CSIR

DIVISION OF WATER, ENVIRONMENT AND
FORESTRY TECHNOLOGY

Report to the

WATER RESEARCH COMMISSION

on

COMPARISON OF PREDICTED SECONDARY DILUTIONS TO MEASURED FIELD DATA AND THE DETERMINATION OF PROTOTYPE DIFFUSION COEFFICIENTS

by

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PRETORIA

SCOPE

Between 1991 and 1993 the CSIR conducted full-scale field exercises at three deep sea outfalls along the South African coast to verify the initial dilution prediction methods applied in South Africa. During these exercises the transport of the waste field was also monitored.

These data, together with other related field data, collected over a period of 10 years along the South African coastline, were used to assess the accuracy and applicability of the methods and controlling parameters, e.g. diffusion coefficients, generally used in South African to predict achievable secondary dilutions and subsequent impact at distant locations.

The results of this assessment are presented in this report. The report was compiled by W A M Botes from WAM Technology cc. and Susan Taljaard (CSIR).

A VAN TONDER
COASTAL DEVELOPMENT
AND MARINE RESOURCES

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EXECUTIVE SUMMARY

The aim of this project is to compare actual secondary dilutions obtained from field data with predicted secondary dilutions, as well as to determine prototype diffusion coefficients at a number of areas along the South African coast to verify the applicability of a standard prediction method used in South Africa for marine outfall design purposes.

The total achievable dilution which can be expected at a distant location is the product of the initial dilution, secondary dilution, dilution due to the die-off of microbiological organisms and the chemical/biological dispersion of non-conservative substances. The initial dilution is the dilution achieved by the entrainment of seawater at the periphery of the plume during the rise of the buoyant effluent from the diffuser to the surface of the sea, thereby reducing pollutant concentrations in the effluent. The subsequent transport of the effluent (waste field) away from the initial surfacing plume, referred to as the 'boil', brings about further reduction of the pollutant concentrations. This process is generally referred to as secondary dilution, which is caused by turbulence, eddies and shears, causing further entrainment/mixing of seawater. Together with chemical and biological dispersion of non-conservative substances and the die-off or decay of certain organisms during the transport of the waste field (dilution due to decay), the initial dilution and secondary dilutions determine the ultimate concentration of pollutants, originating from an effluent, and the subsequent impact on the designated uses at any location away from the discharge location.

From 1991 to 1993 the CSIR conducted full-scale field tests on three outfalls on behalf of the Water Research Commission to verify the methods used for the prediction of initial dilution. These sites were chosen to represent typical coastal conditions and various types of deep sea outfalls in South Africa. A tracer material, Rhodamine-B, was introduced to the outfall system. The concentration of the tracer was then measured in the system and in the initial surface plume (referred to as the 'boil') to determine the achievable initial dilutions. Although not part of those studies, the growth and dispersion of the moving waste field was also monitored by circumnavigation and the sampling of tracer concentrations in the moving waste field.

During 1995 the CSIR was commissioned by the Water Research Commission to assess the applicability of the methods used for prediction of secondary dilutions to South African near-shore conditions, using the available data from these field tests and others. Due to the diversity of near-shore conditions along the South African coastline, it was expected that the dispersion characteristics, i.e. the diffusion coefficients, might be site or region specific.

Because the dispersion of a waste field, after surfacing of the plume, is a spatial and time dependent process, the following data are required to predict behaviour and subsequent impact of the moving waste field:

- ambient current velocities;
- frequency of occurrence of these current speeds and directions;
- frequency of occurrence of wind speeds and directions;
- spatial behaviour of the current, i.e. the near-shore circulation patterns;
- typical diffusion coefficients.

The accuracy of the predicted secondary dilutions depends on the accuracy and completeness of the above-mentioned data sets. For both analytical and numerical methods the diffusion coefficient has to be estimated from experience or relevant data if prototype tests are not conducted at a specific location. The diffusion coefficient cannot be 'modelled' due to the complex physical processes causing the eddy diffusion.

The physical measurements of the dispersion characteristics are a time consuming and costly operation and until present, a 'general' dissipation parameter, referred to as a α-value, of 0,0005 $m^{2/3}\,s^{-1}$ was applied to determine the secondary dilutions for all deep sea outfalls in South Africa, based on the proposals of several researchers and from a once-off field exercise conducted on the Natal coast. The prediction method basically relates to the method of Brooks (1960) applying the so-called '4/3 law', considered to be applicable to 'open sea' conditions.

Various theories can be used to estimate the diffusion coefficients for a specific site, including a procedure whereby 'drogue pair' measurements are used. Between 1981 and 1992, the CSIR undertook numerous studies at a number of coastal development areas to determine the feasibility of ocean outfalls as options for sewage disposal. These studies included the Lagrangian recording of currents, using surface and sub-surface drogues. The path of the drogues were recorded by accurate position fixing in time and space. Drogue data collected were from Noordwesbaai (on the west coast), Hout Bay, False Bay, Vlees Bay and East London.

This valuable source of data is also assessed in this report to estimate the magnitude of the diffusion coefficient at various coastal regions. Tracer measurements, collected at Richards Bay, Vlees Bay and Hout Bay, were also assessed to estimate diffusion coefficients on the days of the exercises.

The comparison between predicted and measured secondary dilutions yielded the following:

- *Richards Bay.* Using a α-value of 0,0005 $m^{2/3}$ s^{1}, the predicted secondary dilutions at Richards Bay were about 2,5 times less than the measured dilutions. Previous studies in the area (Pearce, 1969), had also indicated that a α-value of 0,0005 $m^{2/3}$ s^{-1} can be considered as conservative. The actual α-value on the day of the exercise was 0,0017 $m^{2/3}$ s^{-1}, applying the '4/3 law'. The predicted waste field width was also about two times less than the measured width.

- *Vlees Bay.* The predicted secondary dilutions, using a α-value of 0,0005 $m^{2/3}$ s^{-1}, were slightly less than the measured values. The predicted waste field width was about two times less than the measured width, possibly associated with the estimation of the angle between the current direction and the diffuser orientation (i.e. θ). This angle is used to calculate the effective diffuser width (i.e. the initial waste field width, b, where $b = w \sin \theta$). The estimation of the effective diffuser width also affects the prediction of secondary dilutions, but not as drastically as for the prediction of waste field width. For a relatively short diffuser, the effective diffuser width would be less affected by an inclined current considering the width of the initial waste field ('boil'), relative to the length of the 'boil'.

- *Hout Bay.* Changing current conditions, which caused reversal of the moving waste field, limited the time period during which concentration measurements after the initial dilution process (i.e. after surfacing of the plume) could be conducted at Hout Bay. Due to the 'near stagnant' conditions, measured secondary dilutions were only limited to about 1,5 after 36 minutes, which were slightly less than the predicted secondary dilutions.

The estimation of the α-values from the selected drogue data yielded the following:

Although the median α-value of 0,00052 $m^{2/3}$ s^{-1} for all sites compare well with the generally suggested value of 0,0005 $m^{2/3}$ s^{-1} for open sea conditions, the individual values for certain areas, for example Noordwesbaai differ substantially from the general α-value of 0,0005 $m^{2/3}$ s^{-1}.

The effect of current velocity on the turbulent behaviour of the receiving water and subsequent α-value is shown, where the α-value for currents less than 0,1 m s^{-1} is 0,00046 $m^{2/3}$ s^{-1} compared to 0,00083 m $^{2/3}$s $^{-1}$ for currents greater than 0,2 m s^{-1}. In sheltered areas, where currents are weaker, a value of less than 0,0005 $m^{2/3}$ s^{-1} should be used for a conservative approach, whereas in a more dynamic environment, for example east coast conditions (Richards Bay), values greater than 0,0005 $m^{2/3}$ s^{-1} can be applied.

The estimated median α-value for sub-surface currents (-5 m water depth) is approximately 20 percent lower than the estimated value for surface currents. This is important especially when conducting performance evaluations of deep sea outfalls by measuring of actual dilutions using tracer material in an effluent, as most of the samples are taken close to the sea surface.

The influence of the length scale (L_x) obtained from the drogue data illustrated that for a length scale of between 80 and 120 m the α-value is less than two times the α-value for a length scale of less than 40 m.

The following *conclusions and recommendations* can be drawn from the findings of this project:

- Results from this project indicate that the 'general' procedure applied in the prediction of achievable secondary dilutions for deep sea outfall along the South African coast, i.e. the method of Brooks (1960), assuming the '4/3 law' and a α-value of 0,0005 $m^{2/3}$ s^{-1} does not always apply.

- Although the median α-value of 0,0005 $m^{2/3}$ s^{1}, obtained for grouping all available drogue measurements, confirmed the 'general' α-value suggested by numerous authors, the α-values estimated for the individual sites, clearly showed the diversity of conditions along the 3 000 km South African coastline.

- Based on the findings of this report the use of a 'general' α-value is not recommended in determining the secondary dilutions and subsequent impact of an effluent waste field at distant locations in South Africa. The most typical values for certain areas should be considered and if detailed field measurements cannot be obtained to establish the actual diffusion coefficients, at least a range of values should be considered. The diffusion coefficients and α-values determined in this report could be used as a rough guideline.

- Although the *prediction* of achievable secondary dilutions and subsequent impact at distant locations is considered appropriate for planning and feasibility phases of an outfall project, taking into account the near shore processes and the coastline configuration, it is strongly recommended that *field measurements* be conducted to obtain more accurate site specific diffusion characteristics of the area for the optimisation of the outfall during the detailed design phase.

- Irrespective of the procedure or method used to predict the behaviour of a moving waste field, i.e. analytical methods or numerical modelling, a thorough understanding of the physical processes, the sensitivity and limitations of the prediction method or procedure to all variables, as well as the applicability of a certain methods to a specific area or near shore conditions is essential before any quantitative conclusions can be made with regard to the detailed outfall design. A simple equation or a 'black box' approach is therefore not always considered to be sufficient in providing reliable quantitative results on achievable secondary dilutions, especially taking into account the consequences of detrimental impact in terms of ecological, health and economical aspects, both in the short and long term.

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Comparison of predicted secondary dilutions to measured field data and the determination of prototype diffusion coefficients.

The project was coordinated by Dr T C Erasmus of the Water Research Commission.

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1. INTRODUCTION

The aim of this project is to compare actual secondary dilutions obtained from field data with predicted secondary dilutions, as well as to determine prototype diffusion coefficients at a number of areas along the South African coast to verify the applicability of a standard prediction method used in South Africa for marine outfall design purposes.

When a buoyant effluent is discharged into the sea, the reduction of concentrations of constituents is brought about by various physical, chemical and biological processes. The physical dilution of an effluent can be considered as two distinct processes, i.e.

i. The initial dilution process where a buoyant plume rise from the diffuser or an open end pipeline to the surface of the sea. The dilution is brought about by the entrainment of seawater during the rise of the plume. The influencing parameters are the buoyant and momentum flux of the jet, the ambient currents and the density structure of the receiving water column. The dilution obtained from this process can be optimised by adapting the diffuser design for a certain ambient environment.

ii. Secondary dilution or subsequent dilution (after dissipation of the energy during the initial dilution phase) where the plume (waste field) is transported by ocean currents to distant locations. During the transport of the waste field, mixing occurs due to eddies which arise from various physical processes, also referred to as eddy diffusion. Unlike during the initial dilution process, this cannot be influenced by the design of the outfall and is primarily dependent on the near-shore oceanographic conditions.

In a previous research project financed by the Water Research Commission the applicability of different methods for the prediction of initial dilution was investigated at three outfall sites, i.e. Richards Bay, Vlees Bay and Hout Bay (WRC, 1994). This project will focus on the methods and controlling parameters used in the prediction of secondary dilution.

From the planning to the final design phase of a deep sea outfall, the estimation of the secondary dilutions, and subsequent impact at distant locations, are essential, irrespective of whether analytical or numerical models are used for the assessment. Detailed field measurement, for this purpose, are time consuming and costly, especially when considering the seasonal variations of physical conditions. Detailed measurements are, therefore, only conducted during the final design phase. For the planning and feasibility phases, secondary dilutions need to be predicted as realistically as possible.

At present a standard prediction method for secondary dilution has been applied for outfall design purposes along the South African coast. It is primarily based on the method developed by Brooks (1960) which defines the diffusion coefficient, a controlling parameter in the determination of secondary dilutions as:

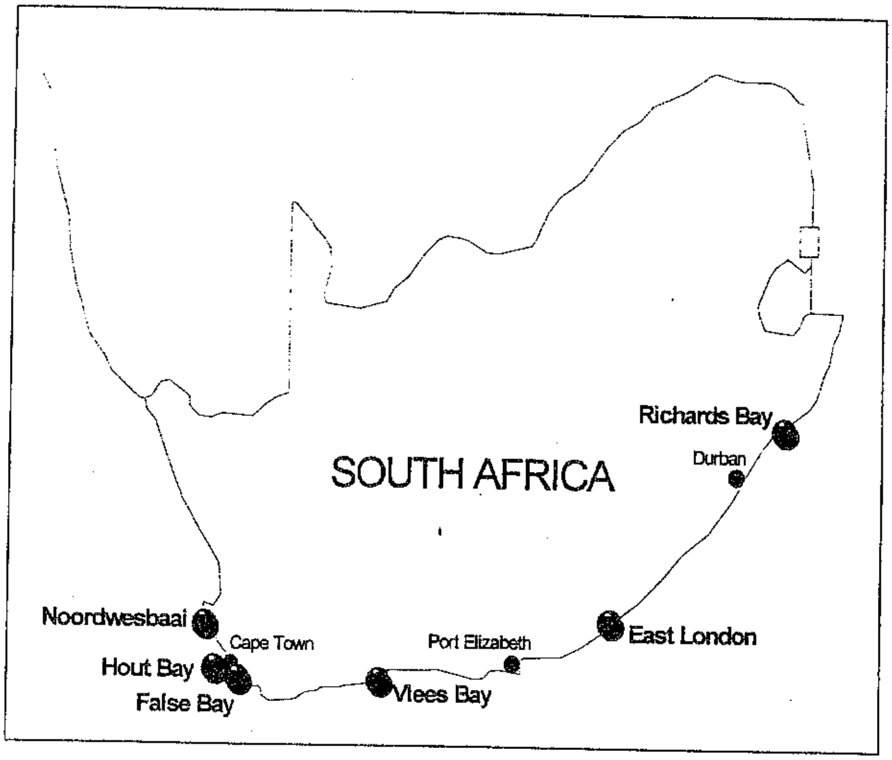
$$K = \alpha L^n$$

For open ocean conditions, assumed to be representative of deep sea outfalls, a value of 4/3 is recommended for n, referred to as the '4/3 law'. The α-value assumed for the South African situation is 0.0005 $m^{3/2}\ s^{-1}$ (Brooks, 1960; Pearce, 1969).

However, due to the diversity of the coastal processes along the 3 000 km South African coastline, the application of a 'general diffusion' coefficient has caused some concern over the last few years and, therefore, warranted investigation.

Between 1981 and 1994, the CSIR undertook numerous studies at certain coastal development areas to determine the feasibility of ocean outfalls as options for sewage treatment and to investigate initial dilution methods commonly applied in South Africa (i.e. Noordwesbaai, Hout Bay, False Bay, Vlees Bay, East London and Richards Bay). Measurements included the Lagrangian recording of currents, using pairs of surface and sub-surface drogues and tracer (i.e. Rhodamine B) measurements. The path of the drogues were recorded by accurate position fixing in time and space. These data provide a valuable basis for determining the magnitude of eddy diffusivity at various locations along the South African coastline (i.e. diffusion coefficients). The analysis of this data not only contributes to a better understanding of South African conditions, but will also supplement any future studies on diffusity and the refinement diffusion coefficients elsewhere.

The location of the different sampling sites mentioned throughout this report are indicated below:



This report presents the results from this investigation. The report is structured as follows:

- *Literature review*, where theories and methods, specifically related to deep sea outfall studies are assessed.

- *Materials and Methods*, where the data used for this project are defined and the methods used in the assessment are outlined.

- *Results and Discussion*, where measured secondary dilutions are compared with predicted values and where prototype controlling parameters (i.e. diffusion coefficients) in the determination of secondary dilutions, are investigated for a number of areas along the South African coast.

- *Conclusion and Recommendations*, where the important findings of the study are summarised and recommendations, related to these findings, are outlined.

2. LITERATURE REVIEW

Since the scope of this study was not to evaluate the numerous theories and methods used to determine secondary dilution, but rather to compare field measurements to prediction methods generally applied in South Africa, the literature review will focus on the practical application of diffusion coefficients and secondary dilutions in the near shore environment related to the discharge of long sea outfalls. Theories related specifically to diffusion in the ocean were developed by Okubo (1962), Joseph and Sendner (1958) and Brooks (1960), and were summarised by Yundelson (1967).

Because the dispersion of a waste field after surfacing of the plume is a spatial and time dependent process, the following data are required to predict behaviour and subsequent impact of the moving waste field:

I. ambient current velocities;
ii. frequency of occurrence of these current speeds and directions;
iii. frequency of occurrence of wind speeds and directions;
iv. spatial behaviour of the current, i.e. the near shore circulation patterns;
v. typical diffusion coefficients.

The accuracy of the predicted secondary dilutions depends on the accuracy and completeness of the above-mentioned data sets. For both analytical and numerical methods the diffusion coefficient has to be assumed if prototype tests are not conducted at a specific location. The diffusion coefficient cannot be 'modelled' due to the complex physical processes causing the eddy diffusion.

Numerous studies have been conducted to develop mechanisms and theories to predict the turbulent diffusion and behaviour of a surface waste field when transported away from a discharge location. Researchers who made valuable contributions include Brooks (1960 and 1972), Yudelson (1967) and Pearce (1969). These and many others facilitated in formulating and quantifying complex oceanographic processes in order to provide 'tools' to assist with the design of marine outfalls with regard to the impact which a discharged effluent may have at distant locations.

The theory of turbulent diffusion has been studied since the beginning of the century and numerous field experiments contributed to the development of rational methods which can be applied. Various theories and concepts to define this process were developed:

With reference to Yudelson (1967):

- Einstein defined the diffusion coefficient as:

$$K_x = \frac{d(\sigma_x^2)}{2dt} \quad \text{in units of length}^2 \text{ time}^{-1} \qquad \text{.......1}$$

Where σ_x^2 = mean square dispersion (or variance of distribution) of the diffusing particles in one direction after time t.

- Fick's law relates the variation of the concentration C of a substance to eddy diffusivity and mathematically described diffusion as:

$$\frac{\delta C}{\delta t} = K_x \frac{\delta^2 C}{\delta x^2} \qquad \text{.......2}$$

Where K_x is a function of the distance x.

Brooks (1960) described the diffusion process with regard to the scale of the waste field as:

> *When the waste field is transported away from a discharge location, it is mixed with the adjacent seawater due to irregular turbulent circulation, super-imposed on the main flow field. This mixing will only occur if the turbulent fluctuations or eddies are smaller than the main flow of the waste field. If the main flow or waste field is smaller than the ocean eddies mixing will not be promoted. Thus in the ocean, the larger the scale of the waste field becomes, the larger the effect of eddies will be on the mixing process. However, this does not apply for molecular diffusion when the mixing of one substance with another relates to the random molecular motion.*

For this study the works of Brooks (1960) and Yundelson (1967), reviewed by many other authors, is considered to be the most applicable and relevant when considering a rational method to predict secondary dilutions.

According to Brooks (1960) the linear diffusion law is the simplest for engineering applications and can be expected to be reasonably reliable if the diffusion coefficient (K_x) is considered a variable. He used the basic Fickian equation to determine the dispersion of a waste field, i.e.:

$$Flux\ x\text{-}direction = K_x \frac{\delta C}{\delta x} \qquad \text{...}3$$

Where C = concentration of the substance being diffused
x = a coordinate in the direction of the flow path.

He also assumed that K_x is a function of the length scale (L_x), i.e. the width of the waste field and that vertical mixing as well as longitudinal mixing are negligible and that the main flow (transport) is steady. The die-off of microbiological organisms was not considered as part of the physical mixing during transport, but is handled separately as a 'dilution of decay' which is defined as e^{-kt} , where t can be expressed in terms of the distance x and the current velocity U. Because the nature of the field data used in this project, i.e. physical drogue measurements and tracer (Rhodamine-B) measurements, the dilution due to decay will not be discussed.

Neglecting vertical mixing, yields a more conservative approach although the magnitude of the vertical dilution is several magnitudes lower compared to horizontal diffusion as reported by Koh and Brooks (1975). Typical diffusion coefficients for vertical mixing range from 0,0001 to 0,004 $m^2\ s^{-1}$. Generally, for a fresh water effluent the relative buoyancy (compared to the ambient water) will curtail the vertical mixing, while vigorous wave action will enhance the vertical mixing.

Considering the assumption that the diffusion coefficient is a function of the size and width of a waste field, the initial horizontal diffusion coefficient (K_o) for a spreading effluent plume which varies with the length scale of the waste field can be expressed as follows:

$$K_0 = \alpha L^n \qquad \text{.......... 4}$$

Where	L	=	length scale
	α	=	a dissipation parameter ('variable constant')
	n	=	a power exponent

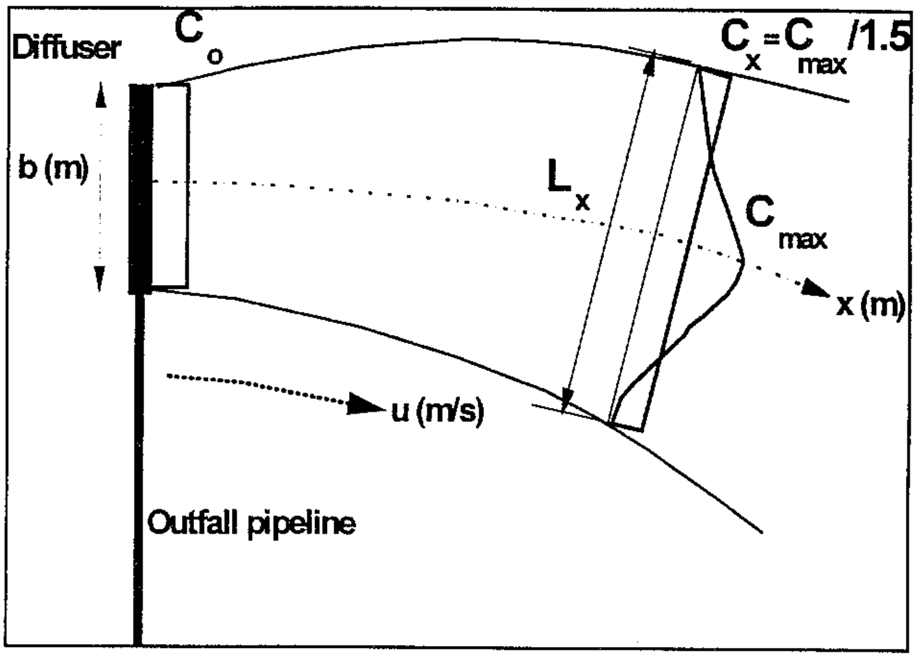
Field measurements by Okubo (1974) and Pearce (1969) concluded that in the near shore environment where the spreading of the waste field is unobstructed n values range from $1{,}0 < n < 4/3$.

