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TRACER APPLICATION IN MARINE OUTFALL STUDIES

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ABSTRACT

~~Artificial tracers are very suitable~~ for field studies to predict or investigate waste water transport and dispersion from marine outfalls.

~~Based on the Danish Isotope Centres fifteen years of experience~~ The ~~feasibility~~ applicability of radioactive and fluorescent tracers ~~are~~ is evaluated. The application of either instantaneous or continuous tracer release, "in situ" detection of tracers and data processing are considered. The necessity of a combined use of tracer techniques and conventional hydrographic methods for a statistical prediction of transport and dilution of waste water are pointed out. A procedure to determine an outlet distance from the coast, which satisfy a bathing water criteria is outlined.

TRACER APPLICATION IN MARINE OUTFALL STUDIES

1. INTRODUCTION

The selection of an acceptable discharge location play an important role in sewerage planning for urban and industrial regions near coastal areas.

In situ simulation of transport and dispersion of the soluble fraction of waste water has been performed by release of artificial tracers. This has proven to be a valuable technique to predict pollution from planned outfalls. Tracer techniques can also be used in the study and control of discharges from existing outfalls.

The Danish Isotope Centre (DIC) has carried out some 400 predictive studies since the early sixties by use of radioactive tracers. Of these about 120 has been carried out abroad. The fluorescent tracer rhodamine-B has regularly been used by the DIC since an sensitive in situ fluorometer has been purchased.

This presentation gives the present stage of application of radioactive and fluorescent tracer to study and predict waste water spread and dilution.

2. TRACERS

A tracer may be defined as any substance which can be measured demonstrating the course of a process.

Tracers to be used in water can be devided in naturally occurring and artificial tracers. Figure no. 1 lists some of these tracers, however, it is not a complete list. The general use of an artificial tracer in receiving water studies is to introduce at some point a known amount of tracer material of which concentrations may be measured at varions times and places.

The ideal tracers should have the following characteristics:

1. Soluble and chemically stable in water
2. Detectable in low concentrations
3. Identifiable from naturally occurring substances
4. A well-defined decay-rate (if any)
5. Low sorbtion in the actual waterbody
6. Non toxic to human, aquatic or animal life
7. Commercially available at low cost
8. Easy to handle

The existence of a background, its concentration and degree of variation determine the measurement sensitivity. High sensitivity is useless if the background variations are of the same magnitude as the minimum limit of the tracer detectability.

In the study of coastal and Estuarine dynamics the possibility of using the naturally occurring tracers or already present artificial tracers (chemicals from domestic or industrial waste water) should always be evaluated. If these are found unsufficient the choice between fluorescent dyes, radioactive tracers or the activable tracers.

The most important advantages of fluorescent dyes are: Immediate availability, easy handling, easy detection, the obtaining of fast results and no risk of health hazards. The most important disadvantages are the variable decay-rate and the possibility of variable background. The problems with variable and high background will often occur in Estuarine waters.

Radioactive tracers offer significant advantages in areas and type of studies where the use of fluorescent dyes is impractical, primarily because of their well defined invariable background and decay-rate. They are easy to detect both in situ and on water samples and the cost of reliable and sensitive field instruments is low. The major limiting factor of radioactive tracers is generally the real or imaginary health hazard involved in their use in large scale systems.

Stable isotopes can in conjuction with activation analysis (activable tracers) be used as an alternative tracer to radioactive isotopes (and fluorescent dyes). The major advance of great sensitivity is retained, but without the problem of radiation hazard. The disadvantage is that concentration determination has to be done on samples - in situ measurements are impossible.

Fluorescent tracers have been and are widely used. The classic reference is FEUERSTEIN ans SELLECK /1/. A study of residence time distribution by simultaneous injection of a flurescent tracer (Pontacyl Brilliant Pink) and a radioactive tracer (Bromine-82) was performed in a Swedish fjord by HANSEN and CEDERWALL /2/.

Bromine-82 with a half-life on 36 hours is the most often used radioactive tracer in receiving water studies, se HARREMOES /3,4/, and GILATH et al /5/. Because of its half-life it is suited for both instantaneous injections which should be repeated to cover several hydrographic conditions as well as for continuous releases.

Activable tracers are well suited for residence time and accumulation studies because of their stability. Indium was used by DAHL et al. /6/ in a (three days) continuous injection to a study in the Trondheim fjord, Norway and by KUOPPAMÄKI /7/ in a 4 weeks continuous injection in a Finnish Archipelago Recently lanthanum has been used in an instantaneous injection by DIC to study residence time in an Danish fjord. When introducing the tracer the choice is between instantaneous (single pulse) and continuous injection. The major advantage of continuous injection is in the study of concentration distributions (variation with time and space) created in a certain water body from a (continuous discharging) source. Some of the disadvantages are large quantities of tracer material and that the presence of the tracer will delay initiation of new studies with the same tracer for a certain duration of time.

Instantaneous injection is preferable in the detailled study of processes of shorter duration and variable characteristics because the studies can be repeated with short intervals. It is easy to correct for the decay of tracer-material.Results can,based on certain assumptions,be used to calculate the effect of an continuous release.

In the study of some processes (like bacterial die-away) a combined use of two different tracers in continuous and instantaneous releases may be favourable.

3. PREDICTION OF WASTE WATER SPREAD

In a systematic planning of field studies to predict waste water spread it is useful to classify those with respect to the spatial scale of the physical processes of major interest. At the DIC there is distinguished with respect to three phases of the waste water spread.

- The phase of initial dilution.
- The phase of primary transport and dispersion
- The phase of accumulation

The phase of initial dilution cover processes in the immediate surroundings of the outfall. A light sewage released at the bottom into a heavier ambient sea-water will rise because of buoyancy forces. The mixing of sewage and sea-water which take place during the rise is here referred to as initial dilution. When the sea-water is vertical homogenous in the outfall zone the diluted sewage will rise to the surface. If the sea-water is stratified the rising mixture may achieve a density equal to the sea-water at a specific depth below surface and consequently the sewage will thus be trapped at that level.

After trapping the phase of primary transport and dispersion takes place. The sewage will be transported due to convective currents which may vary horizontally, vertically and with respect to time. During this convective transport dispersion takes plan. Dispersion is here defined as the combined effect of turbulant diffusion and shear due to horizontal and vertical velocity variations.

In coastal areas and enclosed bays or Estuaries with oscillating currents the phase of primary transport and dispersion will gradually go into the phase of accumulation. This is the largest scale of the waste water spread phenomena.

The purpose of the marine outfall studies is to prevent unacceptable levels of contamination from the various soluble and settleable substances which may be present in the waste water planned to be discharge. The tracer techniques which are referred to below focus on soluble substances.

