Influence of rivers on geotemperatures

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Summary. — An estimation is made of the thermal disturbance that the eventual difference between the mean annual temperature of a river and that of the ground would cause on the normal geothermal field.

Riassunto. — Viene eseguita una stima del disturbo termico che l'eventuale differenza tra temperatura media annua di un fiume e quella del suolo potrebbe causare sul campo geotermico normale.

1. Introduction.

During a research on the geothermal flow in the Fossa Bradanica [1] it has been necessary to investigate under what conditions and to what extent a river influences the normal geothermal field, under the hypothesis of heat conduction in steady state.

In order that the river provokes a thermal perturbation, it suffices merely for the river to have a mean annual temperature different from that for the ground. Therefore, with the aim of carrying out this type of investigation, it would be just necessary to know the mean annual temperatures of the river and of the soil in the area under examination.

Available literature provides no direct comparisons between these two temperatures. However, they may be obtained by comparison between the temperature of the river water and the air temperature (investigations run by hydrologists) and by comparison between air temperature and that of the ground (made by climatologists and, especially, by agronomists).

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2. Comparison of River and Air Temperatures.

Hydrologists have not paid much attention to variations in river temperature (2) and so present knowledge is incomplete.

However, from the few papers available (for a brief bibliography see (3, 4, 5)) on medium-high latitude areas, there emerge, inter alia, two important factors bearing on the present investigation:

1°) *mean annual river temperature differs from that of the air, generally being higher*

2°) the temperature gradient of rivers (with elevation) is also different and generally above that of the air.

In the case of Italy, Tonini (5) maintains that the mean annual temperature of river waters in this climate is some 2°C higher than that of the air. Visentini (6) observed a temperature gradient of about 1°C for every 200 m in the case of surface waters in the Po basin. On comparing this with that of the air (0.4-1°C/100m) it will be seen that the difference increases with elevation.

3. Comparison of Air and Ground Temperatures.

The results of these investigations are generally utilized in geothermal studies for making the topographic correction (7).

If local climatic conditions present no particular features and if there are no shallow groundwaters in movement and there is no evaporation, it is generally held that, in the case of elevations which are not too high, the mean annual air and ground temperatures can be considered equal or differ *by no more than a few tenths of a degree Centigrade*, the ground surface temperature being higher than that of the air.

In mountain regions, on the other hand, this difference increases with elevation, since the air temperature gradient is greater than that of the ground.

Exhaustive references on comparisons of air-ground temperatures in Italy are given in works by the agronomists Scotton (8) and Macchia (9). Mention of the results of air and ground temperature gradients in the Alps and the Fossa Bradanica are in the works of Birch (7) and Mongelli and Ricchetti (1).

It is apparent that in general the mean temperature of river water is higher than that of the air, and that the mean temperature of the air is lower than that of the ground. Since it is unlikely that these two will balance out exactly, it is to be expected that there will be a difference between the temperature of river water and that of the ground, and that this may be of the order of a few degrees.

In all probability this fact will have no influence on the temperature readings taken in bores a considerable distance from rivers, but the disturbance in holes fairly nearby must be assessed.

Since the absolute value of the disturbance cannot be calculated, we estimate its percentage value, that is the ratio between its value and the difference between the mean annual temperature of the river and that of the soil.

4. Theory.

The temperature under stationary conditions at any given point of a semi-infinite solid, whose surface coincides with plane xy (axis z being oriented towards the inner part of the body) and with a surface temperature is $F(x', y')$, is given by the following expression (10):

$$T(x, y, z) = \frac{1}{2\pi} \int_{-\infty}^{\infty} dx' \int_{-\infty}^{\infty} \frac{z \cdot F(x', y')}{[(x - x')^2 + (y - y')^2 + z^2]^{3/2}} \, dy' \, . \quad [1]$$

Expression [1] can also be applied when the surface temperature is $F(x', y')$ in a given zone S and nil over the remainder of the surface. This given zone may represent the area occupied by a river having any form; in which case:

$$T(x, y, z) = \frac{1}{2\pi} \int_S \frac{z \cdot F(x', y') \quad dx' \, dy'}{[(x - x')^2 + (y - y')^2 + z^2]^{3/2}} \, . \qquad [2]$$

Let us assume that near a borehole P (Fig. 1) the river can be considered as being straight, is L metres wide and only a few metres deep, and that the river-ground mean annual temperature difference is T_o.