The best agreement with open coastal waters according to Okubo (1974) and Pearce (1956) corresponds with a n-value of 4/3 (generally referred to as the '4/3 law'). This value of n applies to waste field widths (L_x) ranging from 10 m to 10 000 m and is generally applicable to deep sea outfalls. In calmer coastal waters the spreading of the waste field becomes curtailed due to limited eddies and confined areas which limit mixing (proximity of the coastline). In these instances the values for n are more likely to be in the range 0,5 to 1,0. In restricted areas such as estuaries and small embayments where flow is homogenous and the lateral mixing is limited by adjacent estuary banks a value of zero can be used for n.

The estimated dilution factor relates to the average concentration at the discharge location (C_0) and the centre line concentration (C_{max}) at a distant location (x).

Assuming a transverse Gaussian distribution (situation is illustrated schematically in the sketch below), the average concentration at a distance (x) from the discharge location is:

$$C_x = \frac{C_{max}}{1,5} \qquad \text{......} \; 5$$



The diffuser of the outfall is taken as a steady line source of a width b and the plume is transported by a uniform steady flow u in m s^{-1}. The concentration, C_o, is the concentration at the surface after the initial dilution process had taken place:

$$C_0 = \frac{C_e}{S_i} \qquad \text{......} \; 6$$

Where C_e = concentration in the effluent in the pipe
S_i = initial dilution which occurred when the effluent rises to the surface due to jet momentum and the relative buoyancy of the effluent

The minimum secondary dilution is:

$$S_{e_{min}} = \frac{C_0}{C_{max}} \qquad \text{......} \; 7$$

For the prediction of the secondary and eddy dilution (S_e) when concentrations are not measured, the initial horizontal diffusion coefficient (K_o) is the key parameter.

For a constant value of K_o, K_o increasing linearly with the length scale and for K_o proportional to $L^{4/3}$, the maximum concentrations along the centre line of a moving waste field, according to Brooks (1960), are:

Description of K_o	$C_{max}/C_o = 1/S_e$
K_o= constant	$erf\sqrt{\frac{3}{4\beta x/b}}$
$K_o = \alpha L$	$erf\sqrt{\frac{3/2}{(1+\beta x/b)^2-1}}$
$K_o = \alpha L^{4/3}$	$erf\sqrt{\frac{3/2}{(1+2/3\beta x/b)^3-1}}$

Where
β = $12K_o/ub$
K_o = initial horizontal diffusion coefficient
b = initial plume width (m)
U = uniform current speed ($m\ s^{-1}$)
x = distance downstream (m)
C_{max} = concentration at distance x.

Substituting a dimensionless distance p = β x/b, these equations to describe the concentrations along the centre line become:

Description of K_o	**$C_{max}/C_o = 1/S_e$**
K_o= constant	$erf\sqrt{\frac{3}{4p}}$
K_o= αL	$erf\sqrt{\frac{3/2}{(1+p)^2-1}}$
K_o= $\alpha L^{4/3}$	$erf\sqrt{\frac{3/2}{(1+2/3p)^3-1}}$

The travel time t can be expressed as u/x which will result in:

$$\beta = 12K_o t/xb$$
$$P = 12K_o t/b^2$$

The error function which is defined as:

$$erf\ (X) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-p^2}\, dp$$

relates to the solving of the partial differential equations that involve convection and diffusion.

Similarly the plume width (L_x) at distance x along the centre line of the path can be expressed, according to Brooks (1960), as:

Description of K_o	**L_x (plume width)**
K_o= constant	$b[1 + 2p]^{1/2}$
K_o= αL	$b[1 + p]$
K_o= $\alpha L^{4/3}$	$b[1 + 2/3p]^{3/2}$

For direct onshore conditions this method is conservative, since onshore currents are complex physical processes which are normally deflected, resulting in horizontal and vertical counter currents. Together with the more complex behaviour of onshore ambient currents, other oceanic processes such as wind shear and wave action are not easy to describe mathematically in shallower water. This results in more complex and vigorous mixing processes and, subsequently, larger dilutions. This phenomenon, especially in instances where ambient currents are dominated by the tide, can be simulated better by numerical models during the final design stage of a project.

The values of α depend on the natural turbulence (related to wave, wind and current conditions) and the initial plume width. According to Yudelson (1967) the most common range is between 0,02 and 0,005 $cm^{2/3}\ s^{-1}$. Okubo (1974) compared data from numerous experiments and found a good agreement between the diffusion coefficients and length scales for an α-value of 0,0005 $m^{2/3}\ s^{-1}$ applying the 4/3 law for open coastal waters. Pearce (1969) also recommended a 'conservative' value of 0,0005 $m^{2/3}\ s^{-1}$, which according to him, can be considerably higher in the presence of shearing currents and a severe wave climate. Nine experiments on the Natal coast yielded values ranging from 0,0005 $m^{2/3}\ s^{-1}$ to 0,014 $m^{2/3}\ s^{-1}$ using data from drift cards, tracers and transport of a waste field. The recommended lower value was preferred. Although it was shown to be conservative, confirmation of this became necessary considering the diversity of the coastal conditions along the South African. The value of α may vary from 0,00001 to 0,03 $m^{2/3}\ s^{-1}$ and for more detailed assessments of impacts from sea outfalls, site specific investigations may be a requirement in the future. This would not only be for the determination of the achievable secondary dilutions, but also for the prediction of the geometry of the plume (i.e. plume width). This is not only a requirement for analytical assessments, but also for the calibration and verification of numerical models.

Prototype diffusion coefficients can be estimated by:

i. measuring the change in concentration of a tracer material (e.g. Basazol Red or Rhodamine B) over distance and time, measuring the actual change in size of the spreading waste field and through accurate photographic records;

ii. the recording and statistical analysis of spreading of particles (drift cards);

iii. studying the separation in time and distance of drogue pairs (floats).

The mean eddy diffusion coefficient from Einstein's definition for a distribution of particles can be estimated as follows:

$$K=\frac{\sigma_2^{\,2}-\sigma_1^{\,2}}{2(T_2-T_1)} \qquad \text{.......... 8}$$

Where σ_1 and σ_2 are the variance of the distributions at times T_1 and T_2 (rate of change of σ^2)

The assumption is that at any time t, the concentration C_x at a distance x can be expressed as a normal curve:

$$C_x=\frac{C_0}{\sigma\sqrt{2\pi}\;e^{\frac{(x/\sigma)^2}{2}}} \qquad \text{Where} \qquad \sigma=\sqrt{2Kt}$$

Richardson and Stommel's approach (1948) proposed a theory to define neighbour diffusivity of which the concept is based on the separation of the particles in the waste field instead of a unit concentration C_x at a distance x.

Richardson's Law (Yudelson, 1967) expressed the neighbour diffusivity $F(\ell)$ by the following equation:

$$F(l) = \frac{(mean\ of\ l_1 - l_0)^2\ for\ all\ pairs\ of\ particles}{2T} \qquad \text{.............................9}$$

Where l_0 = the initial separation of the particle at t = 0
l_1 = the separation after time t = T

The length scale should be defined as l_0 if $(l_1 - l_0)$ is relatively small and as $(l_1 - l_0/2)$ if $(l_1 - l_0)$ is large.

Referring to equation (8), the length scale (L) of the waste field can be expressed as L = 4σ since 95 % of the lateral concentrations of a substance in the plume will be within the width (-2σ + 2σ).

Thus, the diffusion coefficient can be expressed in terms of the width of the waste field as follows:

$$K = 1/32 \frac{(w_2^2 - w_1^2)}{(t_2 - t_1)} \qquad \text{.............................10}$$

Where w_1 and w_2 are the width at times t_1 and t_2

For drogue pairs it is suggested by Pearce (1967), according to Richardson and Stommel (1948), that the diffusion coefficient can be determined as follows:

$$K = \frac{L_2^2 - L_1^2}{8(T_2 - T_1)} \qquad \text{.............................11}$$

Where L_1 = initial distance (m) at time T_1 between the drogue pairs
L_2 = distance between the drogue pairs at time T_2
$T_2 - T_1$ = total time in seconds.

3. MATERIAL AND METHODS

3.1 Data

I. Drogue measurements

Between 1981 and 1992, the CSIR undertook numerous studies at a number of coastal development areas to determine the feasibility of ocean outfalls as options for sewage disposal. These studies included the Lagrangian recording of currents, using surface and sub-surface drogues. The paths of the drogues were recorded by accurate position fixing in time and space. Drogue data were collected from the following areas:

1. *Noordwesbaai* (north of Saldanha Bay). Representing a 'rugged' west coast coastline, subjected to typical southerly and north-westerly wind conditions;

2. *False Bay*. The bay is relatively calm with regard to wave conditions but the northern part of the bay is exposed to the strong south-easterly and north-westerly conditions. Ambient currents are relatively weak, averaging less than 0,2 m s^{-1};

3. *Hout Bay*. A semi-enclosed bay exposed to the south-easterly and northerly wind conditions, but the wind fields are not homogeneous and varied continuously due to the complex coastline configuration and surrounding mountain areas;

4. *Vlees Bay*. Studies were undertaken at Vlees Bay, south-west of Mossel Bay. This bay is not sheltered against waves or from the summer and winter wind conditions. Ambient currents are subjected to the west flowing Agulhas Current and anti-clockwise eddies.

5. *East London*. A 'straight' coastline subjected to strong ambient longshore currents (Agulhas) and strong south-westerly and north-easterly winds which together with the ambient currents result in a dynamic, turbulent environment.

Data from each study site, including surface and sub-surface drogues, were assessed to select suitable data sets. Suitable data were defined as those where drogue pairs were released and retrieved more or less simultaneously. Data sets were evaluated and qualified for the estimation of the diffusion coefficients according to equation 8. The selected data for each site are provided in Appendix A.

ii. Tracer (Rhodamine-B) measurements

Between 1991 and 1993 initial dilution performance tests were conducted at three deep sea outfalls along the South African coastline (WRC, 1994), i.e Richards Bay (Mhlathuze Water A-line), Vlees Bay (Mossgas discharge into Vlees Bay) and Hout Bay (sewage outfall).

The aim of this study was to determine the actual achievable initial dilutions for comparison to theories generally applied in South Africa. During these field exercises the concentrations in the moving waste field were also recorded as accurately as possible, although a review of the secondary dilutions was not part of the scope of the project. The raw data for Richards Bay, Vlees Bay and Hout Bay is presented in Appendix A. The data parameters are time, concentration and distance from diffuser.

1. *Richards Bay.* During 1980 two marine outfalls (A and B-line) were constructed at Richards Bay for the discharge of various industrial effluents and domestic sewage. The location of the outfalls are illustrated in Figure 1a. The entire outfall scheme is managed by the Mhlathuze Water.

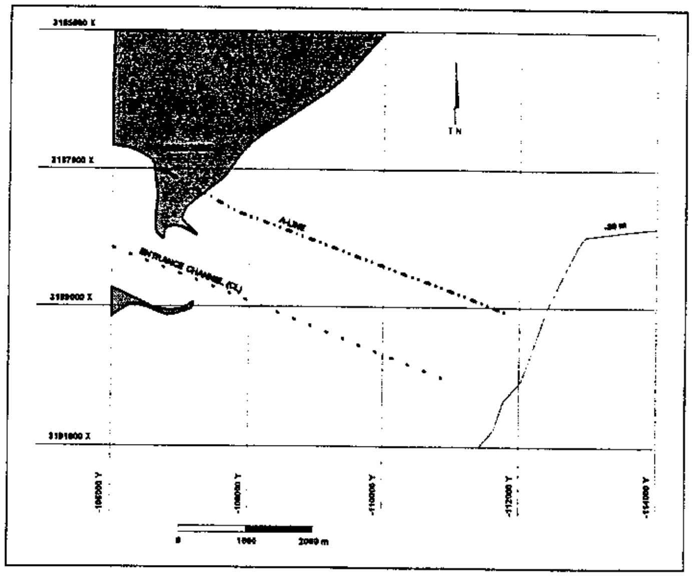


Figure 1a. Richards Bay: Locality map of sea outfall (A-line)

The A-line, which discharges in 29 m water depth approximately 4,8 km offshore, was designed to accommodate buoyant effluents from various industries and the domestic sewage from Richards Bay.

Another pipeline, the B-line discharges in 24 m water depth and was designed for discharging 'dense' effluents from the fertilizer factory (presently owned by Indian Ocean Fertilizers).

The main features and specifications of the Richards Bay marine outfall (A-line) which has been in operation since 1984 are:

- Effluent type: Industrial and domestic (buoyant in comparison with seawater)
- Discharge pattern: Continuous
- Material: HDPE (High density polyethylene)
- Pipeline length: 4,8 km offshore
- Water depth: 29 m
- Internal diameter: 920 mm
- Diffuser length: ~630 m
- Port configuration: 69x75 mm Ø, 6x115 mm Ø and 21x75 mm Ø
- Port spacing: 6,5 m
- Design flow rate: 160 000 m^3 day^{-1} (1,85 m^3 s^{-1})

The following data refer to the conditions on the day of the field experiment:

- Flow: Constant at 1,35 $m^3 s^{-1}$
- Effluent density: 1 010,1 g l^{-1}
- Diffuser: 96 ports discharged without obstruction. However, measurements refer only to the 6 x 115 mm Ø ports which, for the estimation of secondary dilutions, represented a diffuser with a length of 32,5 m.
- Currents: The surface and sub-surface currents were as follows:

	SPEED (m s^{-1})	DIRECTION (degrees to N)
Surface	0,47 - 0,63	202 - 225
-5 m	0,34 - 0,48	202 - 225
-10 m	0,32 - 0,38	202 - 225

The current patterns and velocity vectors are illustrated in Figure 1b.

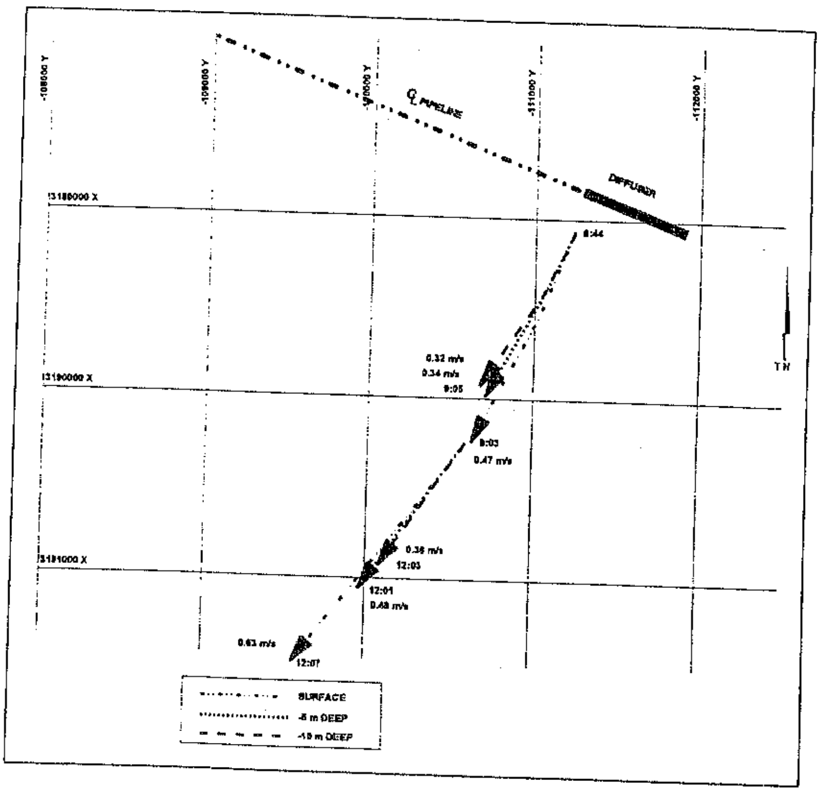


Figure 1b. Richards Bay: Currents measured on 11 September 1991

2. *Vlees Bay.* This ocean outfall at Vlees Bay, approximately 10 km west of Mossel Bay, was constructed in 1991 for discharging effluent from the Mossgas refinery. This outfall is owned and operated by Mossgas. The location of the outfall is illustrated in Figure 2a.

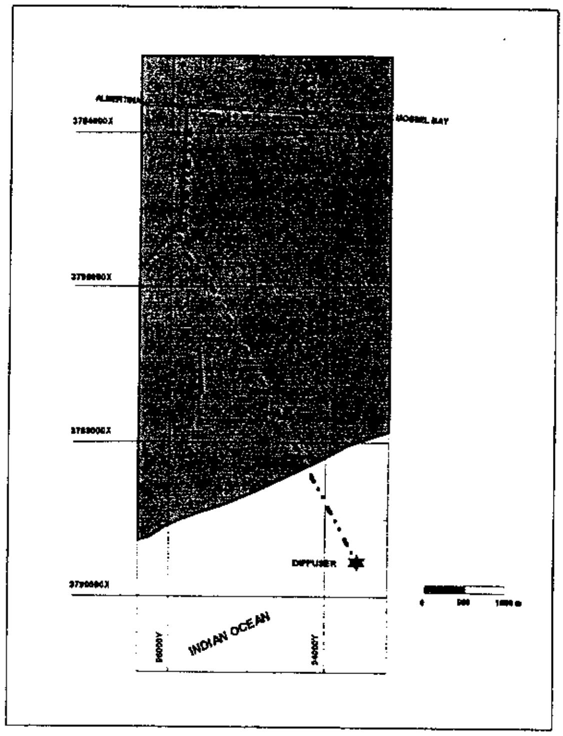


Figure 2a. Vlees Bay: Locality map of the sea outfall

The main features and specifications of the Mossgas pipeline at Vlees Bay which has been in operation since 1992 are as follows:

• Effluent type:	Industrial (buoyant)
• Discharge pattern:	Intermittent
• Material:	Steel
• Pipeline length:	9 km (refinery to diffuser) Diffuser is 1,4 km offshore
• Water depth:	27 m
• Internal diameter:	203,2 mm
• Diffuser length:	50 m
• Port configuration:	4 x 75 mm Ø and 1 x 79 mm Ø
• Port spacing:	3 x 10 and 1 x 8,5 m

- Design flow rates in phases: 0,052 $m^3 s^{-1}$
  0,136 $m^3 s^{-1}$
  0,167 $m^3 s^{-1}$

The following data refer to the conditions on the day of the field exercise:

- Flow: Constant at 0,08 $m s^{-1}$
- Effluent density: 1 000 $g l^{-1}$
- Diffuser: All 5 ports were discharging without obstruction
- Currents: The surface and sub-surface currents were as follows:

	SPEED ($m s^{-1}$)	DIRECTION (degrees to N)
Surface	0,11 - 0,18	315 - 0
-5 m	0,07 - 0,18	317 - 315
-10 m	0,06 - 0,10	337 - 315

The current patterns and velocity vectors are illustrated in Figure 2b.

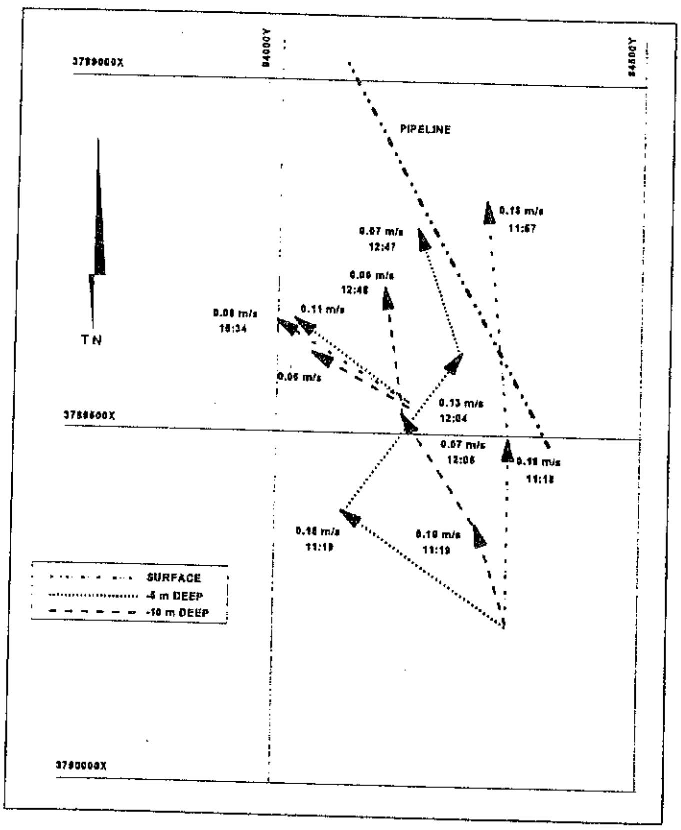


Figure 2b. Vlees Bay: Currents measured on 10 November 1992

3. *Hout Bay.* The pipeline is owned by the Cape Metropolitan Council (formerly the Western Cape Regional Services Council). The location of the outfall is shown in Figure 3a. For discharging of the pre-treated effluent from the treatment works to the sea, the system operates on gravity flow but uses booster pumps to provide the additional pressure head when required.

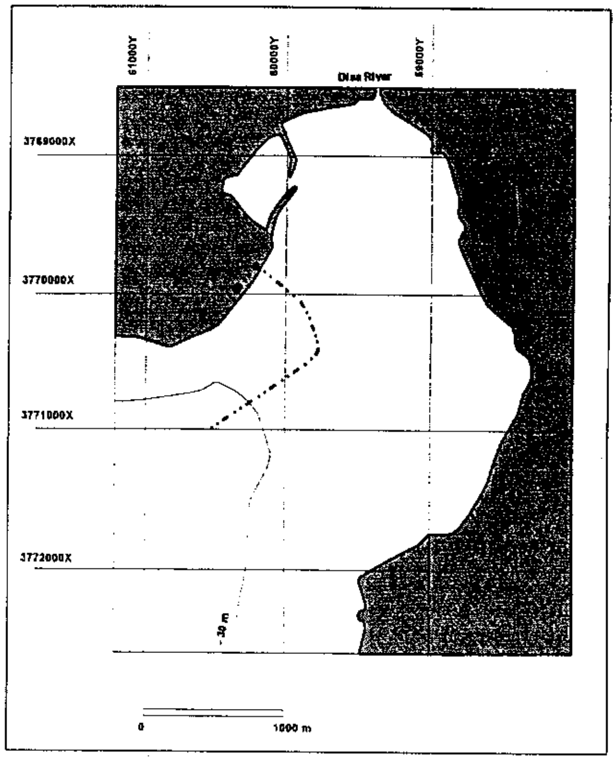


Figure 3a. Hout Bay: Locality map of the sea outfall

The main features and specifications of the marine outfall at Hout Bay which has been in operation since October 1993 are as follows:

- Effluent type: Domestic and industrial (Fishing industry)
- Pre-treatment: Maceration and fine screening
- Discharge pattern: Intermittent
- Material: High density polyethylene (HDPE)
- Pipeline length: 1,8 km offshore
- Water depth: 37 m
- Internal diameter: 364 mm
- Diffuser length: 114 m

- Port configuration: 10 x 110 mm Ø and 5 x 140 mm Ø
- Port spacing: 10 m
- Maximum design flow rate: 250 $m^3 s^{-1}$
- Flow rate in 1993: 125 $m^3 s^{-1}$

The following data refer to the conditions on the day of the field experiment:

- Flow: Constant at 0,123 $m s^{-1}$
- Effluent density: 1 000 $g l^{-1}$
- Currents: The surface and sub-surface currents were as follows:

	SPEED ($m s^{-1}$)	DIRECTION (degrees to N)
Surface	0,02 - 0,16	344 - 66
-5 m	0,02 - 0,08	152
-10 m	0,02 - 0,11	354 - 89

The current patterns and velocity vectors are illustrated in Figure 3b.

