IMPACT OF A FERTILIZER PLANT ON THE AIR QUALITY IN A COASTAL ENVIRONMENT

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"The air is precious - for all things share the same breath - the beast, the tree, the man... the air shares its spirits with all the life that it supports.....

Chief Seattle

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CERTIFICATE

This dissertation "Impact of a Fertilizer Plant on the Air Quality in a Coastal Environment" embodies the work carried out in the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi. This work has not been submitted either in part or in full for any degree or diploma of any university.

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CHAPTER I

INTRODUCTION

Pollution, though a natural phenomenon, has acquired dangerous dimensions in recent years due to growing demands of everincreasing population, industrialization and urbanization. Until recently the major developmental projects were assessed according to technical and economical factors neglecting the environmental factors. However, in recent years, the environmental impact assessment has become an integral part of these projects for their approval. One of the major components of the environmental impact assessment is air quality simulation.

Impact assessment of an industry on the air environment involves a number of essential steps including identification, prediction, and evaluation of critical variables, and potential changes in the air quality as a result of the proposed project. Such assessment can be thought of as a basic necessity for the sound management of major developmental projects. It can provide decision makers with an account of implications of proposed courses of action before decision is made. Air quality simulation can also be used as a screening device for setting priorities for air-pollution control. Thus, impact assessment of an industry on air quality can play an important role in formulation of environmental policies and plans.

Air pollutants are the substances which when present in the atmosphere under certain conditions, may become injurious to human, animal, plant or microbial life or to property, or which may interfere with the use and enjoyment of life (T.R.Oke,1978). This definition stresses the effects upon receptors and includes modification due to both natural and anthropogenic sources.

Two classes of factors determine the amount of pollution at a site. They are (1) nature of the relevant emissions and (2) state of the atmosphere. Obviously the rate of emission and the physical and chemical nature of the pollutants are central to the determination of the amount and type of pollutant loading. It is also important to know about the characterstics of source including shape of emission-area, the duration of release and the effective height at which the injection of pollutants occurs. After release, the dispersion of pollutants is controlled by the atmospheric motions on many scales. The temperature stratification is important because it defines the atmospheric stability and this in turn controls the intensity of the thermal turbulence (buoyancy) and the depth of surface mixed layer. Together they regulate the upward dispersion of pollutants and the rate of replacement of cleaner air from the surroundings. Secondly, the wind field is critical with respect to horizontal dispersion in the boundary layer. The wind speed determines both the distance of downward transport and the pollutant dilution due to plume stretching, and in combination with surface roughness it establishes the intensity of mechanical

turbulence. The wind direction controls the general path the pollutants will follow, and its variability circumscribes the extent of cross-wind spreading.

Even if emission in a given area remains fairly constant, air quality can exhibit wide variations. This variability is introduced by the ever changing state of the atmosphere and therefore its ability to transport, dilute, transform and remove pollutants. In general the atmosphere has a tremendous capacity for dispersal, but at certain times and locations this facility may be substantially curtailed. Under these conditions air pollution can pose severe problems.

Evaluating the dispersion of atmospheric pollutants has become a necessary feature of the modern industrial activity. A variety of techniques for performing these calculations has been advised, taking into account many features of the earth's surface and especially meteorological fields in the lower atmosphere. These atmospheric models form an integral part of the regulatory process and are used for development of air pollution control strategies. These models which are used in the air pollution assessment range from simple empirical models to very complex numerical models and in general they are based on the equations governing the pollutant concentration consistent with the physical principle of mass conservation.

The problem of transport and dispersion of pollutants in complex environmental situations is attracting much attention in recent years all over the world including

India. In particular, coastal site constitutes an important field of study because of ever increasing number of industrial and energy production activities being set-up near the coast due to transportation and disposal facilities and due to availability of water for cooling and other purposes. Impact assessment on air quality involves numerous problems when dealing with a coastal site because of unique meteorological conditions present in coastal areas. A major influence on pollutant dispersion and transport in coastal environment is the presence of land/Sea breeze circulation system. The characterisation of turbulent flow is complicated by the flow reversals and differing atmospheric stabilities.

COASTAL EFFECTS

Due to different thermal heating and cooling during the diurnal cycle, a temperature deference between land and water is established. The thermal and dynamic properties of water bodies make them very important reservoir of energy and mass. The exchange occurring at the air/water interface are, however, complicated by the fact that water is a fluid. This means that heat transfer within water is possible not only by conduction and radiation but also by convection and advection. The main factors responsible for the different thermal capacities of water are summarized below:

(1) Penetration:

Short waves can be transmitted into water, with the extinction coefficient dependent upon both the nature of

water and the wavelength of the radiation. In most water bodies short wave radiation is restricted to the uppermost ten meters, but in some very clear tropical waters it has been observed to reach 700 to 1000 meters.

(2) **Mixing:**

Convection and mass transport fluid motion also permit the heat gains/losses to be mixed throughout a large volume.

(3) **Evaporation:**

Unlimited water availability provides an efficient latent heat sink and evaporative cooling tends to destabilise surface layer and further enhance mixing. In other words we can say that water converts much of its surplus energy into latent heat rather than sensible heat.

(4) **Thermal Capacities:**

The thermal capacity of water is exceptionally large such that it requires about three times as much heat to raise a unit volume of water through the same temperature interval as most soils. Energy balance of surface layer of water bodies is given by

$$Q^{*} = Q_H + Q_E + \Delta Q_S + \Delta Q_A \quad \ldots . \quad (1.1)$$

here

Q^{*}=net incoming radiation which is a sum of the net short and long wave streams.

$$Q^* = K\downarrow - K\uparrow + L\downarrow - L\uparrow = K^* + L^* \quad \ldots \quad (1.2)$$

where

K^* = net incoming short wave radiation

L^* = net incoming long wave radiation

$K\downarrow$ = incoming short wave radiation

$K\uparrow$ = reflected short wave radiation which depends on albedo

$L\downarrow$ = incoming long wave radiation emitted by atmosphere

$L\uparrow$ = out going long wave radiations from surface governed by temperature and emissitivity

Q_H = sensible heat

Q_E = Latent heat

ΔQ_S = change of heat storage in the layer

ΔQ_A = net horizontal heat transfer due to water currents.