3.1 INITIAL DILUTION

The disposal of waste water through an outfall involves the creation of a hydraulic jet. Jet diffusion theories to quantify the waste water dilution during rise has been presented by ABRAHAM /8/ and CEDERWALL /9/. These theories describe the initial dilution in a homogeneous ambient sea as a function of:

- Densities of sea-water and waste water
- Portdiameter and distance from port
- Discharge velocity.

The theory of jet diffusion in homogenous ambient fluid has been tested in several laboratories. The results are summarized by HANSEN and SCHRØDER /10/, who also report a series of experiments by use of radioisotopes (P-32).

A modified theory which take into consideration vertical variations in sea-water density has been presented by HANSEN /11/. This theory is the basis for a mathematical model developed for computer calculations of jet dilution in the stratified sea. The modified theory has been tested by results from a field study on jet diffusion in the stratified sound between Sweden and Denmark. In this study a temporary outlet was established 13 metre below sea-surface. Domestic sewage was pumped through the outlet. The initial rise, trapping level and dispersion was studed with Br-82 as tracer /4/. HANSEN /12/ has also presented a matematical model for calculations of the initial dilution of sewage with a density exceeding that of the ambient sea-water.

As a result of the above mentioned work it is to day possible to predict the initial dilution and trapping of sewage which is released into a sea with arbitrary density variating with depth. Thus measurements of the vertical variations of salinity and temperature which determine the sea-water density are the only field measurements required for those calculations.

The vertical destribution of salinity and temperature at a certain coastal location may vary with respect to time (seasonal variation in air temperature and freshwater drainage). Prediction of initial dilution and trapping level thus has to be given in statistical terms. In the open sea variations in stratifications are quite slow and dependent on season. Here measurements taken once every second week in the summer and once in each of the winter month's may give a suitable statistical basis. In Estuarine waters frequent measurements (two or three times a week) may be necessary.

It has to be mentioned that none of the existing jet diffusion theories take into account the effect of currents on the degree of initial dilution. Based on a series of extensive laboratory studies the Hydraulics Research Station, England /13/ has established emphirical solutions adapted to the theories of ABRAHAM and CEDERWALL.

3.2 PRIMARY TRANSPORT AND DISPERSION

When an outfall is planned to be established, the major decisive pollutants for selection of discharge point, may be a criteria on hygienic water quality in coastal areas. Some of the substances (like the indicator organism Escharichia coli) considered in this criteria has decay-rates of an order which means that their major importance is connected to what is happening within the first day (and- or night) after release. Prediction of transport and dispersion possibilities of sewage within this scale of time require a combined use of several different survey instruments and techniques. Some of these are combined to identify characteristics in the local currents system and others are combined to demonstrate dispersion characteristics.

3.2.1 STUDY OF THE LOCAL WATER MOVEMENT

These studies shall primarely demonstrate the local current system around the discharge point (area ~10 to 100 km^2) and identify typical and critical current phenomena.

A suitable way to establish knowledge on the local current system is to trace the movements of dye spots or floats. Simultaneous tracing of a number of dye spots may yield information on the existence of surface eddies. Figure no. 2 show examples of current tracks and velocities found by this technique. At the DIC is used a solution of sodiumfluorescin (Uranin) for dye-spot tracing of surface-water movements and floats with the resistance body in various depths to demonstrate the tracks of subsurface movements. Divergense (due to wind drift) in the movement of dye spots and floats with resistance in the surface layer are then used to correct the observed float movement for wind drift on the divices above surface.

Vertical variations in current velocity and direction can also be measured with portable currentmeters which are lowered from an anchored boat. However,when there is a swell or stronger winds the measured velocities and directions may be doubtfull due to swinging of the boat.

Moored self recording systems can be set in the outfall area to establish long time-series of data on velocity and direction. They will demonstrate the presense of oscillating currents and significant net-currents. When the measurements of current tracks are related to winds, tidal variations and the recordings from fixed submerged stations, it may be possible to identify typical and critical local water movements.

3.2.2 TRACER STUDY OF DISPERSION

Tracer studies of dispersion are more expensive due to the more advanced instrumentation and the more specialized personnel required, than studies which focus on the current system only. Therefor tracer studies of dispersion characteristics may be limited to a number of situations which are selected on the basis of initial studies of the local current system.

For the study of dispersion of water soluble substances the choice with respect to tracer release is between instantaneous or continuous release. Advantages and disadvantages connected to the two techniques has been touched on in section 2.

3.2.2.1 Instantaneous tracer release

Instantaneous tracer release to surface water require the least with respect to instrumentation and manpower, since there is no demand for a boat for the injection or problems with maintenance of a pumping set.

The choice of tracer may then be between a radioisotope or a fluorescent dye, assuming sufficient reliable instrumentation for in-situ determination of both are available. The instrumentation available for marine tracing of radioisotopes at the DIC are 10 sets of scintillation detector + ratemeter + recorder and for the tracing of fluorescent dyes two sets of in-situ fluorometer + depth gauge + ratemeter + recorder. At the DIC bromine-82 with a half life of 36 hours normally as preferred as the radioactive tracer. For fluorescent tracer work the DIC most often select rhodamine-B in a 30 per cent solution (Rhodamine-B flüssig from BASF, W. Germany).

If there are high background fluorescense or any risk of local variation in the background the radioactive tracer should always be selected (if available). The use of rhodamine-B must also be avoided if studies are performed at a locality with oscillating currents because rhodamine which has a slower decay (half life more than a week) than bromine-82 may for some days build an artificial increased background at the study area. This could delay repetition of studies.

The sensivity of the DIC standard scintillation detector is about 20 cps/micro Curie/m^3. Because the natural background count rate in sea water is about 1 cps the lowest amount of injected radioactivity which is detectable from a boat in motion corresponds to 0.05 $\mu Ci/m^3$ (1 Ci evenly mixed in $20 \cdot 10^6$ m^3 of water).

The in-situ fluoremeters used by DIC has a detection range between 0.05 and 50 ppb of rhodamine-B Flüssig. Due to the natural background fluorescense in sea water the lower detection limit may go up to the order of 0.1 ppb (1 ℓ of rhodamine-B evenly diluted in 10×10^6 m^3 of sea water).

For instantaneous injections at the surface the DIC use either 1 Ci of Br-82 or 2 to 4 litre of rhodamine-B. The bromine-82 is used in the form of ammonium bromide (16 gram of NH_4Br), which is dissolved in 1 litre of water. Both the radioactive and the fluorescent tracer solution has to be adjusted to the sea water density before injection or in the phase af injection. The latter may simply be done by a short "blow" from the tracer boats propeller, which immedially establish a tracer labelled patch of about 30 square metres. When the patch is small the position has to be recorded from time to time. This determines the drift of the tracer (equals surface water movement). When the patch has dispersed to a sufficient size the tracer boat begin to cross and recross the patch whilst recording the tracer concentration and position. From these results the concentration distribution within the tracer cloud can be mapped from time to time. Figure 3 show an example with a series of subsequent tracer cloud determinations. A thorough description of the sailing technique and primary data evaluation can be found in HARREMOES /3/.

