CHAPTER 137

FIELD AND MODEL DATA OF SPREADING IN ESTUARIES

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INTRODUCTION

The coastal regions in the highly industrialized zones of
western Europe and other comparable parts of the world are a
preferable field of new industrial settling. The economic
reasons are: 1. Situation on deep water reachable by big ves-
sels and 2. The increasing of the units of power plants and
chemical industries demands for great quantities of water.
For instance 200 up to 500 m^3/s are no longer utopic today.
Generally such great quantities are not available but in
coastal regions especially on estuaries where the water move-
ment is governed mainly by tidal action. Fig. 1 shows new
industries and power plants in the region of the German Bay
the shaded areas are consisting tidal models.

In order to avoid environmental damages by pollution of in-
dustrial or thermal wastes and to diminish the recirculation
effects of power plant, it is necessary to get correct in-
formation of the concentration rates resp. temperatures that
will appear in these regions.

The ways to get this information are well-known:
1. Direct measurements in prototype, 2. Mathematic models,
3. Hydraulic models or hybride models. Direct measurement
is to some degree a necessary presumption to the latter two
ways, but furthermore it afterwards gives information of the
accordance of the model predictions. But often there is no
money to do so.

Of course it is not necessary to measure the whole area -
that would mean model investigations scaled 1:1 - but some
specific data will be sufficient.

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Such comparisons could be made by the Bundesanstalt für Was-
serbau, Fed.Rep. of Germany, who carried out model investiga-
tions and field measurements in estuaries of the Elbe and
the Ems which belong to the well mixed types with a tidal
range of 2.5 up to 3.5 m.

RECIRCULATION EFFECTS

One subject of investigation was the recirculation of cool-
ing water. Fig. 2 shows the scheme of the thermal circuit;
during half a tidal cycle recirculation is nearly unavoid-
able. The temperature rise was in one case about $5^\circ C$, where
the heat output at the condenser was $\Delta T_o = 10^\circ C$. The re-
circulation rate $\varrho = \frac{\Delta T_i}{\Delta T_o}$ (ΔT_i is the temperature rise at
the intake after the first cycle) can be expressed as $\varrho = \frac{\varrho_\infty}{1+\varrho_\infty}$
where $\varrho_\infty = \frac{\Delta T_{i\infty}}{\Delta T_o}$ and $\Delta T_{i\infty}$ is the maximum possible tempe-
rature rise. For $\Delta T_{i\infty} = 5^\circ C$, $\varrho = 0,33$ results. This rela-
tion is derived from the geometrical progression $\varrho_\infty = \sum\limits_{n=1}^{\infty} \varrho^n$.

The recirculation rates can also be regarded as a mixing
factor. The temperature curves (Fig. 3) show two peaks
which appear just after and before slack tide respectively
when the longitudinal flow velocity in the ambient estuary
water approaches zero, and thus the lateral spreading be-
comes dominant. Without mixing there would be complete re-
circulation ($\varrho = 1$).

With the aid of model investigations it could be achieved
to diminish the recirculation rate of a power plant from
0.52 to 0.23 i.e. more than 50 %. The solution was a sheet-
piling of 30 m length beneath the outlet structure. The
situation of the inlet and outlet structures is shown in
Fig. 4, a bird's view picture of the power plant in model.
From left to right: inlet, outlet of the nuclear station;
inlet, outlet of the oil fired station.

In order to seperate the influence of one power plant to
the other, Rhodamine-B-Tracer was used. By this way the
influence of the indirect recirculation from earlier tidal
cycles could be eliminated too.

SPREADING MECHANISM

During the slack tide, a remarkably large lateral spreading
can be observed which apparently is caused by larger ini-
tial jet spreading. Therefore the plume of the pollutant
shows a special shape which is depicted in Fig. 5. Fig. 6
demonstrates the enlargement of the plume at lower fluvial
velocities. But the lateral spreading in a free stream is
also substantially larger during the slack tide than in
times of a higher velocity, and originates from intensified
convective lateral transport, resulting from large volume
eddies. The interaction between convection and turbulent
diffusion largely governs the spreading process in the tidal
region.