Although Q^* may be large over water bodies due to their low albedo, the effectiveness of Q_E and ΔQ_S as thermal sinks means that Q_H (sensible heat) is small. By day Q_H is small because most of the energy is channeled into storage or latent heat, at night Q_H is small because the long wave radiational cooling is largely offset from the same water store. The reduced convective heat flux (Q_H) to and from the air means that atmospheric warming and cooling rates (dT/dt) are relatively small over water bodies. In contrast the convective fluxes and rates of temperature change over land are larger and show a marked diurnal variation.

Different thermal capacities and conductivities of earth and sea producing a temperature difference can affect atmospheric dispersion through two mechanisms: (1) a horizontal

pressure gradient is generated which gives rise to the land/sea breeze, and (2) it tends to produce different atmospheric stability in air over water and land, with an interface between them.

LAND AND SEA BREEZE

The land/water temperature difference and their diurnal reversal produce corresponding differences in pressure over land/water surfaces. These in turn result in a system of breezes across the shoreline which reverse their direction between day and night. In the morning the greater sensible heat flux over the land heats the air column more rapidly and to greater heights than over water. The consequent expansion of the air column over land means that at a constant height above the earth the value of atmospheric pressure over land will be greater than the value over water. The horizontal pressure gradient thus formed produces a slight flow from land (B) to water (C) (Fig.1.1). Convergence at C over water surface increases atmospheric pressure near C, causing subsidence in the vertical column from C to a lower level say D. Now the atmospheric pressure at D is greater than that at the same height over land say at A; so an onshore surface flow from D to A (sea breeze). At the same time divergence at B results in an upward air flow from A to B, complexing the circulations (Atkinson,1981).

At night the land cools more rapidly than the adjacent water body and the land breeze develops due to reverse mechanisms. Thus the sea-breeze circulation is a closed cell

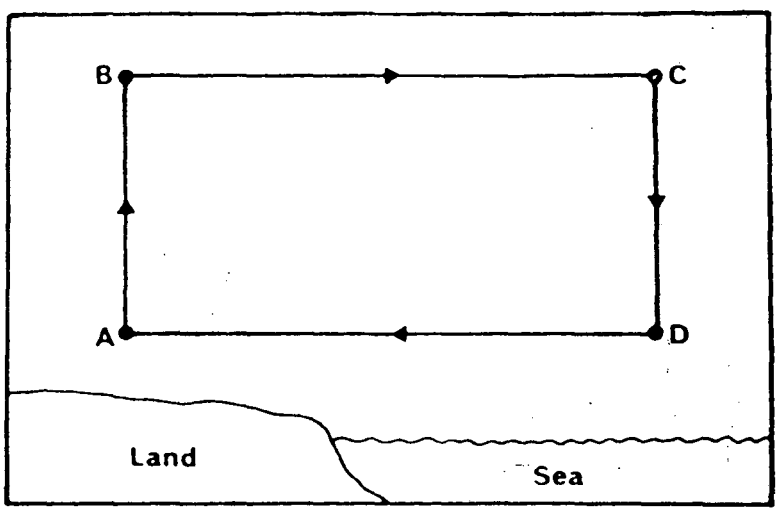


Fig. 1.1 SCHEMATIC CIRCULATION IN A MATURE SEA BREEZE (AFTER ATKINSON, 1981).

circulation however the so-called sea-breeze is actually only the lower portion of the circulation, the upper level offshore flow is called return flow (Fig.1.2). Typically the transition from land breeze to sea-breeze will occur during the morning. By mid-afternoon, sea- breeze is fully developed. Between sunset and midnight, surface temperature equalises and air becomes calm. As the land continues to cool, a land-breeze begins, reaching its peak just before sunrise. Sea-breeze circulation adversely affects the dispersion of pollutants in many ways. Firstly, it can cause *continuous coastal fumigation* as a result of the development of Internal Boundary Layer (IBL) (Fig 1.3) which will be discussed later. Secondly sea breeze is a closed circulation, pollutants may be carried offshore by the return flow and then brought inland by sea breeze, effectively diminishing ventilation by clear air. Thirdly, if there is an along shore component of circulation, pollutants may travel in helical or cork-screw fashion along the coast (Lyons,1972).

The most important and unique effect of coastal terrain is the development of IBL due to different temperature profiles over land and water surface and land/sea breezes. IBL, an interface between stable and unstable atmospheres, is an important component of coastal fumigation models and usually originates at the land-water interface and thickens downwind. Interactions between the IBL and plume from an elevated source at a coastline influences the distribution of ground-level concentration downwind and the location of the maximum value.

