sacking around exposed pipes, constructing a wooden box around them or by a 'tap box', which is filled with soil in winter and can be removed during the summer for maintenance. Soil in the tap box acts as insulation. This principle is illustrated in Figure 3.9. An improvement to the tap box shown is to put a waterproof roof on it to prevent rain from getting in, since soil containing moisture is less insulating than dry soil.

An alternative to filling a tap box with earth is to place a small heat source, such as a small paraffin heater, inside the box at night.[38]

3.6 Water supply in mountainous regions

In the West walkers frequently make the assumption that mountain streams are safe to drink. Streams are sometimes free from pathogens because the population density in mountainous areas is very low, however if refugees arrive in such an area this is no longer true. Also affecting the quality assessment of surface water in mountainous areas is the fact that *E.Coli* are not reliable indicator organisms for protozoan cysts, including *Giardia* and *Cryptosporidium*, and that infectious parasitic cysts can live in water for up to three months.[39] *Giardia* is certainly capable of existing in cold and mountainous areas: *Giardiasis* is an ailment that commonly affects trekkers in Nepal! Therefore even if water tests show an absence of faecal coliforms there may be potentially fatal diseases present in the water.

In refugee camps in mountainous areas all water should be treated to remove pathogens. A proper and safe water supply system should be designed and implemented.

Water sources and treatment

Groups of refugees have used diverse water sources in mountainous regions, including snow, ice, and glacial meltwater streams. In Northern Iraq in 1991, airdrops were made of water in plastic bottles fixed to pallets. According to observers, some 95 per cent of all bottles were destroyed upon impact with the ground.[40] Some water was transported into that same area, in storage tanks , by helicopter. This was very expensive: at that time each litre of water cost

[38] Gould (2001)
[39] tripprep.com (1998)
[40] Cuny (1994)