MODEL INVESTIGATIONS

A good accordance between model and prototype presumes a
correct simultation of the velocity field as well as a fair-
ly good turbulent diffusion all over the tidal cycle.

The latter is only possible with a specific distortion,
where the depth scale has to be

$$\boxed{\lambda_2 = \lambda_1^{3/4}}$$

relation of distortion
for turbulent flow in the rough
region

λ_1 = length scale

This relation is derived, with the aid of dimensional ana-
lysis, from Kolmogoroff's equation (1), the turbulent dif-
fusion equation (2) and the roughness condition $\lambda_r = 1$
through the application of the Manning-Strickler formula (3)
valid for turbulent flow in the rough region (Reynolds'
Number Re > 1200).

(1) $E = c \cdot G^{1/3} \cdot \ell^{4/3}$ (Kolmogoroff)

E = diffusion coefficient

G = energy dissipation per unit
     mass

ℓ = characteristic length of eddies

c = a constant

(2) $\quad \frac{\partial c}{\partial t} + u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} = \frac{\partial}{\partial x} \partial \left(D_x \frac{\partial c}{\partial x} \right) + \frac{\partial}{\partial y} \partial \left(D_y \frac{\partial c}{\partial y} \right)$

(3) $\quad u = \frac{1}{n} R^{2/3} J^{1/2}$ $\qquad$ (Manning-Strickler)

The energy dissipation and the turbulent friction are in this region only dependent upon $\frac{h}{d}$ (h = roughness height), (d = depth), i.e. geometric parameters that are easily to simulate in the model. Models scaled 1:100 (depth) and 1:500 (length and width) fullfill this condition und have shown good results.

COMPARISON OF MODEL DATA WITH MEASUREMENT IN PROTOTYPE
Various field measurements were performed to verify model experiments on lateral spreading of the polluted plume. Fig. 7 shows the lateral distribution of the spreaded plume 1 1/2 hours before low water, 90 m below the outlet, 3 m under the surface (near field test). Temperatures as well as concentrations rates of Rhodamine were measured in prototype and model. To indicate Rhodamine concentration a Turner Fluorometer was used. The field results are almost identical with the model results. Comparisons between the spreading of a dye patch in prototype and model is shown by the graph on Fig. 8 (far field test). Fig. 9 depicts the dye patch of Rhodamine from an airplane.

The recording of time dependent temperature or concentration values has been shown to be advantageous for the estimation of the effect of an inflow (Fig. 10), since here maximum and minimum values are recorded. By this way it is possible to separate the influence from earlier tides. The oscillation is due to tidal action only and after 5 to 10 tidal periods there will be an equilibrium.

APPLICABILITY OF PHYSICAL MODELS
It can be confirmed by comparison between model and prototype data that it is possible to simulate not only the dispersion in the far field area where the mixing process is governed by free turbulent structures and the velocity

field of the stream but also the initial spreading of the
penetrating jet in the near field and the transition zone.
In this region it is necessary to record the width of the
polluted plume in the correct way at all tidal phases. This
is possible by using artificial roughness elements at the
outlet point.

In addition to the report of Dr. Schwarze (7.3.) one should
point out, that the distortion of the model is not only a
good thing in simulating thermal losses (thermal decay) but
besides it is a necessary presumption of recording the dis-
persion process in a physical model. The choice of scales
is not free but fixed to a specific relation.

The usage of the "characteristic length" in Kolmogoroff's
equation in passage 4 is only a mere thing of comparison
without knowing the real value of it. It is used only in
the dimensionless sense in the applicated analysis. In rea-
lity the "characteristic length" is equal to the diameter
of the largest eddies, which may fill the width of the
stream.