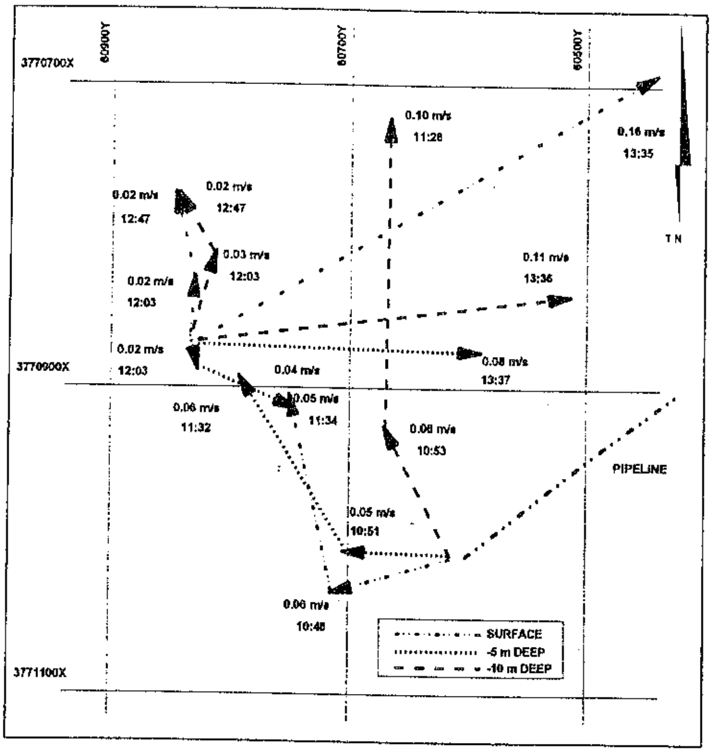


Figure 3b. Hout Bay: Currents measured on 12 October 1993

3.2 Methods

i. Determination of predicted and measured secondary dilutions

The tracer measurements at Richards Bay, Vlees Bay and Hout Bay were used to determine actual secondary dilutions. For each test the secondary dilution (S_e) was determined from C_x/C_o. The initial concentration (C_o) was determined from the measured surface concentrations in the initial surface plume (referred to as the 'boil'), after the initial dilution process. Because the previous project was designed to assess initial dilutions, the data had to be re-organized to obtain the required information for the assessment of secondary dilutions.

For each location a few groups of data points, at a certain time and distance from the release point, were selected to represent the concentrations in the moving waste field. Due to extremely weak currents together with varying directions during the Hout Bay exercise, a meaningful relationship between the concentrations and dilutions versus distance could not be obtained. The reduction in concentrations of the growing waste field can be estimated better in relation to time.

For the prediction of achievable secondary dilutions the method suggested by Brooks (1960) was used (refer to Section 2). Presently this method is generally used in the assessment of secondary dilutions for deep sea outfalls in South Africa. For South African conditions, the controlling parameter, i.e. the diffusion coefficient, is considered to be proportional to $L^{4/3}$, referred to as the '4/3 law' (generally used for 'open ocean conditions') and a α-value of 0,0005 $m^{3/2}\ s^{-1}$.

ii. Determination of prototype diffusion coefficients

To determine prototype diffusion coefficients and, subsequently α-values, from the drogue measurements Equation 11 (refer to Section 2) was used, i.e.:

$$K=\frac{L_2^{\,2}-L_1^{\,2}}{8(T_2-T_1)}$$

Where L_1 = initial distance (m) at time T_1 between the drogue pairs
L_2 = distance between the drogue pairs at time T_2

$T_2 - T_1$ = total time in seconds.

The α-values were subsequently determined, applying the '4/3 law', presently considered to be applicable to all 'deep sea outfall' studies (refer to Equation 4 in Section 2), i.e.:

$$K_0 = \alpha L^{4/3}$$

From the tracer measurements at Richards Bay, Vlees Bay and Hout Bay the actual prototype diffusion coefficient and, subsequently the α-values were determined from the actual secondary dilutions, assuming the Brooks (1960) method for 'open sea conditions', i.e. the '4/3 law', applies.

4. RESULTS AND DISCUSSION

4.1 Comparison of Predicted Secondary Dilutions to Measured Field Data

For the purpose of this project, the actual secondary dilutions measured during three field experiments are compared with predicted secondary dilutions, based on the standard method applied in South Africa, i.e. Brooks method (1960) assuming the '4/3 law' and a α-value of 0,0005 $m^{2/3}$ s^{-1} (Brooks, 1960; Yudelson, 1967; Okubo, 1974; Pearce, 1969).

4.1.1 Richards Bay

The surface concentrations of the tracer and secondary dilutions (log scale) versus distance measured at Richards Bay during the field experiment on 11 September 1991 are illustrated in Figures 4a and 4b, respectively.

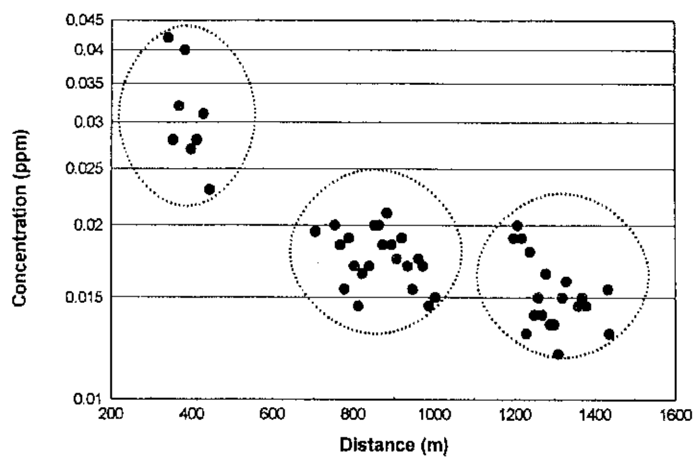


Figure 4a. Surface tracer concentrations (log scale) versus distance from discharge location for Richards Bay on 11 September 1991

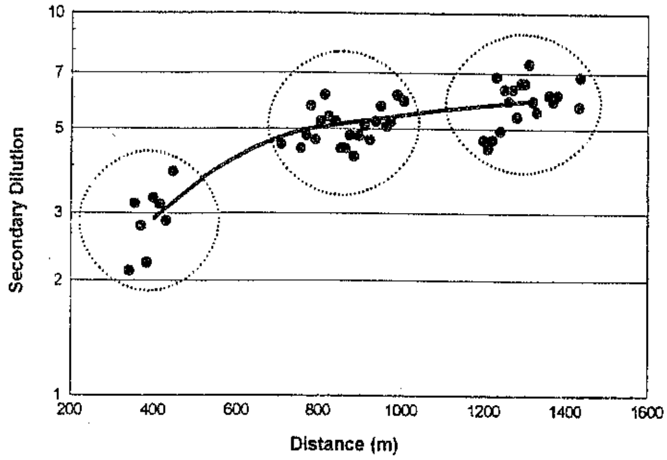


Figure 4b. Secondary dilutions (log scale) versus distance from discharge location for Richards Bay on 11 September 1991

The measured secondary dilutions (averages of grouped data) versus distance measured for Richards Bay are also shown in Table 1a.

TABLE 1a. Measured secondary dilutions versus distance measured for Richards Bay

DISTANCE (m)	SECONDARY DILUTION
400	2,98
900	5,02
1 300	5,87

To obtain a spatial overview of the behaviour of the moving waste field (transport and 'growth'), circumnavigations of the waste field were conducted (Figure 4c). Due to the strong currents on the day of the exercise, the longitudinal dispersion of the waste field was more than five times the lateral dispersion. For comparison with the theoretical predicted waste field width, using Brooks method (1960), the diameter of the 'circle' representing the measured width of the waste field was used as a width. The time it took to circumnavigate the waste field was also taken into account. These estimated waste field widths are tabulated in Table 1b.

TABLE 1b. Measured waste field width versus distance for Richards Bay

DISTANCE (m)	WIDTH (m)
500	168
1 000	185
1 600	209
2 400	280

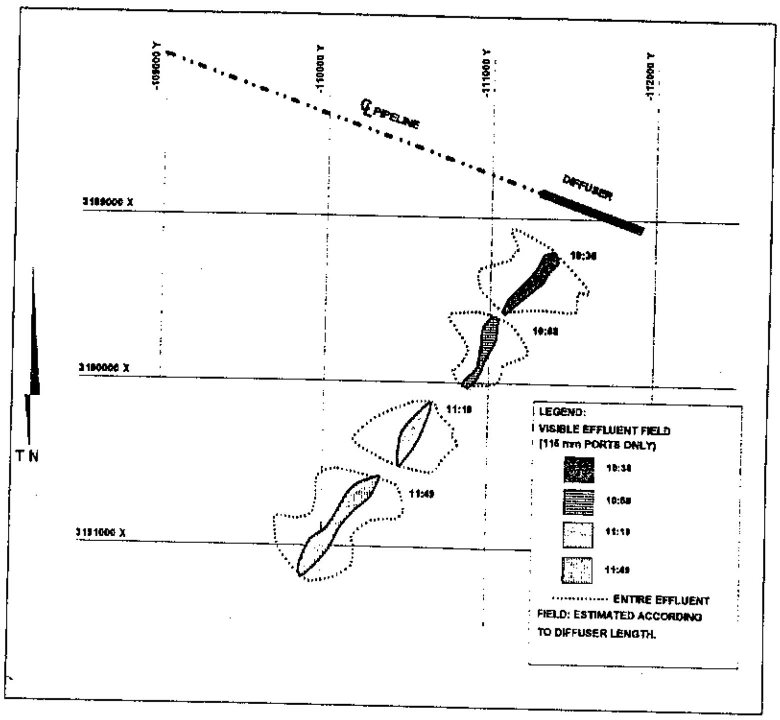


Figure 4c. Richards Bay: Transport of the waste field on 11 September 1991 (taken from WRC [1994])

To predict secondary dilutions for Richards Bay, the following input data were used (refer to Section 3 and WRC (1994)):

- The initial surface waste field (b), also referred to as the 'boil', was 30 m. It relates to the diffuser width (38,5 m, i.e. 6 ports at 6,5 m spacing) and the orientation of the diffuser to the current direction which was 80 degrees on the day of the exercise;

- Current speeds: Surface = 0,55 m s^{-1}
  -5 m = 0,41 m s^{-1}
  -10 m = 0,35 m s^{-1}

The predicted secondary dilutions and predicted width of the waste field (according to Brooks (1960) method, assuming the '4/3 law' and a α-value of 0,0005 $m^{2/3}\ s^{-1}$) versus distance for Richards Bay are provided in Tables 1c and 1d, respectively.

TABLE 1c. Predicted secondary dilutions versus distance for Richards Bay

U_a (m s^{-1})	n	DISTANCE - m					
		250	500	750	1 000	1 250	1 500
0,55	4/3	1,04	1,21	1,43	1,68	1,95	2,23
	1	1,03	1,18	1,36	1,56	1,75	1,95
0,41	4/3	1,08	1,36	1,70	2,06	2,44	2,86
	1	1,07	1,30	1,56	1,83	2,10	2,35
0,35	4/3	1,12	1,48	1,89	2,33	2,86	3,36
	1	1,11	1,39	1,70	2,03	2,33	2,64

TABLE 1d. Predicted waste field width (L_x) versus distance for Richards Bay

U_a (m s^{-1})	n	DISTANCE - m						
		250	**500**	**750**	**1 000**	**1 250**	**1 500**	**2 000**
0,55	4/3	39	48	59	70	81	93	119
	1	38	47	56	64	73	81	-
0,41	4/3	42	55	70	86	102	120	158
	1	41	53	64	76	87	98	-
0,35	4/3	44	60	78	97	117	139	185
	1	43	57	70	83	97	110	-

A comparison of the predicted data and the field data for both secondary dilution and waste field width versus distance from the discharge location for Richards Bay are presented in Figures 4d and 4e, respectively.

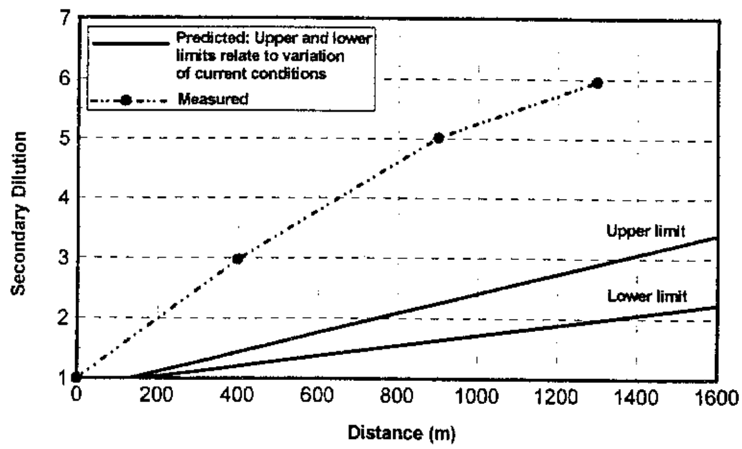


Figure 4d. Predicted and measured secondary dilutions for Richards Bay

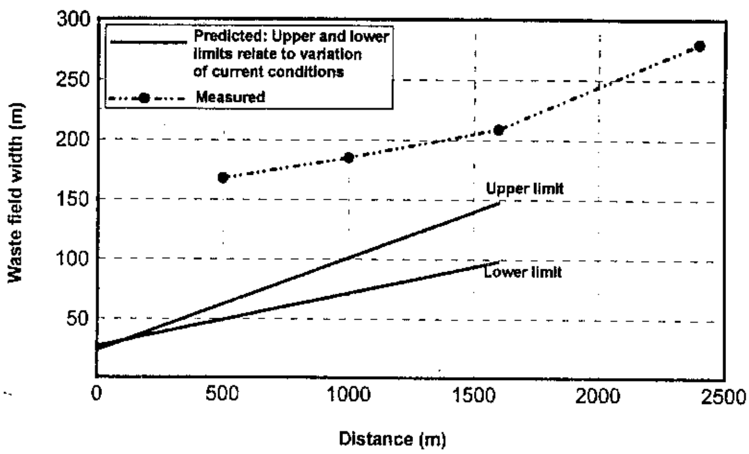


Figure 4e. Predicted and measured waste field width for Richards Bay

Using a α-value of 0,0005 $m^{2/3}$ s^{-1}, the predicted secondary dilutions at Richards Bay were about 2,5 times less than the measured dilutions. Previous studies in the area (Pearce, 1969), had also indicated that a α-value of 0,0005 $m^{2/3}$ s^{-1} can be considered as conservative. The actual α-value on the day of the exercise was 0,0017 $m^{2/3}$ s^{-1} applying the '4/3 law'. The predicted waste field width was also about two times less than the measured width.

4.1.2 Vlees Bay

The surface concentrations of the tracer and secondary dilutions (log scale) versus distance measured at Vlees Bay during the field experiment on 10 November 1992 are illustrated in Figures 5a and 5b, respectively.

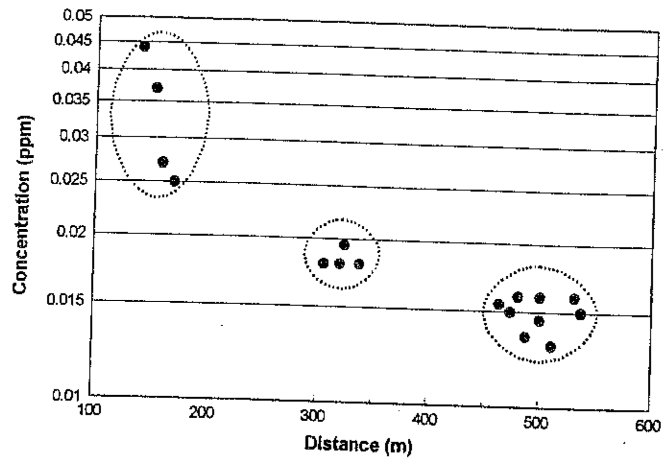


Figure 5a. Surface tracer concentrations (log scale) versus distance from discharge point for Vlees Bay on 10 November 1992

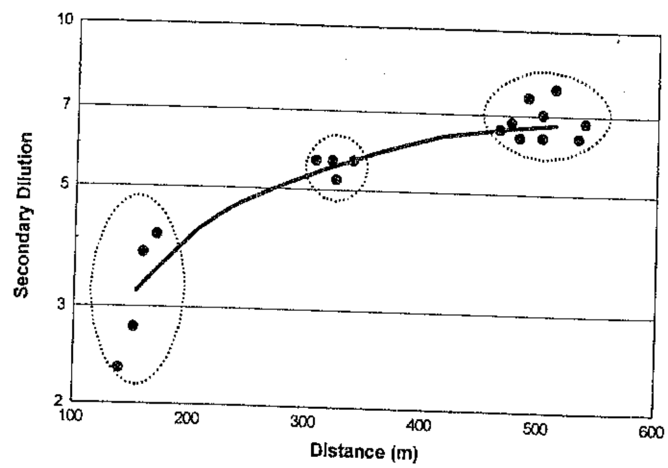


Figure 5b. Secondary dilutions (log scale) versus distance from discharge point for Vlees Bay on 10 November 1992

The measured secondary dilutions versus distance measured for Vlees Bay are also provided in Table 2a.

TABLE 2a. Measured secondary dilutions versus distance measured for Vlees Bay

DISTANCE (m)	SECONDARY DILUTION
150	3,2
320	5,6
500	6,7

To obtain a spatial overview of the behaviour of the moving waste field (transport and 'growth'), circumnavigations of the waste field were conducted (Figure 5c). From these results the waste field widths were determined. The results are tabulated in Table 2b.

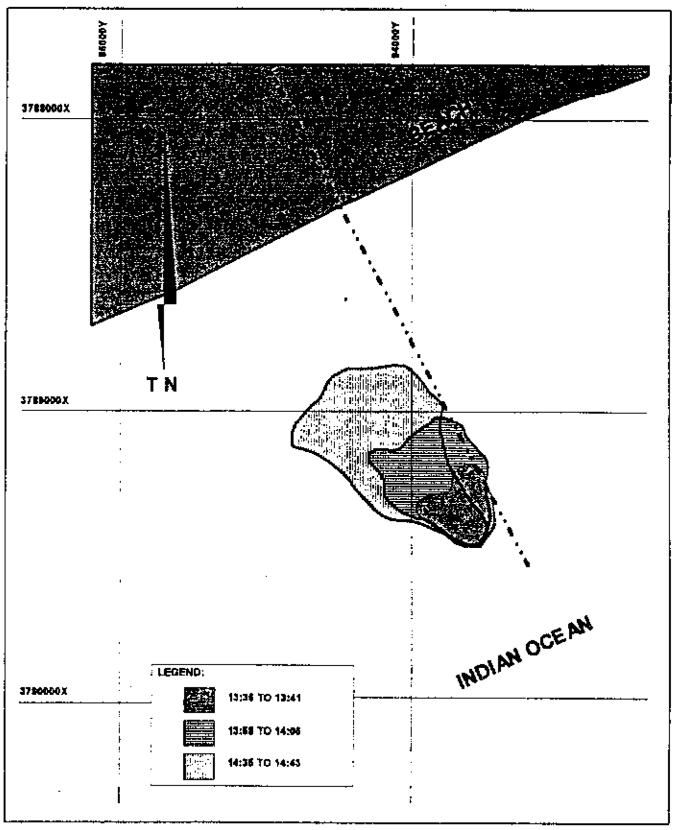


Figure 5c. Vlees Bay: Transport of the waste field on 10 November 1992

TABLE 2b. Waste field width versus distance measured for Vlees Bay

DISTANCE (m)	WIDTH (m)
200	220
360	340
630	450

To predict secondary dilutions for Vlees Bay, the following input data were used (refer to Section 3 and WRC (1994)):

- The initial surface waste field width (b) was 25 m, taking the diffuser length as 38,5 m and the angle between the diffuser orientation and the current direction as 40 degrees;
- Average current speeds: Surface = 0,14 m s^{-1}
  -5 m = 0,13 m s^{-1}
  -10 m = 0,08 m s^{-1}

The predicted secondary dilutions and the predicted waste field width versus distance for Vlees Bay are provided in Tables 2c and 2d, respectively.

TABLE 2c. Predicted secondary dilutions versus distance for Vlees Bay

U_a (m s^{-1})	n	DISTANCE - m		
		200	**400**	**600**
0,14	4/3	1,6	2,7	3,8
	1	1,5	2,2	2,9
0,13	4/3	1,6	2,8	4,1
	1	1,5	2,3	3,0
0,08	4/3	2,3	4,5	6,9
	1	2,0	3,3	4,5

TABLE 2d. Predicted waste field width (L_x) versus distance for Vlees Bay

U_a (m s^{-1})	n	DISTANCE - m		
		200	**400**	**600**
0,14	4/3	54	89	130
	1	50	75	100
0,13	4/3	56	95	141
	1	52	79	106
0,08	4/3	80	153	240
	1	69	113	157

A comparison of the measured data and the field data for both secondary dilution and plume width versus distance from the discharge location for Vlees Bay are presented in Figures 5d and 5e, respectively.

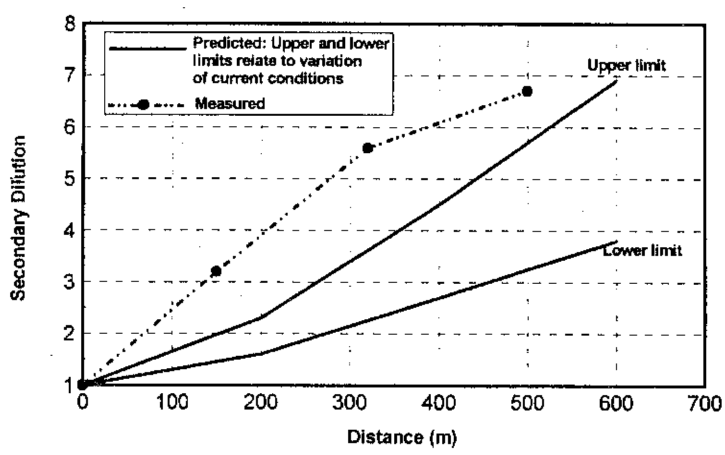


Figure 5d. Predicted and measured secondary dilutions for Vlees Bay

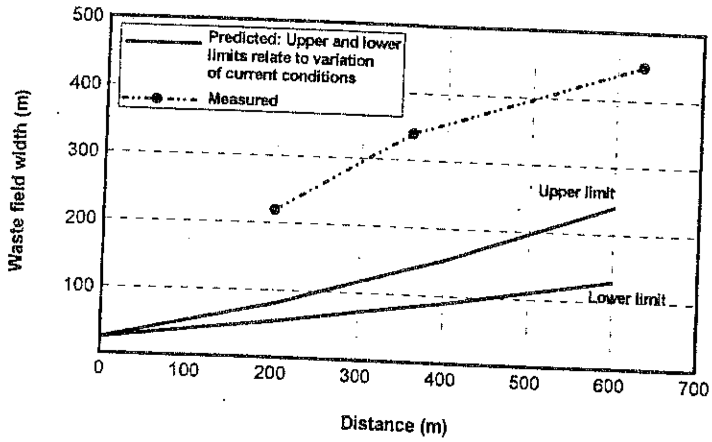


Figure 5e. Predicted and measured waste field widths for Vlees Bay

For the experiment at Vlees Bay, the predicted secondary dilutions, using a α-value of 0,0005 $m^{2/3}$ s^{-1}, were slightly less than the measured secondary dilutions.

