reservoir or stream is seldom below 33° F., as the formation of ice and the density of the water generally prevent the cooling of the water below this temperature. If the water in passing through the main is not reduced in temperature to below 32° F. there will be no danger of freezing. If it is reduced below 32° F. ice will begin to form, the ice forming a coating on the inside of the pipe, due to the high conductivity of the iron. As the ice film thickens, the transmission of the heat of the water to the surrounding earth and thence to the air is greatly retarded, the conductivity of ice being such a small fraction of the conductivity of the iron. If the velocity in the main is reduced through a lowering of the rate of draft, the water in the main is more readily cooled, and the rate of ice formation correspondingly increases. This ice formation may be properly classified as surface ice. It is probable that in a main where the velocity is high, the water is cooled slightly below the freezing point and a form of frazil ice created. Such ice might eventually clog the main, stopping the flow, and the whole mass of water in the main quickly change to solid ice. In the report of the committee of the New England Waterworks Association on the depth at which mains should be laid to prevent freezing, submitted in 1909, reference is made to slush ice forming in a main laid in a salt marsh at New Brunswick, New Jersey. The velocity in this main was high and frazil ice probably formed. A stoppage in flow may also occur after a thaw, due to the loosening of the film of ice which has formed during the cold spell, and which may break up and flow through the water until it reaches a point in the main where the ice may not have broken loose and where the floating ice will become packed in such a manner as to completely stop the flow. While this might account for the stoppage of flow in mains, especially in house services, after a thaw, which is an experience not uncommon to waterworks superintendents, there is a record of an actual reduction in temperature of soil below 32° F. following a thaw, and such reduction would be ample reason for the freezing up of water mains coincident with a thaw.

Prevention of Formation of Ice in Subaqueous Mains.—Where a main is laid in salt water it is common practice to lay the main without any earth cover. The iron is therefore exposed directly to the salt water, which is usually in motion, and heat may be rapidly abstracted from the water in the main through the three agencies of transmission, *i.e.*, radiation, conduction and convection. Radiation is active in clear water and especially so from the black pipe. The iron is also an excellent medium for conduction, with the heat being absorbed from the surface of the iron by the water flowing over the pipe. Convection will readily do its part within the pipe. The temperature of the salt water, during a period of severe cold, may be lowered several degrees below the freezing point and under such conditions ice will form in the water main and the main will be completely clogged, unless the rate of flow is sufficient to maintain the temperature at the discharge end of the main, at or above 32° F. If a main is laid in a body of fresh water, there is little danger of freezing, except at the point where the main enters the water, as the temperature of the water will be above 32° F. and a covering of surface ice will prevent excessive radiation. If the main is laid in the bottom of a rapidly flowing fresh water stream, it is possible that through radiation and the cooling of the water in the stream, ice might form in the main, but it is improbable that such ice would be of sufficient thickness to interfere with the delivery of water through such main.

Frost Penetration on Land.—The committee of the New England Waterworks Association, which reported in 1909 on freezing of water mains, stated in their report that they had received 90 replies from 320 circulars sent out to waterworks engineers and superintendents, 53 communities had had trouble with freezing of mains, 50 per cent. of the freezing had occurred at dead ends, and in all cases there had been little or no velocity. In all but three cases the mains were smaller than 10 inches in diameter, and only seven as large as 8 inches in diameter. In every case the ground was frozen below the axis of the pipe. Forty per cent. of pipe was laid in clay, 48.6 per cent. in gravel, 5.7 per cent. in sand and 5.7 per cent. in rock. The depth of penetration of frost was found to be 1 foot greater in the streets than in the fields, and 1 foot 5 inches deeper in gravel than in clay, the depth in sand being about midway between the depth in clay and in gravel. The ice was found at times in concentric rings in pipe as large as 24 inches in diameter, and no stoppage of the pipe had occurred. The ice formation was not always solid, but sometimes in the form of slush. The depth of frost penetration varied materially. The committee called attention to a belief or tradition that existed in the minds of many plumbers and water works superintendents, that most stoppages occurred during a thaw, following a period of severe cold weather, it being suggested that this might be caused by evaporation from the surface during the early stages of the thaw, producing additional refrigeration or reduction of temperature at the depth of a water main sufficient to cause freezing. The committee comment that the reports received did not support this theory. In the discussion of the report an instance was cited where a pipe was laid in the late fall in rock cut, and the backfilling was composed of frozen earth and rock, giving a very porous filling. A comparatively slight current was maintained in the pipe. In the early spring, on a day when it was warm enough so that it was comfortable to be about in shirt sleeves, the pipe stopped up. It was left until the following morning, when it was found that the pipe was again clear.

Mr. Jesse O. Shipman, division engineer, public service commission, New York City, states that, where services are run through bays in the subway, where, in general, the distance from the surface of the ground to the service is about 4 feet, with 6 inches of earth below the service and 12 inches of concrete forming the roof of the subway, trouble from the service clogging with ice usually occurs a day or so after a thaw, following a severe cold spell, has set in.

The writer endeavored to find records of ground temperature but was able to locate only those of Profs. H. L. Callendar and C. H. McLeod, of McGill University, Montreal, Canada, and recorded in the proceedings of the Royal Society of Canada for the years 1895, 1896 and 1897.

These experiments were started in 1894 by Professor Callendar and he was later assisted by Professor McLeod. The location selected for the experiment was level ground in a garden where there was turf and loose light-brown sand to a depth of 8 feet 6 inches. Below this sand was stiff blue clay to a depth of 30 feet from the surface. Water was found in the sand for some distance above the clay but the sand was nearly dry to a depth of 5 feet.

A trench 3 feet wide and 9 feet deep was dug, with one face vertical. Into this face horizontal holes were bored for nearly 3 feet, using a one-half inch rod. Electrical resistance thermometers, consisting of a carefully insulated coil of platinum wire about 3 inches long and protected by an external tube of glass or copper, were inserted in these holes and connected to the indicating