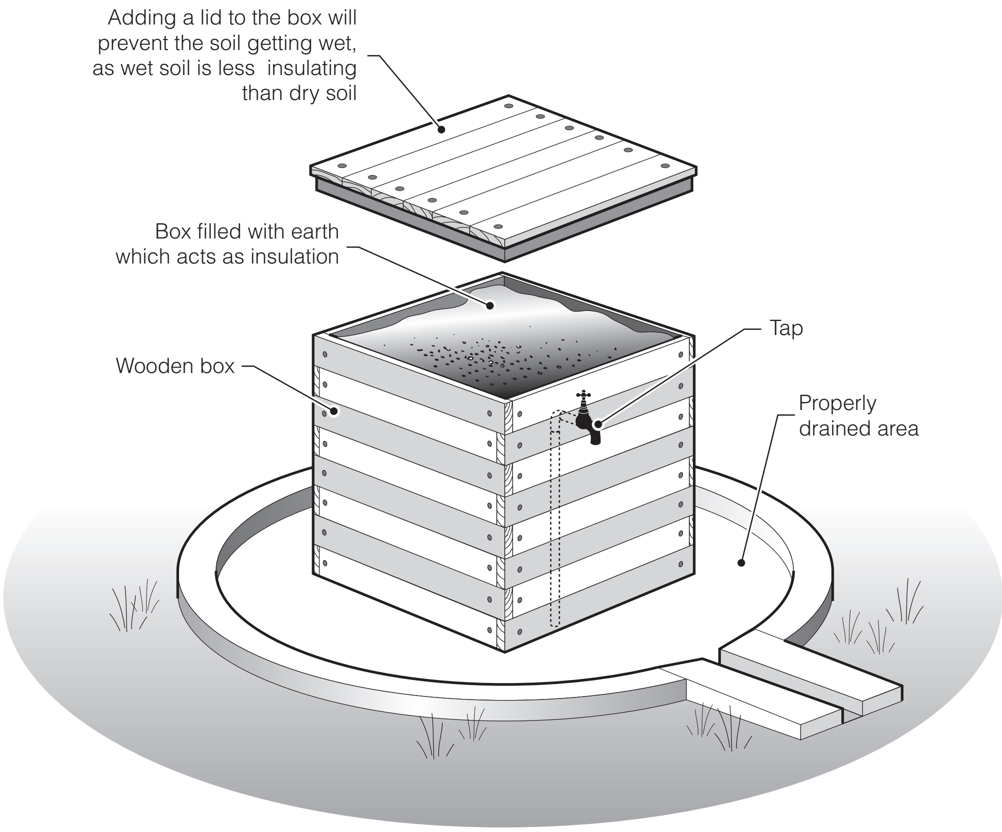
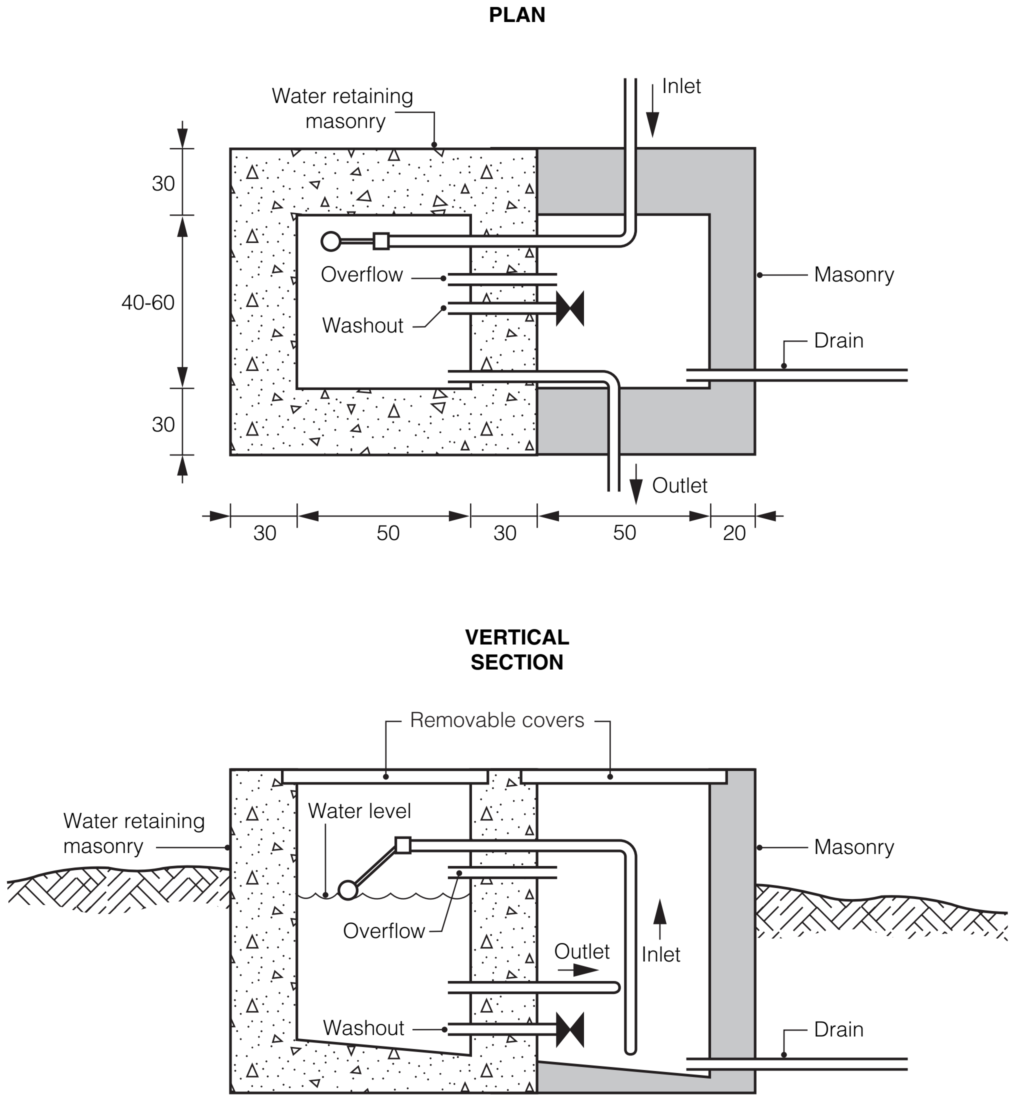


Figure 3.11. Tap box protection of a temporary standpipe

about US$3.50 (in 1991). Therefore careful decisions must be taken concerning which source to use, taking into account the diversity of available sources and the high costs of logistics in mountainous areas. A flowchart to aid water source selection for refugee camps in mountainous areas is shown in Figure 7.2 in Appendix A .

The use and treatment of unusual water sources, including ice and snow, is discussed in detail in the *Water sources* and *Water treatment* sections of this chapter. Also discussed are the effects of altitude on boiling water, and other possible water purification techniques (see section 3.4).