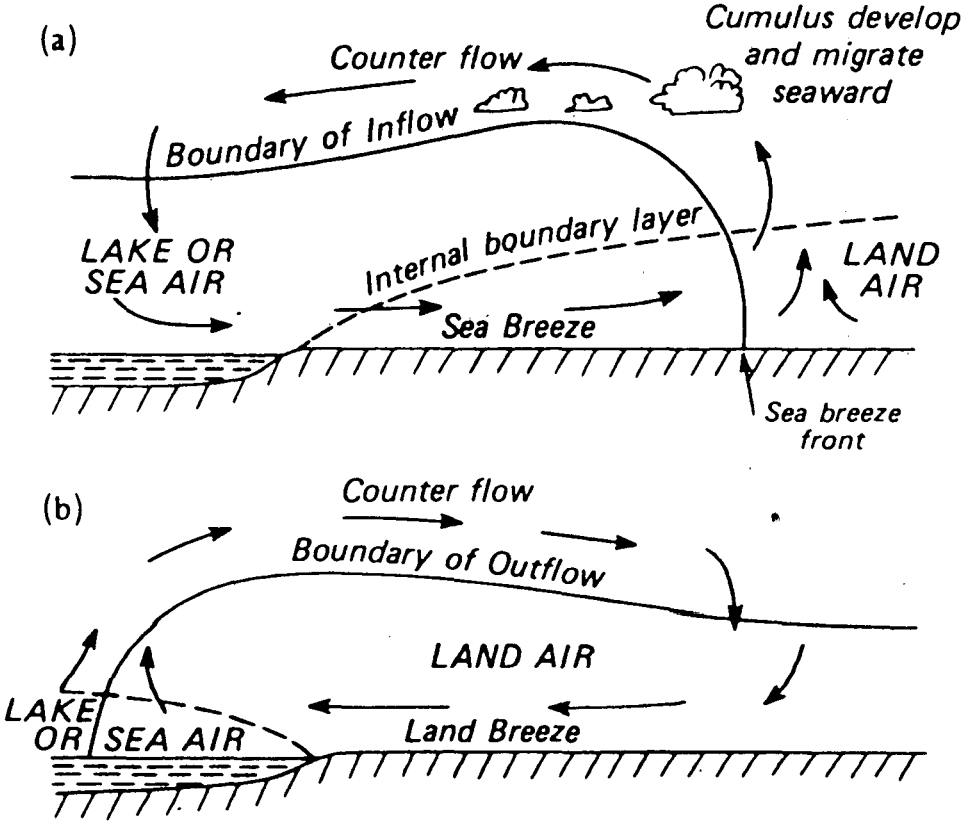


Fig. 1.2 LAND AND SEA(LAKE) BREEZE CIRCULATION ACROSS A SHORELINE (a) BY DAY AND (b) AT NIGHT.

SOURCE: T. R. OKE, 1978.

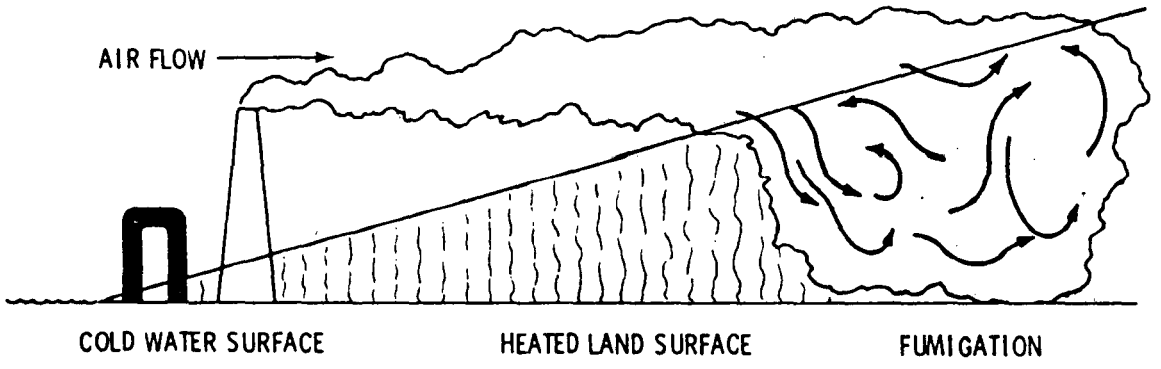


Fig. 1.3 A FUMIGATION CONDITION PROUDCED BY THERMAL INTERNAL BOUNDARY LAYER ALONG A SHORELINE.

SOURCE: MATHEMATICAL MODELS FOR ATMOSPHERIC POLLUTANTS, EPRI EA-1131, APPENDIX D, PROJECT 805,1979.

INTERNAL BOUNDARY LAYER DEVELOPMENT:

As air passes from one surface type to new and climatically different surface, it must adjust to a new set of boundary conditions. The line of discontinuity is called leading-edge. The adjustment is not immediate throughout the depth of air layer, it is generated at the surface and diffuses upwards. The layer of air whose properties have been affected by the new surface is referred to as an Internal Boundary Layer (IBL), and its depth grows with increasing distance, downwind from the leading-edge. Properties of air above IBL remain determined by upwind influences and not those of immediately beneath. The formation of IBL and resultant fumigation have been studied in detail by many authors viz. Peters (1975), Venkatram (1977(a),1977(b),1986), Deardroff and Mishra et al. (1982) and others.

At a coastal site, a free convective IBL forms due to the differences in temperature between land and water, and hence the name *Thermal Internal Boundary Layer* (TIBL) is used commonly. An air-mass advected over a cool lake or ocean surface is not destablised by convective elements as would an overland air mass. Instead, the marine air mass cools from below by conduction from the water's surface and thus becomes stable. As the stable marine air-mass crosses the shoreline (i.e.,onshore flow), it must adjust, first in lower levels, then in higher levels, to the resulting discontinuity in temperature (Fig.1.4). This adjustment is accomplished by generation of turbulence which acts as

