CALCULATION OF POISON CONCENTRATIONS FROM A HYPOTHETICAL ACCIDENT OFF THE SWEDISH COAST

by J. Svensson

SMHI Rapporter

HYDROLOGI OCH OCEANOGRAFI

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ABSTRACT

A model is developed by which the poison concentration due to a discharge of toxic matter in the coastal water is calculated. The outlet arises from a hypothetical accident to a ship loaded with dangerous materials. The oceanographic conditions are assumed to be most unfavourable for a rapid dilution of the toxic matter and the current is assumed to be towards the coast. Calculations of the time development as well as calculations of areas constantly covered with poison during a time period of 45-55 hours are carried out for different conditions.

Calculations of poison concentrations from a hypothetical accident off the Swedish coast

The U.N. is considering regulation of the shipboard transport of dangerous materials, such as poisons, and the right for a country to intervene if an accident occurs. The Swedish Environmental Protection Board together with the Swedish Administration of Shipping and Navigation and the Swedish Board of Customs has commissioned the Swedish Meteorological and Hydrological Institute to calculate the poison concentration from a hypothetical accident.

The results of a model study are presented below.

DESCRIPTION OF A HYPOTHETICAL ACCIDENT WHICH CAUSES A DISCHARGE OF POISON

A ship loaded with some toxic matter, neutrally buoyant or soluble in water, is supposed to collide or ground 4 nautical miles (about 7.5 km) off the Swedish coast. The wreck is supposed to remain in the same position during the discharge of the cargo.

The oceanographic conditions are assumed to be most unfavourable for a rapid transport out of the area or for a rapid dilution. This means that spring conditions are assumed to prevail with a strong vertical density gradient at about 10 m depth. The poison is then spread in the upper layer and no poison is transferred to the deeper layer. The current on the outer boundary of fig. 1 is taken to be towards the coast with the same velocity (10 cm/s) from the surface down to the thermocline (pycnocline).

The coast is straight with two points and the water off the coast is 10 m deep or more (see fig. 1).

The water movements in the vicinity of the ship are assumed to mix the toxic matter evenly in all space directions within a volume 10 m thick and of 2-3 shiplengths diameter.

Two types of accidents have been studied.

1. The cargo (10,000 tons) is released during 8 days (192 hrs). The source concentration is taken to be constant during the first 96 hours and the model is run for this time. The source concentration is then assumed to decrease during the next 96 hours to 1/10 of the initial value. This means that about 2/3 of the cargo is released during the modelled period (see fig. 2).

2. The same cargo is released during 2 hours. The source concentration is this time taken to be constant during 1 hour and assumed to decrease to 1/10 of the initial value during the next hour. The model is run for 96 hours to calculate the poison concentration after the outlet has stopped.

THE MODEL

The concentration of poison can be modelled by a 2-dimensional model if there are no variations in the vertical direction. Velocities and poison concentration are calculated on a net of gridpoints (45x50 points). The model only covers one half of the area in fig. 1b. The other half is a mirror image of the modelled one.

Knowing the concentration in the vicinity of the ship and the other boundary conditions the model gives values of current and poison concentration on every gridpoint. The dilution of poison is due to diffusion and advection of water past the shipwreck and finally out of the region. The mathematical formulation of the model is explained in appendix 1.

The value of the horizontal diffusion coefficient, according to observations, range from the molecular viscosity coefficient $\eta = 0{,}014$ to $A = 10^{11}$ g cm^{-1} sec^{-1}. The coefficient A is considered to be dependent on the size of the turbulence elements and comprise a continuous spectrum. This means that the value of the coefficient among other things is dependent on the size of the basin. Calculations of A for the Irish Sea which is approximately the same size as the Kattegat or the Baltic Sea give the result $A \approx 2 \cdot 10^5$.

This value may be too large, due to the strong tidal current in the Irish Sea. Therefore the poison concentration in the model has been calculated with $A = 2 \cdot 10^5$ and as a comparison also with $A = 4 \cdot 10^4$. Both values are expected to be valid in Swedish coastal waters.

The concentration in the vicinity of the ship is assumed to be different in the different cases.

$A = 2 \cdot 10^5$ Outlet during 192 hrs	$c_o = 75$ ppm
$A = 4 \cdot 10^4$ Outlet during 192 hrs	$c_o = 250$ ppm
$A = 2 \cdot 10^5$ Outlet during 2 hrs	$c_o = 6{,}500$ ppm
$A = 4 \cdot 10^4$ Outlet during 2 hrs	$c_o = 27{,}700$ ppm

All of the above concentrations result in a release of 10,000 tons of toxic material during the outlet time.

The current field which results from the model is shown in fig. 3. The current field is constant with time.

RESULTS OF THE CALCULATIONS

The result from the two runs with an outlet during 2 hours is shown in fig. 4-13. The figures represent the calculated poison concentration 18.8, 37.7, 56.6, 75.5, 94.4 hours after the start of the outlet. The figures show half the calculated poison field. The other half is a mirror image of the field shown.

Fig. 4-13 give the concentration at a certain time. It is also of interest to know how large an area is continuously covered with poison during a certain time period. From fig. 4-13 it is possible to estimate the areas covered with a poison concentration of 1 ppm or 10 ppm for more than 45-55 hours. Such estimations have been carried out for both the outlet during 2 hours and the outlet during 192 hours. The areas are shown in fig. 14-17.

With a large diffusion coefficient large areas are covered with a concentration of 1 ppm while relatively small areas are covered with a concentration of 10 ppm. (In the case of outlet during 2 hours, $A = 2 \cdot 10^5$, no area is covered with 10 ppm during 45-55 hours.) If one assumes the small diffusion coefficient, smaller areas are covered with a concentration of 1 ppm but relatively large areas with high concentration. Parts of the areas are outside the model and it is therefore only possible to roughly estimate the actual areas covered with a certain concentration. The sizes of the areas given in fig. 14-19 represent the area in the model. There is an equal area in the mirror image. We have also given (in fig. 20) a picture of the time dependent poison concentrations at five evenly spaced places at the coast. The figure represents the case with an outlet during 2 hours. Point 1 is situated in the lefthand corner of the modelled region, point 5 at the right-hand corner. Point 3 is situated at the cape. (The location of the five points is given in fig. 1b.) A much higher concentration at the coast results if one assumes the lower mixing rate. It is also demonstrated that the poison reaches the cape before it reaches the part of the coast which is closest to the ship.

This model is a first attempt to describe poison concentrations due to outlet of toxic matter off the Swedish coast. There has up to now been no time for verification. The modelled coast has a very simple shape and the bottom configuration has not been taken into account. Further no current driving elements such as fresh water inflow, heating and wind stress have been incorporated in the model. The concentration figures given above must therefore be looked upon as an attempt to estimate the order of magnitude rather than the correct concentration value for a certain coastal area. Further work and verification studies are proposed to be carried out in order to investigate the reliability of a model of this type.

REFERENCES

Dietrich & Kalle (1957), Allgemeine Meereskunde.

Gary (1969), NCAR Manuscript No. 69-54, The numerical solution of partial differential equations.

Proudman (1953), Dynamical Oceanography.

Wilmot (to be published), Numerical calculation of the gravitational circulation of the Baltic.

The poison concentration in the model is calculated from the equation

$$\frac{\partial c}{\partial t} + \frac{\partial}{\partial x}(uc) + \frac{\partial}{\partial y}(vc) = A\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2}\right) \qquad (1)$$

x = coordinates parallel to the coast
y = coordinates perpendicular to the coast
u, v = velocities in x and y directions
c = concentration
A = horizontal diffusion coefficient.

The boundary conditions are: At the coast and at the two boundaries perpendicular to the coast:

$$\frac{\partial c}{\partial n} = 0 \qquad n = \text{normal direction.}$$

At the outer boundary:

$c = 0.$

At one gridpoint of the left boundary:

c = source concentration.

Eq. (1) is solved as a finite difference equation in which

1. The time change, $\frac{\partial c}{\partial t}$, is represented by a leap frog scheme $\frac{c^{n+1} - c^{n-1}}{2\Delta t}$

2. The advective terms, $\frac{\partial}{\partial x}(uc)$, $\frac{\partial}{\partial y}(vc)$, are written in the flux form so that the mean and variance are conserved; e.g.

$$\frac{\partial}{\partial x}(uc) \approx \frac{\frac{(c_{i+1} + c_i)}{2} u_{i+1/2} - \frac{(c_{i-1} + c_i)}{2} u_{i-1/2}}{\Delta x^2}.$$

The advective terms are given on the n time level.

3. The diffusion is written in the Dufort-Frankel explicit form:

$$A \cdot \frac{\partial^2 c}{\partial x^2} \approx \frac{A}{\Delta x^2}\left(c_{i+1}^{n} - c_i^{n+1} - c_i^{n-1} + c_{i-1}^{n}\right).$$

From these expressions an explicit relation is obtained for c^{n+1} as a function of c^n, c^{n-1}.

This equation is solved on a computer.

Without any friction at the coast or horizontal density gradients the system is not creating any vorticity. If no vorticity is advected into the region and if the vorticity initially is zero the current field is the solution of the equation

$$\eta = 0$$

where $\eta = -\left(\frac{\partial u}{\partial y} - \frac{\partial v}{\partial x}\right)$ = vorticity component in the vertical.

Define a stream function ψ

$$u = -\frac{\partial \psi}{\partial y}\ ; \quad v = \frac{\partial \psi}{\partial x}$$

$$\eta = \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial x^2} = 0.$$

This equation is solved by an over relaxation once since the field is unchanged in time. The boundary conditions for the stream function are: $\psi = 0$ at the coast and at the boundary where the ship is located. At the outer boundary ψ increases linearly and at the right boundary perpendicular to the coast ψ decreases again to 0.

The resulting current field is shown in fig. 3.

The equations in the model are nondimensionalized so that each run represents a family of solutions. The independent parameters are reduced to only two:

ε = ratio of diffusion to advection = advective timescale/diffusive timescale
δ = aspect ratio of the two mixing components.

A run with $\varepsilon = 1$, for example, represents

$$1 = \varepsilon = \frac{A}{H \cdot v} = \frac{10^4}{10^4 \cdot 1} = \frac{10^5}{10^4 \cdot 10} = \frac{10^5}{10^5 \cdot 1} = \frac{10^6}{10^5 \cdot 10}$$

A = horizontal diffusion coefficient in y direction
H = length scale in y direction
v = velocity in y direction.