The predicted waste field width was also about two times less than the measured width, possibly associated with the estimation of the angle between the current direction and the diffuser orientation (i.e. θ). This angle is used to calculate the effective diffuser width (i.e. the initial waste field width, b, where $b = w \sin \theta$). The estimation of the effective diffuser width also affects the prediction of secondary dilutions, but not as drastically as for the prediction of waste field width. For a relatively short diffuser, the effective diffuser width would be less affected by an inclined current considering the width of the initial waste field ('boil'), relative to the length of the 'boil'.

4.1.3 Hout Bay

Due to the varying near-stagnant conditions at Hout Bay (varying wind and near stagnant ambient currents resulted in a complex transport path) the secondary dilutions were determined versus time after surfacing of the plume. The surface concentrations of the tracer and secondary dilutions (log scale) versus time measured at Hout Bay during the field experiment on 12 October 1993 are illustrated in Figures 6a and 6b, respectively.

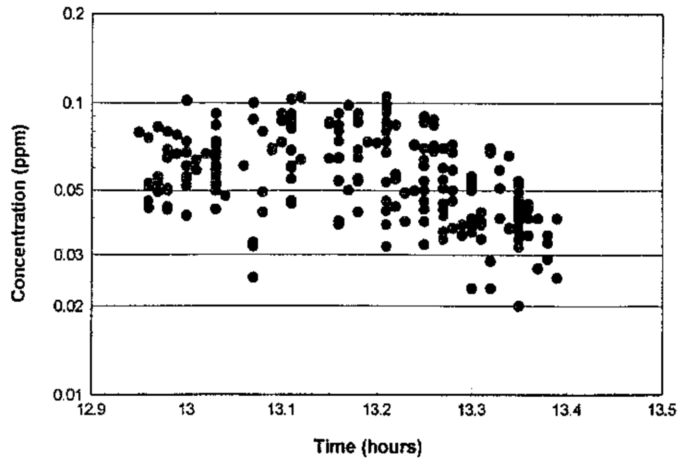


Figure 6a. **Surface tracer concentrations (log scale) versus time from discharge location for Hout Bay on 12 October 1993**

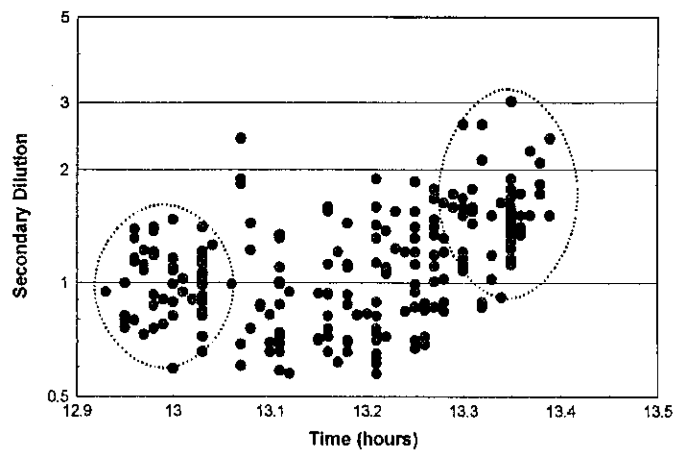


Figure 6b. **Secondary dilutions (log scale) versus time from discharge location for Hout Bay on 12 October 1993**

The measured secondary dilutions versus time measured for Hout Bay are also provided in Table 3a.

TABLE 3a. **Measured secondary dilutions versus time measured for Hout Bay**

TIME (min)	SECONDARY DILUTION
6	1
36	1,5

To obtain a spatial overview of the moving waste field (transport and 'growth'), circumnavigations of the waste field were conducted (Figure 6c). The results are tabulated in Table 3b.

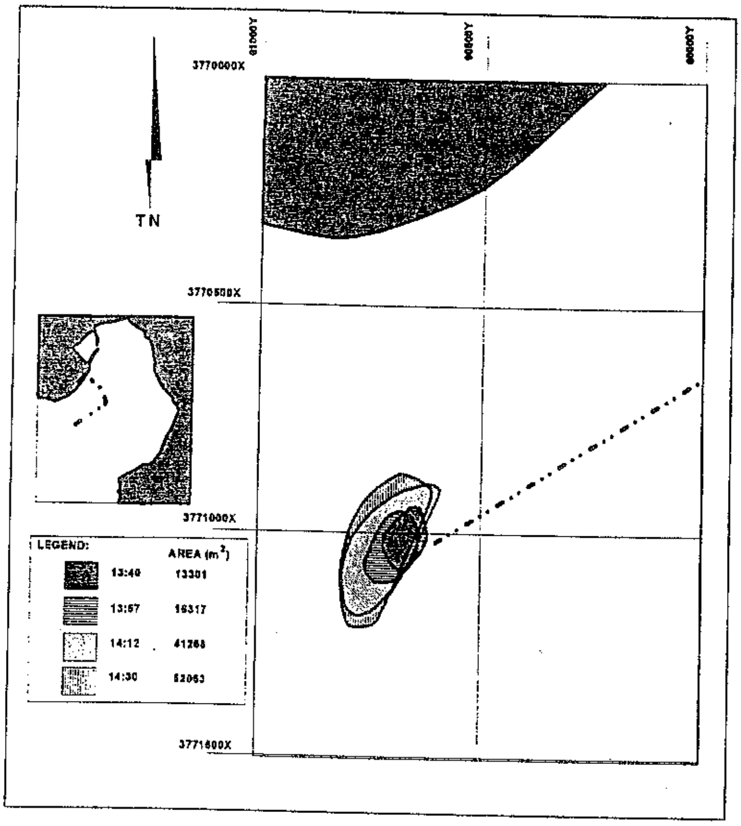


Figure 6c. Hout Bay: Transport of the waste field on 12 October 1993

TABLE 3b. Waste field width versus time measured for Hout Bay

TIME (min)	WIDTH (m)
58	130
75	140
90	220
108	260

To predict secondary dilutions for Hout Bay, the following input data were used (refer to Section 3 and WRC (1994)):

- The initial waste field width (b) was 40 m - only five ports were in operation and the angle between the diffuser orientation and the current was 90 degrees;

- Average current speeds: Surface = 0,09 m s^{-1}
  -5 m = 0,04 m s^{-1}
  -10 m = 0,06 m s^{-1}

The predicted secondary and waste field width versus time for Hout Bay are provided in Table 3c. The dilutions (based on measured concentrations) and waste field width could not be given in distance, due to the lack of a descriptive path owing to varying current conditions. After two hours the total distance was only about 500 m. The effective distance of the waste field width from the discharge location after that time was even less due to the change in currents. For the offshore environment such conditions can be considered as 'almost stagnant'.

TABLE 3c. Predicted secondary dilutions (S_e) and waste field width (L_x) versus time for Hout Bay

	n	TIME (minutes)						
		10	20	40	60	80	100	120
S_e	4/3	1,05	1,25	1,78	2,46	3,16	3,94	4,74
	1	1,04	1,21	1,63	2,06	2,51	2,96	3,37
L_x (m)	4/3	53	67	98	134	172	213	257
	1	52	65	89	114	138	165	148

A comparison of the measured data and the field data for both secondary dilution and plume width versus time for Hout Bay are presented in Figures 6d and 6e, respectively.

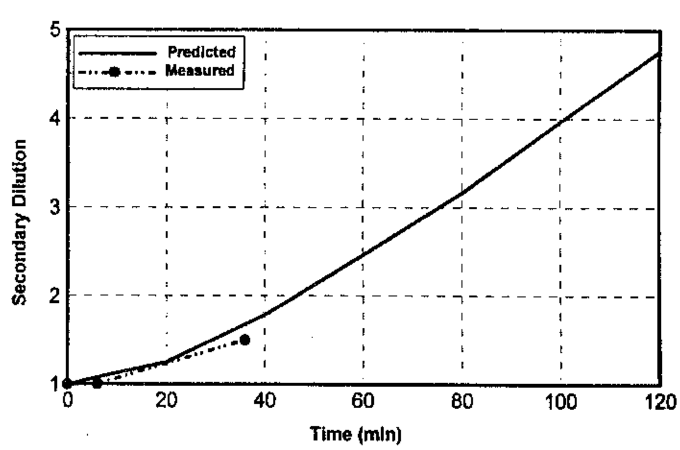


Figure 6d. Predicted and measured secondary dilutions for Hout Bay

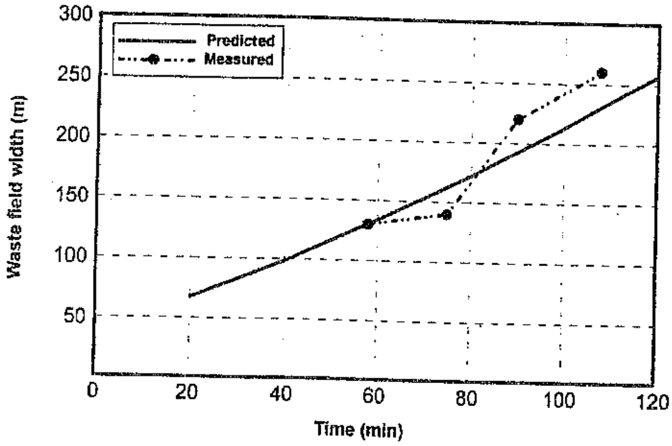


Figure 6e. Predicted and measured waste field widths for Hout Bay

Changing current conditions, which caused reversal of the moving waste field, limited the time period during which concentration measurements after the initial dilution process (i.e. after surfacing of the plume) could be conducted at Hout Bay. Due to the 'near stagnant' conditions, measured secondary dilutions were only limited to about 1,5 after 36 minutes, which were slightly less than the predicted secondary dilutions.

The relationship between the achievable secondary dilutions ($S_e = C_0/C_{max}$) and the dimensionless parameter βx/b for n = 0, n = 1 and n = 4/3 are illustrated in Figure 7. The measured secondary dilutions at Richards Bay, Vlees Bay and Hout Bay, using a α of 0,0005 $m^{2/3}$ s^{-1} , are also super-imposed on these.

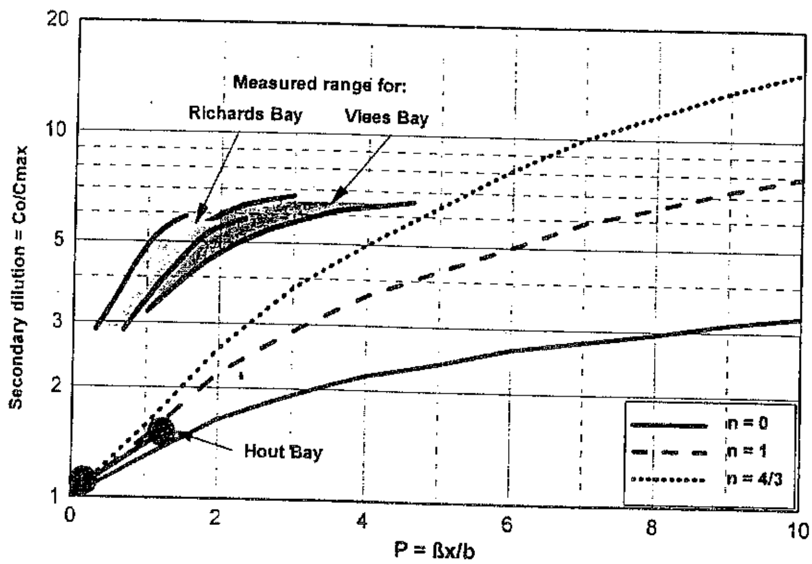


Figure 7. Relationship between secondary dilution and the dimensionless parameter (p), as well as measured secondary dilutions for Richards Bay, Vlees Bay and Hout Bay

The under-prediction of achievable secondary dilutions for Richards Bay and Vlees Bay, using a α-value of 0,0005 $m^{2/3}$ s^{-1}, is clearly illustrated.

4.2 Determination of Prototype Diffusion Coefficients (and α-values)

A comparison of the measured and predicted secondary dilutions (based on the standard procedure applied in South Africa, i.e. method of Brooks (1960) assuming the '4/3 law' and a constant α-value of 0,0005 $m^{2/3}s^{-1}$) yielded a trend from under-estimation on the east coast (Richards Bay) to an over-estimation of secondary dilutions at Hout Bay in the western Cape (refer to Section 4.1) . This could imply that either the '4/3 law', i.e. assuming open ocean conditions, does not apply for all areas along the 3 000 km coastline of South Africa or that the selected α-value are site-related, especially when considering the diversity of conditions along the South African coast.

In this section an attempt will be made to determine prototype α-values (based on actual diffusion coefficient measurements) for a number of areas around the South African coastline, using available data collected along the coast over a period of 10 years (Section 3.1). As it is presently assumed that the 'open sea' condition applies to all deep sea outfalls along the South African coast, Brooks' (1960) method, assuming 'the 4/3 law' was applied in order to estimate α-values from measured diffusion coefficients.

4.2.1 Determination of diffusion coefficients (and α-values) based on drogue measurements

Extensive drogue data from a number of areas along the South African coast were used in this study, i.e. Noordwesbaai, False Bay, Hout Bay, Vlees Bay and East London. The detailed drogue data are presented in Appendix A.

From the selected drogue measurements of each study site the following parameters were calculated to determine the diffusion coefficient according to Equation 11 (refer to Section 2):

I. Initial separation (L_1)

ii. Separation at retrieval (L_2)

iii. Time (T_1) for L_1

iv. Time (T_2) for L_2

v. Total distance (S)

vi. Total time (T_2 - T_1)

vii. Transport velocity: $\frac{S}{T_2 - T_1}$

viii. Diffusion coefficient: $K = \frac{L_2^2 - L_1^2}{8(T_2 - T_1)}$

ix. The α-value based on the '4/3 law', i.e $K = \alpha L^{4/3}$.

The detailed sets of K-values and α-values calculated for each site are presented in Appendix A.

To gain a better understanding of the diffusion processes and the influencing parameters, an attempt was made to obtain a relationship between the estimated α-values and length scale (L_x), transport distance, current velocity, water depth and wind speed. The best fit to the raw data proved to be exponential and yielded the following relationships:

$$\alpha = 0{,}00038\ e^{2{,}0496u}$$

$$\alpha = 0{,}00052e^{0S} = 0{,}00052$$

$$\alpha_{surface} = 0{,}00056e^{0S} = 0{,}00056$$

$$\alpha_{-5m} = 0{,}0005\ e^{0S} = 0{,}0005$$

$$\alpha = 0{,}00069\ e^{-0{,}0049L}$$

$$\alpha = 0{,}00063\ e^{-0{,}0033V}$$

$$\alpha = 0{,}00054\ e^{-0{,}0216T}$$

Where
u = current velocity (m s^{-1})
S = total distance (m)
L = length scale (initial distance between drogues)
V = wind speed (knots)
T = total time (hours)

The relationship versus transport distance (S) yields a constant value of 0,00052 $m^{2/3}s^{-1}$ for α-values.

The data for each study site and for the overall data set (all sites) were grouped in various combinations of current velocities, water depth, total transport distance, length scales and wind conditions in order to determine the effect of these parameters on the estimated α-values. Detailed analysis and plots are presented in Appendix B.

The combinations were as follows:

PARAMETER	COMBINATION
Current velocities	< 0.1; 0,1 to 0,2; > 0,2 m s^{-1}
Depth	surface and -5 m
Total distance (S)	< 500; 500 - 1 000; > 1 000 m
Length scale (L)	< 40; 40 - 80; 80 - 120 m
Wind speed	< 5; 5-15; > 15 knots
Time	<1; 1-2; >2 hours

After a statistical review of the distributions of the selected sets of grouped data (see Appendix C), the *median* value was shown to be more realistic than the average values for K- and α-values, due to the variation in magnitude and limited number of samples for certain sites.

The median K- and α-values for the various combinations are presented in Tables 4a to 4f and illustrated in Figures 8a to 8f. The notation 'S' and 'SS' relates to surface and sub-surface (-5 m) drogue measurements

TABLE 4a. Median K- and α-values for Noordwesbaai determined for various combinations of conditions

SAMPLE #	CONDITIONS					MEDIAN	
	Wind	Currents (m s^{-1})	S/SS	L (m)	S (m)	K-Value	α-Value
147	ALL	ALL	S/SS	ALL	ALL	0,0667	0,000375
79	ALL	ALL	S	ALL	ALL	0,073	0,00039
67	ALL	ALL	SS	ALL	ALL	0,058	0,00036

TABLE 4b. **Median K- and α-values for False Bay determined for various combinations of conditions**

SAMPLE #	CONDITIONS					MEDIAN	
	Wind	Currents (m s^{-1})	S/SS	L (m)	S (m)	K-Value	α-Value
51	ALL	ALL	S/SS	ALL	ALL	0.1252	0,00037
20	ALL	ALL	S	ALL	ALL	0,1248	0,000317
31	ALL	ALL	SS	ALL	ALL	0,1256	0,00038

TABLE 4c. **Median K- and α-values for Hout Bay determined for various combinations of conditions**

SAMPLE #	CONDITIONS					MEDIAN	
	Wind	Currents (m s^{-1})	S/SS	L (m)	S (m)	K-Value	α-Value
57	ALL	ALL	S/SS	ALL	ALL	0,112	0,00077
27	ALL	ALL	S	ALL	ALL	0,227	0,00091
28	ALL	ALL	SS	ALL	ALL	0,0809	0,00074

TABLE 4d. **Median K- and α-values for Vlees Bay determined for various combinations of conditions**

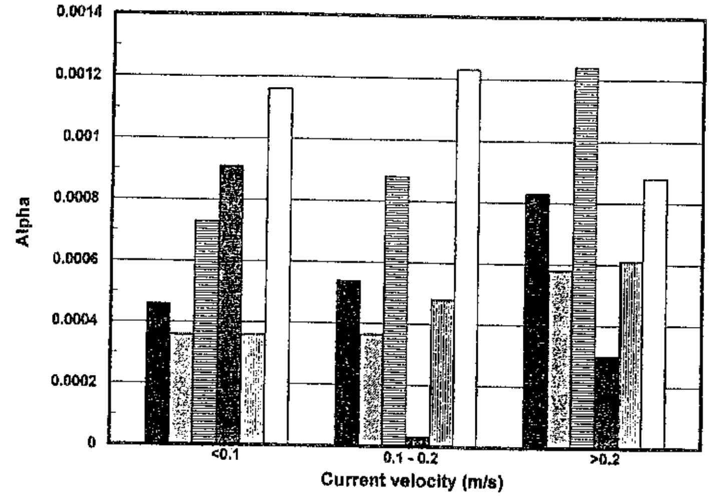
SAMPLE #	CONDITIONS					MEDIAN	
	Wind	Currents (m s^{-1})	S/SS	L (m)	S (m)	K-Value	α-Value
54	ALL	ALL	S/SS	ALL	ALL	0,1632	0,00051
24	ALL	ALL	S	ALL	ALL	0,2064	0,00046
30	ALL	ALL	SS	ALL	ALL	0,1438	0,00052

TABLE 4e. **Median K- and α-values for East London determined for various combinations of conditions**

SAMPLE #	CONDITIONS					MEDIAN	
	Wind	Currents (m s^{-1})	S/SS	L (m)	S (m)	K-Value	α-Value
93	ALL	ALL	S/SS	ALL	ALL	0,1564	0,0011
52	ALL	ALL	S	ALL	ALL	0,1681	0,00112
41	ALL	ALL	SS	ALL	ALL	0,1304	0,00109

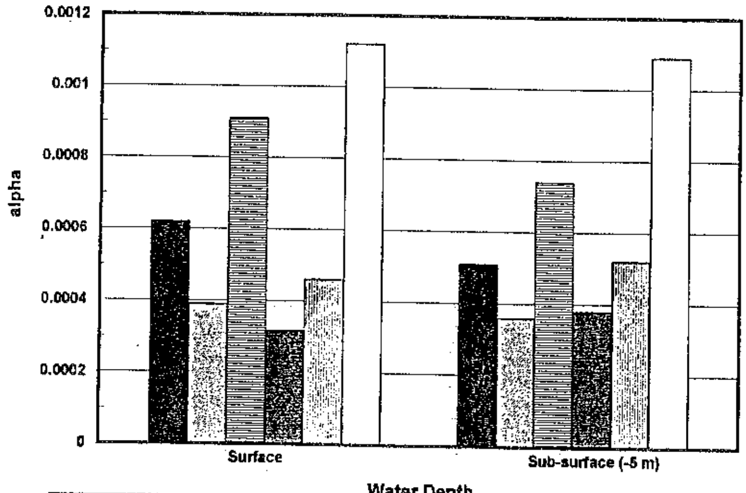
TABLE 4f. **Median K- and α-values for all sites (grouped) determined for various combinations of conditions**

SAMPLE #	CONDITIONS						MEDIAN	
	Wind	Currents (m s^{-1})	Time (hours)	S/SS	L (m)	S (m)	K-Value	α-Value
400	ALL	ALL	ALL	S/SS	ALL	ALL	0.1050	0,00058
205	ALL	ALL	ALL	S	ALL	ALL	0,1197	0,00062
199	ALL	ALL	ALL	SS	ALL	ALL	0,0931	0,00051
158	ALL	< 0,1	ALL	S/SS	ALL	ALL	0,0841	0,00046
137	ALL	0,1-0,2	ALL	S/SS	ALL	ALL	0,1188	0,00054
109	ALL	> 0,2	ALL	S/SS	ALL	ALL	0,1416	0,00083
159	ALL	ALL	ALL	S/SS	ALL	< 500	0,1042	0,00055
114	ALL	ALL	ALL	S/SS	ALL	500-1000	0,0856	0,00050
131	ALL	ALL	ALL	S/SS	ALL	> 1000	0,1263	0,00062
136	ALL	ALL	ALL	S/SS	< 40	ALL	0,0547	0,00079
192	ALL	ALL	ALL	S/SS	40-80	ALL	0,1220	0,00054
76	ALL	ALL	ALL	S/SS	> 80	ALL	0,1782	0,000361
70	< 5	ALL	ALL	S/SS	ALL	ALL	0,0865	0,000727
193	5-15	ALL	ALL	S/SS	ALL	ALL	0,1252	0,00060
73	>15	ALL	ALL	S/SS	ALL	ALL	0,2104	0,00074
133	ALL	ALL	< 1	S/SS	ALL	ALL	0,1429	0,00082
146	ALL	ALL	1-2	S/SS	ALL	ALL	0,0931	0,00051
120	ALL	ALL	> 2	S/SS	ALL	ALL	0,0793	0,00045



	<0.1	0.1 - 0.2	>0.2
All data	0.000460	0.000540	0.000830
Noordwesbaal	0.000360	0.000365	0.000580
Hout Bay	0.000730	0.000880	0.001240
False Bay	0.000910	0.000033	0.000300
Vlees Bay	0.000360	0.000480	0.000610
East London	0.001160	0.001230	0.000880