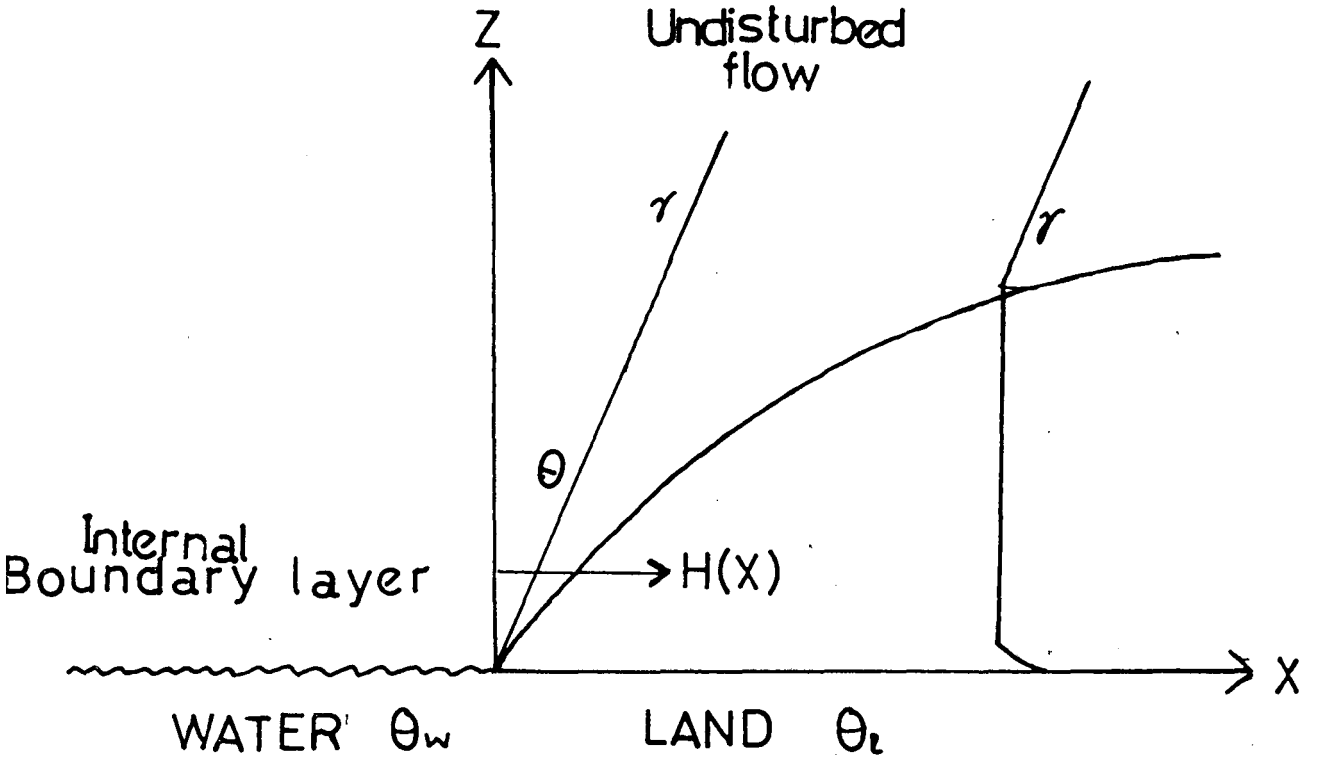


Fig. 1.4 SCHEMATIC IDEALIZED PHYSICAL SITUATION FOR THE FORMATION OF IBL. (AFTER VANKATRAM, 1976).

transport mechanism for surface heat from the land surface. The TIBL interface generally slopes upward from the coastline until at some point downwind (x) it assumes an *equilibrium height* which is the height of inland mixed layer. The adjustment of the once stable flow is complete at this equilibrium height.

COASTAL FUMIGATION

The development of IBL at a coastal site plays a significant role in determining where a coastal elevated plume fumigates to the ground. Two important physical processes concerning dispersion take place in coastal regions due to IBL. These are *fumigation* and *trapping*. Fumigation occurs when plumes emitted into the stable marine air at the shoreline normally move inwards with onshore flow and at some point intersect the deepening IBL. Intense downward mixing takes place at the point of IBL impaction and this process can cause high ground level concentration. *Trapping conditions* occur when stacks are located within the IBL at some inland distance such that plumes are emitted into the convectively mixed IBL and are effectively capped by the IBL interface.

The type of the fumigation mentioned above is *dynamic* or *continuous* contrary to the *inversion break up* fumigation which takes place in land regions. Unlike the later whose duration is less than one hour, the dynamic fumigation can persist for several hours and thus it can create severe pollution problems. So it becomes necessary to incorporate IBL development factor while assessing impact of any industry on the air quality

in a coastal region.

Extensive research is being done in this field and several attempts have been made to develop mathematical model for IBL. Studer and SethuRaman (1984) made a comparative study of six TIBL models available in the literature. Early efforts in specifying the TIBL height are given by Vander Hoven (1967) based on the work done by Prophet (1961). He gave the following general equation

$$h=8.8\ (X/U\Delta\theta)^{(1/2)} \quad \ldots \quad (1.3)$$

where

h= TIBL height (m)

X= distance downwind from land-water interface

U= mean wind speed in TIBL(m/s)

$\Delta\theta$= temperature difference between the top and the bottom of over water surface based inversion(degree C)

The above relationship (1.3) was empirically derived to fit observational data and not dimensionally homogenous.

Plate (1971) using earlier work by Ball (1960) devised an equation for the height of free convective boundary layer given by

$$h = ((4H_o\ X)/(\rho\ Cp\ \beta\ U))^{1/2} \quad \ldots \quad (1.4)$$

here

H_o = surface heat flux over land

Cp = specific heat at constant pressure (0.24cal/(g K))

ρ = density of air ($1.2*10^3 gm^{-3}$)

β = potential temperature gradient over water

U = mean wind speed at a height of 10m downwind

Raynor et al. (1975) derived the following form based on physical and dimensional considerations

$$h = u_\star/U \{(X |T_L-T_W|)/|\gamma|\}^{1/2} \quad \ldots . \quad (1.5)$$

$u_\star$ = downwind surface frictional velocity

T_L = downwind surface temperature (land)

T_W = upwind surface temperature (water)

γ = absolute lapse rate upwind

Equation (1.5) is dimensionally homogeneous and incorporates the use of land-water temperature difference.

In the same year Peter (1975) obtained the following relation

$$h=2H_oX/\rho C_p(T_L-T_W) \quad \ldots . \quad (1.6)$$

Weisman (1976) suggested an equation similar to that of Plate's (1971) (eqn.1.4) as parabolic extension to Peter's (1975) eqn. (1.6).

$$h=\{2H_oX/\beta C_p \rho U\}^{1/2} \quad \ldots . \quad (1.7)$$

Venkatraman (1977(b)) considering TIBL as being 2-dim. suggested

$$h=(u_\star/u_m)[2|T_L-T_W|X/\beta(1-2F)]^{1/2} \quad \ldots . \quad (1.8)$$

where

u_m=Mixed layer mean wind speed

F=entrainment factor

Inspite of availability of a number TIBL height estimation models, it is very difficult to incorporate these in

impact assessment studies. We can easily notice that all these equations either make use of parameters which are not measured normally or are very difficult to measure. Equations given by Peter (1975), Plate (1971) and Weisman (1976) contain H_o whose determination is difficult in most meteorological applications. Other equations contain parameters such as $\Delta\theta$, γ, T_L, T_W, u_* etc. which are also difficult to determine. Stunder and Sethuraman (1984) tested all the above mentioned models and they found that these models tend to produce reasonable results only for limited range of conditions. These models are shown to permit large variation in the value of h and are quite sensitive to uncertainties in input parameters. They also showed that a difference of about 120m between two TIBL heights could mean a difference of 7km in the location of fumigation zone. Thus even a relatively small difference in predicting TIBL height at a given downwind distance may cause serious problems in predicting the location of the groundlevel fumigation and hence the location of maximum groundlevel concentration (Fig.1.5). Every coastal dispersion model must therefore have a reliable TIBL variation module in order to predict the groundlevel concentrations accurately.