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Fig. 1a, 1b, 2

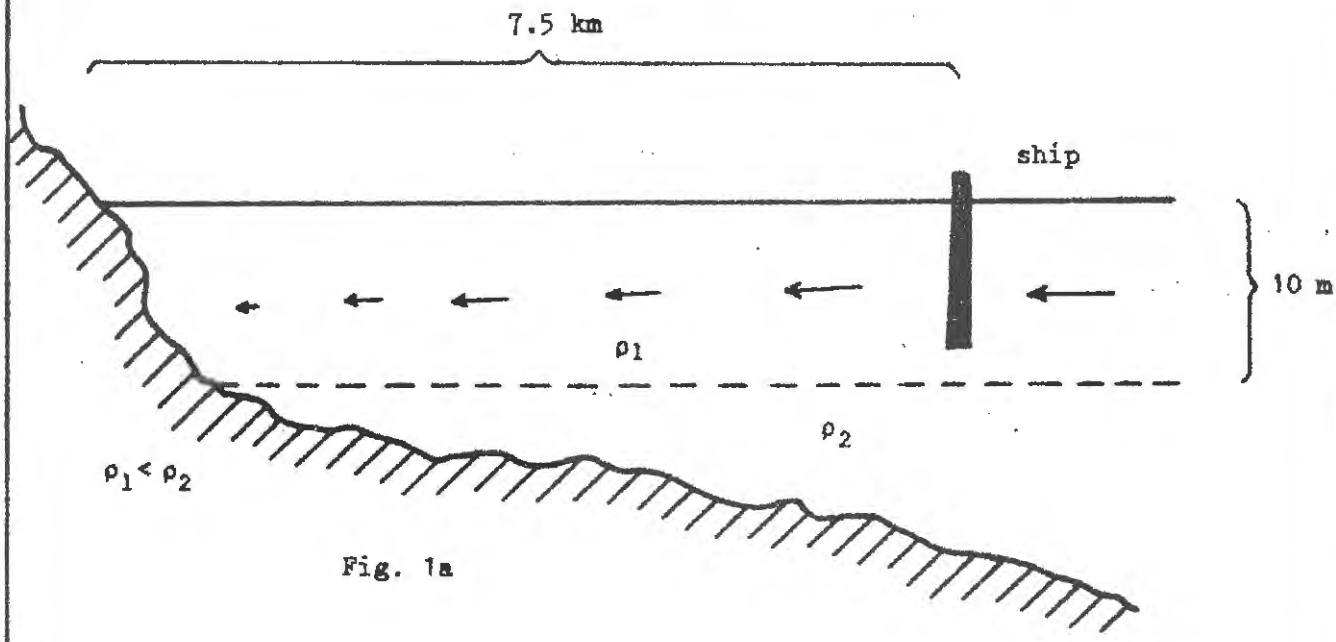


Fig. 1a

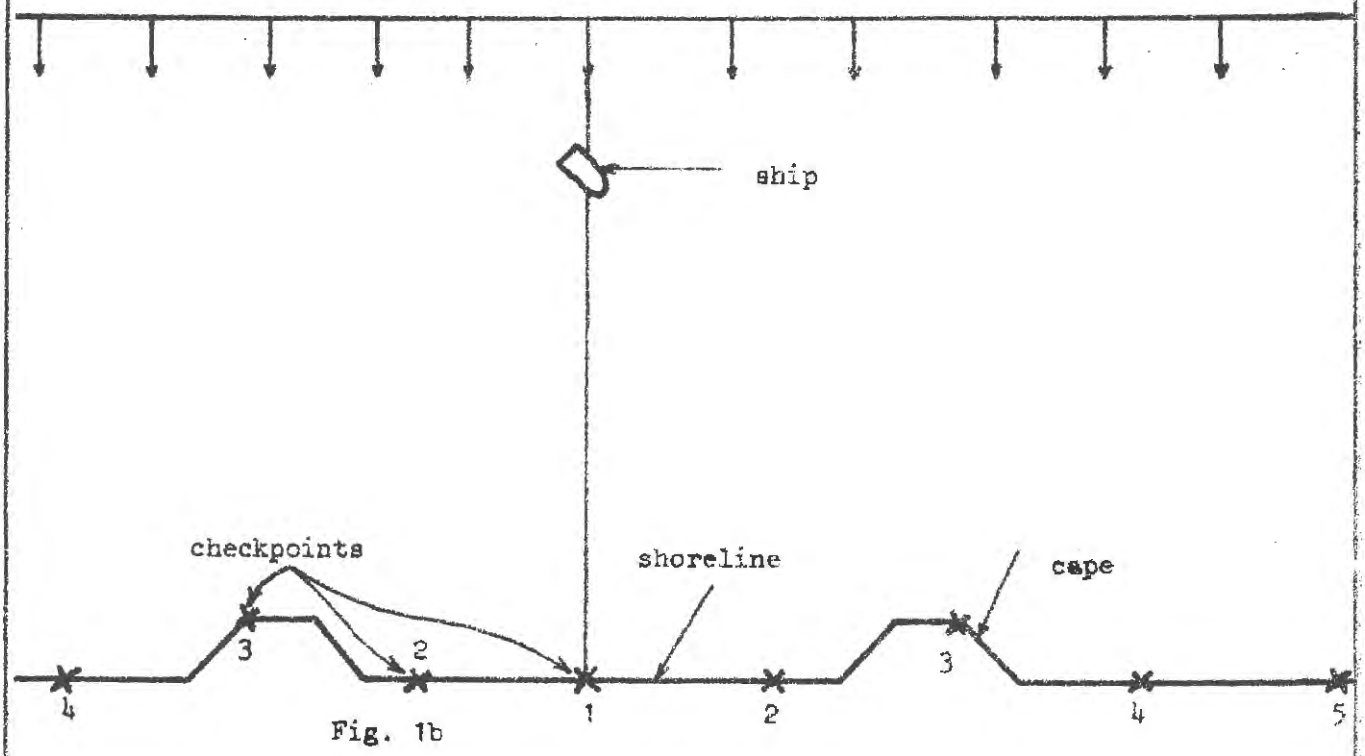


Fig. 1b

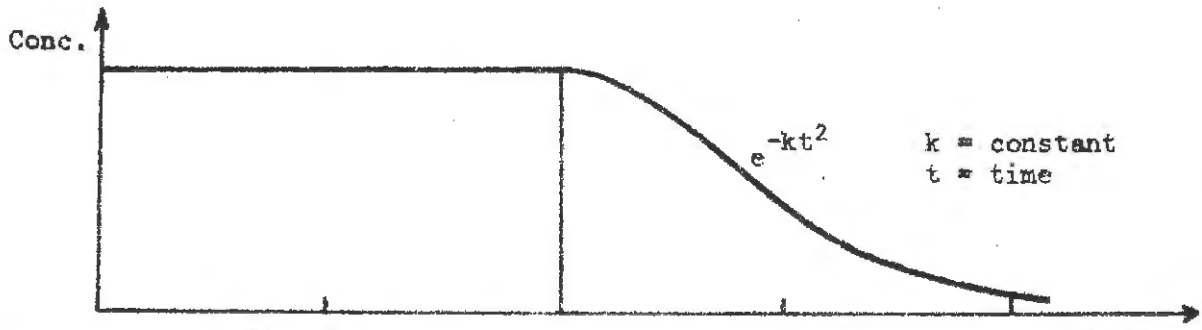
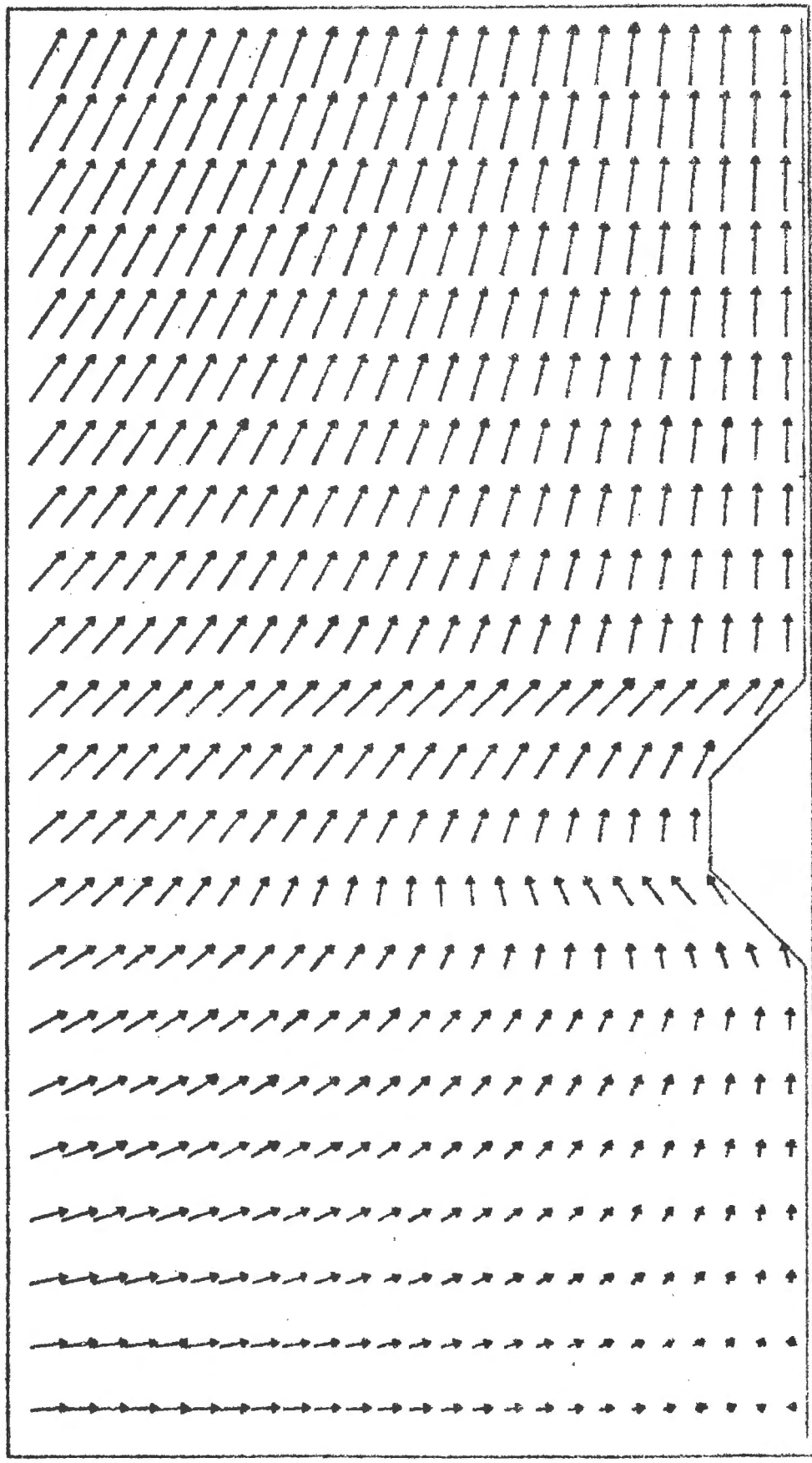