The determination of tracer concentration does not have to be limited to one depth. When a radioactive tracer is used a number of detectors can be mounted on a wire with depressor. Thus the concentration can be measured simultaneously in different depth. This is very hard to do with in situ fluorometres because of their weight and larger volume. Vertical profiling of tracer, salinity and temperature should be done in the centre of the tracer cloud from time to time to demonstrate any change in vertical distribution.

Sewage dilution corresponding to a continuous discharge can be predicted directly from the instantanous tracer release when steady state conditions can be assumed /3/. The basic ideas behind these calculations can be summarized as:

- The instantaneously injected tracer solution is considered as a fraction of a continuous flow.

- The hydrographic conditions (direction and velocity of currents etc.) are stationary so that all fractions of the continuous sewage flow will go through identical events during transport.

- Under these conditions the position and extension of all fractions of the continuous flow is known, if the intire fate of one fraction is measured. This is what should take place during the tracing of an instantaneous injection.

Figure 4 show isodilution curves for a continous discarge of 1 m^3/s calculated on the basis of the instantaneous injection shown on figure 2. Such dilution curves may then be used for a calculation of the concentration distribution of soluble substances contained in the sewage. The equation to be used for a non decaying substance is:

$$C^{*} = F^{*} \cdot Q \cdot C_o$$

C_o = Concentration in the undiluted sewage

Q = Volume flow rate (m^3/second) in outfall

F^* = Dilution factor at a point downstream in the isodelution plume (figure 4).

C^*= Concentration in the point with dilutionfactor F^*

$$\text{Dilution factor} = \frac{\text{part sewage}}{\text{part sewage + sea water}}$$

However, the dilution curves obtained directly from the instantaneous tracer injections are strictly related to those hydrographic and meteorological conditions which occurred during the field measurements.

The spread and dilution of an instantaneously released tracer may further be used for calibration of a mathematical dispersion (plume) model. Several dispersion models are readily available, OKUBO /14/. The actually selected theory must always be adjusted in order to fit the particular oceanographic conditions in the disposal area.

3.2.2.2 Continuous tracer release

Studies of primary transport and dispersion based on a continuous tracer injection are more time consuming and expensive than those based on instantaneous injection.

However, in cases continuous injections may give informations which in practice hardly could be obtained from an instantaneous injection.

Examples are:

1 - Study of dilution in an area with currents of high velocities.

2 - Study of how a tracer (sewage) plume perform close to coastal areas during shifts in the general current direction. See figure 5.

3 - Study of vertical mixing up to surface layers of a tracer released sub-surface in a stratified sea.

4 - Study of plume performance in a coastal region with cross currents and non-horizontal stratifications. See figure 6.

The example on figure 6 demonstrate how a tracer plume injected in the surface layer 1200 m from the coast dive below the surface water closer to the coast. This happens because the surface layer closer to the coast has a lower density (in this case salinity) than the tracer labelled water.

In this type of studies the continuous release may last from 8 up to 40 hours. At the DIC we generally prefer rhodamine-B flüssig for continuous release, because the instrumentation to establish a constant injection rate is very simple.

In study where bromine-82 are used the pumping rate for long time injection has to be increased gradually to keep the injection rate of Br-82 constant. The increase of pumping rate must compensate for decay of tracer in the storage tank.

The amount of tracer which should be discharged continuously depends partly on the lowest future waste water dilution of significant interest and partly on the lowest detectable tracer concentration. The relation valid for a non decaying tracer is given in the equation:

$$Q_t \cdot C_{ot} = C_t \cdot \frac{Q}{F}$$

Q_t = Volume flow rate of tracer

C_{ot} = Concentration of tracer in the released solution

C_t = Lowest concentration of tracer detectable above background

Q = Volume flow rate of future waste water discharge

F = Lowest waste water dilution of interest.

The released tracer must be density adjusted to the sea water in the injection level either before or in the phase of injection. For practical purpose it is normally sufficient to establish an effective dilution of the tracer in the ambient sea water during injection. The rhodamine-B injection systems used by the DIC for surface or sub-surface injections respectively are outlined on figure 8.

The concentration distribution of tracer which develops in the study area is surveyed with a boat and in situ instrumentation by the tracing technique known from instantaneous release. Floats has to be dropped and their movements followed simultaneously with the tracer measurements to given informations on current velocity. These float measurements are in particular of practical importance in studies with subsurface injections to stratified water. Here floats are released with resistance body in the injection level from time to time at the point of injection.

These field recordings of tracer concentrations are then - corrected for decay - worked up to demonstrate physical dilution for a selected flow rate volume. As a generel practice, the DIC presents dilutions corresponding to a flow rate $Q = 1\ m^3/\ sec$. Figure 7 show float tracks, the boat course line and isodilution curves from a continuous surface release.

Point injections of a tracer can not be expected to simulate waste water dispersion from future discharge through a long multipart diffusor. The approximation of a line source with a point source will only be valid far away from the discharge location. However, results from a point injection of tracer may be used for calibration of dispersion parameters in a mathematical model, which then can be used to predict the concentration distribution closer to the discharge location.

3.3 LONG-TIME ACCUMULATION

The environmental effects of long-time accumulation are generally related to substances which has a slow decay in marine waters. The means to avoid an unacceptable build up of such substances are waste water treatment. The level of regional accumulation of slow decaying substances is generally without influence on the choice of outlet distance from a coast bordering open waters.

Rhodamine-B can be selected as tracer for continuous injection if the time scale of the study is within one or two weeks. However, the study may require a huge amount of tracer if the area of interest is large. For studies lasting more than two weeks loss of rhodamine due to decay may be a problem because the actual decay is difficult to determine.

Activable tracers like lanthanum or indium may be preferred rather than rhodamine-B because their presense can be determined in lower concentrations. For further information see DAHL /6/, KUOPPAMÄKKI /7/ and GENDERS /15/.

4. STUDIES OF MICROBIAL DIE-AWAY IN SEA WATER

The presence of certain microorganisms (indicator organisms) is often taken as a measure for the hygienic quality of bathing waters. An indicator organism should have its origin in the human excreta and is then taken as a measure for the risk of the presence of pathogene organisms. Microorganisms from human excreta are said to die-away when exposed to sea water conditions. Since the mecanism of microbial reduction in sea water are not yet precisely specified and understood the term die-away is more used as a synonym for microbial disapperance.

It is a general experience that the die-away rate for microorganisms may vary from one marine location to another.

In order to predict concentration destributions of indicator organisms established from fusion discharges of domestic waste water the local die-away rate must be experimentally determined.