Hanna (1987) gave an empirical model, originally given by Hanna et al. (1985) that involved no meteorological parameters and thus this model does not allow any variation in TIBL height with meteorological conditions at a given downward distance. Though Hanna's model is purely empirical with no theoretical basis, it is preferred because it can be used even

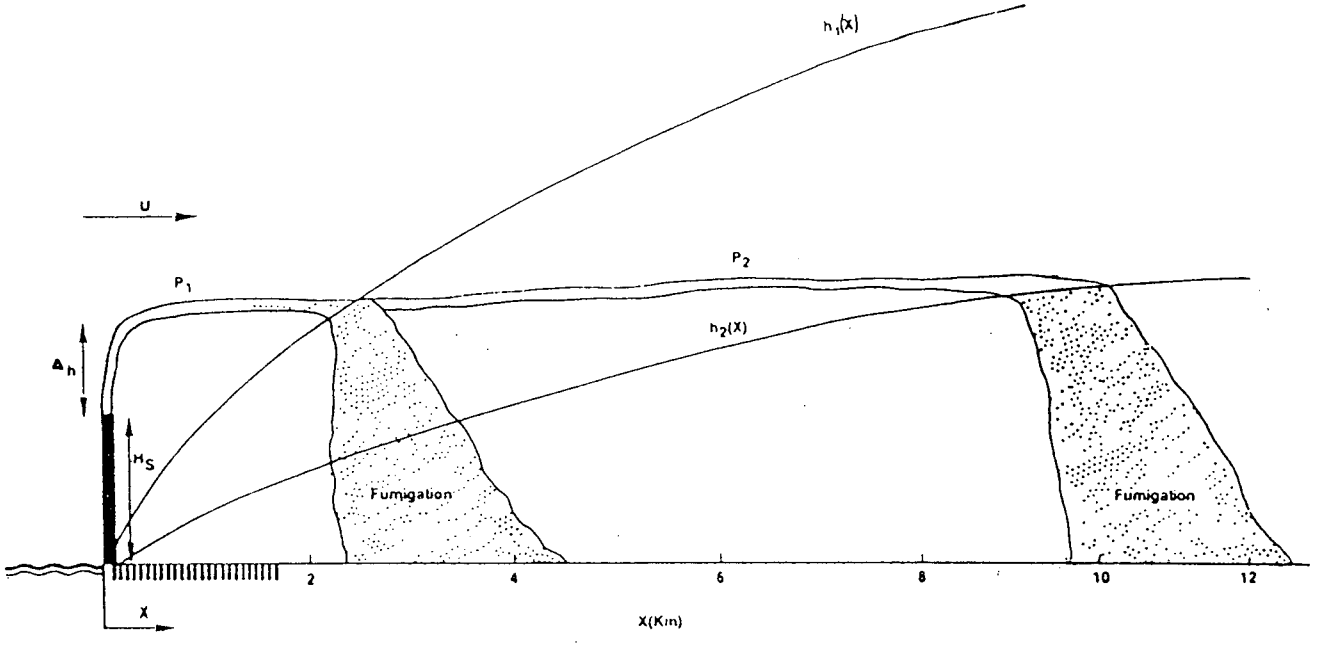


Fig. 1.5 THE EFFECT OF VARIATION OF IBL HEIGHT ON PLUME FUMIGATION. (AFTER STUDER AND SETHURAMAN, 1984).

when adequate data are not available as is the present case. Due to high cost of instrumentation, sampling stations are few and hence it is not possible to cover every area of concern. Another consideration is that Hanna's model avoids the wild errors possible with parameterised models.

In the present study environmental impact assessment is done for a fertilizer plant at Kakinada (lat. $16^{o}57'N$ & long. $82^{o}14'E$) in coastal Andhra Pradesh. Dispersion coefficients are calculated using Briggs interpolation curves (Briggs,1973) for a plain terrain which are further modified by introducing Internal Boundary Layer height using Hanna's equations. The distance of dynamic fumigation zone from the coast and the concentration under fumigation conditions are calculated.

CHAPTER II

MATERIALS AND METHOD

In the present study the impact assessment of a Fertilizer Plant on the ambient air quality is carried out. The fertilizer plant located at Kakinada (Fig.2.1) has seven units in the proposed plan with the specifications given below:

EMISSION DATA

Emission inventory for this plant as given in Table 2.1 has been conducted by Richardson and Cruddas Ltd.(India).

TABLE 2.1

STACK NO.	STACK SPECIFICATIONS	STACK HEIGHT (mts.)	EMISSION RATES (ton/day)			HEAT EMISSION RATES
			SO2	AMMONIA	UREA DUST	
1.	Neptha Preheater	30	0.0157	-	-	374976
2.	Sweet Neptha Preheater	30	0.056	-	-	1354389
3.	Primary Reformer	30	0.600	-	-	6054048
4.	Steam Generation Plant	120	9.710	-	-	10673280
5.	Steam Boiler	120	6.250	-	-	4896000
6.	Urea Prill Plant	90	-	0.683	0.360	5901984
7.	Urea Inert Plant	90	-	0.336	-	15523