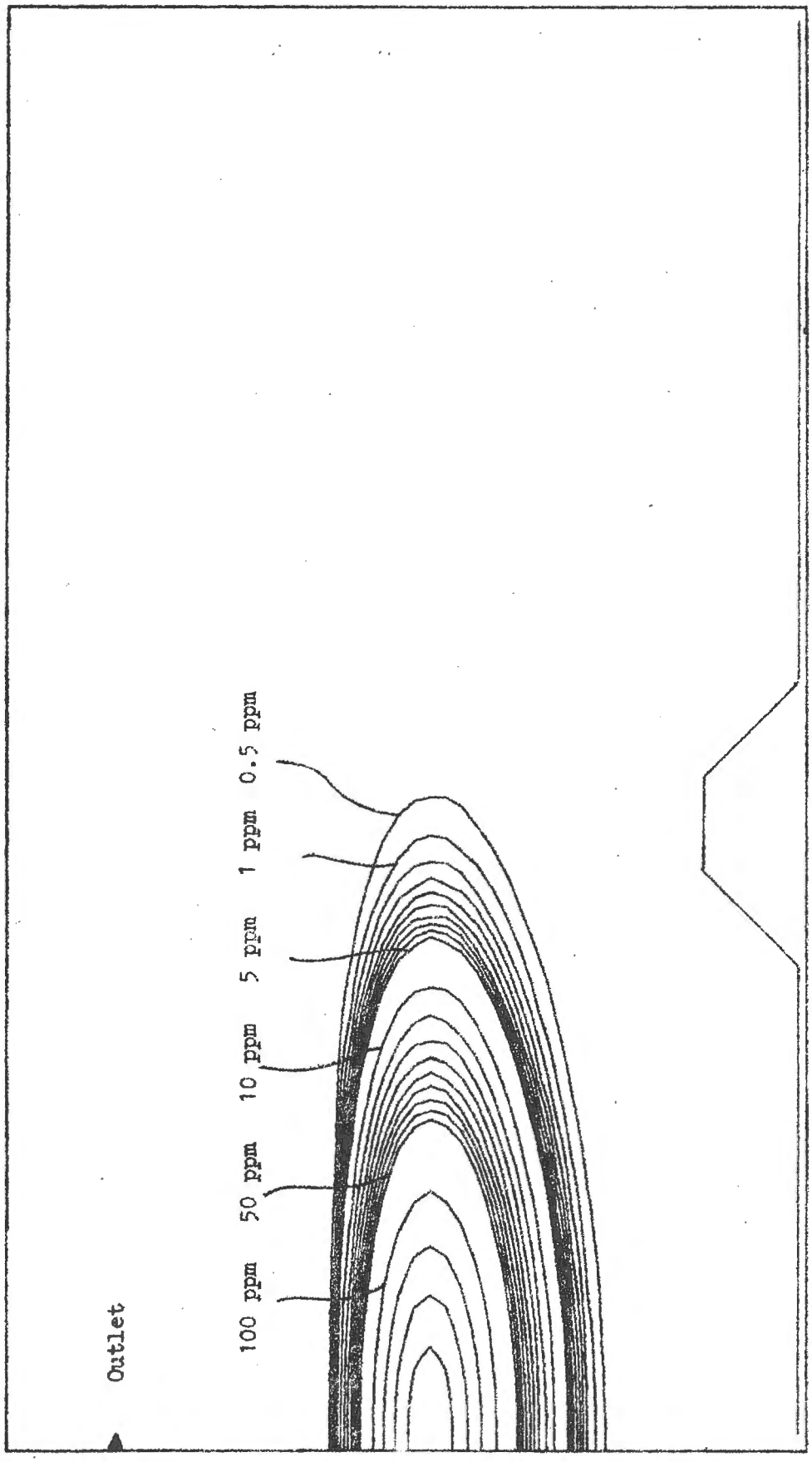
Fig. 2

SMHI HBO	Current field. The current at the outer boundary is directed towards the shore and has a velocity of 10 cm/s	Fig. 3



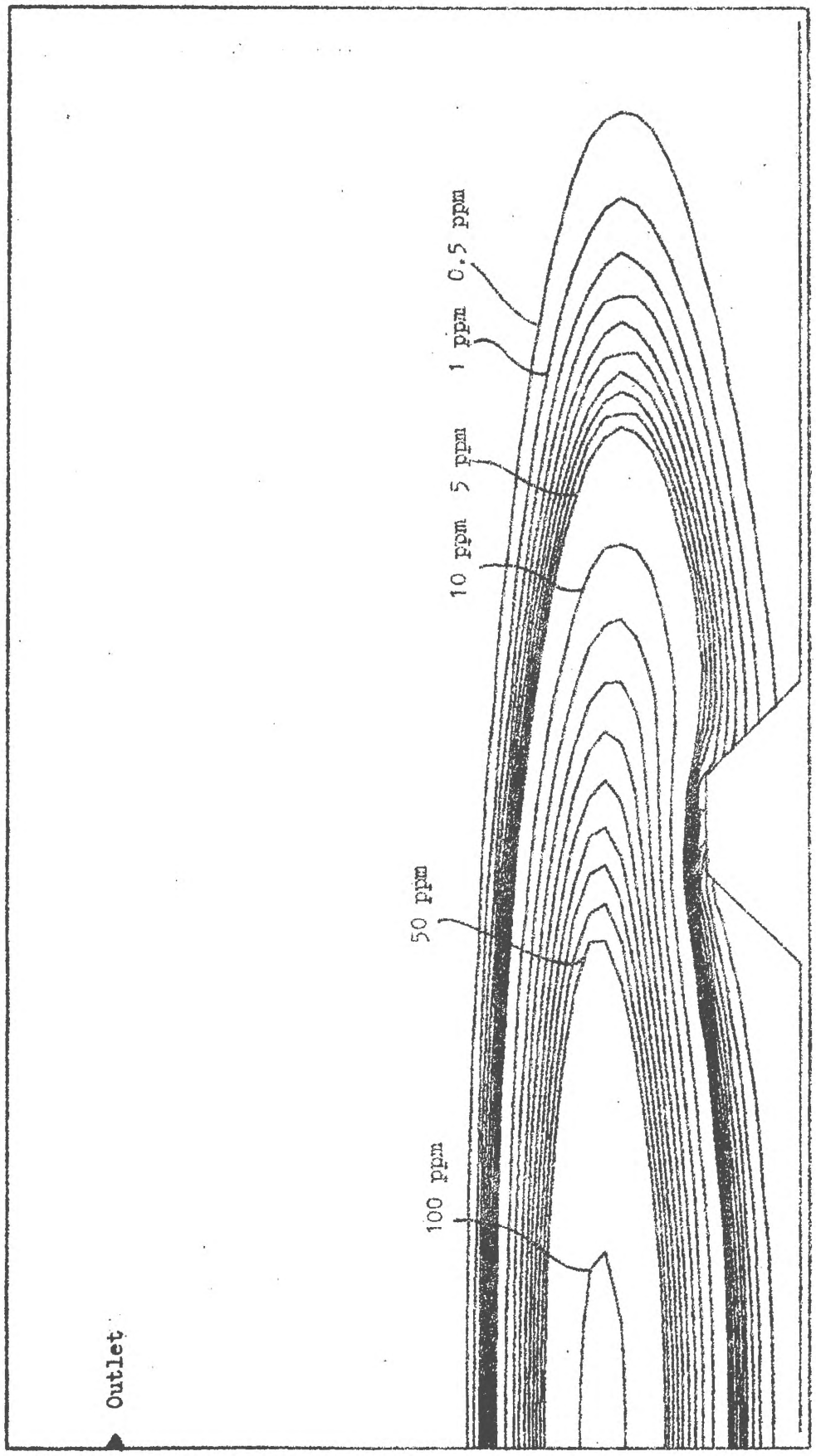
SMHI HBO	Calculated poison field. Outlet of 10,000 tons in 2 hrs Horizontal diff. coeff. $4 \cdot 10^4$	Fig. 4

time 18.8 hrs



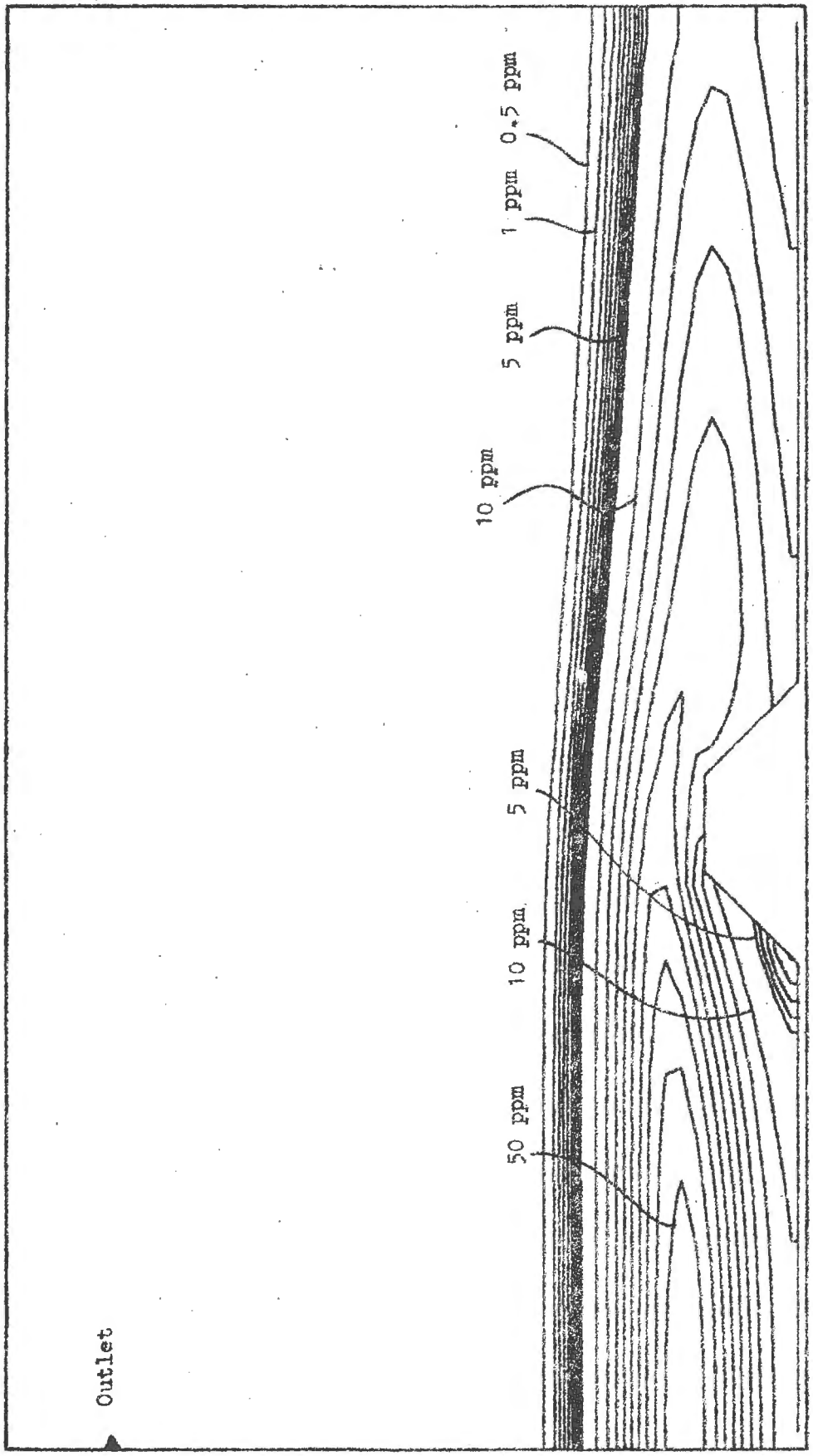
SMHI HBO	Calculated poison field. Outlet of 10,000 tons in 2 hrs. Horizontal diff. coeff. $4 \cdot 10^4$	Fig. 5