DECAY OF A POLLUTANT

Waste water, radioactive pollutants and cooling water are
subject to decay. This decay can't be simulated in the phy-
sical model if one is using a conservative tracer. But the-
re is a method to calculate this decay when getting the con-
centration rates due to the mere spreading process of tur-
bulent diffusion and convection from the model.
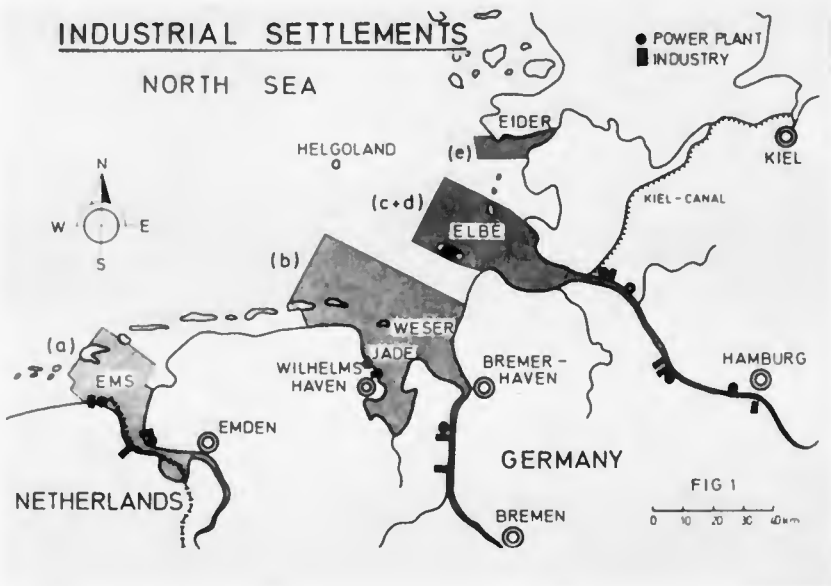
Furthermore, a decay curve has to be known (Fig. 11). Ac-
cording to the demonstrated figure a pollution only over a
one tide cycle is simulated. The occurring concentration
levels have to be reduced by multiplying them by the rate
of decay. An integration then gives the desired curve of a
non-conservative pollutant at the estimated point of the
estuary. The time increment of integration in this opera-
tion is just one tidal cycle.

CONCLUSIONS

Froudian tidal modelling besides two dimensional mathemati-
cal representation has proved to be a useful method to get
information about the concentration levels of pollutants
spreading into an area with tidal actions. The decay of
non-conservative pollutants can be evaluated by using a
decay curve. Distortion with scales of 1:500/1:100 and the
use of special artificial roughness elements seem to coun-
terbalance the effects of a differently turbulent diffusion
in vertical and horizontal directions which is predicted by
theory. The flow pattern in a model should be rough turbu-
lent.

REFERENCES

[1] CRICKMORE, 1972, Tracer tests of eddy diffusion in
        field and model, Proc. of the ASCE HY 10.

[2] OHLMEYER/VOLLMERS, 1973, Thermal and sewage pollution
        in tidal areas, Proc. of the 15th IAHR Congress,
        Vol. 2, Istanbul.