In a reference system like that in Fig. 1, if $F(x', y')$ is nil over the whole of the plane xy, excluding the field given by $0 < x < L$, where is T_o, then [1] may be written:

$$T(x, y, z) = \frac{z T_o}{2\pi} \int_{-\infty}^{\infty} dx' \int_{-L}^{0} \frac{dy'}{[(x - x')^2 + (y - y')^2 + z^2]^{3/2}} \qquad [3]$$

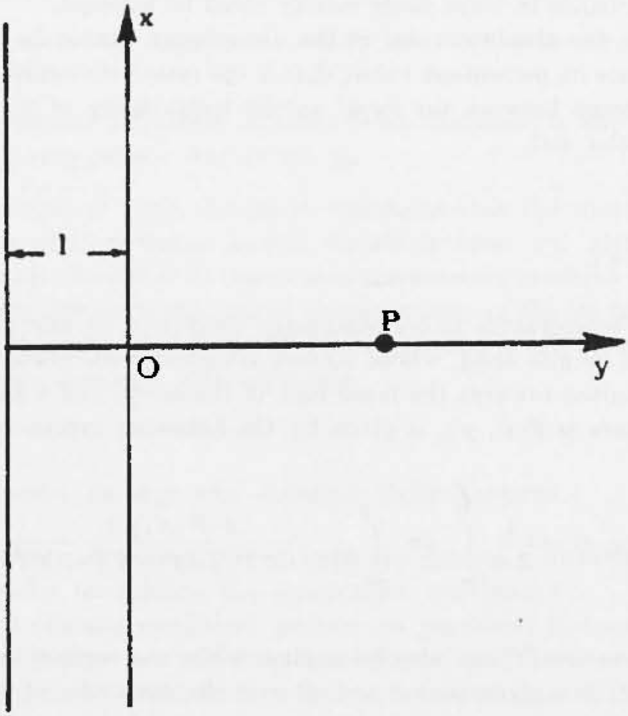


Fig. 1 – Coordinates System for plotting the influence of a river on the temperature distribution of the soil.

which, on integrating gives:

$$\frac{T}{T_o} = \frac{1}{\pi}\left(\text{arctg}\ \frac{y + L}{z} - \text{arctg}\ \frac{y}{z}\right) \qquad [4]$$

where y is the distance from the bore to the nearest bank, z is the depth.

By way of example, Fig. 2 gives the percentage disturbance $\frac{T}{T_0}$ caused in a section of ground at right angles to a river with width $L = 100$ m.