time 37.7 hrs



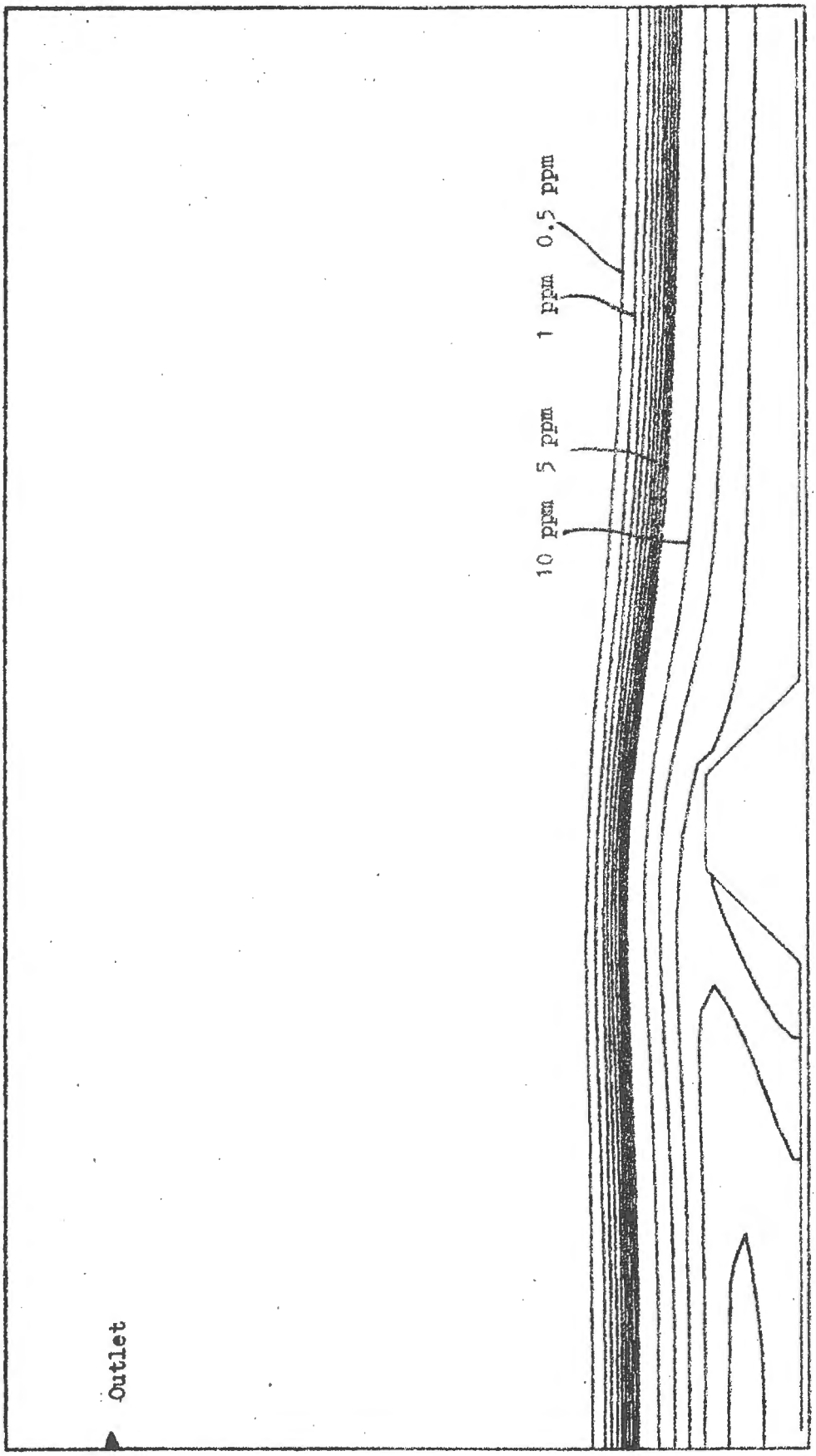
SMHI HBO	Calculated poison field. Outlet of 10,000 tons in 2 hrs. Horizontal diff. coeff. $4 \cdot 10^4$	Fig. 6

time 56.6 hrs



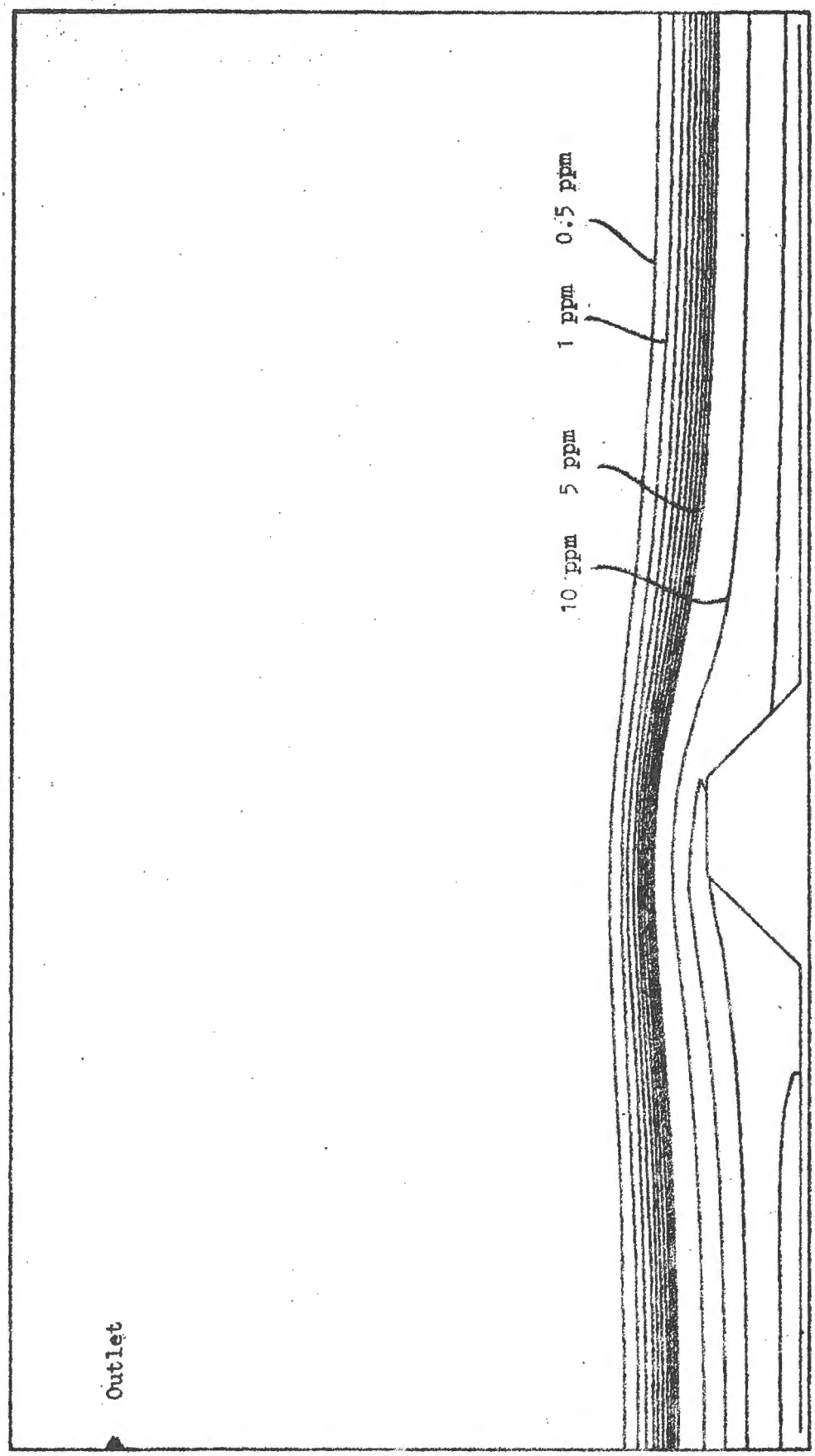
SMHI HBO	Calculated poison field. Outlet of 10,000 tons in 2 hrs. Horizontal diff. coeff. $4 \cdot 10^4$	Fig. 7

time 75.5 hrs



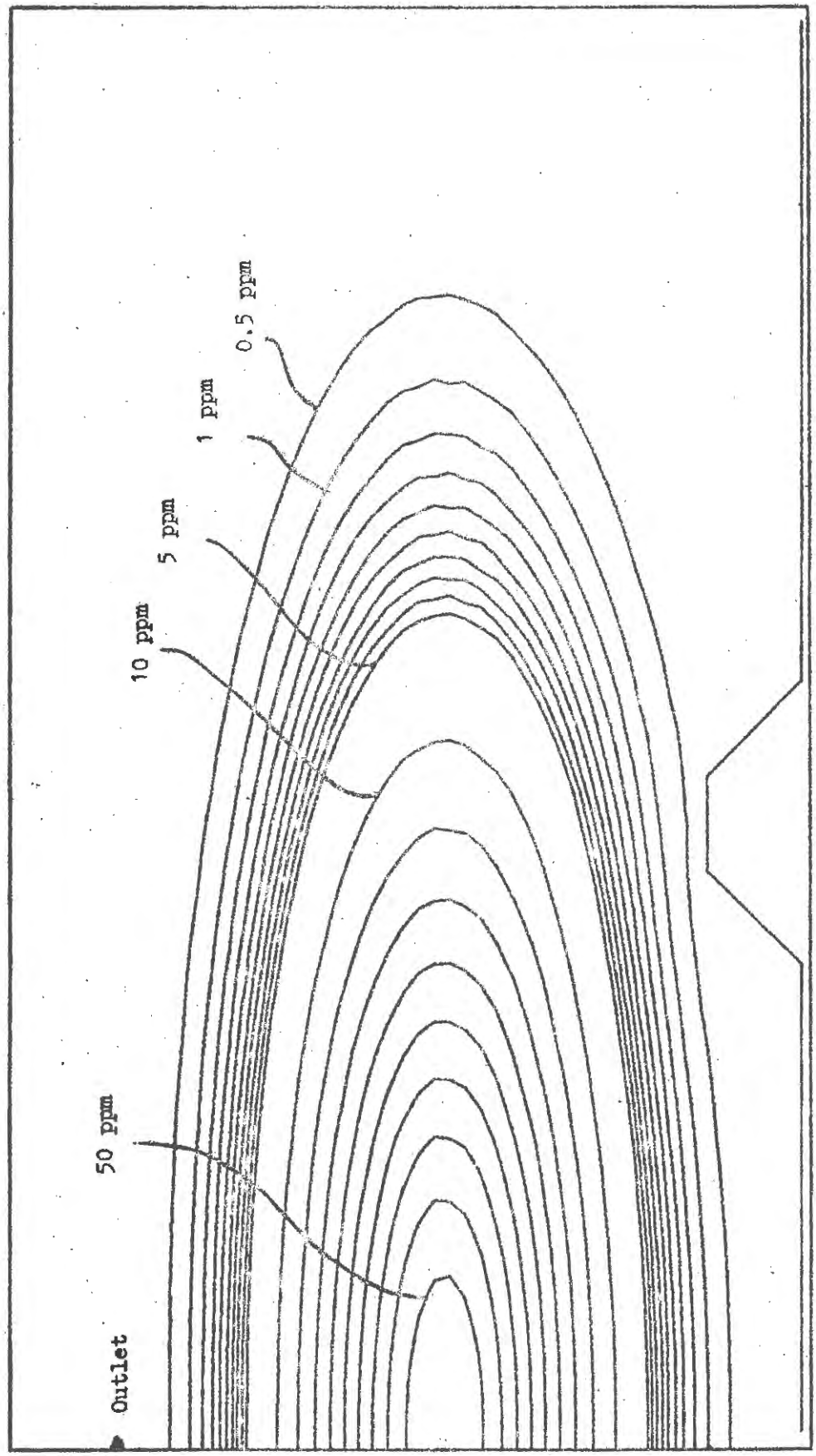
SMHI HBO	Calculated poison field. Outlet of 10,000 tons in 2 hrs. Horizontal diff. coeff. $4 \cdot 10^4$	Fig. 8