Notes:
1. Discharge may or may not have control valve
2. Outlet pipe set 10-15 cm above floor of tank
3. Internal dimensions depend upon fittings

Figure 3.12. Sample design for a break-pressure tank[41]

[41] from Smith (1999)

Pressure problems in pipes

Break-pressure tanks

For gravity-fed water supplies flowing over large vertical distances, excessive internal pressures can cause damage to pipes. The maximum internal pipe pressures occur at the lowest points in the system, but break-pressure tanks located above these can help to reduce that maximum pressure. Break-pressure tanks are designed to allow the flow to discharge into a tank with a free water surface in contact with the atmosphere, reducing the hydrostatic pressure to zero, relative to atmospheric pressure. An example of a design for a break-pressure tank is shown in Figure 3.12.

To decide where to position break-pressure tanks it is necessary to understand the theory of hydraulic flow in pipes: this theory is well explained, with examples, in *A Handbook of Gravity-flow Water Systems*.[42]

Pipe deformation due to negative pressure

The opposite problem to excess pressure is that of suction, causing pipes to collapse. If a gate valve at the top end of a water-filled pipe is closed, water is not prevented from flowing out of the lower end, the resulting negative pressure can make even quite substantial pipes (especially plastic ones) collapse. Atmospheric pressure deforms the pipe into an oval or almost flat cross section, from which it does not necessarily recover afterwards. The result for subsequent flow is a greatly reduced flow capacity and loss of pressure head in that section of pipe. Another negative consequence of low pressure inside a pipe is that water containing pathogens may be sucked into the water supply through any small leaks in the pipe, for example at joints. The solution is to turn off the system's gate valves, starting at the bottom and progressing up the hill while keeping the pipes pressurised. If pipes need to be drained down, air must be allowed to enter the pipe at the higher part of the pipe while water is drained out at the lower end.

Pumping at altitude

Centrifugal pumps are better at 'pushing' water than at sucking it, and pumps should be installed so that the suction head (pressure) in the inlet pipe does not fall below a value at which the water will vaporise. Standard water supply manuals cover the principles of pumping.

Two factors decrease the ability of centrifugal pumps to 'suck' water at high altitudes:

1. The reduction in atmospheric pressure directly reduces the height of the water column corresponding to the maximum suction head of the pump.
2. Frictional losses, causing the maximum suction head to be less than atmospheric pressure at sea level, increase at altitude. This is because the water being pumped at altitude will be colder, and therefore more viscous, than the water used for tests at sea level.

[42] Jordan (1984)

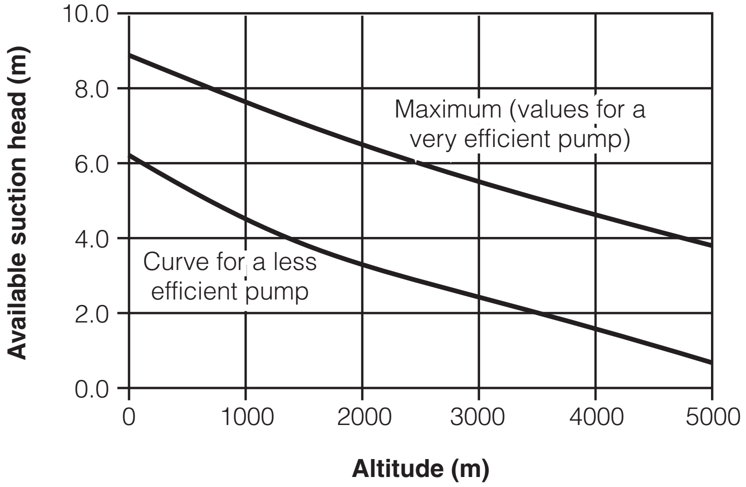


Figure 3.13. The effect of altitude on available suction head for suction pumps

Therefore centrifugal pumps should not be located too far above the water source used, in case the pump has difficulty in functioning. Figure 3.13 shows the likely range of loss of available suction head at altitude, due to loss of pressure and colder water.

3.7 Books on water supply

The following books may be useful to people providing water supplies in emergencies in cold regions:

1. Davis, Jan and Lambert, Bobby, 1995, *Engineering in Emergencies*.
2. House, Sarah and Reed, Bob, 1997, *Emergency Water Sources.*
3. Jordan, Thomas D, 1984, *A Handbook of Gravity-flow Water Systems.*
4. Smith, Dan, 1996, Edited *Cold Regions Utilities Monograph.*