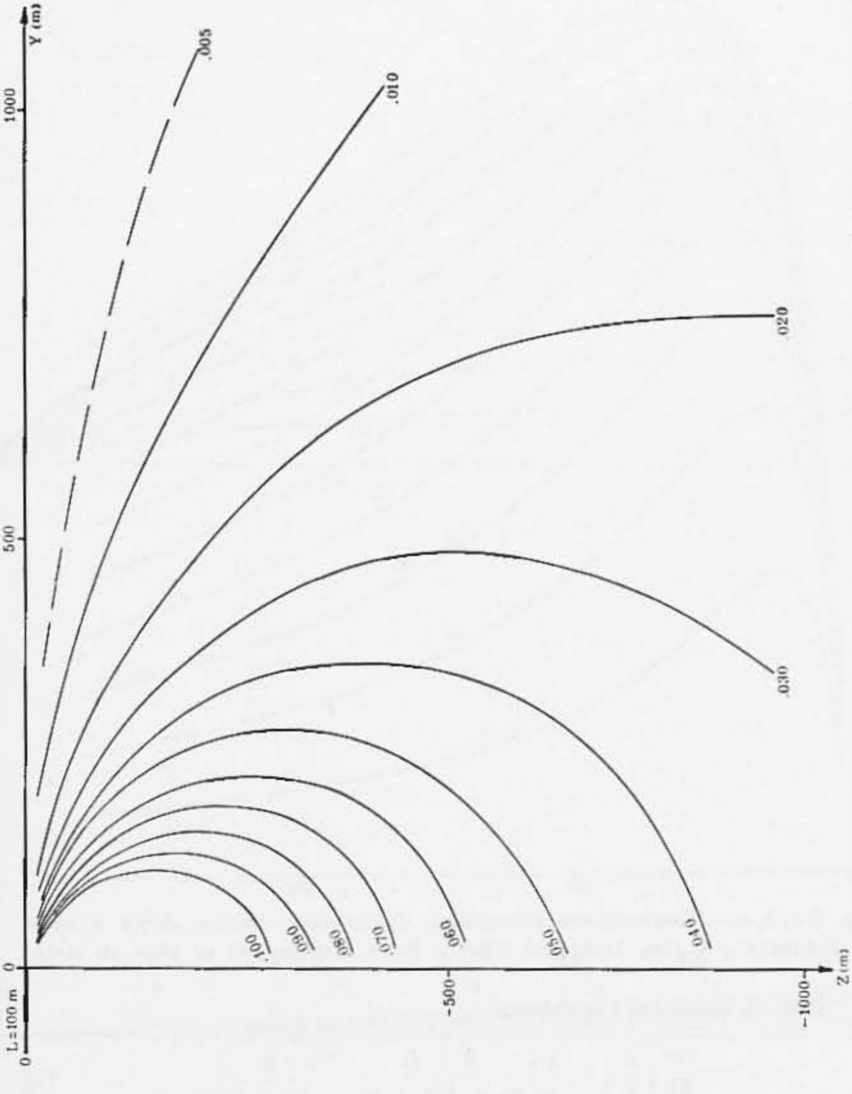


Fig. 2 – Section showing the temperature percentage disturbance in a section of the soil around a river 100 m wide.

Figs. 3 *a*, *b* and *c* which show the percentage disturbance caused down a bore at distances $y = 100$, 1000 and 5000 m from a river 100 to 1000 m wide, indicate more clearly the existence of a $\frac{T}{T_o}$ maximum which shifts to ever greater depth as y and L increase.

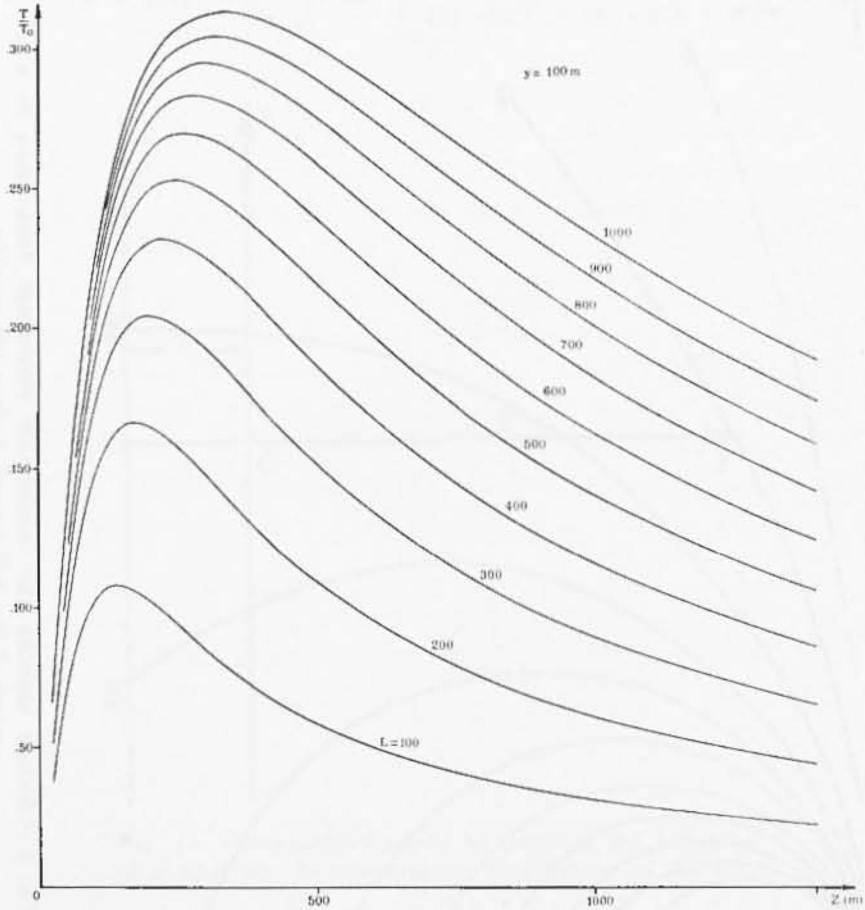
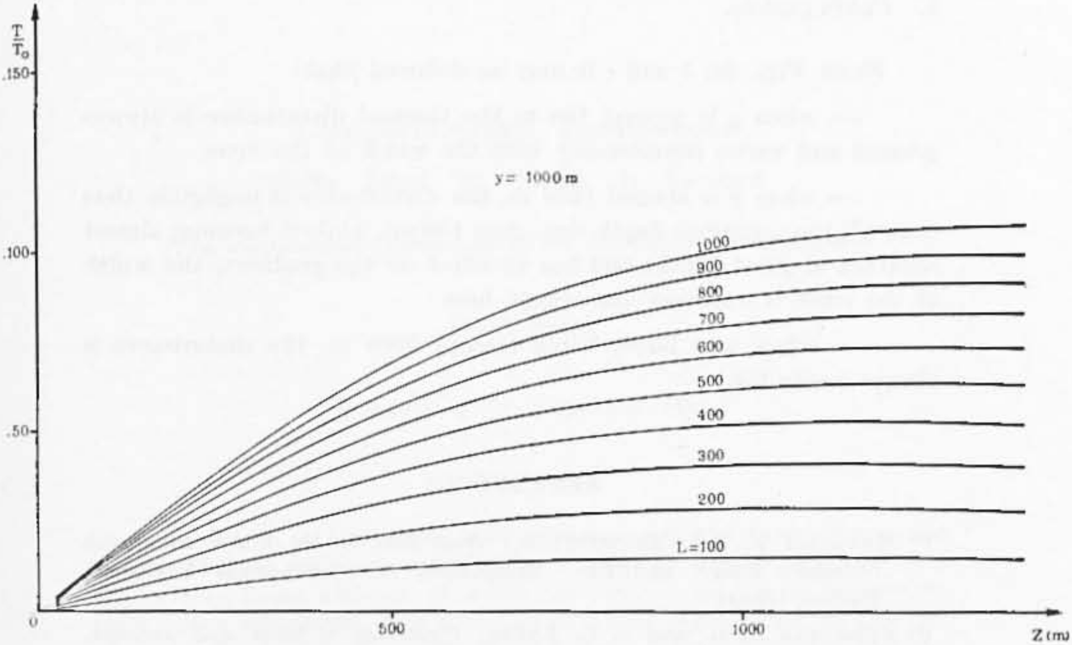