time 94.4 hrs



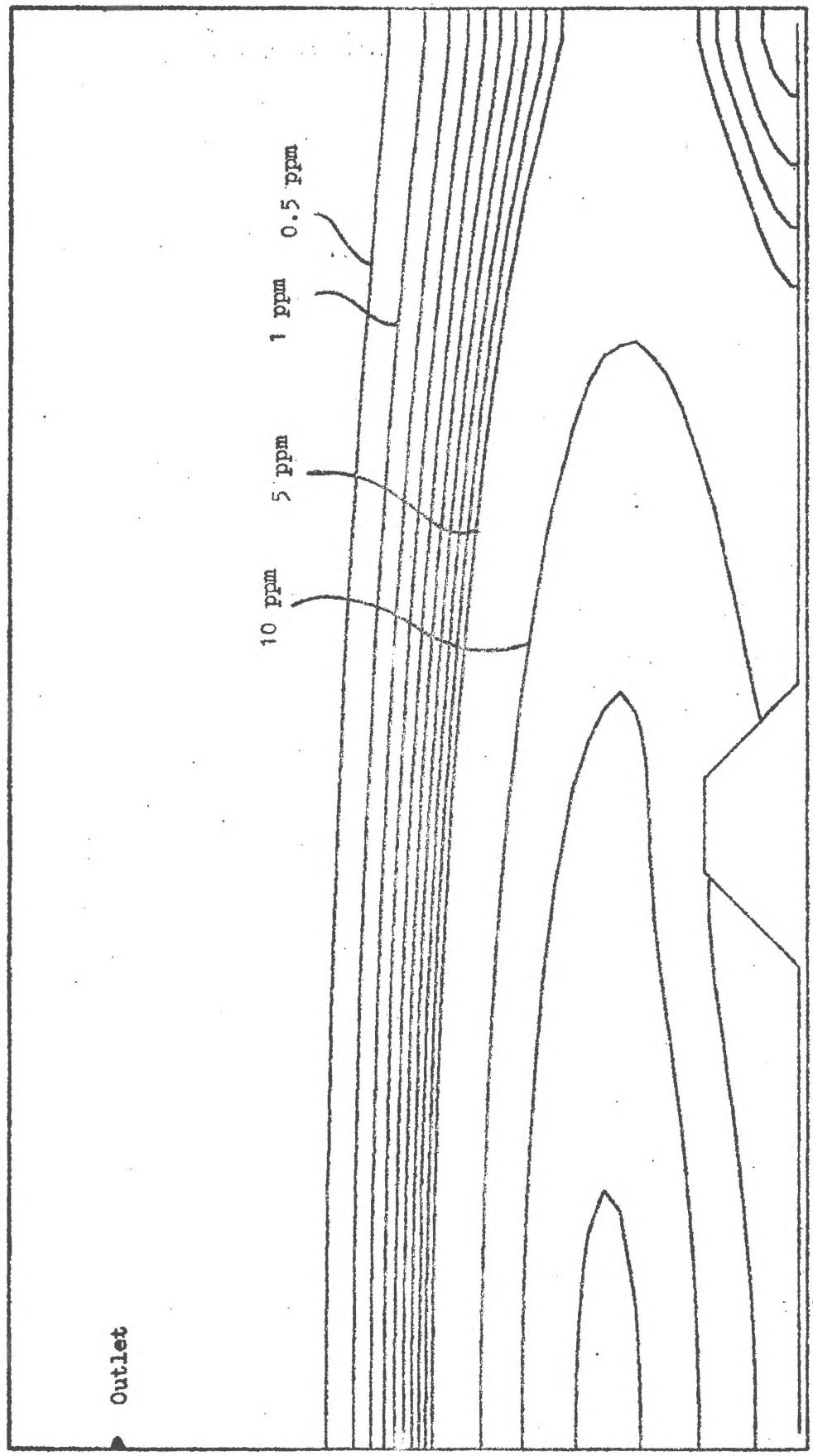
SMHI HBO	Calculated poison field. Outlet of 10,000 tons in 2 hrs. Horizontal diff. coeff. $2 \cdot 10^5$	Fig. 9

time 18.8 hrs



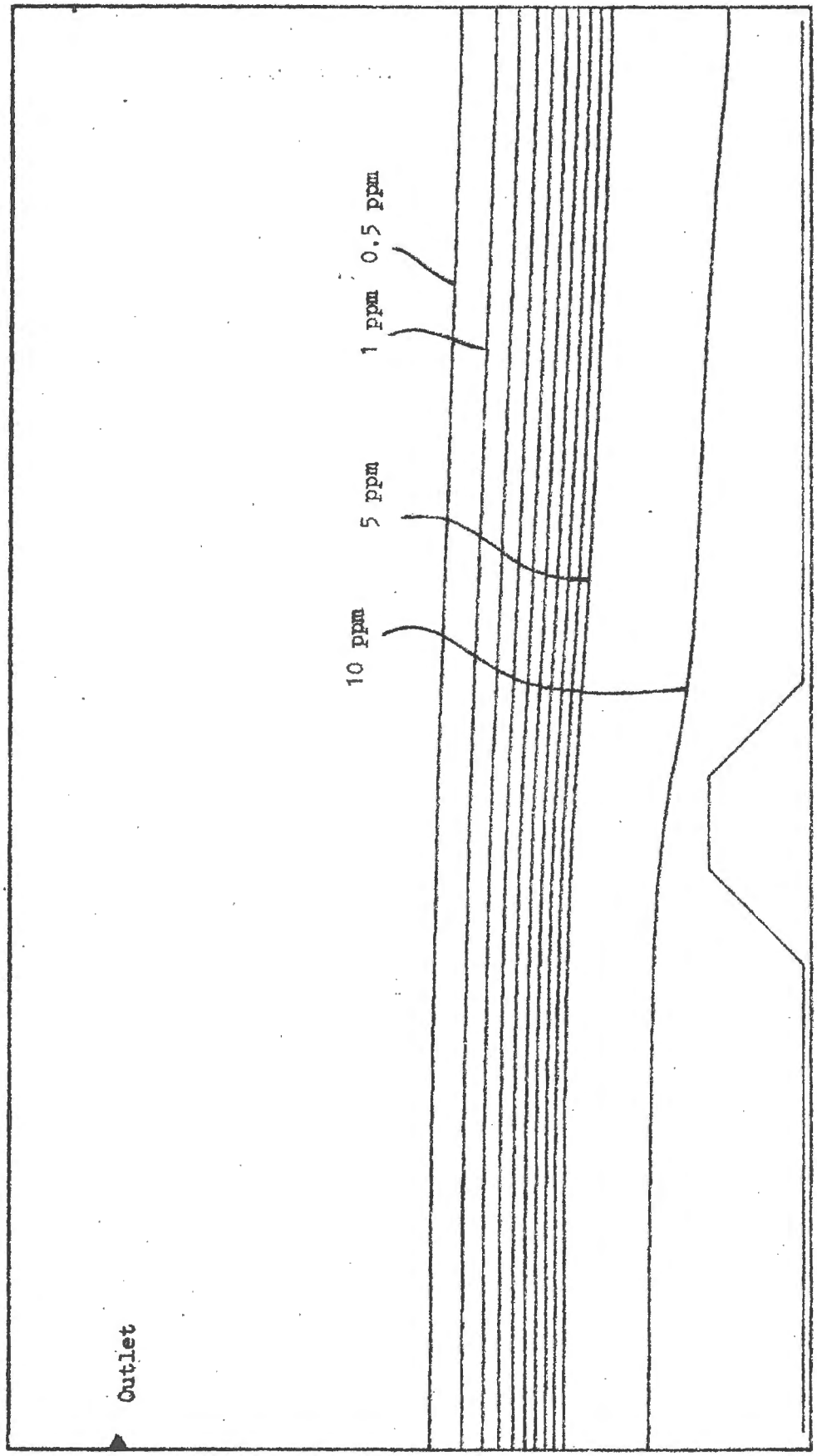
SMHI HBO	Calculated poison field. Outlet of 10,000 tons in 2 hrs. Horizontal diff. coeff. $2 \cdot 10^5$	Fig. 10

time 37.7 hrs



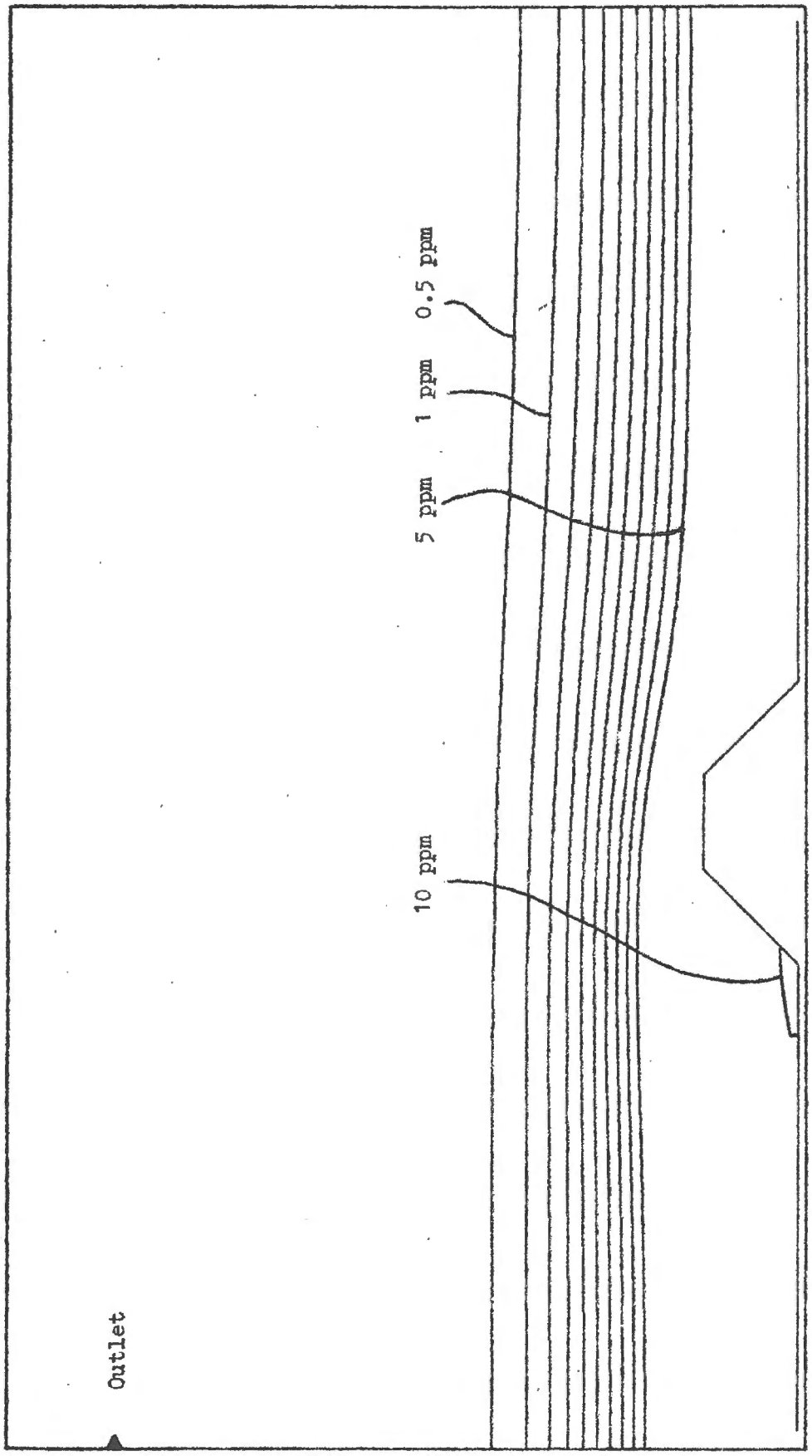
SMHI HBO	Calculated poison field. Outlet of 10,000 tons in 2 hrs. Horizontal diff. coeff. $2 \cdot 10^5$	Fig. 11