Tracer experiments in existing outfalls offers a possibility to determine the die-away rate of microorganisms. The die-away rate is further to the effect of physical dilution of sewage. The total effect of die-away and dilution is often expressed by the following equation:

$$C^1 = C \cdot e^{-\ln 10 \cdot \frac{t}{T_{90}}}$$

C^1 = Actual concentration to be found

C = Calculated concentration without die-away effects

ln = Natural logaritm

e = Basis figure for ln

t = Transport time in sea water from outfall site

T_{90} = Time needed for a 90 % reduction of the actual micro-organism (exclusive dilution)

The various in situ methods for determining die-away rates in sea water are critically reviewed by HARREMOES /16/. The most widely used in situ technique to measure die-away rates is based on continuous release of a tracer in an existing outfall to determine the physical-dilution in the sewage field. The die-away rate is then determined from the ratio between the actually measured bacterial concentration in different distances from the discharge point and the concentration, which should have been expected by pure dilution. One of the more important uncertainties - apart from the analytical measurement of the microbial concentration - is determination of the residence time in sea water for the samples taken.

HARREMOES concluded that the die-away rate is better determined by use of flux ratios (fr) than by a number of single concentration ratios. The fluxes of tracer and microorganisms are calculated for cross sections in the sewage field:

$$fr = \frac{\int c' \, dA}{\int c \, dA} = e^{-\ln 10 \cdot \frac{t}{T_{90}}}$$

Where dA refers to an area element at right angles to the transport direction. Thus, for each cross section one fr - value is calculated and should be plottet versus t to determine T_{90}. An instantaneous release of tracer in the outfall could be used to obtain the best determination of the residence time "t" as well as the transport velocity. Detailed informations on field determination of die-away rates can be found in HARREMOES /17/ and GILATH /5/.

5. DETERMINATION OF OUTFALL LENGTH

When an outlet distance from the coast has to be selected the major decisive factor is often an attention to keep (or establish) an accaptable bathing water quality. A bathing water criteria may be either of a type where a fixed concentration of an indicator organism must never be exceeded or a type where a fixed concentration is allowed exceeded in a fixed per cent of time. An example of the latter may read:

> The concentration of Escherichia coli may exceed 1000 E.coli/ 100 ml in maximum 5% of the time in the summer season.

The engineering procedure to determine the necessary outlet distance include then prediction of the concentration versus time statistics of the discharged indicator organisms in the coastal regions. These statistics are calculated for a number of different outlet-distances. The shortest outlet distance to keep the criteria at all locations of interest is then selected. Figure 9 shows an example with precalculated E.coli-statistics representing three different outlet distances. An outlet distance 1100 m from the coast satisfy the bathing water criteria.

The precalculated E.coli-statistics are based on field measurements of the local water movements and a number of tracer studies to determine the physical transport and dispersion. The posibility of having the sewage trapped completely below surface in a stratified sea - as the result of a proper diffusor design - should also be considered in such a statistical approach. The critical point in this engineering approach is often the correlation of results from a limited number of tracer studies to a basic statistical parameter. A long time statistical representation may be established by correlation to data from some kind of permanent recording station, e.g. wind from a meteorological station, current from a lightship or tidal water level variations. Many years observation at a permanent station may be worked up to yield the long-time statistics.

6. CONCLUSION

It has been proven through a substantial number of field studies that pollution from future disharges of waste water may be predicted quantitativity by use of artificial water soluble tracers. These may be radioactive trac rs like bromine-82, fluorescent like rhodamine-B or activable tracers.

Stable and sensitive field instruments for in situ determination of radioactive or fluorescent tracers are available. Traditional hydrographic measurements are still required when marine outfall studies are performed. For each study the selection of tracer and the combination with other survey instrumentations and techniques should be carefully designed.

7. REFERENCES

/ 1/ FEUERSTEIN, D.L. and SELLECK, R.E., Fluorescent tracers for dispersion measurements. Proc.Am. Soc. Civ. Eng. 89

/ 2/ CEDERWALL, K. and HANSEN, J.AA., Tracer studies on dilution and residence time distribution in receiving waters. Water Research, 1968, vol. 2.

/ 3/ HARREMOES, P., Preduction of pollution from waste water outfalls. J. Wat. Pollut. Cont. Fed. 38, 1966.

/ 4/ HARREMOES, P., Tracer studies on jet diffusion and stratified dispersion. 3rd. Int. Conf. Water Pollut. Res., Munich 1966, section III, paper no. 4.

/ 5/ GILATH, Ch. et al, Radioisotope tracer techniques in the investignation of dispersion of sewage and disappeavance rate of enteric organisms in coastal waters. Proc. Symp. On use of nuclear techniques in the measurement and control of environmental pollution. IAEA, Salzburg 26-30 Oct. 1970.

/ 6/ DAHL, J.B. et al, Water pollution studies by means of inactive indium tracer and activation analysis. Proc. Symp. on Use of nuclear techniques in the measurement and control of environmental pollution, IAEA, Salzburg 26-30 Oct. 1970.

/ 7/ KUOPPAMÄKI, R and MUURINEN, A, The prediction of waste water dilution by a long-time tracer experiment. Nordic Hydrology, vol 7, no. 4, 1976.

/ 8/ ABRAHAM, G., Horizontal jets in stagnant fluid of other density, ASCE HY 4 (1965).

/ 9/ CEDERWALL, K., Hydraulics of marine waste water disposal, hydraulic division, Chalmars Institute of Technology, Gothenburg, Sweden Report 42 (1968).

/10/ HANSEN, J. and SCHRØDER, H., Horizontal jet dilution studies by use of radioactive isotopes, ACTA POLYTECHNICA SCANDINAVICA, Civil Engineering and Building Constrution Series, Ci 49 (1968).

/11/ HANSEN, J. AA., Predeternining trapping of sewage in stratified receiving waters. Symp. on the use of nuclear techniques in the measurement of environmental pollution. Oct. 1970. Salzburg, Austria.

/12/ HANSEN, J.AA., Marine disposal of heavy suspentions. Scandinavian congress of chemical engineering. Nov. 1971, Copenhagen, Denmark.

/13/ Hydraulich research Station, Wallingford, England. Horizontal outfalls in flowing water. Report no. Ex 763, March 1977.

/14/ OKUBO, A., A review of theoretical models for turbulent diffusion in the sea. Journal of the Oceanographical Society of Japan, 20 (1962) 286.

/15/ GENDERS, S., Study of estuarine dynamics, International seminar on the use of isotopes and ionizing radiation in environmental Engineering. Sept. 1979. São Paulo, Brazil.

/16/ HARREMOES, P., In situ determination of microbial disappearance in sea water. Paper no. 19 in Discharge of sewage from sea outfalls.Pergamon Press 1975.

/17/ HARREMOES, P., Field determination of bacterial disappearance in seawater. Wat. Res., 1970, 4,737-749.