Fig. 3 *a*, *b*, *c* – Temperature percentage disturbance caused down a bore at distances $y = 100$, 1000 and 5000 m from a river 100 to 1000 m wide.

Indeed, from [4] we obtain:

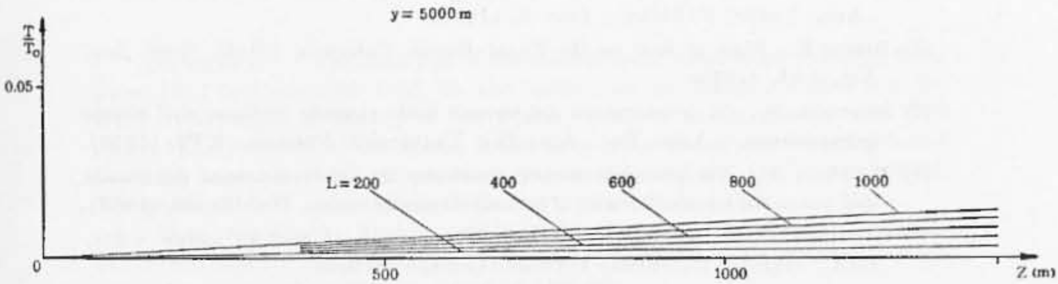
$$\frac{\partial}{\partial z}\left(\frac{T}{T_o}\right) = \frac{1}{\pi}\left[\frac{y+L}{(y+L)^2+z^2} - \frac{y}{y^2+z^2}\right] \qquad [5]$$

which cancels out for $z = \sqrt{y\,(L+y)}$.



T/T₀
.150
.100
.50
0
y= 1000 m
1000
900
800
700
600
500
400
300
200
L=100
500
1000
Z (m)

Fig. 3 *b*



y= 5000 m
T/T₀
0.05
0
L=200
400
600
800
1000
500
1000
Z (m)

Fig. 3 *c*

5. Conclusions.

From Figs. 3*a*, *b* and *c* it may be deduced that:

— when y is around 100 m the thermal disturbance is always present and varies considerably with the width of the river

— when y is around 1000 m, the disturbance is negligible (less than 1%) at a shallow depth (less than 100 m), while it becomes almost constant at great depths and has no effect on the gradient; the width of the river is not very important here

— when y is large, being around 5000 m, the disturbance is always negligible.

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