Figure 8a. **Median of α-values calculated for each sites, in both surface and sub-surface (-5 m) waters at different current velocities**



	Surface	Sub-surface (-5 m)
All data	0.000620	0.000510
Noordwesbaal	0.000390	0.000360
Hout Bay	0.000910	0.000740
False Bay	0.000317	0.000380
Vlees Bay	0.000460	0.000520
East London	0.001120	0.001090

Figure 8b. **Median of α-values calculated for all sites, in both surface and sub-surface (-5 m) waters at different water depths**

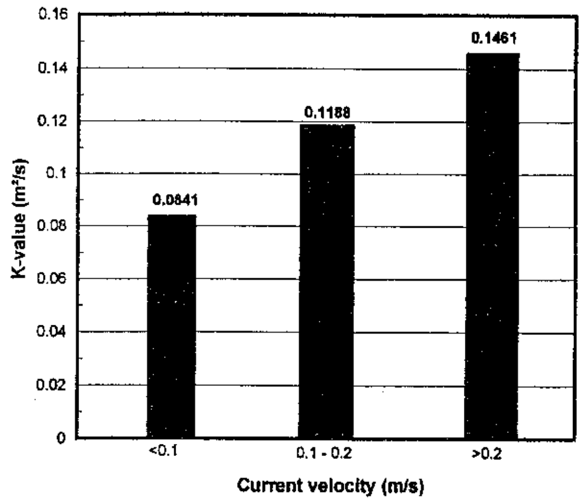


Figure 8c. **Median of K-values calculated for all sites, in both surface and sub-surface (-5 m) waters at different current velocities**

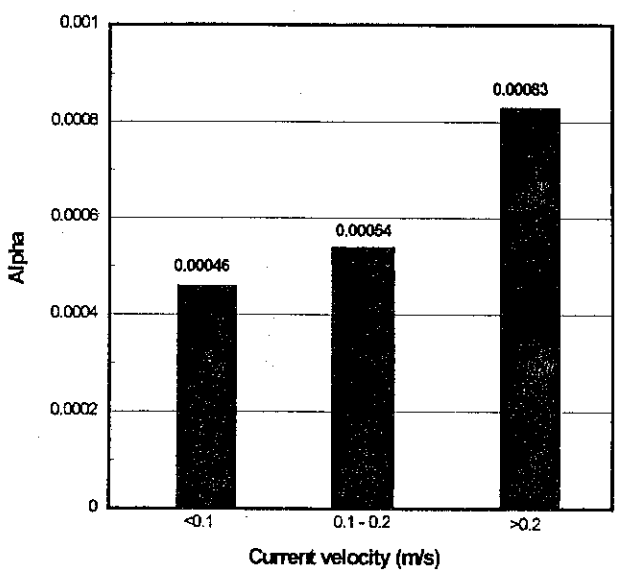


Figure 8d. **Median of α-values calculated for all sites, in both surface and sub-surface (-5 m) waters at different current velocities**

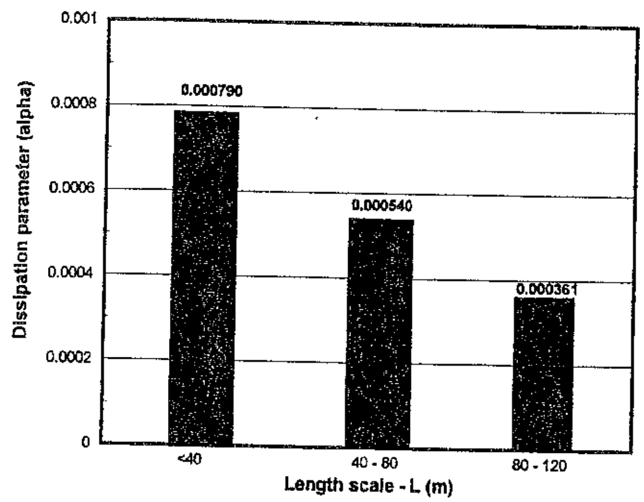


Figure 8e. **Median of α-values calculated for all sites, in both surface and sub-surface (-5 m) waters at different length scales**

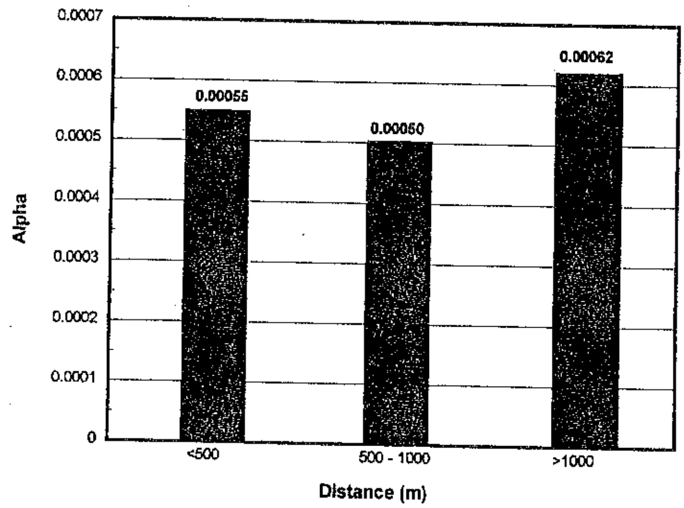


Figure 8f. **Median of α-values calculated for all sites, in both surface and sub-surface (-5 m) waters at different distances**

The median and exponential fit versus distance of all the K- and α-values calculated from the selected drogue data sets presented in Table 5.

TABLE 5. The median and exponential fit versus distance of all the K- and α-values calculated from the selected drogue data sets

LOCATION	K-VALUE		α-VALUE	
	Median	**Exp-fit**	**Median**	**Exp-fit**
All sites	0,105	0,0948	0,00058	0,00052
Noordwesbaai	0,0667	0,05228	0,000375	0,00031
Hout Bay	0,1120	0,1236	0,00077	0,00088
False Bay	0,1252	0,1366	0,00037	0,0005
Vlees Bay	0,1632	0,191	0,00051	0,00057
East London	0,1563	0,166	0,0011	0,00103

Although the median α-values of 0,00058 $m^{2/3}\ s^{-1}$ for all sites compare well with the general suggested value of 0,0005 $m^{2/3}\ s^{-1}$ for open sea conditions, the individual values for certain areas, for example Noordwesbaai differ substantially from the general α-value of 0,0005 $m^{2/3}\ s^{-1}$.

The effect of current velocity on the turbulent behaviour of the receiving water and subsequent α-value is illustrated in Figure 8b, where the α-value for currents less than 0,1 $m\ s^{-1}$ is 0,00046 $m^{2/3}\ s^{-1}$ compared to 0,00083 $m^{2/3}\ s^{-1}$ for currents greater than 0,2 $m\ s^{-1}$. The relation between the α-value and current speed for all available drogue data is:

$$\alpha = 0{,}00038\ e^{2{,}0496u}$$

In sheltered areas, where currents are weaker, a value of less than $0{,}0005 m^{2/3}\ s^{-1}$ should be used for a conservative approach, whereas in a more dynamic environment, for example east coast conditions (Richards Bay), values greater than $0{,}0005 m^{2/3}\ s^{-1}$ can be applied.

The validity of the equation $K = \alpha L^n$ which is independent of the transport distance was confirmed. The difference between the α-values for total distances of less than 500 m and greater than 1 000 m is less than 0,0001 $m^{2/3}\ s^{-1}$. The exponential fit yielded a constant:

$$\alpha = 0{,}00052$$

The estimated median α-value for sub-surface currents (-5 m water depth) is approximately 20 percent lower than the estimated value for surface currents. This is important especially when conducting performance evaluations of deep sea outfalls by the measuring of actual dilutions using tracer material in an effluent, as most of the samples are taken close to the sea surface.

The influence of the length scale (L_x) obtained from the drogue data is illustrated in Figure 8e. For a length scale of between 80 and 120 m the mean α-value (0,000361 $m^{2/3}\ s^{-1}$) is less than two times the α-value for a length scale of less than 40 m (0,00079 $m^{2/3}\ s^{-1}$).

4.2.2 Determination of diffusion coefficients (and α-values) based on tracer measurements

As explained in Section 3, the measured concentration data had to be re-organised in 'groups' so as to obtain a meaningful description of the moving waste field with regard to the reduction of concentrations and the achievable secondary dilutions. The grouped data (concentrations and secondary dilutions) versus distance are illustrated in Figures 4a and 4b and 5a and 5b for Richards Bay and Vlees Bay, respectively and versus time for Hout Bay in Figures 6a and 6b.

The average and median initial surface concentrations (in the initial surface plume, i.e. the 'boil') and concentrations at a distance x from the 'boil' for the experiments at Richards Bay and Vlees Bay are shown in Table 6a and 6b. Due to the weak and varying current directions on the day of the Hout Bay experiment and the subsequent meandering of the waste field, the reduction in concentrations was related to time after the surfacing of the dye. The average and median concentrations in the 'boil' measured at different times are given in Table 6c.

TABLE 6a. Average and median surface concentrations in the initial surface plume and at a distance for Richards Bay

	TRACER CONCENTRATIONS (ppm)			
	INITIAL	400 m	900 m	1300 m
AVERAGE	0,08889	0,0314	0,01766	0,01532
MEDIAN	0,008	0,0295	0,0175	0,0150

TABLE 6b. Average and median surface concentrations in the initial surface plume and at a distance for Vlees Bay

	TRACER CONCENTRATIONS (ppm)			
	INITIAL	150 m	320 m	500 m
AVERAGE	0,1027	0,03325	0,0184	0,01494
MEDIAN	0,1010	0,032	0,0180	0,0150

TABLE 6c. Average and median surface concentrations in the initial surface plume and at specific times after release for Hout Bay

	TRACER CONCENTRATIONS (ppm)		
	INITIAL	6 min	36 min
AVERAGE	0,0619	0,0665	0,0426
MEDIAN	0,0605	0,0683	0,0400

The current velocities on the days of the field measurements for the three sites are presented in Table 7.

TABLE 7. Current velocities on the days of the field measurements at the three sites

	CURRENT VELOCITY (m s^{-1})				
	Before the exercise		After the exercise		Average
	Surface	- 5 m	Surface	- 5 m	
Richards Bay	0,47	0,34	0,63	0,48	0,48
Vlees Bay	0,16	0,12	0,11	0,09	0,12
Hout Bay	0,02	0,02	0,16	0,08	0,07

The average of the surface and sub-surface (- 5 m) current speeds before and after the exercises were determined to apply to analytical estimations of the diffusion coefficients.

For the determination of the initial diffusion coefficient (K_o) and α-value applying the method of Brooks (1960), the initial length scale is taken as the width of the 'boil' in the direction of the ambient current. It was proposed that the length scale (L_x) is equal to the effective width of the diffuser (b), i.e. :

$$L = b \sin \theta$$

Where θ = angle between the ambient current direction and the diffuser orientation.

For Richards Bay, Vlees Bay and Hout Bay these were estimated as follows:

LOCATION	DIFFUSER WIDTH - b (m)
Richards Bay	30*
Vlees Bay	25**
Hout Bay	40***

* The surface plume related only to 6 x 115 mm ports (6,5 m spacing) and an angle of 80 degrees to the current direction.

** Angle between diffuser and current direction was 40 degrees. Total length of diffuser 38,5 m.

*** Only five ports were in operation. Angle between diffuser and current approximately 90 degrees.

The estimated diffusion coefficients and α-value, based on the '4/3 law' according to the method of Brooks (1960), for Richards Bay and Vlees Bay at selected distances and in the case of Hout Bay, after 6 minutes and 36 minutes after the surfacing of the dye are presented in Table 8.

TABLE 8. Diffusion coefficients (K) and α-value (assuming the '4/3 law') calculated for the three sites at different distances from the discharge location

SITE	DISTANCE (m)	DILUTION	p	u (m s^{-1})	K/L^2	α-value
Richards Bay	400 900 1300	2.98 5.02 5.87	2,4 4,1 4,6	0,4 0,48 0,56	0,0002 0,00018 0,00017	0,00193 0,00174 0,00164
Vlees Bay	150 320 500	3.2 5.6 6.7	2,6 4,5 5,2	0,14 0,12 0,10	0,0002 0,00014 0,00009	0,0011 0,00077 0,0005
Hout Bay	**TIME (min)** 6 36	1 1,5	- 1,1	- 0,07	- 0,00006	- 0,0007

The median α-values, calculated from the tracer measurements, for Richards Bay, Vlees Bay and Hout Bay were 0,00177, 0,00079 and 0,0007 $m^{2/3}$ s^{-1}, respectively, assuming that the '4/3 law' applied.

Although measured on one occasion only, the median α-value of 0,00177 $m^{2/3}$ s^{-1} at Richards Bay (as determined from tracer concentration measurements) corresponds to similar dynamic conditions such as at East London where the average α-value determined from measurements with drogue pairs yielded a median value of 0,0011 $m^{2/3}$ s^{-1}.

For Vlees Bay, the median α-value (0,00079 $m^{2/3}$ s^{1}) determined from the tracer measurements is approximately 50 percent higher than the median value (0,00051 $m^{2/3}$ s^{-1}) calculated from the drogue measurements.

For Hout Bay the α-value of 0,0007 $m^{2/3}$ s^{-1} calculated from the tracer measurements, corresponds well with the median value 0,00077 $m^{2/3}$ s^{-1} derived from the drogue measurements.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Results from this project indicate that the 'general' procedure applied in the prediction of achievable secondary dilutions for deep sea outfalls along the South African coast, i.e. the method of Brooks (1960), assuming the '4/3 law' and a α-value of 0,0005 $m^{2/3}\ s^{-1}$ does not always apply. This could imply that either the '4/3 law', i.e. assuming open ocean conditions, does not apply for all areas along the 3 000 km coastline of South Africa or that the selected α-value are site-related, especially when considering the diversity of conditions along the South African coast.

5.2 Although the median α-value of 0,0005 $m^{2/3}s^{-1}$, obtained for grouping all available drogue measurements, confirmed the 'general' α-value suggested by numerous authors, the α-values estimated for the individual sites, clearly showed the diversity of conditions along the 3 000 km South African coastline. However, the expected effects of current velocities, transport distance, the length scale and water depth were also confirmed by the drogue measurements.

5.3 For Richards Bay, the conservative prediction of secondary dilutions was most probably due to an incorrect α-values, taken that 'open sea condition', i.e. the '4/3 law' according to the method of Brooks (1960), definitely apply. However, the relatively low α-values obtained at Noordwesbaai on the west coast, may indicate that the '4/3 law' does not apply to a 'rugged' coastline (often found on the South African west coast), where the configuration of the coastline may affect the 'free spreading' (as is assumed by the '4/3 law') of the waste field.

5.4 Based on these findings the use of a 'general' α-value is therefore not recommended in determining the secondary dilutions and subsequent impact of an effluent waste field at distant locations in South Africa. The most typical values for certain areas should be considered and if detailed field measurements cannot be obtained to establish the actual diffusion coefficients, at least a range of values should be considered. The diffusion coefficients and α-values determined in this report could be used as a rough guideline.

5.5 Although the *prediction* of achievable secondary dilutions and subsequent impact at distant locations is considered appropriate for planning and feasibility phases of an outfall project, taking into account the near shore processes and the coastline configuration, it is strongly recommended that *field measurements* be conducted to obtain more accurate site specific diffusion characteristics of the area for the optimisation of the outfall during the detailed design phase.

5.6 Irrespective of the procedure or method used to predict the behaviour of a moving waste field, i.e. analytical methods or numerical modelling, a thorough understanding of the physical processes, the sensitivity and limitations of the prediction method or procedure to all variables, as well as the applicability of a certain methods to a specific area or near shore conditions is essential before any quantitative conclusions can be made with regard to the detailed outfall design. A simple equation or a 'black box' approach is therefore not always considered to be sufficient in providing reliable quantitative results on achievable secondary dilutions, especially taking into account the consequences of detrimental impact in terms of ecological, health and economical aspects, both in the short and long term.

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APPENDIX A

SELECTED DROGUE DATA

TABLE A.1 Drogue measurements, K-values and Alpha-values for Noordwesbaai

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
851118	SS	113459	87516	8893	144358	89858	9276	113442	87495	8884	144548	90006	9255	0.24057457	0.0037108156
811215	S	111800	106981	38443	135500	106734	36653	111800	106932	38406	135400	106727	36541	0.11707803	0.0004833345
811215	SS	112100	106920	38643	125100	106725	38448	112000	106970	38623	125300	106777	38294	0.54444444	0.0026772458
811215	S	123300	108961	37415	142700	108648	34889	123200	108936	37418	142800	108652	34792	0.16065424	0.002176871
811216	S	115800	106864	38588	130200	106629	38368	115800	106917	38623	130300	106710	38374	0.08343099	0.0003292331
811216	SS	115900	107060	38690	134400	107336	38582	115900	107120	38684	134400	107390	38563	0.00712302	3.01241E-05
811216	S	123600	107390	38342	141700	107210	37582	123600	107462	38332	145500	107283	37176	3.40101073	0.0112107017
811216	SS	123800	107527	38470	141200	107640	38218	123900	107607	38455	141200	107752	38199	0.1391844	0.0003945784
820209	S	105700	109063	38222	115500	109106	38524	105700	109044	38198	115500	109093	38497	0.00140086	1.46297E-05
820209	SS	103000	108941	38109	114900	108921	38464	103000	108924	38073	115000	108900	38441	0.01621835	0.0001193037
820209	S	104100	106946	38709	121400	106735	38947	104100	106948	38676	121300	106704	38871	0.12643369	0.0011915604
820209	S	124800	106680	37168	1332	106178	37220	124700	106692	37116	133000	106117	37194	-0.0042773	-2.12884E-05
820209	SS	125100	106833	37184	131500	106743	37254	124700	106692	37116	133000	106117	37194	32.2023438	0.038169606
820209	S	130000	105682	38404	135700	105567	38351	130000	105715	38389	135600	105598	38336	0.00467836	3.89969E-05
820209	SS	125800	105820	38442	135400	105913	38425	125800	105834	38406	135300	105934	38385	0.02042411	0.0001564218
820209	SS	143100	105280	39639	152400	105220	39485	143300	105262	39766	152500	105176	39675	0.84838836	0.001311489
820209	S	155800	106930	38500	165600	106977	38280	155900	106940	38505	165700	106951	38278	0.01993534	0.0007974138
820209	SS	155700	106966	38614	170200	107133	38764	155700	107020	38582	170300	107205	38720	0.10192308	0.0004085781
820209	S	161200	108633	37691	171300	108014	37351	161100	108663	37753	171100	108140	37387	0.42445355	0.0015033741
820209	SS	162800	108565	37855	170900	108223	37794	162800	108537	37870	170800	108230	37830	0.01707317	0.0001697149
820301	S	165400	108853	37513	173500	108887	37976	165500	108895	37530	173600	108907	36993	49.0160569	0.3034443615
820301	SS	165200	108920	37744	171200	108973	37690	165100	108965	37774	171200	109021	37697	0.05958333	0.0002913226
820302	S	85900	109161	37860	105400	109981	38097	90000	109120	37878	105200	109856	38079	0.2526087	0.0015886884
820302	SS	90100	109126	38018	110000	109747	38738	90100	109104	37999	110200	109735	38706	0.00565476	6.32669E-05
820302	S	95200	107261	38101	112800	107625	37468	95100	107252	38133	113000	107636	37488	0.01267361	0.0001185747
820302	S	121200	106256	38007	131900	106461	37425	121300	106220	38028	131800	106419	37445	0.01327736	9.18851E-05
820302	SS	122300	105594	39646	141400	105485	39147	122300	105562	39606	141600	105460	39000	0.36805556	0.0019346578
820302	S	122500	105604	39338	142400	105754	37700	122600	105583	39317	142300	105720	37700	0.00479692	5.21575E-05
820302	S	145800	107034	38295	155100	107186	37773	145900	106994	38327	155300	107138	37801	0.01823899	9.5872E-05
820302	SS	151100	108980	37892	160800	109096	37845	151100	108990	37930	161000	109126	37940	0.3063231	0.0022930572
820329	S	134200	108934	37175	160600	110106	33946	134300	108942	37155	160600	110116	33840	0.15729167	0.0026243821
820329	SS	134500	108907	37292	155900	109966	34961	134500	108921	37299	155800	109845	35075	0.42587065	0.0108767793
820329	S	143300	106953	37775	152700	107085	37030	143300	106903	37801	152900	107027	37035	0.00821759	3.80327E-05
820329	SS	135600	106997	38455	153400	106975	37910	135500	106940	38375	153300	106966	37594	1.91938776	0.0042348807

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
820331	SS	103800	108803	37530	114200	108952	37297	103800	108851	37579	121600	108956	37224	0.02083333	7.41969E-05
820331	S	103700	108755	37460	121400	108897	37014	104000	108818	37411	114100	108921	37125	0.14018471	0.0004079507
820331	S	105100	107049	38537	123600	107223	38157	105100	107099	38561	123600	107266	38178	0.01559524	7.3734E-05
820331	SS	112600	107088	38824	124500	107146	39106	112600	107116	38726	124400	107209	39121	0.16334388	0.0003430954
820331	S	130900	107287	36520	133500	107150	36202	130800	107282	36558	133600	107104	36229	0.11025641	0.0008532101
820331	S	135900	105978	38162	150400	106006	37511	135900	105977	38130	150500	105985	37452	0.09285256	0.0009133656
820331	S	144900	105400	39347	151900	105374	38999	144800	105434	39309	151800	105409	38940	0.14625	0.0007734762
820331	SS	145100	105464	39599	160100	105425	39433	145200	105493	39448	160100	105525	38782	12.2071131	0.0148191568
820401	SS	113400	107032	38404	125300	107134	37990	113600	107036	38375	125500	107144	37852	0.48225211	0.0053450724
820401	S	114800	108919	37202	131200	109146	36230	114700	108902	37212	131400	109124	36208	0.01436012	0.000269479
820401	SS	114900	108918	37361	131900	109298	36732	114900	108872	37314	131700	109188	36612	0.51331019	0.0019337002
820402	S	103100	108536	37553	105300	108480	37603	103000	108567	37543	105300	108486	37574	0.01742424	0.0001674983
820402	SS	102600	108661	37531	105000	108597	37529	102700	108624	37614	105100	108569	37634	0.30824653	0.0007544809
820402	S	94600	106919	38522	111100	106618	38527	94400	106870	38501	110900	106514	38534	0.19664216	0.0009800779
820402	SS	94500	106949	38571	111600	106802	38651	94500	106906	38551	111400	106728	38622	0.09313187	0.0005425486
820805	S	125400	108719	37232	140800	108818	35746	125300	108738	37175	140600	108854	35631	0.30717905	0.0013053294
820805	SS	124900	108710	37490	132600	108583	37081	125100	108694	37410	132500	108630	36992	0.19560811	0.0005528127
820805	S	133900	107262	37559	142400	107435	36858	133900	107261	37604	142500	107464	36955	0.38074074	0.0023779518
820805	SS	130700	107116	38291	143200	107283	37765	130600	107101	38247	143100	107220	37776	0.04727941	0.0002828583
820806	SS	121900	107107	38467	133500	107134	38170	121900	107121	38492	133700	107156	38165	0.00855263	9.75448E-05
820806	S	115900	109302	37561	135100	109430	36021	120100	109310	37521	135200	109444	36007	0.02366071	0.0001684971
820806	SS	120000	109261	37586	135900	109182	36820	115900	109302	37561	135800	109195	36755	0.03655462	0.0002094287
820806	S	145100	108200	36685	160600	108548	35546	145100	108184	36713	160500	108552	35646	0.24933333	0.0024289847
820806	SS	145200	108196	36880	161200	108512	36233	145300	108152	36901	161400	108415	36334	0.44877604	0.0025196693
820806	S	154500	106181	38565	164200	106269	38037	154500	106212	38580	164200	106280	38068	0.00380117	3.39256E-05
820806	SS	150800	106131	39123	163200	106160	38842	150800	106167	39093	163000	106195	38800	0.01966766	0.000116412
820903	S	103400	109142	37070	112900	109393	35872	103200	109112	37120	112800	109335	35925	0.10503788	0.0004645438
820903	SS	105500	109108	36992	112400	109180	36517	105500	109099	36970	112300	109162	36506	0.00862069	0.0001261372
820903	S	10440	107218	38345	114300	107560	37815	104400	107109	38347	114200	107530	37818	0.03582245	6.87843E-05
820903	SS	104500	107197	38500	114800	107300	38309	104500	107180	38475	114700	107323	38286	0.0047619	5.05611E-05
820903	S	122000	105824	38336	135600	106238	37160	122000	105798	38316	135400	106185	37291	0.41002604	0.0039048401
820903	SS	122200	105855	38450	134200	106219	38121	122130	105785	38436	134400	106184	38327	1.00429688	0.0033913751
820903	S	125930	107250	36405	132800	107399	36017	130000	107299	36350	132700	107445	35976	0.11907895	0.0003856398
820903	SS	123030	107151	36877	133100	107467	36353	123030	107168	36842	133000	107475	36283	0.11880165	0.0009010286
820903	S	145100	107144	38265	154900	107372	37545	145130	107151	38288	155000	107375	37609	0.12668822	0.0018257908
820903	SS	145000	107078	38465	152330	107203	38364	144930	107100	38494	152200	107196	38424	0.14452736	0.0011980442
820903	S	150830	109109	37209	162530	109785	35432	150800	109130	37250	162400	109797	35622	0.92321429	0.0055907782