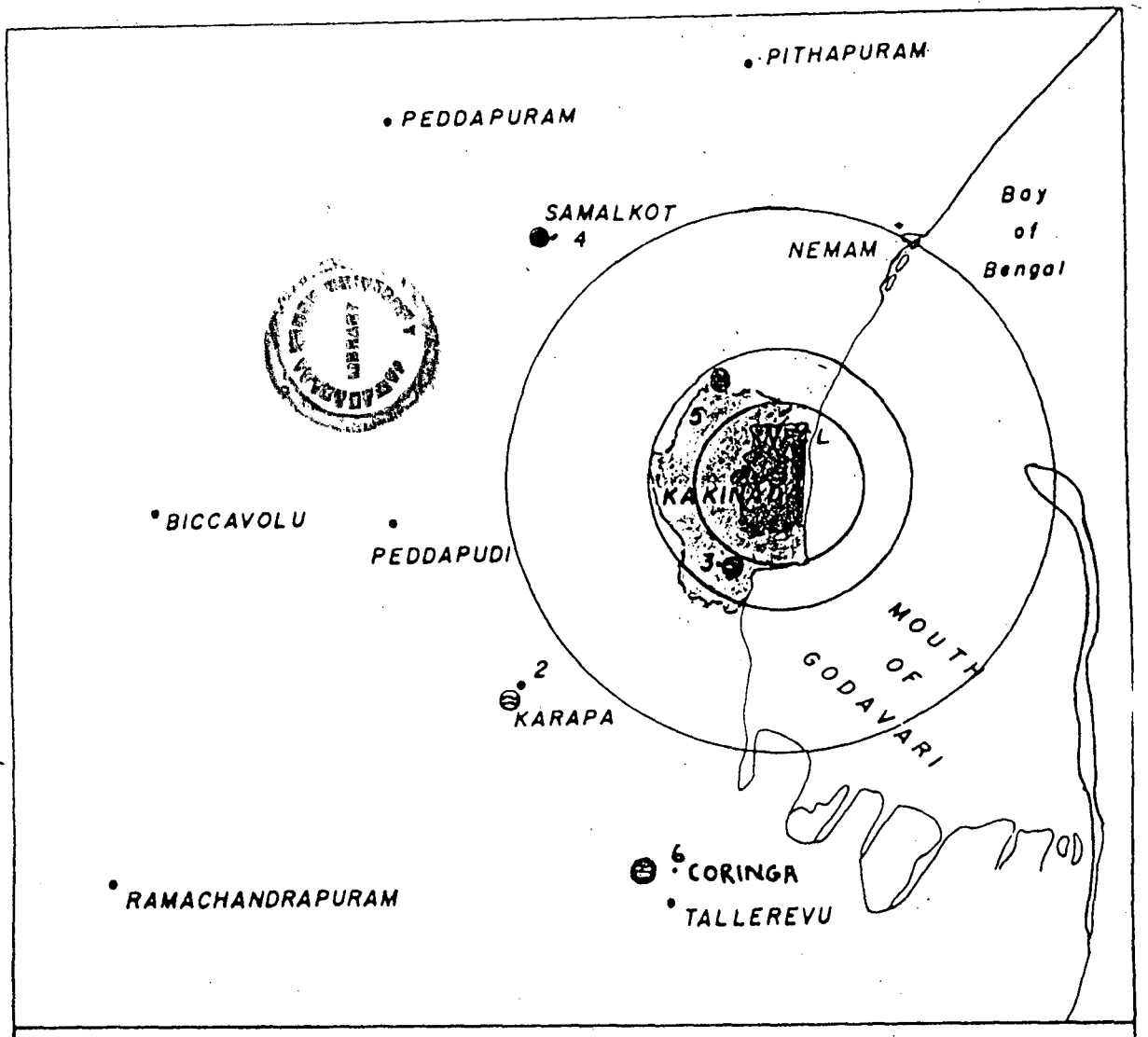


Fig. 2.1

METEOROLOGICAL DATA:

Hourly values of wind speed, wind direction and temperature are also provided by Richardson and Cruddas. These are available for every day for four months namely January, April, July and October representatives of four seasons winter, premonsoon, monsoon and postmonsoon respectively. Daily cloud data of the four months mentioned above were also available.

GEOGRAPHICAL LOCATION OF KAKINADA:

Kakinada (lat. $16^{o}57'N$ & long. $82^{o}14'E$) is a coastal city in Andhra Pradesh on the coast of Bay of Bengal.

In the present study an attempt is made for predicting air quality due to proposed seven units of Nagarjuna Fertilizer and Chemical Ltd. The work can be divided into two parts. Part one covers the short term and long term concentration computations upto a distance of 30 km. from the plant site using conventional **Gaussian Plume Model** for plain terrain completely overlooking its location near the coast. In the second part, the fact that the plant is situated in a coastal region is taken into consideration. Due to the development of Internal Boundary Layer (IBL), a phenomenon usually called **Dynamic Fumigation** takes place at some inland position (during day time) and an attempt is made to estimate approximately the concentration under such conditions which is obviously higher than the concentration in the absence of IBL. As actual distance of each stack from the water/land interface is not available, an average distance of the plant site from the coast is considered as the distance of each stack from

coast. This average distance between coast and plant in the present case is 1 km.

MODEL:

In carrying out the present study, "Gaussian plume model" forms the basis of all the computational work. Gaussian plume model is preferred because it is the most widely used model. It forms the backbone of nearly all models in the U.S.EPA's UNAMAP models (Turner,1979) and in the U.S. Nuclear Regulatory Commission guidelines (NRC:1977, 1979) and is used by most of the countries participating in the NATO plume-modeling exercise in Frankfurt, Federal Republic of Germany (Jost and Gutsche,1976). This is widely used because of the following reasons (Hanna,1982(c))

1. It produces results that agree with experimental data as well as any model.

2. It is fairly easy to perform mathematical operations on this equation.

3. It is appealing conceptually.

4. It is consistent with the random nature of turbulence

5. It is a solution to the Fickian diffusion equation for constant k and u.

6. Other so-called theoretical formulae contain large amount of empiricism in their final stage.

The real atmosphere is non-isotropic; i.e, it is non- homogeneous and the diffusion rate is not the same in all three dimensions, nor is diffusion necessarily constant in any direction. Also the atmosphere contains a wide range of eddy

sizes or turbulence cells which affect a puff or a plume differently. So there exists a number of complications in dealing with dispersion in the real atmosphere which are to be accommodated in mathematical models using a number of simplifying assumptions are (Moroz,1987):

* All the pollutants are emitted from a "point source" of infinite strength.

* Wind is uniform through the layer in which dispersion occurs and an average or "mean wind" can be used in estimating concentrations of pollutants.

* The concentration distribution across the width and depth of plume is taken to be Gaussian.

* The edges of the plume are taken to be where the concentration of pollutant has decreased to 1/10 of the centerline value.

* The pollutant under consideration is not lost by decay, chemical reaction or deposition; i.e, it is conservative.

* Solution is to be used over relatively flat, homogeneous terrain. It should not be used routinely in coastal or complex terrain with mountains or buildings of irregular profiles.

* Solution is steady-state solution; i.e, $\partial/\partial t=0$, over averaging periods.