WATER TRACERS

NATURALLY OCCURING	ARTIFICIAL		
	RADIOISOTOPES	FLUORESCENT	OTHERS
- DISSOLVED CHEMICALS	NAME (HALF LIFE)	FLUORESCEIN (URANIN)	SALT
SALINITY	BR-82 (36 h)		
IONIC RATIOS	I-131 (8 d)	RHODAMINE B	CHEMICALS IN INDUSTRIAL WASTE
- SUSPENDED MATTER	H-3 (12.3 yr)	RHODAMINE WT	CHEMICALS IN DRAIN WATER
- NATURAL TRITIUM	LA-140 (40 h)	PENTACYL PINK	
- PLANKTON	NA-24 (15 h)		
- HEAT BUDGET			

ACTIVABLE TRACERS

LANTHANUM

INDIUM (IN)

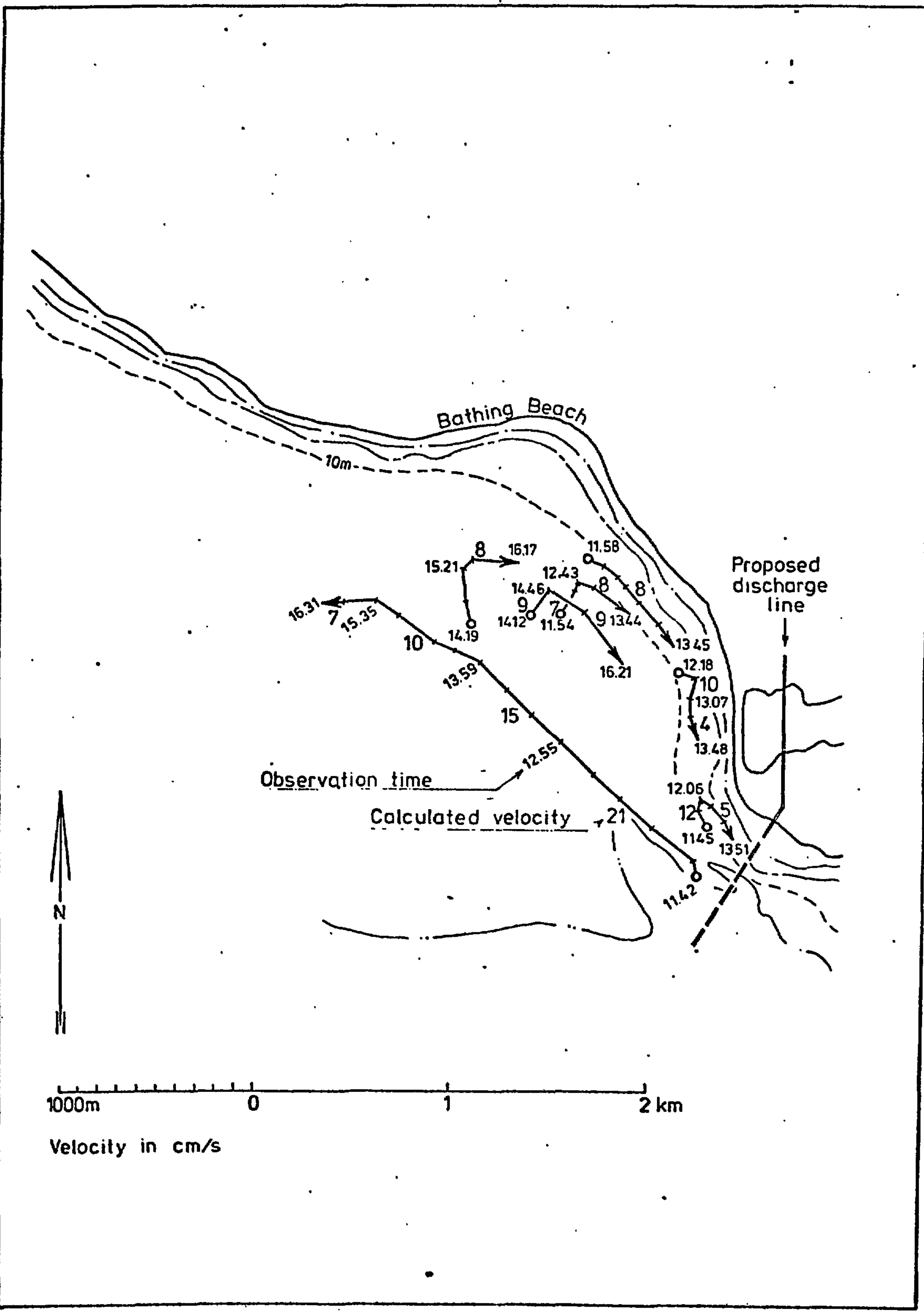


FIGURE NO. 2 DYE SPOT TRACING ON AUGUST 30, 1973

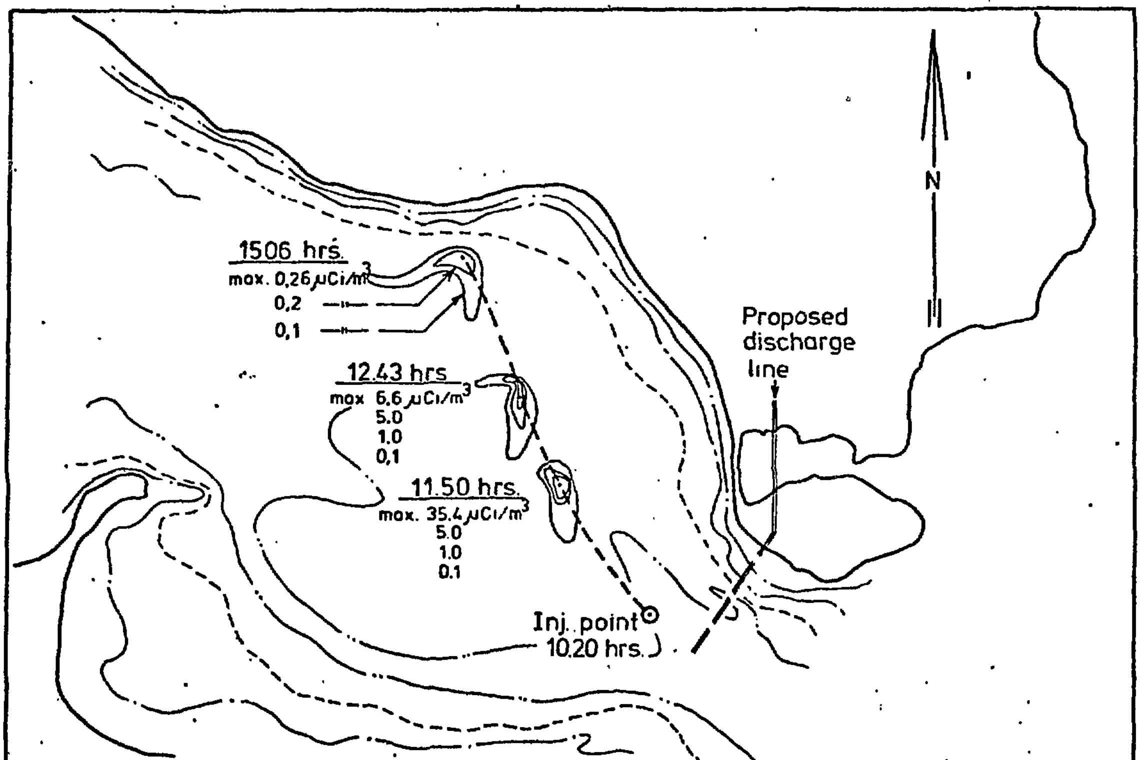


Fig. 3 Transport and dispersion of the tracer cloud

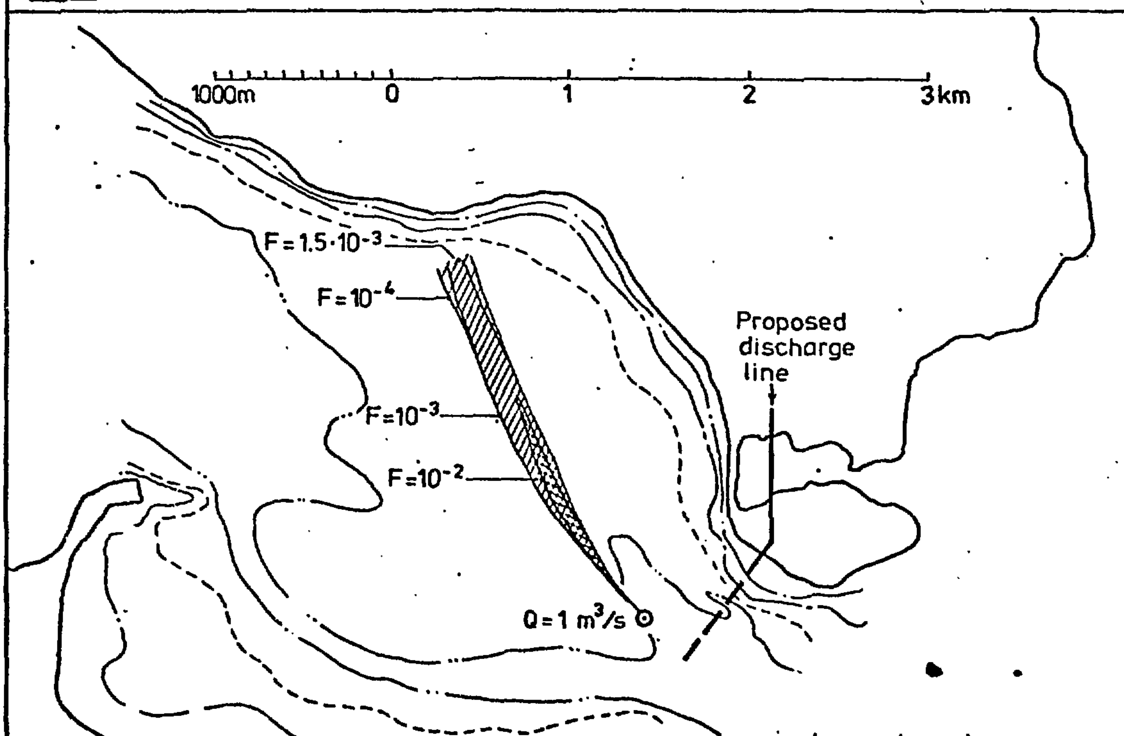


Fig 4 Calculated dilution factors $F = \frac{\text{parts waste water}}{\text{parts waste water + parts sea water}}$