time 56.6 hrs



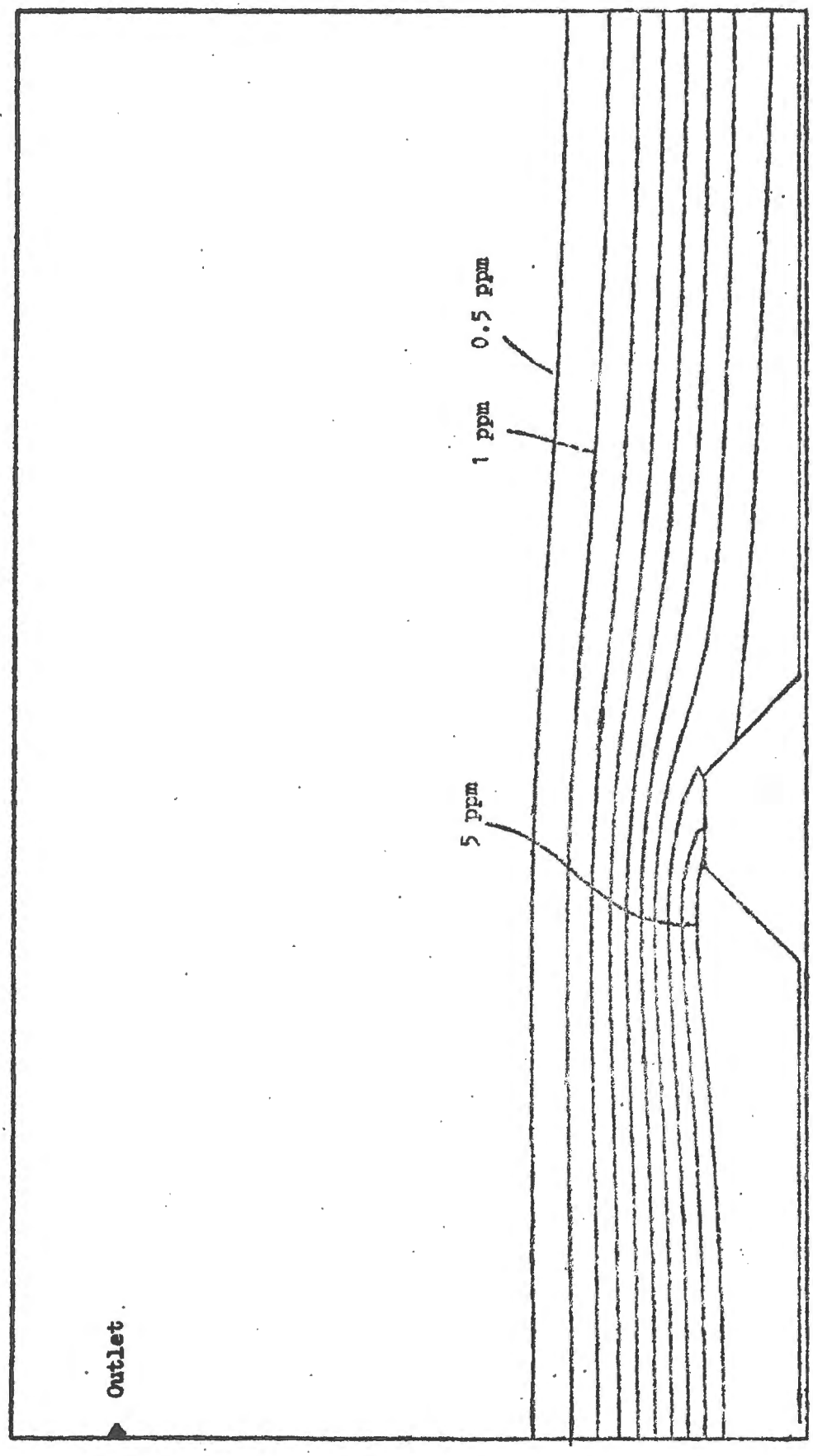
SMHI HBO	Calculated poison field. Outlet of 10,000 tons in 2 hrs. Horizontal diff. coeff. $2 \cdot 10^5$	Fig. 12

time 75.5 hrs

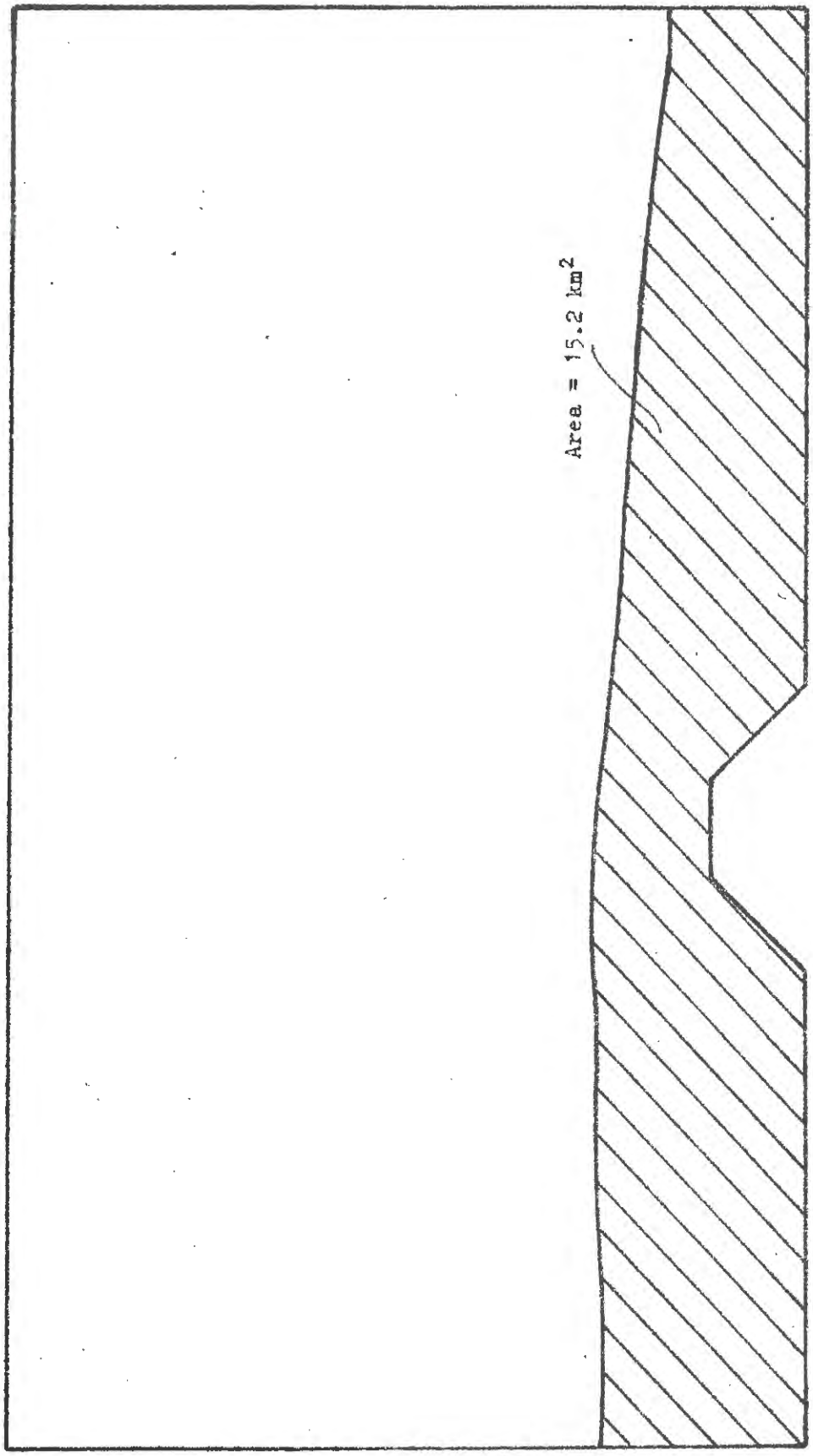


SMHI HBO	Calculated poison field. Outlet of 10,000 tons in 2 hrs. Horizontal diff. coeff. $2 \cdot 10^5$	Fig. 13