FIG 1

DIRECT   RECIRCULATION
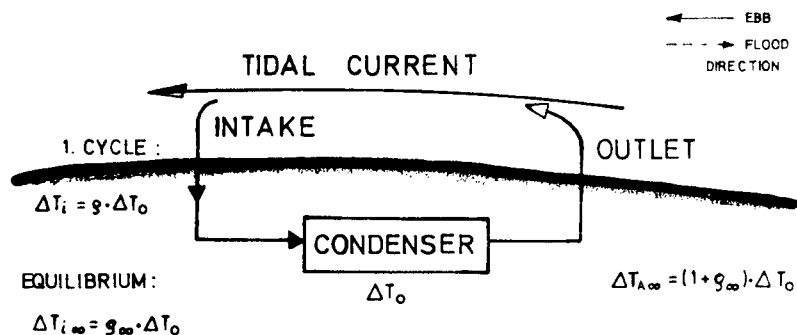
FIG. 2   THERMAL CIRCUIT OF A POWER PLANT
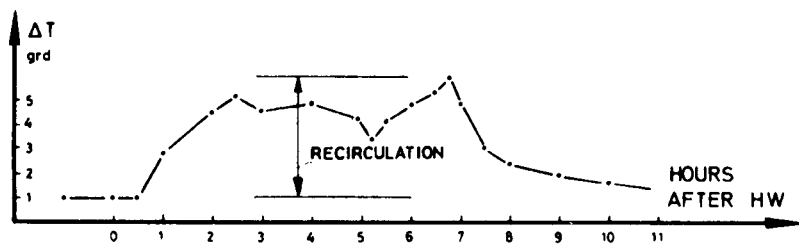
FIG. 3   INCREASING TEMPERATURES DURING EBB CURRENT
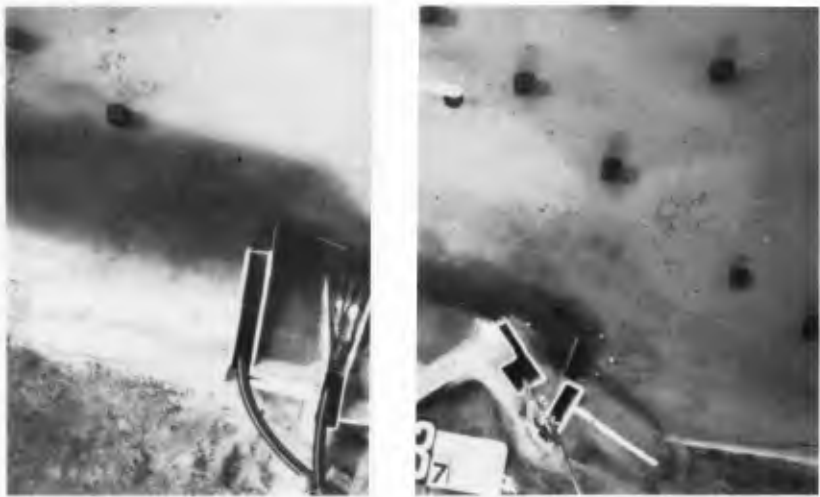
FIG. 4   THE POWER PLANTS   MODEL
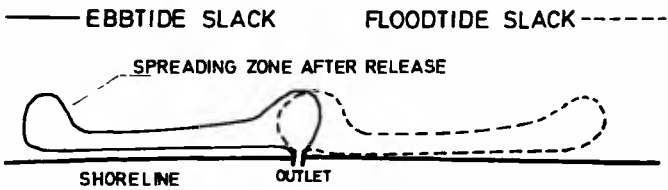
FIG. 5   THE SHAPE OF THE PLUME
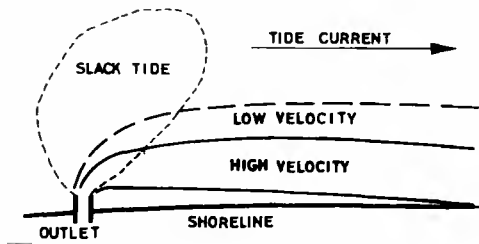
FIG. 6   THE PLUME AT VARIOUS TIDE PHASES
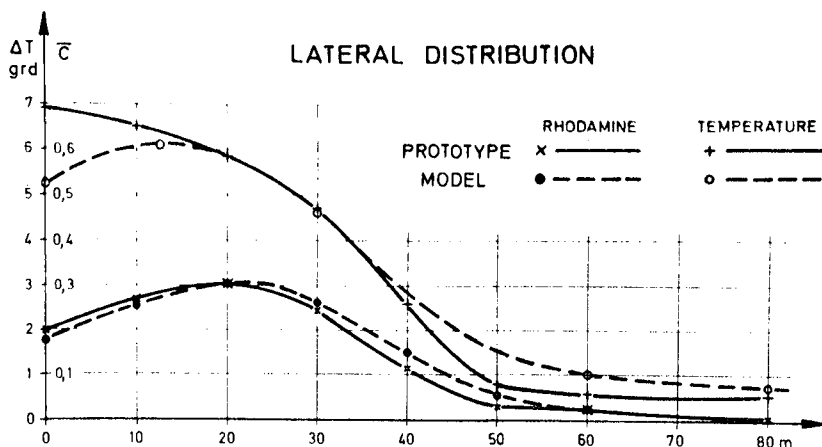
FIG. 7 LATERAL DISTRIBUTION CURVES 1 1/2 h BEFORE LW
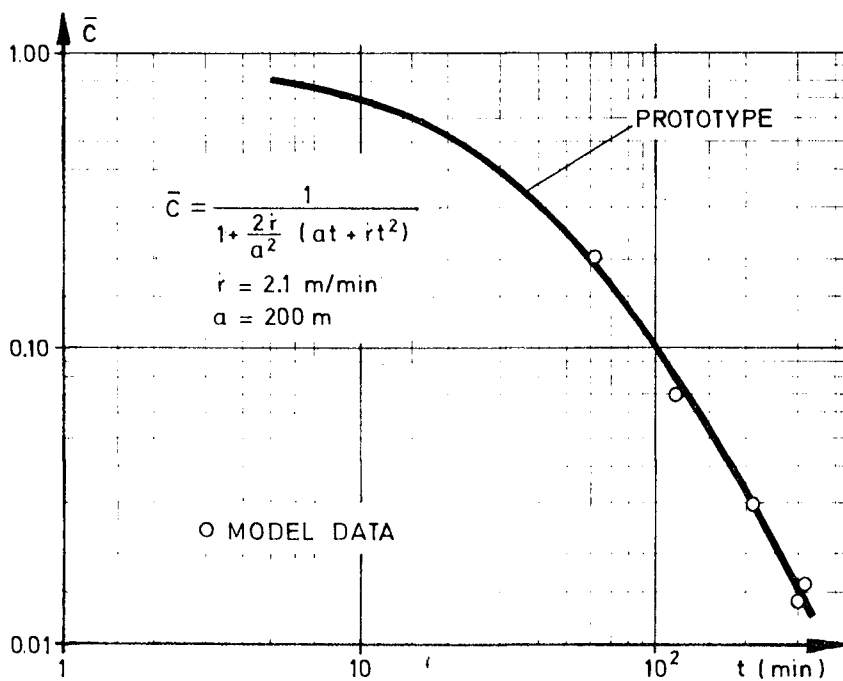
FIG. 8 DECREASING CONCENTRATION MAXIMUM OF A DYE PATCH IN PROTOTYPE AND MODEL