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
820903	SS	151100	109109	37364	161000	109454	36585	151030	109120	37354	161200	109493	36583		
821010	S	105420	108881	37711	133200	108923	36457	105440	108864	37679	133340	108883	36374	0.0460452	0.0012596682
821010	S	111520	106942	38609	142100	106691	37177	111420	106865	38658	142140	106587	37160	0.0948203	0.0007907845
821010	SS	111840	106981	38867	125740	107131	38841	111740	106931	38935	125640	107082	38887	0.03113779	7.57747E-05
821012	SS	91040	108674	38159	113520	108289	38810	91120	108712	38198	113600	108308	38873	0.05486111	0.0001481774
821012	S	90920	108668	38241	115300	107833	40119	90840	108711	38277	115140	107864	40206	0.01965726	9.52445E-05
821012	S	92140	106872	38798	104420	106689	39003	92220	106922	38804	101420	106725	38945	0.06854633	0.0003193281
821012	S	125800	107780	38971	132720	107579	39346	125900	107781	38944	132600	107582	39291	0.05352823	0.0002878393
821012	SS	140900	108688	38140	152520	108558	38652	140820	108740	38114	152700	108649	38645	0.16363636	0.0020183567
821012	S	143820	108488	38720	153340	108262	39454	143800	108530	38692	153220	108303	39450	0.13509825	0.0005998444
821104	S	900550	109302	38091	120140	109332	39517	90130	109380	38074	115930	109486	39486	0.03204066	0.000171752
821104	SS	903350	109367	38228	115020	109975	39399	90250	109421	38211	114950	110360	39387	-0.0081409	-2.36834E-05
821208	S	80940	109166	37758	90320	109501	37591	80840	109241	37779	90430	109590	37630	-0.0640256	-0.000294534
821208	SS	80700	109081	37819	90000	109216	37790	80740	109130	37805	90100	109282	37740	0.1310559	0.0003940231
821208	S	82136	107222	38864	84730	107268	38880	82036	107255	38857	84720	107268	38862	0.16741352	0.0008860861
821208	SS	81956	107210	38820	92240	107400	38898	82036	107255	38857	92330	107424	38917	0.06547619	0.0006006967
821208	S	100510	108028	39896	112200	107881	39748	100540	108080	39903	112210	107889	39751	0.08159538	0.0003612914
821208	SS	100720	108029	39987	112610	107819	40129	100600	108080	39990	112530	107853	40123	0.07266811	0.0003699472
821208	S	102550	105540	37642	110350	105454	37457	102610	105542	37604	110430	105442	37435	0.03747357	0.0001976809
821208	S	124430	108617	35968	141410	108265	34864	124450	108653	35967	141250	108307	34827	0.04495614	0.0003512449
821208	S	131020	111132	35640	135330	111237	34657	131000	111158	35616	135410	111280	34599	0.04265799	0.0003586799
830112	S	95339	109355	36827	103848	109534	36353	95354	109325	36818	103819	109509	36362	0.19116795	0.0016456806
830112	SS	84809	109031	37631	114001	109578	36676	84828	109029	37571	113817	109599	36636	0.01268918	0.000128525
830112	S	90325	107036	38322	100809	107257	37451	90349	107014	38158	100710	107233	37349	0.01894637	8.06002E-05
830112	S	125729	108740	37105	154224	108877	34937	125755	108676	37100	145045	108836	34993	0.52780639	0.0005810128
830112	SS	125557	108745	37365	144051	108680	36443	125526	108712	37416	143907	108630	36452	0.00879232	3.4206E-05
830225	S	85222	109327	37843	94417	109317	37662	85202	109348	37819	94258	109328	37653	0.02202494	9.22353E-05
830225	SS	75825	108996	37834	94145	109250	37582	75927	109042	37881	94046	109165	37560	0.03270465	0.0003233917
830225	S	90337	107068	38925	95741	107128	38835	90249	107045	38880	95712	107127	38803	0.06822581	0.0002570147
830225	S	111452	107158	36860	123944	107482	36010	111442	107163	36877	123847	107496	35996	0.05891646	0.0003153233
830225	S	133757	108056	37742	144753	108101	36808	133804	108055	37726	144846	108118	36799	0.00191477	4.14473E-05
830225	SS	133531	107983	38036	144039	107962	37732	133553	108020	38046	144133	107966	37732	0.0033663	8.32781E-05
830225	S	135023	105843	39169	141949	105681	38978	135000	105876	39191	142039	105711	38943	0.04647518	0.0003596443
830225	SS	134852	105930	39278	141747	105807	39204	134844	105940	39265	141708	105795	39166	0.03907135	0.0002888723
														0.09502882	0.0022804496

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
830227	SS	84538	108966	37736	113430	109119	36675	82418	108880	37795	113532	109103	36577	0.01254688	2.55582E-05
830227	S	125006	108145	37371	151855	108246	36982	124948	108160	37351	151746	108280	36972	0.00883358	0.0001208416
830304	S	82523	108903	37785	104141	108835	37799	82617	108984	37710	104012	108684	37667	0.42857361	0.0008093157
830304	SS	85047	109030	37707	94213	109057	37779	85056	109049	37701	94137	109090	37740	0.08963869	0.0016594665
830304	S	83826	106869	38770	95624	106600	38986	84028	106924	38821	95452	106748	39213	1.8118587	0.0057278439
830304	SS	83804	106890	38794	111518	106717	39570	83717	106936	38824	111716	106899	39684	0.57112572	0.0027359668
830304	S	131550	107808	38253	133116	107749	38214	131601	107797	38227	133017	107756	38174	0.1150108	0.001337929
830419	SS	90841	108912	37464	105143	108239	36244	90903	108870	37406	105227	108149	36261	0.0659374	0.0002217344
830419	S	91039	108891	37401	105351	108207	36077	90957	108830	37398	105433	108195	35988	0.08751211	0.0003638555
830419	SS	114309	106861	38844	121848	106850	38826	114326	106891	38844	121903	106891	38828	0.04587424	0.0004921232
830419	S	95537	106821	38973	133315	106485	38276	95526	106794	38975	133425	106471	38251	0.0008424	1.03621E-05
830419	SS	113159	107010	36965	131307	106863	36952	113213	106987	36951	131219	106857	36927	0.00131839	1.63363E-05
830419	S	113251	106981	36860	124053	106870	36467	113314	106940	36817	124141	106820	36434	0.00180671	7.79302E-06
830419	S	115452	107911	38066	140833	107907	37376	115423	107913	38017	140748	107918	37336	0.01065952	5.93828E-05
830419	SS	122940	107676	37910	141257	107495	37448	123010	107671	37832	141152	107517	37316	0.23799822	0.0007121863
830419	SS	142603	109104	37582	144012	109133	37443	142522	109052	37591	144048	109103	37447	0.27517668	0.0013901494
830423	S	85724	108996	37959	134323	109579	36659	85714	108971	37947	134222	109533	36802	0.15877965	0.0018916638
830423	SS	85833	108997	37998	142211	109374	38680	85844	108982	37976	142310	109436	38672	0.02059301	0.0002589935
830423	S	94305	107075	38759	133047	107286	36044	94321	107047	38757	133145	107286	36075	0.00158286	1.85534E-05
830423	SS	90956	106976	38853	140836	107132	37355	90925	106951	38828	140727	107182	37266	0.06397182	0.0005512924
830424	S	91438	108788	37765	112738	107872	37199	91511	108708	37777	112819	107881	37305	0.07476504	0.0002136993
830424	SS	91446	108771	37773	110201	107803	37338	91538	108678	37825	110123	107850	37417	0.05639083	0.0001116353
830424	S	92604	107109	39000	140657	107786	38423	92542	107069	39005	140527	107920	38403	0.12409512	0.0008978128
830424	SS	94724	107099	39134	141319	107786	39740	94705	107053	39146	141422	107776	39793	0.00508461	2.95247E-05
830424	S	120947	107938	38087	143246	107723	36525	120920	107931	38027	143137	107713	36557	0.03679042	0.0001552216
830424	SS	121104	108039	38130	142622	107863	37365	121043	108040	38090	142720	107841	37334	0.00240207	1.75519E-05
830424	S	124205	107046	36938	135437	107104	36626	124210	107035	36935	135426	107086	36612	0.01120175	0.0004365059
830524	S	110201	108787	38076	134121	108159	38346	110146	108769	38095	134037	108137	38369	0.0042887	5.51907E-05
830524	SS	110319	108818	37953	115505	108728	37830	110355	108772	37945	115520	108701	37820	0.05437057	0.0003233897
830524	S	105143	106954	38757	140945	106307	39073	105005	106966	38710	141025	106242	39128	0.051517	0.0002912075
830524	SS	124806	106686	38597	140547	106536	38576	124812	106677	38611	140534	106534	38591	0.00128728	3.02937E-05
830524	S	142946	108752	38077	152432	108508	38035	142919	108698	38127	152621	108431	38113	0.250951	0.0008137103
830524	SS	143106	108932	37975	153101	109034	37846	143037	108880	38030	153015	108966	37917	0.13685675	0.0004274451
830524	S	144445	106912	38934	151430	106822	38979	144437	106935	38938	151331	106891	38954	0.3390056	0.0050809221

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
830524	SS	144236	106993	38896	150938	107051	38919	144326	107021	38940	151102	107064	38971	0.011791	6.05115E-05
830629	S	93304	109395	37693	120951	109898	36391	93328	109348	37682	120904	109774	36414	0.18038429	0.0010263483
830629	SS	93233	109326	37743	120009	109571	37053	93220	109293	37735	120028	109521	37055	0.01906899	0.0001734236
830629	S	94359	107195	38792	140212	107896	37997	94414	107167	38826	140318	107843	38207	0.36281708	0.0023324906
830529	SS	94539	107147	38835	114301	107413	39029	94529	107122	38854	114312	107394	39044	0.00710026	7.16731E-05
830701	S	92946	109257	37915	113010	109740	37698	93012	109270	37905	113150	109743	37866	0.4838732	0.0116117243
830701	S	133041	108919	38308	145554	108909	38648	133101	108957	38289	145512	108842	38610	0.10091923	0.0006807523
830701	SS	92845	109212	38001	120200	109522	38190	92838	109195	37991	120342	109635	38198	0.16916803	0.0031745722
830701	SS	125406	109166	38178	145744	109012	38601	121353	109174	37962	145657	108983	38626	0.76257077	0.0005878659
830701	SS	94001	107314	38824	114732	107891	39430	94010	107193	38835	114748	107871	39410	0.22810744	0.0003790612
830701	SS	134354	106979	39130	144207	106957	39407	134406	106961	39101	144139	106946	39365	0.02576582	0.0002327162
830701	S	94113	107208	38783	123333	108186	39524	94107	107192	38791	123249	108120	39546	0.05464217	0.0011679599
830728	S	95340	106923	38714	130906	105732	38115	95448	106881	38694	130735	105626	37895	0.61265564	0.0036619431
830728	SS	95331	106969	38763	131312	106102	38826	95317	106942	38749	131245	106101	38755	0.04295343	0.0004524494
830728	S	94217	108849	38212	124055	108026	39284	94207	108834	38188	123935	108057	39209	0.06746828	0.0007822483
830728	SS	94104	108776	38231	133322	107817	39823	94100	108776	38220	123409	107832	39862	0.01457347	0.0005957161

TABLE A.2 Drogue measurements, K-values and Alpha-values for Hout Bay

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
840607	S	84838	60556	70790	125744	60245	71374	84845	60559	70790	125652	60289	71359	0.01799813	0.004159735
840607	SS	84838	60556	70790	130139	60149	71183	84845	60559	70790	125942	60175	71186	0.00556617	0.001286455
840607	SS	90001	60236	70589	130652	60182	70968	90005	60235	70590	130527	60199	70985	0.00486125	0.003062397
840607	S	90001	60236	70589	125916	60175	71191	90005	60235	70590	130247	60116	71228	0.04221526	0.026593945
840607	S	151147	60051	70508	154901	60006	70475	151129	60074	70494	154812	60037	70458	0.02937556	0.000363994
840607	SS	135324	60269	70586	154604	60295	70695	135343	60275	70608	154511	60282	70751	0.05149778	0.000796379
840607	S	135656	60469	70887	154218	60173	70953	135723	60439	70860	154122	60226	70939	0.02720658	0.000196514
840607	SS	135603	60541	70829	153931	60466	70954	135538	60524	70796	153839	60491	70907	0.02931701	0.000236748
840608	S	121817	60541	71078	141238	60264	71158	121909	60539	71129	141153	60295	71175	0.02468663	0.000130394
840608	SS	130636	60826	70858	140757	60939	70955	130646	60841	70892	140842	60934	71004	0.03548628	0.000286153
840704	S	133046	59864	71016	150013	59411	71484	133144	59845	70967	150128	59441	71389	0.1668297	0.00084747
840726	S	104210	60290	70242	161522	58297	70081	104102	60252	70196	161607	58294	70093	0.02130227	9.1368E-05
840726	SS	123858	59835	70131	162354	59389	69768	123756	59878	70211	162214	59406	69902	0.09258299	0.000226776
840726	SS	112633	60434	70426	162543	59619	69752	112613	60457	70445	162742	59760	69707	0.14635097	0.001581742
840726	S	123955	59886	70122	161714	58269	70032	123756	59878	70211	161812	58219	70066	0.0415005	0.000103881
840727	SS	111754	60476	70618	132921	60308	70394	111811	60458	70588	132948	60287	70409	0.00884367	7.7288E-05
840727	SS	122317	59793	70562	134804	59575	70536	122250	59797	70515	134901	59566	70470	0.05435424	0.000318919
840907	SS	93700	60193	70742	124343	59974	71733	93741	60215	70685	123745	60058	71394	1.31933411	0.005482552
841003	SS	124927	60510	70886	152619	60605	71533	125000	60444	70899	152406	60470	71495	0.20112622	0.000735173
841003	S	125124	60282	71032	133020	60082	71238	125140	60254	71053	133057	60005	71300	0.45740582	0.003995253
841003	SS	133637	60035	70540	154429	60087	70617	133735	60087	70557	154523	60093	70751	0.24437891	0.001176682
841005	SS	91932	60164	71359	103251	59160	71444	92021	60114	71417	103156	59102	71492	0.00556945	1.7127E-05
841005	S	92230	60013	71245	95704	59645	71372	92146	60068	71321	95528	59551	71452	0.38783751	0.000909833
841005	S	115807	60602	70616	132944	59904	71534	115844	60630	70581	133123	59788	71609	0.38821175	0.002438271
841005	S	92546	59706	70831	111424	58987	70637	92450	59760	70832	111245	59011	70725	0.10361691	0.000507543
841005	SS	122843	60313	70359	131308	60352	70421	122933	60286	70403	131424	60342	70488	0.0902439	0.000469483
841029	SS	112910	59873	70901	121315	60058	70904	112826	59949	70938	121134	60177	70924	0.35047259	0.000944755
841029	SS	140050	59917	72025	153235	60029	71856	135938	60014	72047	144909	60095	71945	0.05413261	0.000117465
841029	SS	102319	60463	70755	104938	60665	70810	102341	60495	70787	104605	60697	70882	0.32932236	0.002042057
841029	SS	141250	59392	71621	145828	59456	71601	141343	59343	71598	150206	59316	71550	0.87979364	0.004296707
841031	S	152821	59952	70249	163617	59661	69959	152909	59873	70289	163501	59626	70023	0.07728165	0.000195807
841203	SS	104353	60633	71098	111210	60585	71197	104418	60646	71134	111130	60581	71242	0.04242781	0.000328921
841203	S	94716	60559	71268	103930	60471	71779	94748	60501	71303	103842	60390	71864	0.36682355	0.001328348
841203	SS	92302	60173	70650	111408	60377	70880	92338	60151	70596	111641	60331	70830	0.02280228	0.000100846

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
841203	S	95650	60291	71126	103542	60292	71605	95735	60212	71220	103658	60155	71707	0.75557461	0.001238038
841205	SS	141029	60118	70647	150818	60132	70790	141052	60154	70651	150914	60215	70790	0.20095849	0.00167681
841205	S	140904	60155	70578	150508	60023	70732	140926	60108	70552	150635	60044	70656	0.12381094	0.000610935
841205	S	140740	60360	70615	151102	60253	70822	140712	60398	70599	151214	60308	70737	0.28110205	0.001973474
841206	S	104334	60307	70697	145220	59948	70678	104356	60347	70720	145300	59865	70580	0.12029345	0.000726872
841206	SS	120651	59572	70619	145459	59728	70968	120751	59578	70672	145527	59788	71044	0.08092536	0.000403054
850121	SS	142215	60646	70717	150725	60917	70704	142045	60611	70744	150555	60863	70801	0.47836716	0.003060636
850214	SS	142549	60258	70608	145608	60499	70623	142608	60229	70632	145644	60454	70618	0.04349918	0.0003448
850328	SS	114832	60461	71099	142444	60299	71200	114812	60491	71072	142317	60371	71170	0.05941901	0.000429185
850328	S	115007	60374	70842	144023	59433	69645	114704	60415	70920	144310	59556	69376	0.97549188	0.002487689
850329	SS	94909	60818	70883	101809	60945	70857	94936	60764	70893	101931	60856	70847	0.3595546	0.001722439
850329	S	111002	60184	71157	114652	60864	70785	111027	60144	71179	114811	60933	70719	0.39779412	0.002438147
850422	S	92457	60528	71467	95955	60431	71784	92418	60440	71482	95829	60333	71838	0.2711511	0.000679635
850422	S	131108	59652	71289	133803	59616	71441	131149	59815	71371	133624	59584	71565	0.64295666	0.001595054
850422	S	92031	59890	71240	95506	59730	71653	92104	59855	71321	95317	59737	71716	0.22698795	0.000577821
850422	S	122519	59846	70696	134242	59513	71358	122451	59804	70719	134051	59436	71516	0.76997631	0.004428004
850520	SS	102853	60327	71305	104921	60234	71425	102919	60347	71257	105022	60292	71374	0.33194218	0.001710244
850520	S	95204	60406	71258	104425	60284	72129	95140	60408	71203	104244	60194	71922	1.90703598	0.009109461
850520	SS	121120	59723	69736	125758	59738	69843	121103	59693	69762	125610	59685	69983	0.93070944	0.006872424
850520	S	120835	59565	70114	124645	59574	70624	120751	59644	70161	124745	59526	70696	0.05251092	0.000126574
850520	SS	101605	59948	70770	110701	59795	71078	101621	59952	70815	110613	59771	71062	0.0494519	0.000307341
850520	S	101819	59891	71207	105749	59808	71748	101838	59878	71258	105846	59811	71850	0.40311181	0.002043803
850520	SS	123529	59735	70457	125003	59704	70505	123447	59761	70397	125209	59690	70461	0.30663616	0.001163943
850522	S	93048	59964	71006	115834	59086	70788	93112	59939	71060	115922	59102	70868	0.04391778	0.000189041