GAUSSIAN PLUME DISPERSION MODEL:

For a continuous release at X=0 at stack height (Z=H) Pasquill (1962) gave a simple formula which assumes constant wind speed u and complete reflection from ground surface and neglects time-averaged along-wind dispersion relative to across-

wind dispersion, given by

$$X(x,y,z) = Q/(2\pi u \sigma_y \sigma_z) \exp\{-y^2/2\sigma_y^2\}$$
$$[\exp\{-(z-H)^2/2\sigma_z^2\}+\exp\{-(z+H)^2/2\sigma_z^2\}] \quad \ldots \quad (2.1)$$

where

$X(x,y,z)$ = Concentration of pollutant in air ($\mu g/m^3$)

Q = continuous point source strength ($\mu g/sec$)

u = mean wind speed at height H (m)

σ_y = lateral dispersion parameter (m)

σ_z = vertical dispersion parameter (m)

y = lateral distance from plume centerline (m)

z = height above ground (m)

H = final plume rise above ground (m)

This equation predicts the concentration for a continuous point source release from a fixed source emitting into a uniform wind.

To use the Gaussian plume model to make practical estimates, we must select the appropriate diffusion parameters σ_y and σ_z for travel distance, surface conditions and meteorological conditions under consideration. This involves determination of a functional form for $\sigma_y(x)$ and $\sigma_z(x)$, where x is selected as the travel distance. These functions clearly depend on atmospheric stability; so the second major parameterization effort has been to select best available measures of stability. The third major parameter used is the effective plume height. There exists a large number of plume rise formulae in literature and to select the best possible for the present nature of work makes an important exercise. The other parameters used are wind velocity at stack

height and concentration of pollutants.

CONCENTRATION COMPUTATION:

As already mentioned the work can be divided into two parts.

PART I

Short term (hourly) ground level concentrations along Plume axis is given by (Turner, 1970)

$$X(x,0,0) = Q/(\pi u \sigma_y \sigma_z) \exp[-.5 H^2/\sigma_z^2] \quad \ldots \quad (2.2)$$

where all parameters have their usual meaning.

Long term ground level concentrations for periods over a month or more are computed by

$$X(x,0,f) = 360\ f\ Q/(\phi \pi^{3/2} \sqrt{2}\ \sigma_z U\ x) \exp[-1/2H^2/\sigma_z^2] \quad \ldots \quad (2.3)$$

where

$X(x,0,f)$ = Long term (seasonal) concentration ($\mu g/m^3$)

f = percentage frequency

ϕ = Angular width of direction sector (degree)

Q, U, H and σ_z have the usual meanings (Smith 1968, Turner 1970).

PART II

Here the mixing height limited by the Internal Boundary Layer (IBL) is incorporated. The following cases are possible for stacks of different heights.

FUMIGATION:

When the plume is released above the IBL and at some distance downward if it intercepts the increasing IBL then conditions for fumigation are being satisfied and down mixing of pollutants will take place. The fumigation process was described by Hewson and Gill (1944). Equations for estimating concentration under fumigation conditions caused by breakup of surface based inversion have been given by Holland (1953), Hewson (1955), Gefford (1960), Bierly and Hewson (1962) and Pooler (1965).

To estimate ground level concentrations under inversion breakup fumigations, one assumes that the plume was initially emitted into a stable layer. Therefore σ_y and σ_z characterstics of stable conditions must be calculated from Briggs equations for such atmospheric stabilities. If the inversion is eliminated upto the effective stack height, half of the plume is presumed to be mixed downward, other half remaining in the stable layer above. Downward diffusion begins when the surface layer reaches stack top. The downward diffusion continues as the layer increases until it reaches a maximum when the layer elevation reaches top edge of plume i.e maximum concentration under fumigation is obtained when the inversion layer touches the plume top edge (Turner, 1970). In the present case, in analogy with the above process, maximum fumigation concentration is obtained at a distance x_F where increasing IBL height and plume rise approaches to each other.

Elevation of the plume top h_f is the sum of the

effective stack height plus the vertical half width of the plume 2.15 $\sigma_{z,f}$ given by the following equation

$$h_f = h_e + 2.15\ \sigma_{z,f} \quad . \ . \ . \ . \qquad (2.4)$$

So condition for maximum fumigation concentration is achieved when $H_T = h_f$ and is calculated from the equation given below

$$X_F = Q/\sqrt{(2\pi)}\ u\ \sigma_{yf} H_T \quad ; \quad \text{at } x = x_F \quad . \ . \ . \ . \qquad (2.5)$$

where

$$\sigma_{yF} = \sigma_y + EH/8 \quad . \ . \ . \ . \qquad (2.6)$$

where

EH= Effective stack height (m)

σ_{yf} takes into account the additional horizontal spreading which takes place during mixing of stable plume through a vertical depth under fumigation. Initially the plume is emitted into the stable layer and so diffusion coefficients are the characterstics of stable layer. When plume intercepts IBL, unstable layer envelopes the plume and downwind diffusion in this layer is greater than that in the stable layer and σ_y increases to provide σ_{yf} characterstic of fumigation. The approximation of σ_{yf} is suggested by Bierly and Hewson (1962).

TRAPPING:

When plume is released within the IBL then at some distance downwind the increasing plume may intercept the increasing IBL satisfying the condition for Trapping. Analysis of plume development under trapping condition is given by Turner (1970) where an unstable layer is capped by an inversion layer

limiting the dispersion. The only difference between the present case and the Turner's analysis is that the IBL height which serves as inversion layer varies with downwind distance.