FIG. 9   THE DYE PATCH FROM 600 ft HIGHT
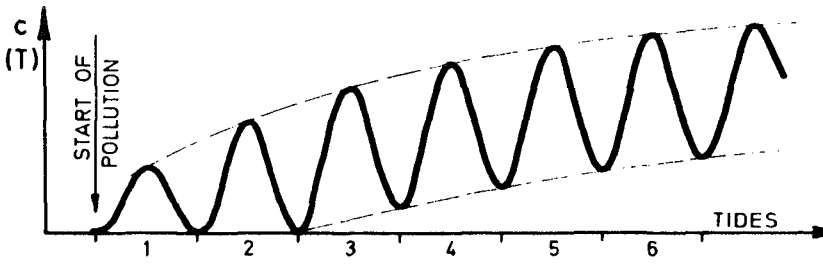
FIG. 10   INCREASING CONCENTRATION (OR TEMPERATURE) CURVE
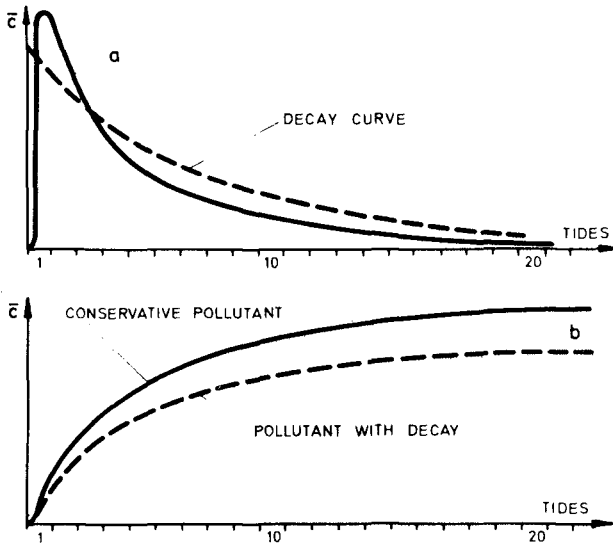
FIG. 11   CONCENTRATION CURVE WITH ONE TIDE CYCLE
          POLLUTION