TABLE A.3 Drogue measurements, K-values and Alpha-values for False Bay

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
870126	S	161222	37422	74027	170650	37629	73765	150024	37052	74302	161117	34388	73893	394.275551	0.1107116093
870126	SS	162715	36138	76547	172658	36340	76505	162643	36175	76521	172546	36430	76446	0.33268211	0.0020649074
870127	SS	100017	23257	77515	121412	22461	77659	100103	23306	77471	121222	22470	77637	0.05868077	0.0002206495
870127	S	95038	22589	76193	110841	21899	76900	94954	22648	76132	110646	22040	76640	2.14283045	0.005745825
870128	S	102921	23380	77071	112451	23324	76847	102849	23362	76983	112551	22831	75723	56.2446321	0.1398203831
870128	SS	113658	22637	75782	125446	22328	75526	113716	22635	75822	125341	22330	75625	0.2196069	0.0016026662
870128	SS	103110	23366	77327	131902	22959	76956	103133	23357	77380	132107	22998	77027	0.04557188	0.0002246114
870129	SS	104019	35686	74604	122405	34921	74362	104133	35788	74566	122638	35019	74367	0.04455108	8.57225E-05
870129	SS	100527	35603	74998	123333	34946	74998	100610	35626	76080	123529	35043	75135	16.0797181	0.0014471425
870129	S	152600	28594	76192	165304	28306	75575	152509	28596	76114	165411	28278	75417	0.47042496	0.0014109358
870129	S	142554	27755	74526	155302	26506	73963	142644	27703	74588	155143	26651	74075	0.64606446	0.0018458797
870129	SS	120027	22333	78450	154547	27395	74722	120107	22314	78493	154429	27442	74870	0.20250555	0.001193554
870129	S	143529	27532	76391	152810	26762	76046	143446	27470	76341	152929	26574	75990	1.27080038	0.0037082461
870202	S	132746	43867	78693	171647	42230	79553	132804	43858	78733	171810	42264	79289	0.62923914	0.0044507915
870202	S	144142	44393	79513	183513	43634	79753	144043	44398	79639	183639	43753	79795	0.13582185	0.0017211721
870202	S	134624	44334	77073	174444	42679	77067	134706	44265	77004	174248	42490	77050	0.23153846	0.000515392
870202	SS	144957	44954	77851	182642	44253	78327	144935	45010	77861	182747	44307	78304	0.00200884	9.182063E-06
870203	SS	104716	22929	76428	170737	36115	73196	104857	22970	76516	170641	36206	73229	0.00030126	6.751762E-07
870203	SS	165015	36203	75027	172618	35943	74969	165033	36238	75002	172736	36033	74920	0.49994221	0.0033174571
870203	S	94252	23540	77867	173344	35171	75238	94328	23509	77855	173449	35116	75420	0.15505097	0.0014506622
870203	SS	101437	23463	77898	124331	22769	78941	101453	23486	77877	124424	22780	78933	0.01098332	0.0001120863
870204	SS	121552	28449	76998	164005	28793	76332	121628	28423	77074	164211	28841	76396	0.00041002	1.183057E-06
870204	S	122235	28419	76551	141218	28466	75795	122124	28468	76620	141413	28566	75792	0.0540597	0.0001454959
870204	S	105607	29156	74782	134801	29636	73155	105510	29079	74892	134617	29463	73233	0.21795618	0.0003169967
870204	SS	91044	28968	74889	170144	30335	74282	91101	28969	74924	170248	30331	74359	0.02087314	0.0001822192
870205	SS	113532	22071	76892	161500	26223	75003	113649	22081	76782	161743	26348	74988	0.02720957	5.134306E-05
870205	S	95545	22670	76486	160419	25110	75927	95607	22637	76528	160523	25005	75815	0.11709777	0.0005821221
870206	S	123747	37331	74926	132721	37617	74355	123655	37314	74989	132832	37571	74419	0.08212845	0.0003126246
870206	SS	125112	36808	74337	131706	36854	74252	125203	36801	74427	131917	36824	74344	0.09773166	0.0002413417
870206	S	110850	36717	74587	124421	36879	73645	110921	36679	74622	124554	36875	73714	0.04597801	0.0002389559
870316	SS	110812	28336	76535	115606	27957	76384	110736	28321	76491	115539	27937	76339	0.01148225	6.869482E-05
870316	S	102422	28778	74810	122002	28073	73779	102539	28746	74907	122058	28057	73675	0.01150937	2.410527E-05
870316	SS	121145	27851	75246	124823	27594	75399	121118	27846	75313	124642	27596	75487	0.1839172	0.000673361
870316	SS	150607	43968	76624	162927	43793	76440	150647	44003	76573	162754	43900	76245	1.1412	0.0046651447
870316	S	152024	43507	77833	163427	43514	77222	151920	43572	77714	163237	43616	76940	2.0127729	0.0028893708

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
870317	SS	134537	36533	74858	150143	36563	74584	134511	36545	74806	145930	36495	74473	0.38592313	0.0019207646
870318	S	143424	43703	75905	154200	43447	75054	143502	43688	75803	154318	43406	74940	0.12475345	0.0002580621
870318	S	155309	43254	76407	165209	43076	75606	155342	43271	76461	165305	43140	75613	0.03319209	0.0001526919
870319	S	115517	22797	77526	161045	21393	75476	115415	22734	77559	160907	21333	75630	0.18151422	0.0006160152
870319	S	120640	22006	76440	161715	20795	74460	120705	21942	76456	161901	20712	74422	0.03309777	0.000124167
870320	SS	132448	36252	76095	135731	36397	75942	132603	36255	76250	135930	36377	76135	0.86697657	0.0010410142
870323	S	123613	42862	78384	161900	41411	76180	123632	42825	78411	162035	41350	76230	0.03855577	0.0002352623
870326	SS	114659	26015	74305	152622	23257	74694	114610	25960	74300	152500	23158	74654	0.07930373	0.0003770744
870326	S	122714	30083	76977	155926	29440	75469	122626	29989	76900	160232	28895	75486	2.77400448	0.0046091219
870511	SS	155620	43632	77684	173400	43217	78257	155557	43607	77738	173600	43141	78284	0.06322526	0.0002721489
870511	S	144811	43593	78216	175400	42160	80487	144901	43664	78290	175200	42311	80506	0.1417728	0.0002953464
870520	S	94410	45047	75258	114130	44895	74626	94510	45041	75230	114300	44902	74560	0.06365412	0.0007265808
870520	S	94830	45442	75071	102710	456326	74809	94740	45453	75121	102540	45364	74914	9099664.54	47868.229914
870520	SS	90052	43814	77740	124245	44015	77249	90013	43767	77686	124340	43925	77351	0.1256197	0.000422599
870520	S	120930	45184	74897	122500	45100	74780	121030	45936	76447	122410	45106	74717	398.386962	0.0192898476
870715	SS	85048	43753	76938	132600	42753	76345	85112	43796	76972	132750	42722	76707	0.9765625	0.0046896136
870901	SS	110507	44188	77705	130900	44444	77551	110554	44082	77761	131124	44220	77805	1.68707117	0.0028540085
870903	SS	105409	27890	75077	140751	27706	74783	105505	27986	75115	140437	28007	75178	2.53792377	0.0052397082
870904	SS	91238	44024	76918	103417	44015	76855	91215	44083	76907	103307	44161	76763	0.66794244	0.0028425617
870907	SS	213844	25636	80010	23002	25011	82902	213945	25556	79866	23247	25055	82448	-0.3281173	-0.000363356
870909	SS	185444	40730	76237	104054	36306	74457	185320	40621	78383	103906	36022	74697	-18.895296	-0.000681451
871116	SS	125807	42802	75943	193539	39786	74862	125905	42683	76047	193730	39775	75120	0.21857706	0.0002558062
871117	SS	234443	38947	76460	13333	38085	75697	234615	38926	76640	13557	38050	76082	-0.1824981	-0.000177957
871117	SS	35221	37100	76449	55905	36135	76013	35304	37071	76545	60041	36153	76221	0.5512066	0.0011830473
871117	SS	81910	35656	77944	95033	35693	77536	82022	35620	78121	95232	35634	77878	2.00209739	0.0019608823
871118	SS	100525	23342	79367	121951	22004	79116	100413	23274	79141	122157	22117	79018	0.51647347	0.0003541152
871118	SS	111551	22457	75580	163232	21318	76604	111413	22368	75761	163446	20934	76839	1.0657268	0.0009009714
871118	SS	204431	19938	80394	41143	18623	86197	204512	19877	80443	40957	18539	86211	-0.0023712	-7.08565E-06
871118	SS	202325	20339	76267	2655	19849	77103	202521	20453	76300	2830	19914	77204	-0.0005937	-1.01803E-06
871118	S	81728	16496	79934	104555	14878	81816	81704	16488	79981	104420	14902	81838	0.01702313	9.847056E-05
871118	SS	82841	16590	79560	92257	16204	79935	82728	16654	79459	92351	16241	79801	0.19302826	0.0003276858
871123	SS	91736	42846	79476	102939	42685	79006	91849	42771	79610	103134	42576	79258	1.49791811	0.0018215731
871123	SS	91206	43144	78842	154148	41578	76479	91235	43110	78873	154102	41592	76602	0.07060987	0.0004282705
871123	SS	84749	43729	77456	155815	41101	75439	84733	43746	77423	155947	41171	75305	0.10395532	0.0008394868
871123	SS	110144	43171	76188	115346	42909	75882	105952	42977	76459	115640	42616	76233	3.92268578	0.001697595
871126	SS	214410	30650	76977	828	30235	76491	214322	30644	76855	610	30391	76207	-0.1448252	-0.000238963

TABLE A.4 Drogue measurements, K-values and Alpha-values for Vlees Bay

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
851118	SS	113459	87516	8893	144358	89858	9276	113442	87495	8884	144548	90006	9255	0.24057457	0.003710816
851118	S	113734	87735	8828	121938	88417	8742	113716	87712	8857	121904	88415	8826	0.28179477	0.002284472
851118	SS	112755	87038	8049	142046	98114	8295	112651	86980	8032	141939	89166	8170	965.175441	4.069176065
851118	S	112905	87122	7956	122553	88234	7789	112844	87094	7978	122521	88219	7859	0.1414686	0.001207574
851120	S	125531	88429	9056	140035	87365	8597	125500	88365	9102	140130	87281	8678	0.23709657	0.000701624
851120	SS	123722	89176	8463	144831	86194	8118	123834	89138	8508	145022	86143	8211	0.12360211	0.000539374
851123	SS	133455	89138	9409	143749	89760	9515	133409	89113	9335	143913	89755	9404	0.20684287	0.000619498
851123	S	112405	88442	9490	134511	91171	10127	112342	88490	9504	134649	91410	10215	0.92081562	0.004998956
851123	SS	122000	88074	8062	141819	89109	8169	121946	88066	8108	141959	89130	8252	0.09068179	0.000539365
851127	S	105358	88817	8168	122554	90603	8353	105421	88874	8106	122426	90656	8291	0.00997099	2.701E-05
860129	SS	113539	90252	9854	135018	91015	9188	113457	90194	9940	134804	90850	9352	0.67089058	0.001376502
860129	SS	103209	90385	8290	114952	90161	8098	103059	90459	8379	114815	90284	8262	0.7674244	0.001360496
860201	SS	113320	89877	9644	151827	89065	8628	113414	89781	9663	152030	88873	8677	0.27474643	0.000609227
860201	S	132245	89652	8463	140431	89479	8157	132212	89724	8472	140355	89588	8180	0.35639465	0.001177603
860204	S	104900	88489	8158	145512	80783	6510	104835	88494	8122	145428	80882	6498	0.0729759	0.000606146
860204	SS	115721	88496	7707	122941	87917	7626	115802	88540	7734	123133	88005	7651	0.36752577	0.001912008
860204	S	112721	88453	7510	120322	87810	7257	112540	88338	7504	120429	87630	7218	1.19504859	0.002133052
860207	SS	94602	90115	9957	124838	89826	8720	94625	90128	10006	125054	89819	9019	0.99123768	0.005283103
860207	SS	124208	90955	8443	132913	90840	8091	124149	90937	8407	132957	90890	8093	0.03911504	0.000283574
860410	SS	121942	86348	7617	124759	86309	7581	121857	86392	7512	124918	86397	7463	0.64135239	0.001162352
860410	S	122159	86028	7547	125317	85763	7518	122234	85936	7560	125356	85650	7527	0.28068424	0.000666976
860410	S	125712	85697	7942	144943	84750	7187	125835	85838	8003	144705	84915	7298	0.29521552	0.00035879
860414	SS	122631	85696	7191	131442	85128	7161	122613	85662	7223	131317	84147	7214	41.6374092	0.247654393
860415	SS	111351	85987	7350	113827	85757	7322	111410	86008	7386	113656	85829	7336	0.30851965	0.00213509
860415	SS	111719	85909	7759	130331	84846	7518	111652	85968	7718	130523	84807	7484	0.04874843	0.000163211
860415	S	104548	85915	7749	114614	84863	7468	104632	85803	7700	114738	84660	7393	1.09931743	0.001811865
860416	S	130750	85227	8451	141354	84486	7893	130816	85188	8483	141503	84433	7928	0.04695383	0.000251891
860418	SS	114830	86992	7362	134309	86849	7347	114743	86950	7302	134406	86793	7271	0.06447158	0.000210398
860418	SS	124859	86788	8094	144240	87002	8162	124812	86726	8123	144138	86970	8177	0.06296731	0.000224893
860418	S	110753	86480	7976	131221	86489	7470	110824	86467	8011	131336	86375	7606	0.50378281	0.004037087
860418	SS	121955	86392	8733	144910	86630	8588	121919	86313	8750	145034	86613	8620	0.07282245	0.000208444
860418	S	111750	86134	8966	142956	86082	8012	111827	86210	8936	142824	86203	7989	0.09211782	0.000259816
860424	S	115511	87077	7738	132315	88189	7992	115359	87152	7678	132207	88291	7958	0.05523751	0.000125581
860424	SS	113559	86001	9192	150002	85849	9221	113636	85960	9147	150155	85850	9117	0.07260271	0.000303167

Date	S/SS	Time-In	Y	X	Time-out	Y	X	Time-In	Y	X	Time-out	Y	X	K-value	Alpha-value
860424	SS	133355	87094	8183	142306	87382	8192	133452	87042	8243	142408	87333	8230	0.10415961	0.000305226
860425	S	95514	87597	8010	110926	88730	8070	95618	87587	7957	110848	88676	8048	0.01378594	6.7651E-05
860718	S	102231	86342	7944	122027	85318	8641	102248	86370	7926	121831	85507	8572	0.6955554	0.006495888
860718	SS	111225	86153	9199	123919	85960	9324	1112441	86208	9201	123740	86014	9418	0.20912447	0.000998938
860718	S	111109	85951	9348	114956	85615	9622	111047	85895	9396	114851	85535	9793	1.62231414	0.005244882
860723	SS	140922	85586	8312	145054	85398	7961	140933	85581	8274	144925	85381	7917	0.03792135	0.000293451
860725	SS	120114	86469	8726	144011	86575	8104	120138	86476	8783	143818	86661	8256	0.35653245	0.001609158
860725	S	91523	86265	9115	130241	85397	8689	91413	86208	9135	130458	84884	8827	2.55319695	0.010772134
860725	SS	115650	86597	7751	131700	86626	7576	115548	86514	7746	131550	86846	7543	1.10641892	0.003048597
860725	S	95424	86261	8116	114606	85755	8043	95438	86226	8135	114820	85398	8244	3.10101462	0.022801759
860726	SS	113319	86614	8244	142453	87681	8158	113412	86534	8232	142320	87632	8060	0.0663129	0.000189541
860726	S	113537	86539	8179	123255	86878	7966	113706	86574	8108	123132	86629	7872	2.34769488	0.006907402
860726	S	111952	87357	9267	115245	88005	9228	111934	87306	9274	115224	87946	9233	0.05423213	0.0002832
860728	SS	112900	85938	8880	143700	85154	8290	112836	85918	8920	143848	85090	8264	0.03071809	0.000193512
860728	S	101430	85921	9128	153220	82735	7032	101411	85948	9096	153239	82705	7031	0.00558469	3.8413E-05
860729	S	114025	87032	8632	135548	88382	8431	113959	87001	8586	135732	88357	8318	0.15876216	0.000750462
860728	SS	123621	86904	7545	134848	87177	7536	123541	86960	7523	134542	87157	7487	0.02355072	9.9892E-05
860728	S	124115	87740	7419	133336	88173	7241	124026	87636	7470	133555	88193	7324	0.24387138	0.000431907
860731	SS	130455	84740	8337	170939	82298	7038	130529	84743	8399	170709	82372	7152	0.12444668	0.00050635
861004	S	102701	85088	8077	112748	84262	7404	102537	85189	8071	112633	84381	7429	0.15591582	0.000330706
861007	S	100228	86246	7970	125802	86072	6886	100209	86310	7982	125940	86074	6910	0.0434308	0.000165788
861011	SS	120108	85849	8970	142040	85864	8877	115952	85829	9050	142159	85784	8919	0.0203655	5.674E-05
861011	S	105854	86235	9200	125846	86941	9487	105927	86334	9197	125655	87083	9448	0.20639252	0.000450382
861011	S	114736	87647	8041	124649	88430	8118	114657	87625	7918	124444	88375	7974	0.28665916	0.00045889
861011	SS	114212	87052	7862	123646	87303	7888	114350	87035	7979	123725	87304	7801	0.24465486	0.000421623
861015	SS	91722	86860	7952	115801	88026	7949	91827	86974	7962	115841	88011	7932	0.16316527	0.000293676
861016	SS	114513	87826	7532	130545	88154	7369	114539	87913	7544	130721	88292	7365	0.29353787	0.000751938

TABLE A.5 Drogue measurements, K-values and Alpha-values for East London

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
840215	S	74708	-85429	58453	91502	-83749	59163	74724	-85422	58475	91645	-83753	59198	0.01678043	0.000255261
840215	SS	74708	-85429	58453	90742	-83563	59402	74724	-85422	58475	90936	-83507	59468	0.17994932	0.002737361
840215	S	84812	-86909	57946	104021	-84891	59083	84849	-86879	57968	103739	-84863	59003	0.10774261	0.000867554
840215	SS	84812	-86909	57946	102643	-84614	59196	84849	-86879	57968	102708	-84573	59248	0.06346219	0.000511004
840216	S	100551	-90024	54845	155506	-87659	54539	100625	-90033	54877	155432	-87681	54558	0.00155094	1.45107E-05
840216	SS	100551	-90024	54845	161002	-87354	55992	100625	-90033	54877	161449	-87263	56058	0.06596952	0.000617213
840216	S	102718	-89073	54048	125256	-88783	53520	102751	-89031	54058	125339	-88714	53493	0.05187114	0.000342475
840216	SS	102718	-89073	54048	160150	-87736	55077	102751	-89031	54058	160330	-87637	55213	0.16461364	0.001086847
840221	S	93244	-85882	57626	101619	-85515	57616	93328	-85917	57793	101731	-85569	57516	0.77428298	0.000818148
840221	S	123429	-84617	58262	130738	-84113	58383	123347	-84594	58289	130700	-84082	58409	0.0238185	0.00020439
840221	S	74419	-85179	58194	85434	-84567	57861	74441	-85217	58188	85330	-84758	57863	1.03810795	0.007993458
840221	SS	74419	-85179	58194	85803	-84582	58064	74441	-85217	58188	85620	-84715	58028	0.4946033	0.003808458
840221	S	103637	-84591	58611	114515	-83950	58411	103712	-84547	58626	114556	-83867	58449	0.18734823	0.001120847
840224	S	82031	-90271	53617	101600	-92759	51736	82023	-90250	53604	101423	-92686	51799	0.15673257	0.002179078
840224	SS	83935	-89669	53507	103301	-90739	52359	83924	-89656	53545	103609	-90659	52387	0.10231781	0.000743924
840229	SS	81638	-90932	54297	90628	-91675	53898	81644	-90934	54319	90504	-91654	53944	0.08649666	0.001395467
840229	S	80512	-89093	53743	101402	-88897	53504	80447	-89046	53785	101327	-88785	53487	0.14327296	0.000571152
840229	SS	80605	-89105	53818	120148	-89214	53399	80412	-89116	53872	120247	-89237	53402	0.0220669	0.000105319
840229	S	102634	-88749	55101	123855	-87948	54702	102622	-88735	55144	123626	-87963	54719	0.02409961	0.000149583
840512	S	83956	-85852	59006	100425	-84005	60652	84029	-85813	58990	100309	-84040	60533	0.33559381	0.002287471
840512	SS	83956	-85852	59006	100709	-83653	60688	84029	-85813	58990	100621	-83690	60675	0.00570896	3.89134E-05
840512	S	85105	-85049	58059	113815	-84703	58874	85145	-85038	58105	114140	-84798	58871	0.08470837	0.00049524
840512	SS	85105	-85049	58059	113410	-84327	58915	85145	-85038	58105	113130	-84190	59051	0.44747062	0.002616097
840512	S	102851	-85481	58523	111944	-84673	59267	102916	-85497	58523	112700	-84559	59270	0.52198657	0.012946907
840513	S	83838	-89975	55058	112421	-88345	55451	84147	-89938	55144	112221	-88413	55379	0.01311224	3.08443E-05
840513	SS	83838	-89975	55058	110923	-88328	56400	84147	-89938	55144	110454	-88334	55944	2.75299889	0.006475969
840513	S	92749	-89076	53918	114158	-90506	52362	92847	-89098	53950	114315	-90482	52386	0.00552864	4.2042E-05
840513	SS	92749	-89076	53918	114957	-89966	53147	92847	-89098	53950	115146	-89880	53268	0.30090584	0.002288213
840513	S	120138	-89498	54489	130355	-88470	54262	120218	-89489	54516	130318	-88516	54271	0.04639417	0.000533917
840513	S	120749	-88503	54581	125935	-88628	53752	120839	-88510	54593	125907	-88598	53757	0.02945911	0.000882094
840513	SS	120749	-88503	54581	131852	-88584	53858	120839	-88570	54593	131644	-88528	54010	0.63356205	0.002279717
840518	S	81125	-86110	59117	100339	-88094	59203	81159	-86122	59105	100532	-88222	59150	0.35092441	0.008046714
840518	S	82950	-85045	58113	94040	-85708	58612	83035	-85038	58136	94026	-85737	58646	0.04173529	0.000601476
840518	SS	82950	-85045	58113	94236	-85429	58382	83035	-85038	58136	94206	-85512	58434	0.25810238	0.00371969

Date	S/SS	Time-in	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
840519	S	83027	-90239	54819	95812	-92531	52476	83100	-90258	54819	95900	-92518	52629	0.55121083	0.010872087
840519	S	103453	-89610	54316	121548	-90523	52126	103609	-89633	54291	121439	-90568	52180	0.07817919	0.000710593
840519	S	104438	-88380	53672	110935	-88303	53488	104523	-88396	53625	110948	-88325	53448	0.03181363	0.000174342
840519	SS	104438	-88380	53672	110914	-88271	53550	104523	-88396	53625	110928	-88288	53507	0.02769309	0.000151761
840519	SS	111831	-88711	53673	122957	-88552	53336	113832	-88679	53523	113810	-88750	53495	1.19461619	0.001455082
840525	S	84144	-85989	59073	101842	-83835	61009	84247	-85951	59103	101859	-83774	61024	0.03441904	0.000195056
840525	SS	84144	-85989	59073	101842	-83835	61009	84247	-85951	59103	101859	-83774	61024	0.03441904	0.000195056
840525	S	104436	-86119	57919	125657	-83952	59522	104509	-86144	57956	125843	-83947	59627	0.14255132	0.000899818
840525	SS	104436	-86119	57919	130006	-83982	59842	104509	-86144	57956	130121	-83967	59964	0.20164514	0.001272832
840525	S	90207	-85031	57969	120555	-85933	56875	90702	-85044	57963	120730	-86191	56612	1.53618063	0.044184815
840525	S	133612	-85123	58230	135558	-84997	58305	133553	-85162	58170	135710	-85030	58281	0.36424958	0.001226015
840525	SS	90207	-85031	57969	134789	-85711	57109	90239	-85032	57952	134814	-85727	57022	0.05481754	0.001251183
840527	S	92539	-90057	54958	133318	-91446	52578	92554	-90049	54943	133449	-91401	52667	0.08123864	0.001858507
840527	SS	92539	-90057	54958	131951	-90483	53755	92554	-90049	54943	132208	-90360	53908	0.34024516	0.007783831
840527	S	121304	-88491	53508	122747	-88671	53283	121345	-88501	53528	122819	-88676	53296	0.04331823	0.000687634
840527	SS	121304	-88491	53508	122914	-88657	53343	121345	-88501	53528	123048	-88682	53348	0.0193299	0.000306843
840527	S	94319	-89088	54196	115402	-90691	52481	94357	-89099	54183	115310	-90789	52567	0.26632029	0.006078628
840527	SS	94319	-89088	54196	115942	-90431	52941	94357	-89099	54183	115751	-90419	52936	0.00184834	4.21875E-05
840809	S	100144	-84215	58348	103104	-84078	58285	100215	-84228	58232	103317	-84281	58207	2.39119318	0.004191701
840810	S	90138	-88502	53570	102040	-88698	53284	90213	-88521	53517	101933	-88572	53328	0.38596584	0.001788584
840810	SS	83222	-88672	53488	130234	-88873	53063	83110	-88666	53446	131118	-88302	53506	4.01315384	0.027120903
840810	SS	85020	-88004	54876	91953	-87238	55676	85020	-87913	54935	91856	-87308	55566	0.36928934	0.000714024
840810	S	103454	-89087	54664	112342	-87686	55806	103403	-89082	54710	112420	-87669	55959	0.92029542	0.005540081
840815	S	94044	-84001	58974	103147	-83262	59258	94059	-83992	58924	103229	-83335	59225	0.15658668	0.000832203
840816	SS	84844	-88825	54658	100214	-87944	55316	84839	-88818	54673	100418	-87855	55369	0.29637188	0.007025382
840816	S	85023	-89058	54656	101236	-88520	55232	85040	-89099	54628	101417	-88676	55148	0.73299716	0.0040169
840816	SS	105106	-89861	53159	105832	-89786	53189	104948	-89927	53123	105705	-89872	53157	0.77578475	0.002444968
840816	SS	103951	-88718	53215	110538	-88868	53112	103937	-88755	53204	110418	-88890	53118	0.0783775	0.000600806
840816	S	85934	-88607	53487	104621	-89392	52930	85946	-88572	53503	104434	-89261	52947	0.31155377	0.002397892
840822	S	114733	-86859	61555	123300	-85361	62166	114714	-86874	61583	123136	-85413	62226	0.24271177	0.002412663
840823	SS	113336	-88541	56670	114906	-88058	57000	113350	-88511	56727	115037	-87999	57089	0.97486559	0.003775569
840823	S	105248	-89807	55810	115335	-88071	56838	105348	-89741	55870	115603	-87944	56923	0.52776254	0.001324266
840823	SS	124944	-88545	53416	131249	-88579	53388	124954	-88542	53384	131058	-88568	53340	0.12563177	0.001229417
840823	S	112559	-87709	55662	120847	-86762	56438	112548	-87747	55681	120959	-86644	56451	0.59813084	0.004034701
840824	S	101322	-90947	56037	103633	-90847	56044	101340	-90888	56022	103908	-90719	56066	1.18278217	0.004938948
840824	S	112747	-89750	54861	114807	-89626	54815	112858	-89692	54897	114718	-89520	54868	0.96157787	0.003446624
841107	SS	64208	-84298	60459	65402	-83749	60900	64227	-84235	60488	65228	-83772	60888	0.72426471	0.002541756