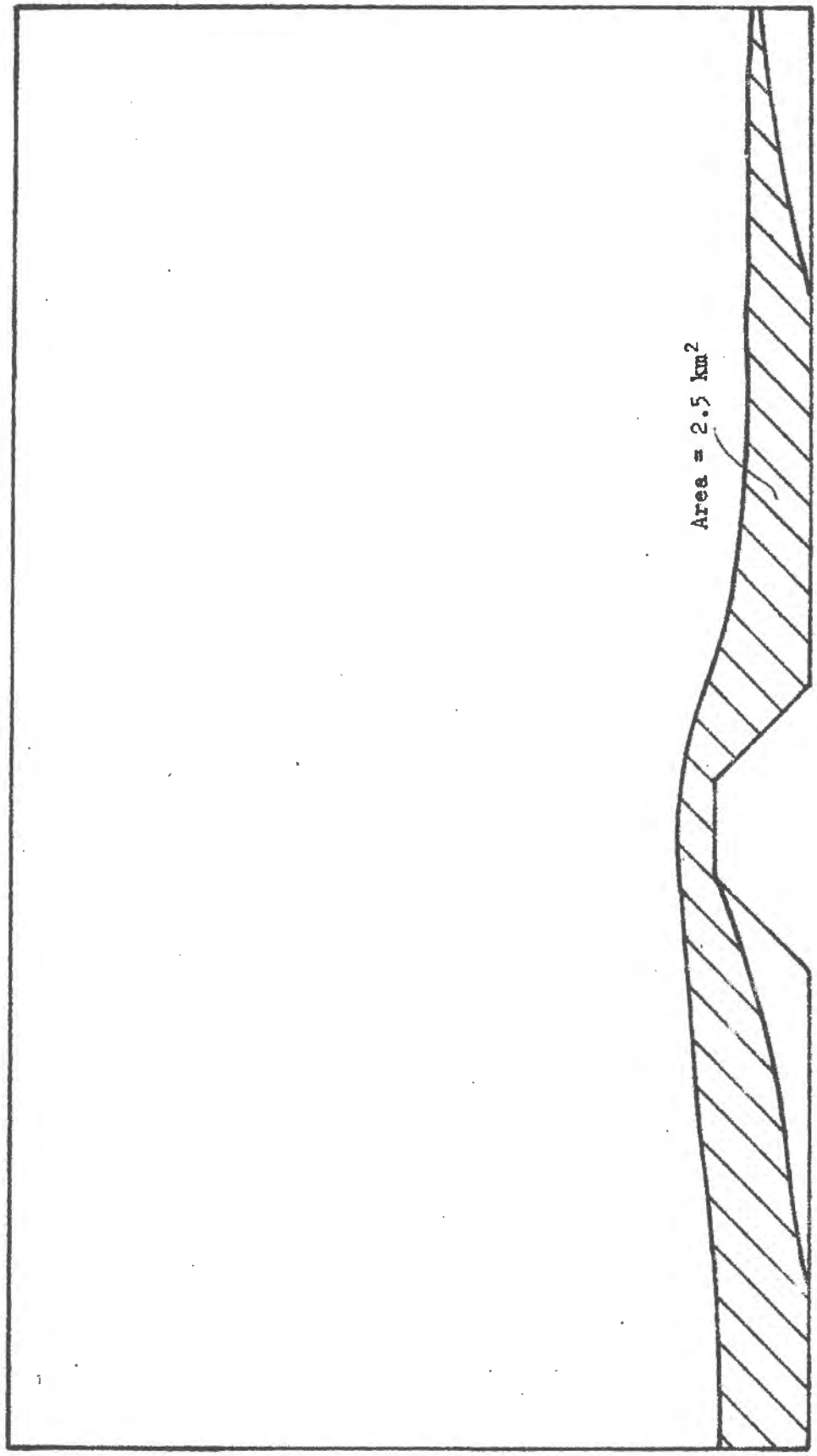
time 94.4 hrs



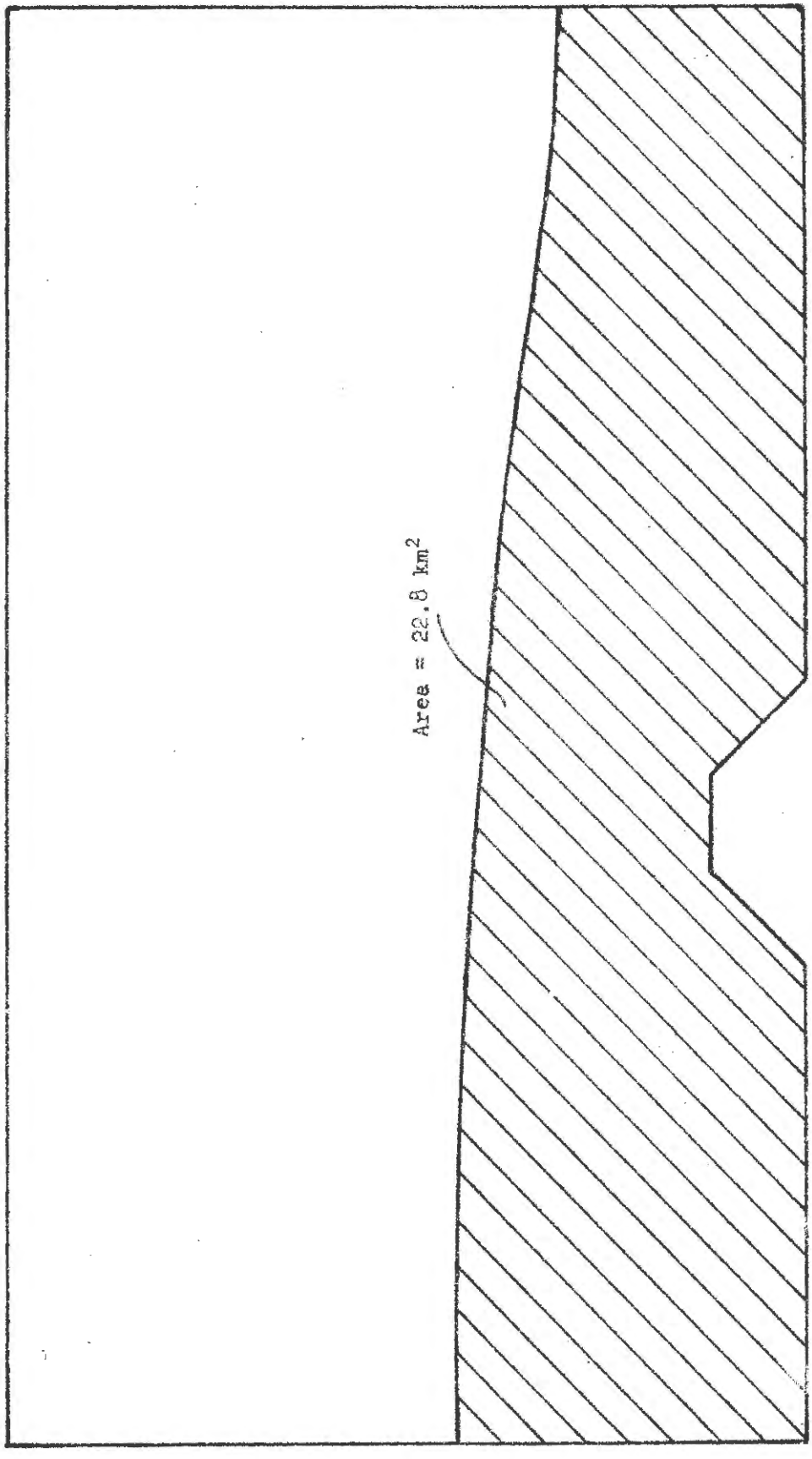
SMHI HBO	Area covered with 1 ppm or more during 45-55 hrs. Outlet of 10,000 tons during 2 hrs. Horizontal diff. coeff. $4 \cdot 10^4$	Fig. 14



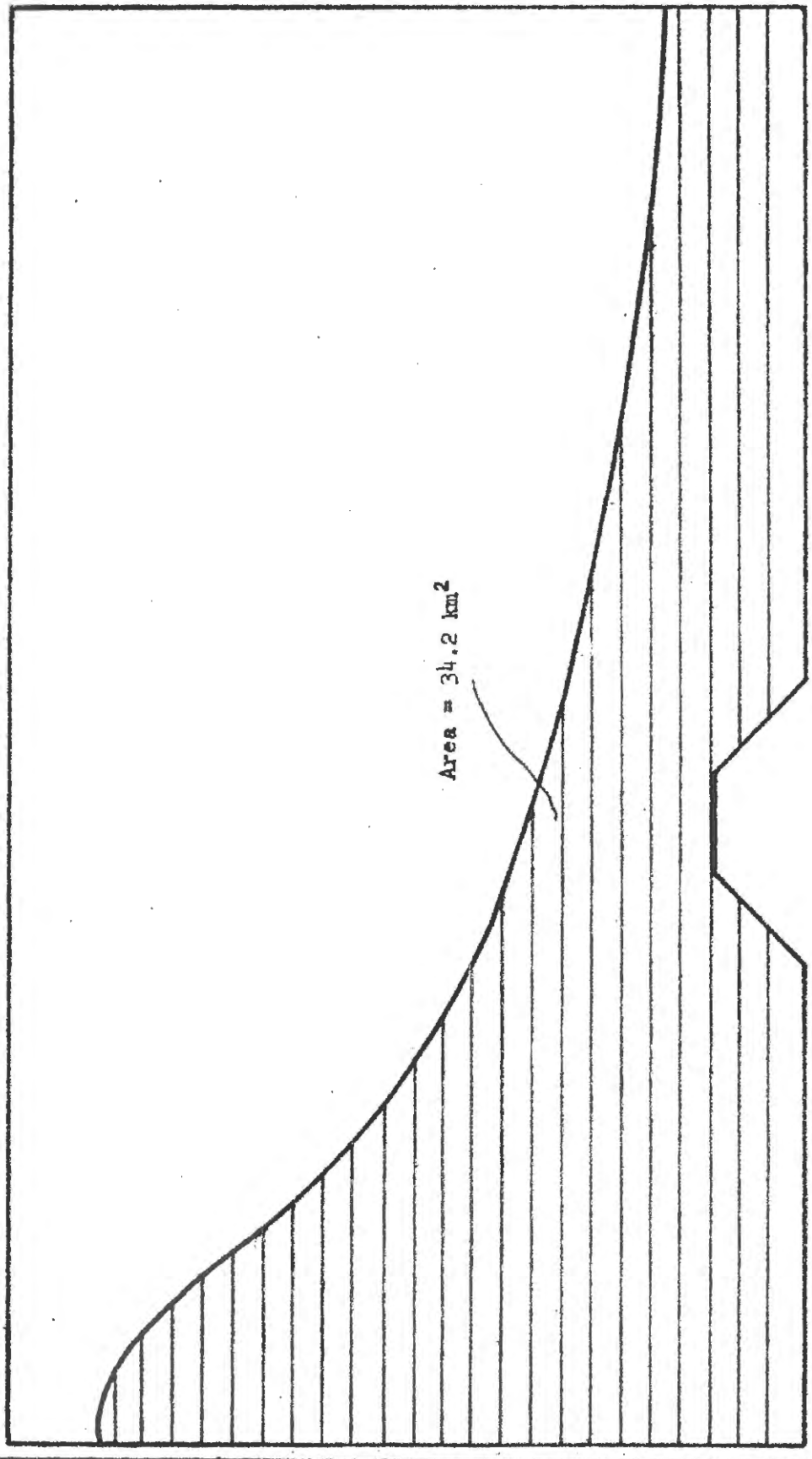
SMHI HBO	Area covered with 10 ppm or more during 45-55 hrs. Outlet of 10,000 tons during 2 hrs. Horizontal diff. coeff. $4 \cdot 10^4$	Fig. 15



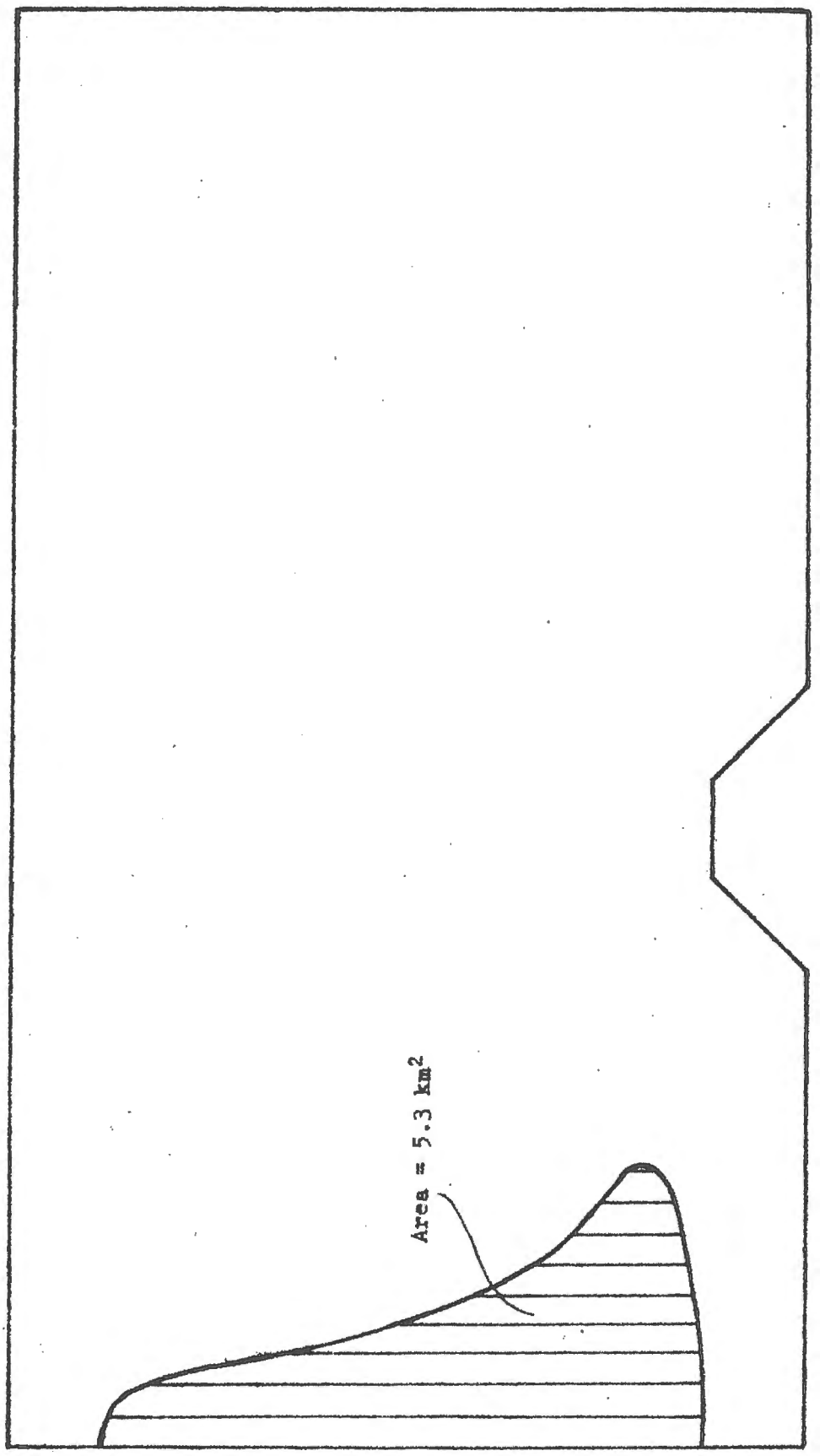
SMHI HBO	Area covered with 1 ppm or more during 45-55 hrs. Outlet of 10,000 tons during 2 hrs. Horizontal diff. coeff. $2 \cdot 10^5$	Fig. 16