FIGURE NO. 3 AND 4. RESULTS FROM INSTANTANEOUS INJECTION OF Br-82

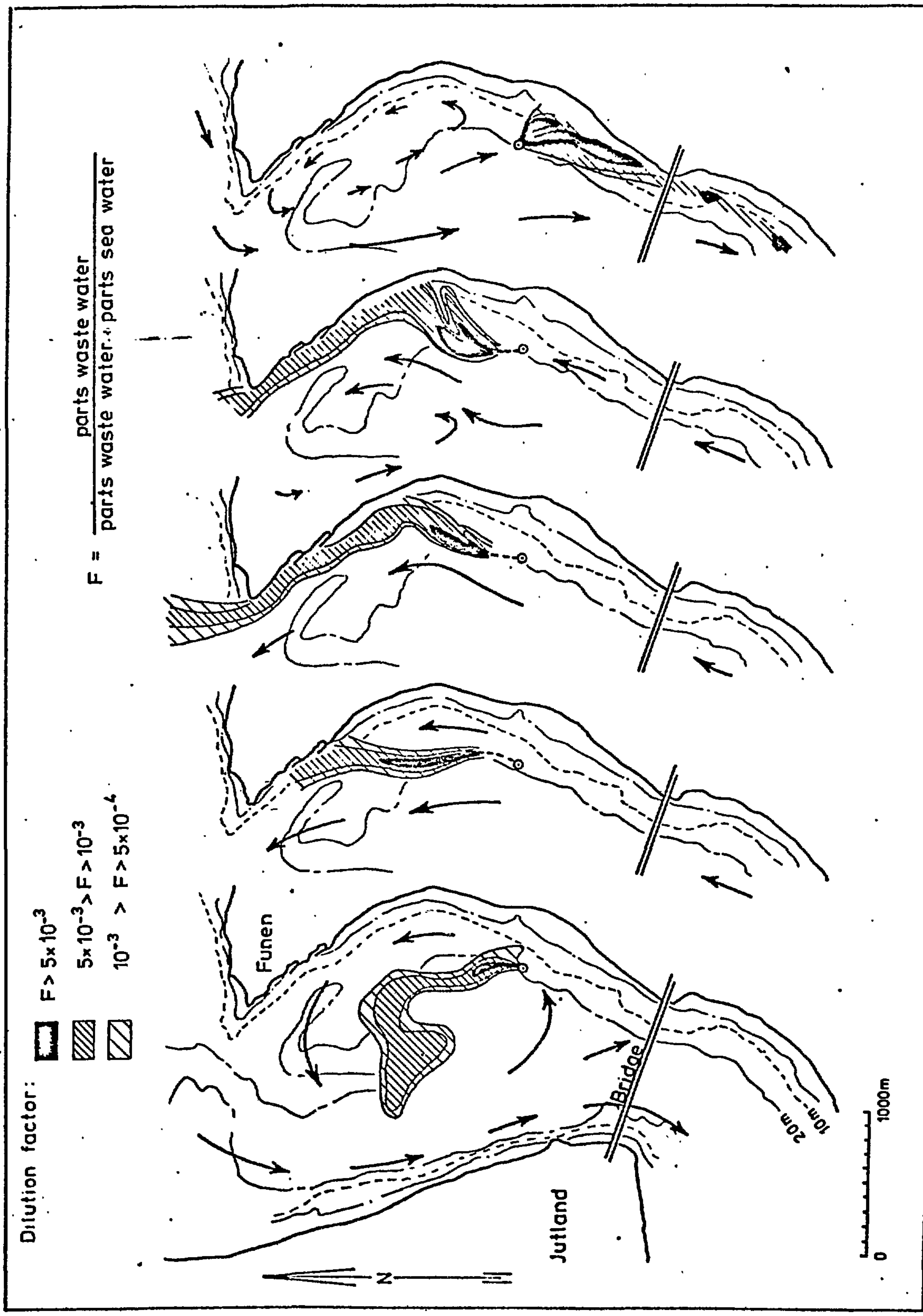
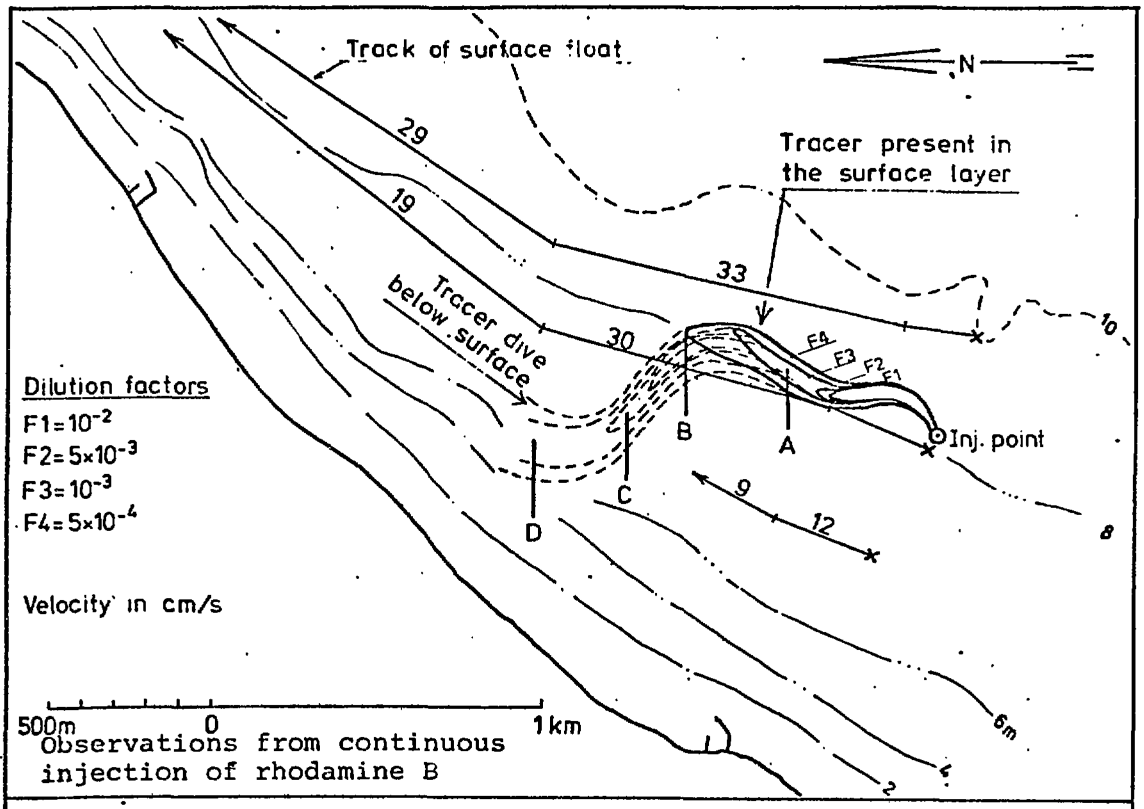
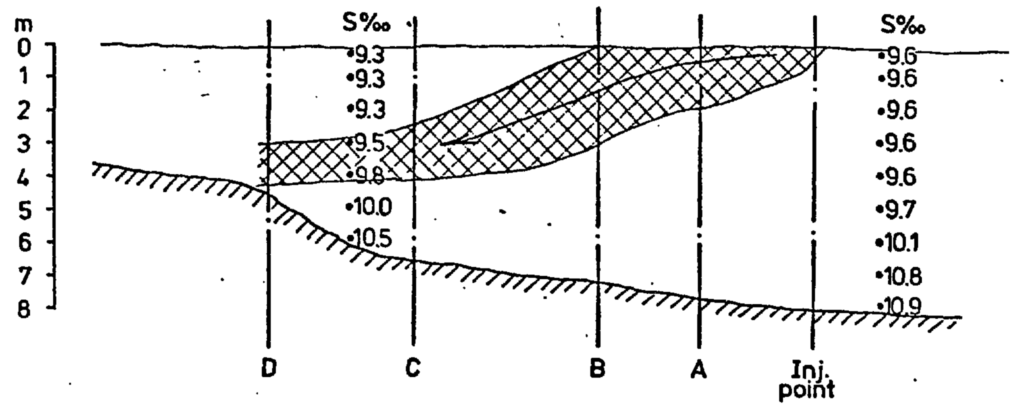


FIGURE NO. 5 DIFFERENT PHASES OF PLUME COURSES, MEASURED FROM A CONTINUOUS INJECTION OF RHODAMINE B.