Date	S/SS	Time-In	Y	X	Time-out	Y	X	Time-in	Y	X	Time-out	Y	X	K-value	Alpha-value
841107	SS	75323	-84631	58151	84338	-83797	58774	75341	-84665	58137	84656	-83821	58743	0.00766998	6.27302E-05
841107	S	75102	-84626	58224	83614	-83592	59156	75114	-84590	58267	83809	-83515	59124	0.17551622	0.000817655
850228	SS	104941	-84736	58117	114717	-84474	58231	105002	-84746	58071	114533	-84480	58153	0.1412037	0.000830742
850228	S	111009	-84209	58739	115407	-83799	59150	110944	-84196	58778	115508	-83781	59234	0.26961713	0.001900304
850228	S	113010	-84451	59689	120109	-84023	60125	112959	-84439	59672	120041	-84016	60112	0.0144567	0.000252587
850306	SS	75444	-89728	55079	122527	-88098	53488	75526	-89764	55122	122713	-88015	53449	0.04051745	0.000188754
850306	S	81653	-89581	55095	100401	-88589	55152	81641	-89576	55056	100455	-88616	55043	0.21515246	0.001609188
850309	S	104430	-85752	59259	120934	-85184	59650	104439	-85724	59248	121016	-85176	59564	0.16053585	0.001715825
850309	SS	115032	-86241	57245	141905	-87534	56587	115022	-86243	57214	141818	-87450	56533	0.1263183	0.001293545
850311	S	100934	-88779	54246	112830	-88000	55148	104822	-88455	54697	112844	-88028	55191	8.06967905	0.001767943
850311	SS	115304	-88624	53676	124356	-88545	53835	115240	88585	53708	124602	-88585	53904	1286165.81	0.129215888
850311	S	111533	-88421	53869	125356	-87786	54773	111605	-88395	53930	125503	-87702	54814	0.09190242	0.000342418
850313	SS	134815	-85072	57536	141950	-84815	57642	134804	-85105	57544	141849	-84864	57669	0.13040897	0.001186009
850313	S	135220	-84506	58096	145238	-83706	58982	135210	-84522	58069	145126	-83765	58874	0.48922056	0.004941747
850605	SS	90001	-86402	58611	93022	-86862	58202	90010	-86426	58608	93109	-86893	58243	0.14119989	0.002018663
850605	S	90148	-86610	58551	100037	-87720	57655	90213	-86637	58507	100204	-87764	57581	0.16814253	0.000874741
850605	SS	94918	-86403	57724	101641	-86824	57424	94933	-86417	57747	101544	-86835	57455	0.02716068	0.000336549
850605	S	94640	-86695	57713	101145	-87228	57401	94606	-86709	57722	101025	-87235	57417	0.00232558	5.47283E-05
850606	SS	85146	-90170	55037	102846	-90567	54854	85106	-90162	54976	102643	-90389	54727	0.94561856	0.003893487
850606	S	91827	-90531	55038	103343	-91105	54723	91753	-90545	54975	103513	-91111	54566	0.56798051	0.002194102
850606	SS	90529	-88996	54127	105744	-88954	54249	90555	-89025	54085	105906	-89002	54197	0.04459911	0.000235571
850606	S	90409	-89154	54196	104745	-89682	54163	90352	-89191	54178	104900	-89783	54137	0.18468468	0.001300148
850611	SS	123057	-86020	58886	142208	-85866	58103	123116	-86009	58938	142327	-85850	58164	0.02158597	0.000108017
850612	SS	90434	-90879	54118	94154	-91750	53507	90302	-90840	54193	94228	-91746	53489	0.37979911	0.001023714
850612	S	105725	-90329	53391	115207	-91357	52246	105704	-90375	53377	115053	-91458	52196	0.39568099	0.002263011
850612	SS	102300	-90170	53330	105218	-90579	52970	102315	-90141	53344	105328	-90572	52982	0.06001138	0.000585753
850612	S	121033	-88867	53199	122035	-88925	53155	121026	-88874	53181	122056	-88906	53146	0.01432724	0.000276497
850618	S	131928	-88223	54583	140108	-87838	54979	131903	-88227	54639	140241	-87768	55094	0.74865	0.003482475

APPENDIX B

DETAILED STATISTICAL ANALYSES AND PLOTS OF DATA

ALL STUDY SITES (GROUPED)

n	CONDITIONS						K- VALUES					α-VALUE				
	Wind (knts)	Currents ($m\ s^{-1}$)	Time (hrs)	S/SS	L (m)	S (m)	Mean	Median	Std Dev	Max	Min	Mean	Median	Std Dev	Max	Min
404	ALL	ALL	ALL	S/SS	ALL	ALL	0.2205	0.1050	0.2809	1.92	0.0003	0.00131	0.00058	0.0022	0.0266	0.00000068
205	ALL	ALL	ALL	S	ALL	ALL	0.2175	0.1197	0.2642	1.27	0.00084	0.0015	0.00062	0.0026	0.0266	0.0000078
199	ALL	ALL	ALL	SS	ALL	ALL	0.2235	0.0931	0.2972	1.92	0.0003	0.00114	0.00051	0.0015	0.0109	0.00000068
158	ALL	< 0,1	ALL	S/SS	ALL	ALL	0.2038	0.0841	0.3011	1.92	0.00041	0.00127	0.00046	0.00258	0.0266	0.0000012
137	ALL	0,1-0,2	ALL	S/SS	ALL	ALL	0.2256	0.1188	0.2566	1.04	0.0016	0.00106	0.00054	0.00136	0.008	0.0000078
109	ALL	> 0,2	ALL	S/SS	ALL	ALL	0.2379	0.1416	0.2785	1.27	0.0003	0.0017	0.00083	0.0023	0.013	0.00000068
159	ALL	ALL	ALL	S/SS	ALL	< 500	0.2228	0.1042	0.2800	1.2	0.0013	0.00103	0.00055	0.0012	0.0069	0.0000078
114	ALL	ALL	ALL	S/SS	ALL	500-1000	0.2157	0.0856	0.3060	1.92	0.00041	0.0014	0.00050	0.0029	0.0266	0.0000012
131	ALL	ALL	ALL	S/SS	ALL	> 1000	0.2268	0.1263	0.2614	1.1	0.0016	0.0016	0.00062	0.0024	0.013	0.000015
136	ALL	ALL	ALL	S/SS	< 40	ALL	0.1298	0.0547	0.1781	1.038	0.00084	0.0019	0.00079	0.0033	0.0266	0.00001
192	ALL	ALL	ALL	S/SS	40-80	ALL	0.2342	0.1220	0.2769	1.271	0.0018	0.00113	0.00054	0.00132	0.0056	0.0000078
76	ALL	ALL	ALL	S/SS	> 80	ALL	0.2891	0.1782	0.3486	1.92	0.00041	0.00066	0.000361	0.000793	0.00424	0.0000012
70	< 5	ALL	ALL	S/SS	ALL	ALL	0.1192	0.0865	0.2603	1.195	0.00155	0.00153	0.000727	0.00332	0.0266	0.000015
193	5-15	ALL	ALL	S/SS	ALL	ALL	0.2511	0.1252	0.3057	1.195	0.0019	0.00135	0.00060	0.0018	0.0108	0.0000092
73	> 15	ALL	ALL	S/SS	ALL	ALL	0.285	0.2104	0.2853	0.27	0.00041	0.0015	0.00074	0.0020	0.01295	0.0000012
133	ALL	ALL	< 1	S/SS	ALL	ALL	0.2537	0.1429	0.2837	1.27	0.0014	0.0013	0.00082	0.0016	0.013	0.000015
146	ALL	ALL	1-2	S/SS	ALL	ALL	0.233	0.0931	0.3104	1.919	0.0013	0.00129	0.00051	0.0018	0.0109	0.0000078
120	ALL	ALL	>2	S/SS	ALL	ALL	0.1734	0.0793	0.2342	1.066	0.00041	0.00138	0.00045	0.003	0.0266	0.0000012

NOORDWESBAAI

SAMPLE #	CONDITIONS					K- VALUES					α-VALUE				
	Wind	Currents ($m\ s^{-1}$)	S/SS	L (m)	S (m)	Mean	Median	Std Dev	Max	Min	Mean	Median	Std Dev	Max	Min
147	ALL	ALL	S/SS	ALL	ALL	0.152	0.0667	0.2377	1.92	0.00084	0.00096	0.000375	0.00162	0.0116	0.0000078
79	ALL	ALL	S	ALL	ALL	0.1295	0.073	0.1632	0.923	0.00084	0.00098	0.00039	0.00162	0.0116	0.0000078
67	ALL	ALL	SS	ALL	ALL	0.1781	0.058	0.301	1.92	0.0013	0.000952	0.00036	0.00136	0.0109	0.000016
77	ALL	< 0,1	S/SS	ALL	ALL	0.152	0.0593	0.266	1.92	0.00084	0.000919	0.00036	0.00164	0.0116	0.00001
40	ALL	0,1-0,2	S/SS	ALL	ALL	0.1367	0.0564	0.197	1.004	0.0016	0.00067	0.000365	0.000845	0.00366	0.0000076
26	ALL	> 0,2	S/SS	ALL	ALL	0.176	0.1103	0.205	0.923	0.0034	0.00157	0.00058	0.0023	0.0109	0.000034

FALSE BAY

SAMPLE #	CONDITIONS					K- VALUES					α-VALUE				
	Wind	Currents ($m\ s^{-1}$)	S/SS	L (m)	S (m)	Mean	Median	Std Dev	Max	Min	Mean	Median	Std Dev	Max	Min
51	ALL	ALL	S/SS	ALL	ALL	0.2593	0.1252	0.3203	1.27	0.00031	0.00096	0.00037	0.00123	0.0047	0.00000068
20	ALL	ALL	S	ALL	ALL	0.2239	0.1248	0.2962	1.27	0.0116	0.000916	0.000317	0.00116	0.00445	0.000024
31	ALL	ALL	SS	ALL	ALL	0.2834	0.1256	0.3335	1.14	0.0003	0.000986	0.00038	0.00127	0.00409	0.0000068
14	ALL	< 0,1	S/SS	ALL	ALL	0.3521	0.1358	0.3947	1.14	0.00041	0.00148	0.000901	0.00151	0.00469	0.000012
24	ALL	0,1-0,2	S/SS	ALL	ALL	0.2169	0.1171	0.2291	0.867	0.011	0.00071	0.00033	0.00101	0.00445	0.000024
13	ALL	> 0,2	S/SS	ALL	ALL	0.2317	0.10344	0.354	1.271	0.0003	0.00081	0.00030	0.00105	0.0037	0.00000068

HOUT BAY

SAMPLE #	CONDITIONS					K- VALUES					α-VALUE				
	Wind	Currents ($m\ s^{-1}$)	S/SS	L (m)	S (m)	Mean	Median	Std Dev	Max	Min	Mean	Median	Std Dev	Max	Min
57	ALL	ALL	S/SS	ALL	ALL	0.2269	0.112	0.2514	0.976	0.00486	0.00173	0.00077	0.0036	0.0266	0.000017
27	ALL	ALL	S	ALL	ALL	0.285	0.227	0.265	0.976	0.018	0.00243	0.00091	0.00509	0.0266	0.000091
28	ALL	ALL	SS	ALL	ALL	0.1893	0.0809	0.2349	0.9307	0.0049	0.00123	0.00074	0.0015	0.0069	0.000017
30	ALL	< 0,1	S/SS	ALL	ALL	0.1587	0.0594	0.2215	0.9307	0.0049	0.00203	0.00073	0.0047	0.0266	0.000077
17	ALL	0,1-0,2	S/SS	ALL	ALL	0.3088	0.3002	0.2697	0.9756	0.0213	0.0014	0.00088	0.0013	0.0044	0.000091
	ALL	> 0,2	S/SS	ALL	ALL	0.3185	0.3882	0.2349	0.7557	0.0056	0.00127	0.00124	0.00098	0.0024	0.000017

VLEES BAY

SAMPLE #	CONDITIONS					K- VALUES					α-VALUE				
	Wind	Currents ($m\ s^{-1}$)	S/SS	L (m)	S (m)	Mean	Median	Std Dev	Max	Min	Mean	Median	Std Dev	Max	Min
54	ALL	ALL	S/SS	ALL	ALL	0.2778	0.1632	0.3067	1.195	0.0056	0.00108	0.00051	0.0014	0.0065	0.000027
24	ALL	ALL	S	ALL	ALL	0.2981	0.2064	0.3291	1.195	0.0056	0.00121	0.00046	0.0016	0.0065	0.000027
30	ALL	ALL	SS	ALL	ALL	0.2608	0.1438	0.2855	1.106	0.0204	0.00098	0.00052	0.0012	0.0053	0.000057
18	ALL	< 0,1	S/SS	ALL	ALL	0.2745	0.1566	0.2938	1.106	0.0204	0.00088	0.00036	0.00105	0.00404	0.000057
20	ALL	0,1-0,2	S/SS	ALL	ALL	0.2561	0.1848	0.252	0.991	0.0056	0.00111	0.00048	0.0017	0.0065	0.000038
16	ALL	> 0,2	S/SS	ALL	ALL	0.3119	0.1559	0.3689	1.19	0.01	0.00126	0.00061	0.00136	0.005	0.000027

EAST LONDON

SAMPLE #	CONDITIONS					K- VALUES					α-VALUE				
	Wind	Currents ($m\ s^{-1}$)	S/SS	L (m)	S (m)	Mean	Median	Std Dev	Max	Min	Mean	Median	Std Dev	Max	Min
93	ALL	ALL	S/SS	ALL	ALL	0.2695	0.1564	0.2981	1.195	0.00155	0.00193	0.0011	0.0024	0.01295	0.000015
52	ALL	ALL	S	ALL	ALL	0.2843	0.1681	0.2995	1.183	0.00155	0.00219	0.00112	0.00273	0.01295	0.000015
41	ALL	ALL	SS	ALL	ALL	0.2504	0.1304	0.2953	1.200	0.00185	0.00159	0.00109	0.00173	0.0078	0.000039
15	ALL	< 0,1	S/SS	ALL	ALL	0.3264	0.1498	0.3903	1.200	0.0221	0.00176	0.00116	0.002	0.0078	0.0001
31	ALL	0,1-0,2	S/SS	ALL	ALL	0.2908	0.1605	0.3031	1.04	0.0016	0.0017	0.00123	0.00167	0.008	0.000015
47	ALL	> 0,2	S/SS	ALL	ALL	0.2361	0.1566	0.2506	0.975	0.00185	0.00217	0.00088	0.0028	0.01295	0.000039

Plots of α-values for all the data versus current velocity, distance from discharge location, length scale, wind speed and time and water depth.

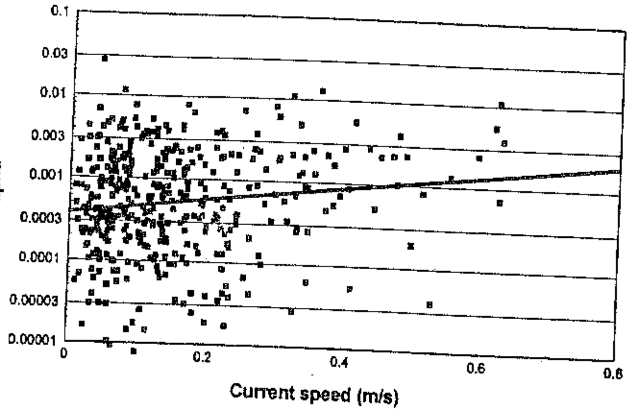

Figure B.1 α-values (log scale) for all sites versus current speed

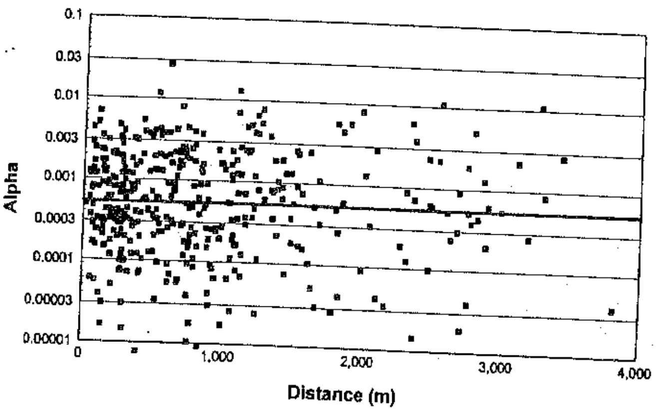

Figure B.2 α-values (log scale) for all sites versus total distance from discharge point

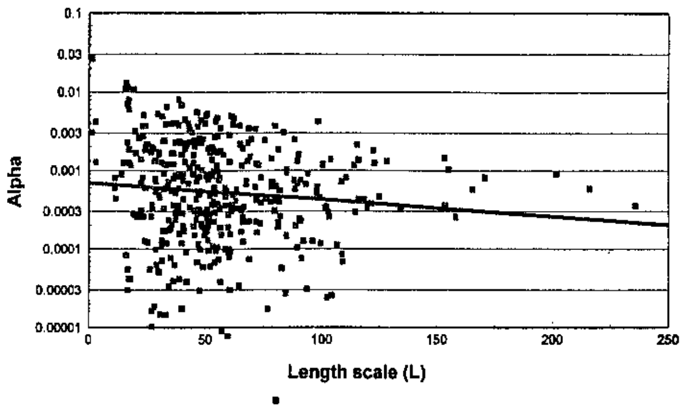

Figure B.3 α-values (log scale) for all sites versus length scale (L)

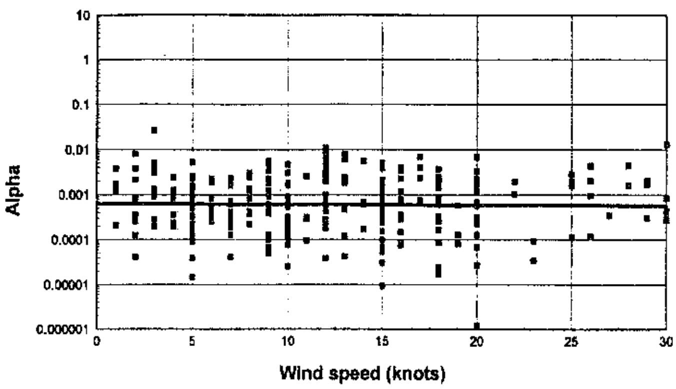

Figure B.4 α-values (log scale) for all sites versus wind speed

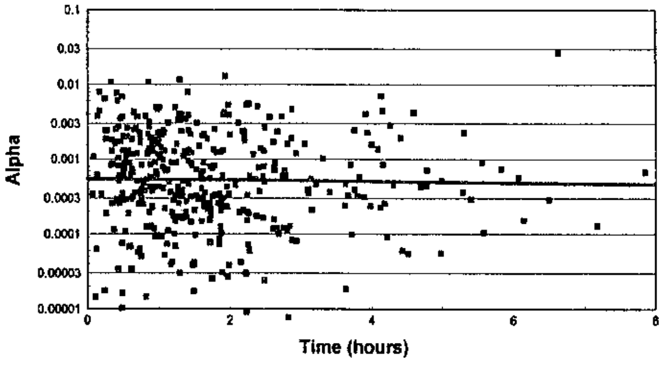

Figure B.5 α-values (log scale) for all sites versus time

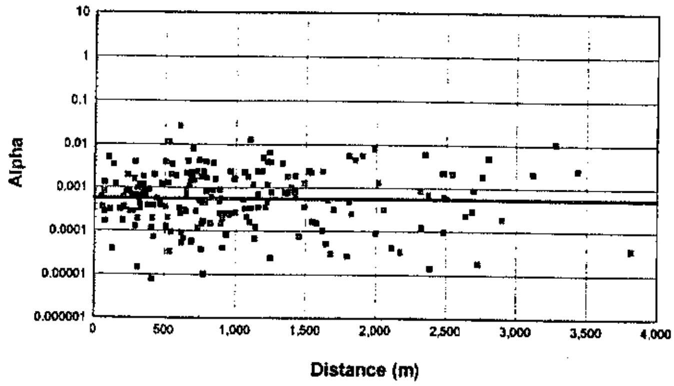

Figure B.6 α-values (log scale) for all sites (surface) versus distance

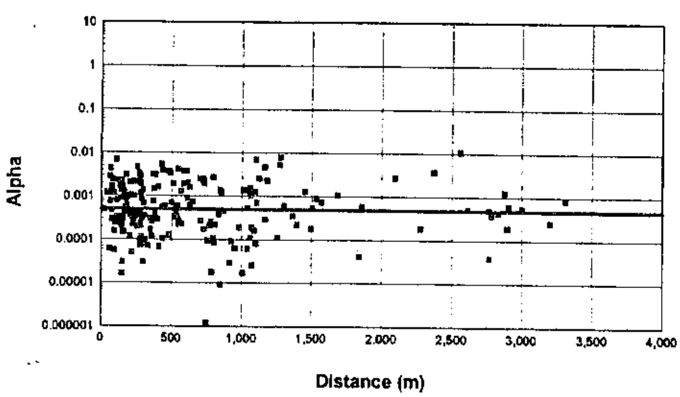

Figure B.7 α-values (log scale) for all sites (-5 m) versus distance