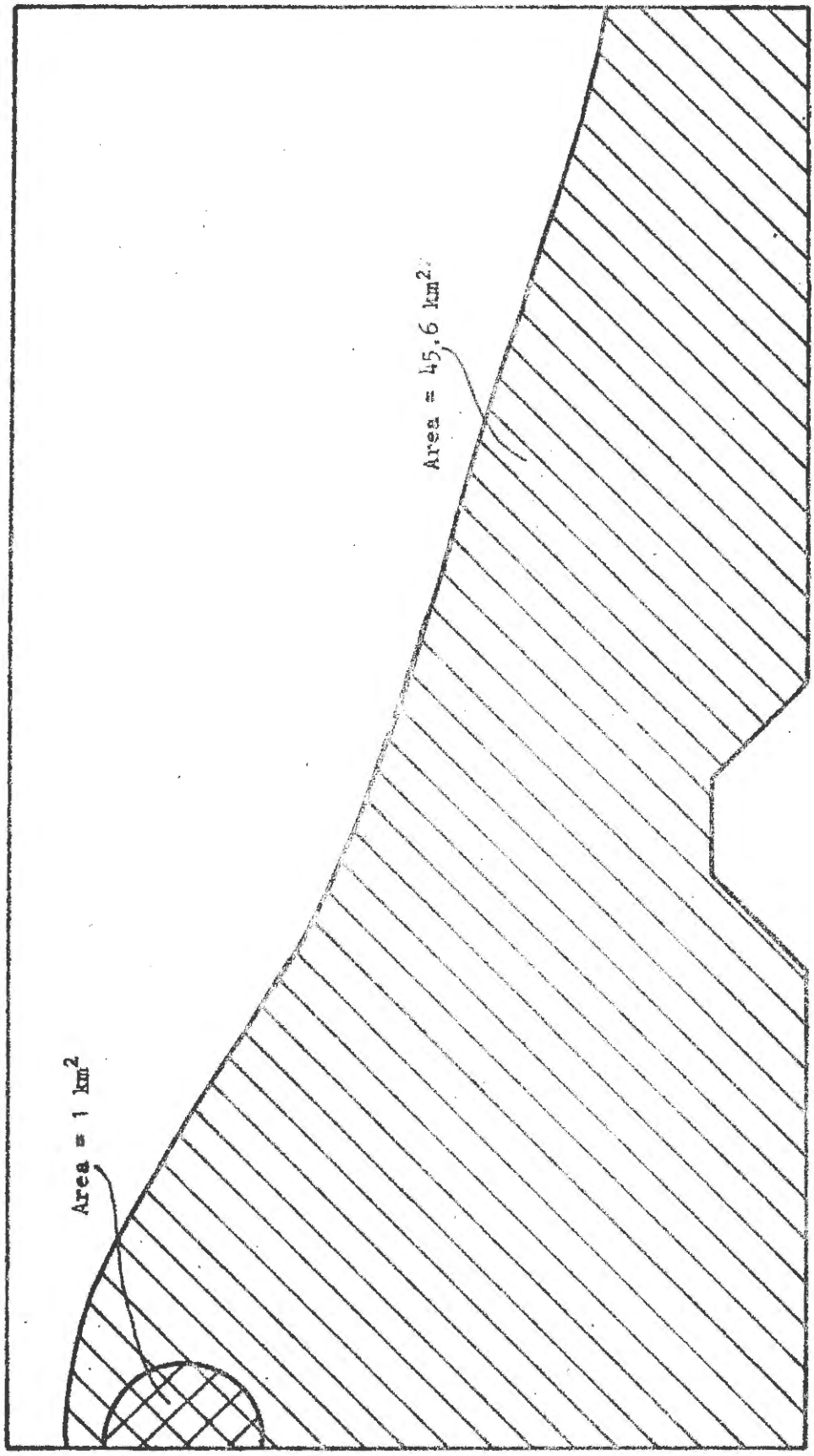
SMHI HBO	Area covered with 1 ppm or more during 45-55 hrs. Outlet of 10,000 tons during 192 hrs. Horizontal diff. coeff. $4 \cdot 10^4$	Fig. 17



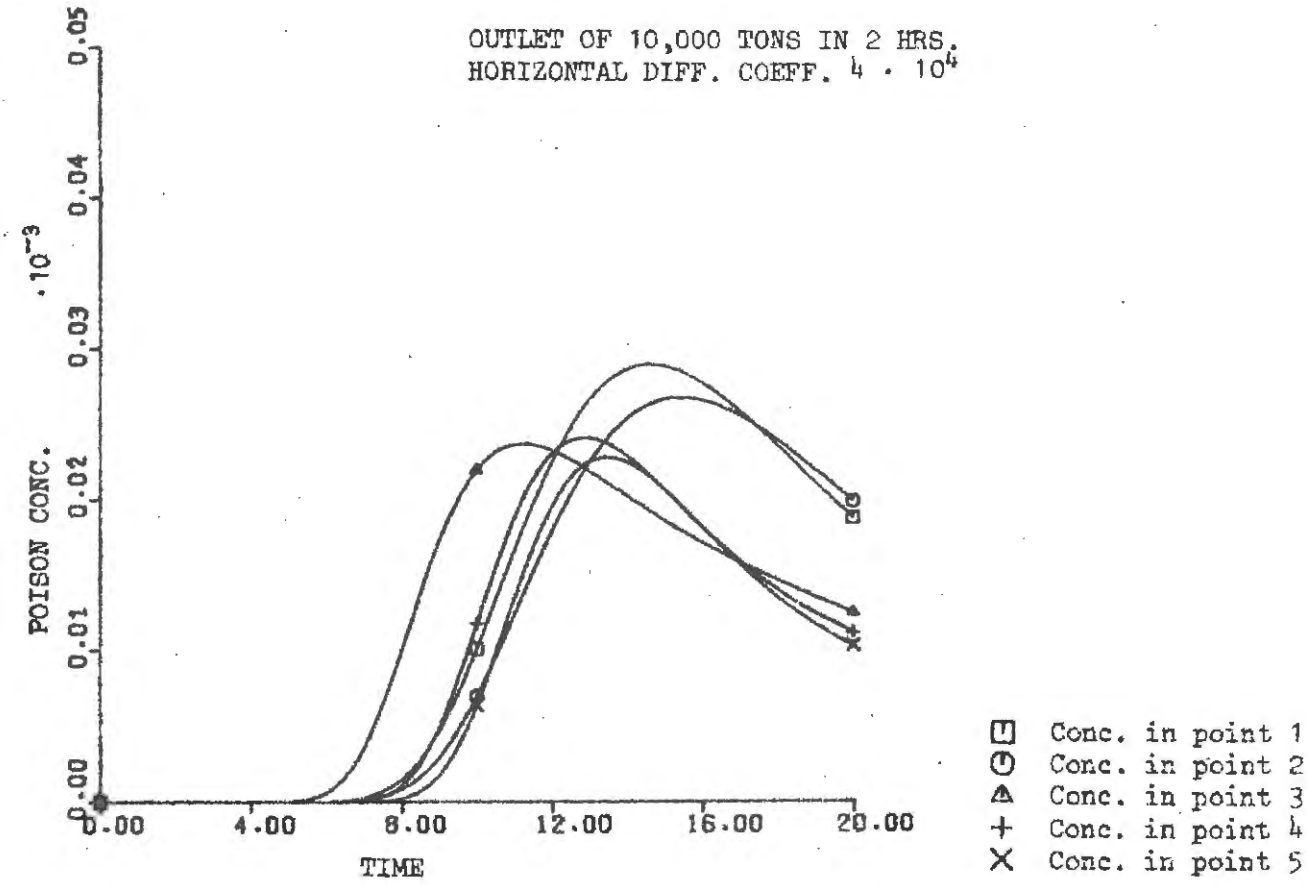
SMHI HBO	Area covered with 10 ppm or more during 45-55 hrs. Outlet of 10,000 tons during 192 hrs. Horizontal diff. coeff. $4 \cdot 10^4$	Fig. 18

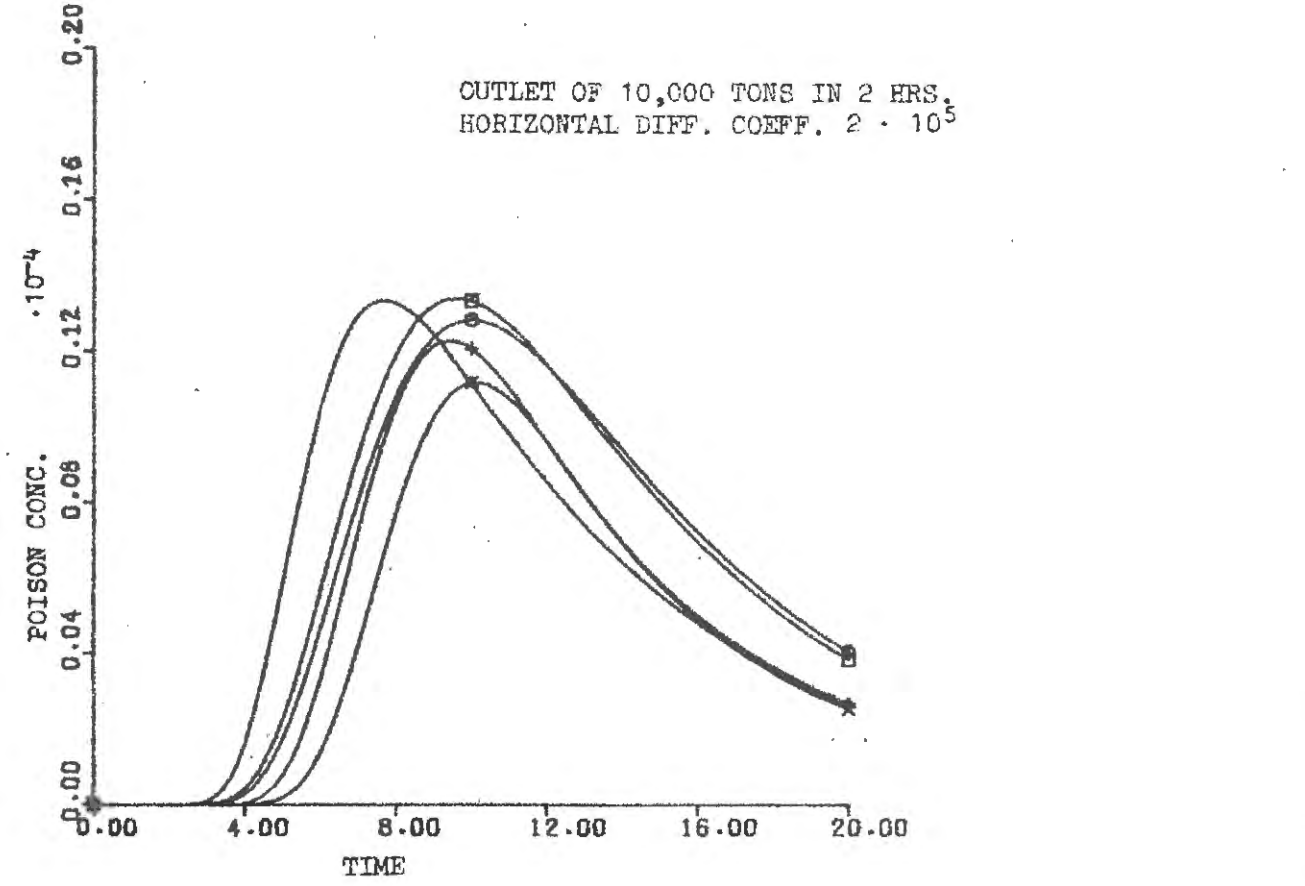


SMHI HBO	Area covered with 1 ppm (10 ppm) or more during 45-55 hrs. Outlet of 10,000 tons during 192 hrs. Horizontal diff. coeff. $2 \cdot 10^5$	Fig. 19



SMHI HBO	Poison concentration at the coast	Fig. 20





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