Vertical cross section along plume axis - Principle

FIGURE NO. 6 COASTAL SURFACE WATER OVERLAPPING A SURFACE INJECTED TRACER PLUME

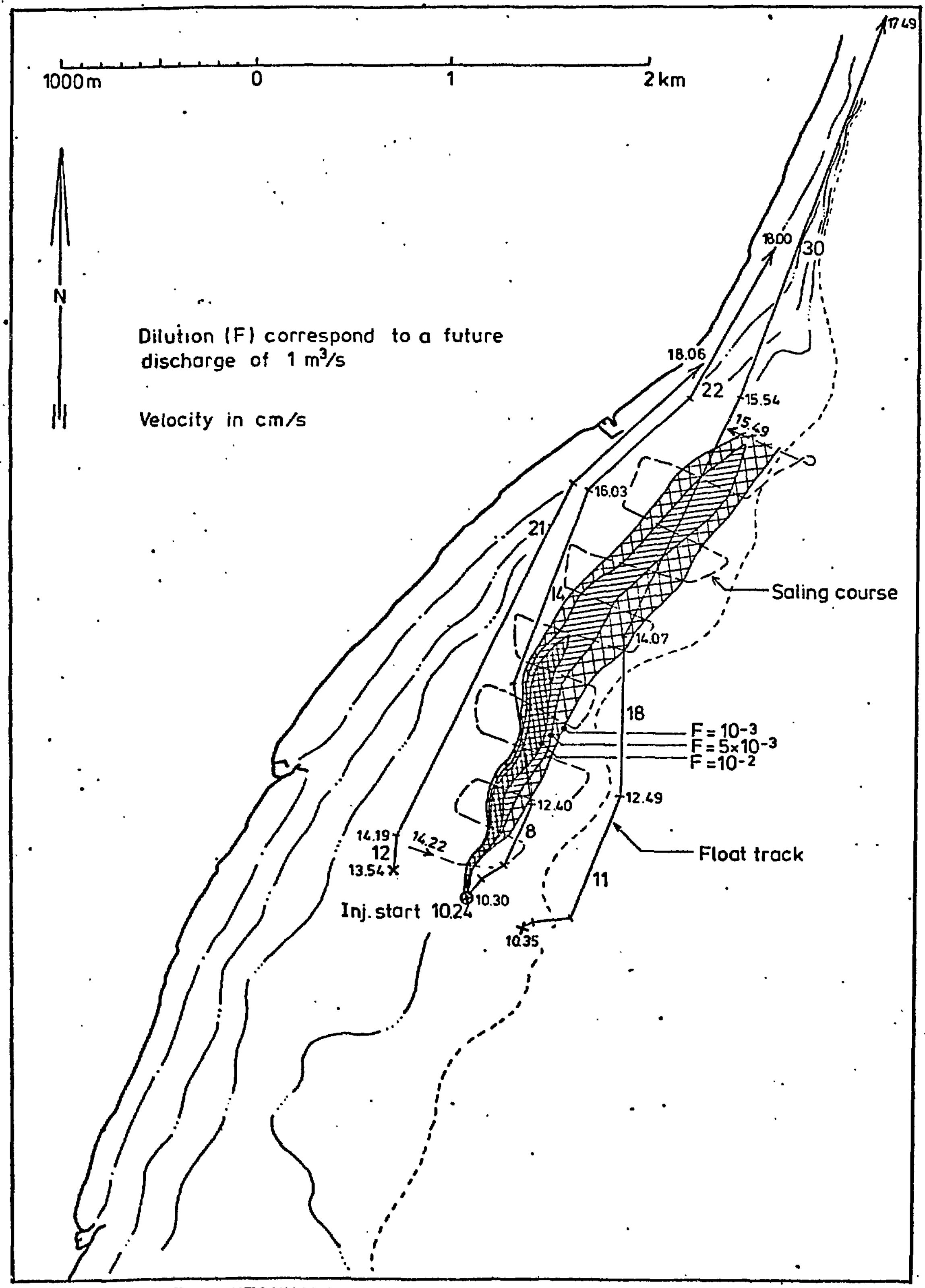


FIGURE NO. 7 CONTINUOUS INJECTION OF RHODAMINE B.
FLOAT TRACKS AND ISODILUTION CURVES.

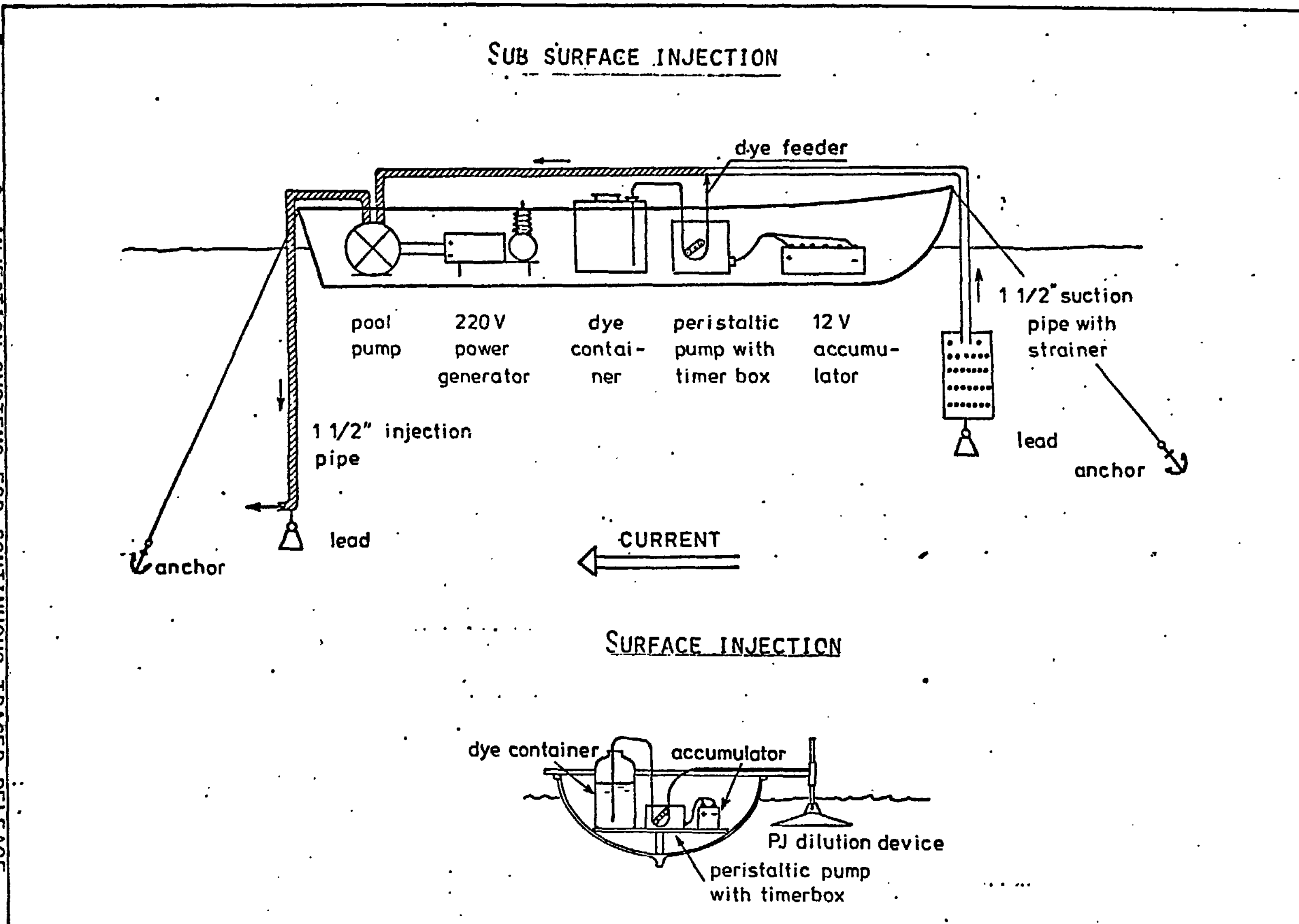


FIGURE NO. 8 INJECTION SYSTEMS FOR CONTINUOUS TRACER RELEASE.

FIGURE NO. 9 PREDICTED E.COLI-STATISTICS