A stable layer existing above an unstable layer will have the effect of restricting the vertical diffusion. At a height 2.15 σ_z above the plume centerline the concentration is one tenth the plume centerline concentration. This height is considered the upper edge of plume. When upper edge of plume extends to the stable layer (IBL), at height $H_T(x)$, it is assumed that concentration distribution starts being affected by the "lid" (IBL). Following method is suggested to take care of this situation (Turner,1970). Allow σ_z to increase with distance to a value of $H_T/2.15$ or $0.47H_T$ i.e, $H_T = 2.15\sigma_z$. At this distance x_L, plume is assumed to have a Gaussian distribution in the vertical. Assuming that by the time plume travels twice this distance($2x_L$), plume has become uniformly distributed between the earth's surface and the height H_T i.e, concentration does not vary with height. For the distance greater than $2x_L$, concentration (plume centerline) for any height between the ground and H_T are calculated from :

$$X_T(x,0,0) = Q/\sqrt{(2\pi)}\,\sigma_Y H_T U \quad \text{for any z from 0 to } H_T \text{ for } x > 2x_L \quad \ldots(2.7)$$

Determination of Diffusion Coefficients:

Concentration pattern of air pollutants in the atmosphere are controlled by atmospheric diffusion and since turbulence is the fundamental cause of diffusion, it becomes logical to use this property of atmosphere while predicting

diffusion. Earlier attempts in determination of diffusion coefficients used this property (turbulence) of atmosphere widely. Early attempt using turbulence observations in this field was made by Giblett (1932), Doran et al. (1978), Draxler (1976), Pasquill (1976) and Irwin (1979). They all suggested formula based on actual observation of wind direction fluctuations in horizontal and vertical direction. Cramer (1957) has favoured azimuth wind direction fluctuations as a more direct measure of the turbulence that accounts for diffusion. But atmospheric turbulence is difficult and expensive to measure directly so research has been directed to develop empirical relations between the meteorological quantities and atmospheric diffusion. These empirically based procedures are known as turbulence typing schemes. However if turbulence observations are available then it's always better to use these information for computing diffusion coefficients instead of using empirical formulae.

A number of other diffusion typing schemes are presented in graphical forms (Fig 2.2 to 2.4) based on different experimental data. The BNL turbulence typing scheme, as originally presented by Smith is based on the non-bouyant plume dispersion data from an elevated (108m) source for a distance out to several kilometres. All measurements refer to average value over a period of the order of 1 hour. The BNL turbulence typing scheme is given in Fig. 2.2. Smith (1972) has solved the diffusion equation in order to derive revise σ_z curves as a function of surface roughness and Hosker (1974) has published graphs of σ_z based on Smith's results.

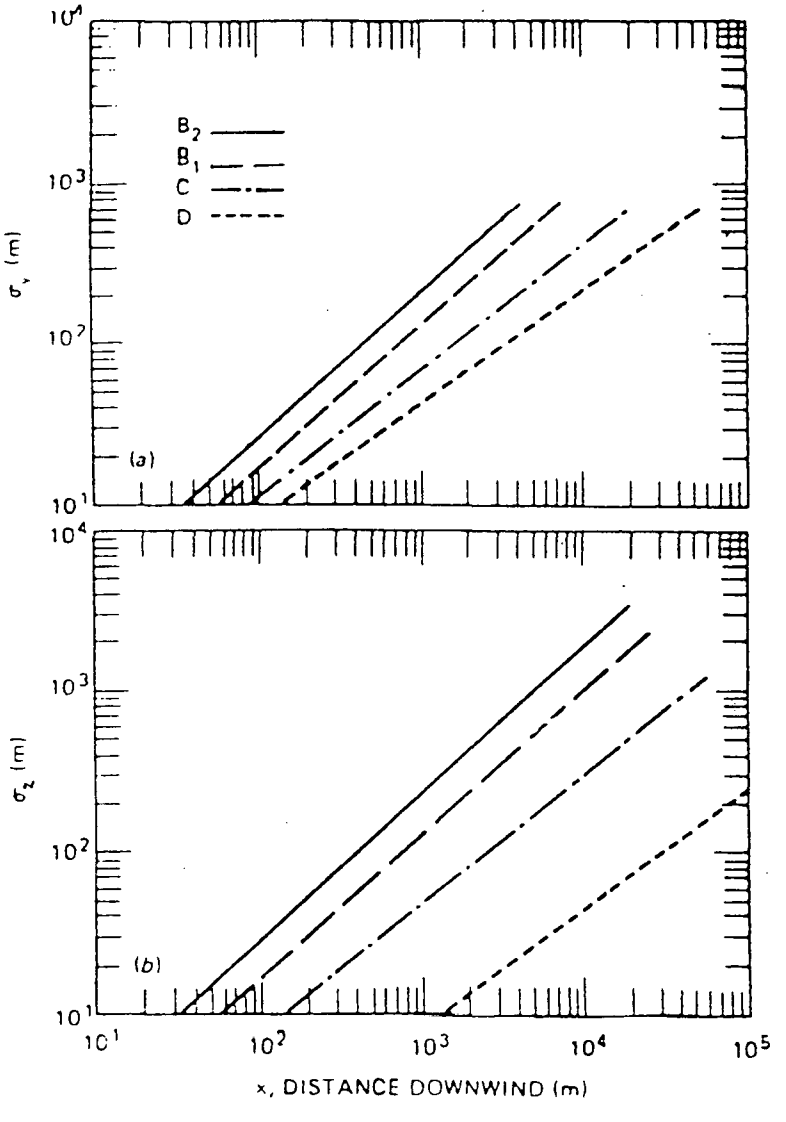


Fig. 2.2 Curves of σ_y and σ_z for BNL turbulence types from Singer and Smith.[9] Letters refer to BNL stability types in Table 1.

Project Prairie Grass (Haugen,1959) is the most frequently quoted diffusion experiment and Pasquill (1961) curves, which were later adopted by Gifford (1961, 1968, 1976) are based on these experiments only (Fig. 2.3.). These curves are based on these diffusion measurements made to a distance of 800 m using a passive (non-bouyant) tracer gas release near surface. P-G curves use six stability classes ranging from A (highly unstable) to F (moderately stable). These classes are based on cloudiness, surface wind-speed and insolation as explained in Table 2.2. Turner (1964) introduced a different version of Pasquill's scheme to include Sun angle, cloud cover, and cloud height. This has been shown by Golder (1972) to depart somewhat from the P-G categories.

Carpenter et al. (1971) summarized 20 years of Tennessee Valley Authority (TVA) experience with the measurement of concentration pattern and related values of meteorological parameters. The emissions in this case are in the form of buoyant plumes from tall stacks with stack heights ranging from 75m to 250m and effective stack heights even more than that. TVA used six-category typing scheme, ranging from neutral to strong inventions based on lapse rate. The TVA sigma schemes are shown by Fig. 2.4. The TVA data extended to 10 km. from the source.

In the absence of turbulence data it becomes a necessity to use the empirical graphical diffusion typing schemes which are of course based upon experimental data. The different graphical diffusion scheme discussed above i.e, BNL, PG, and TVA

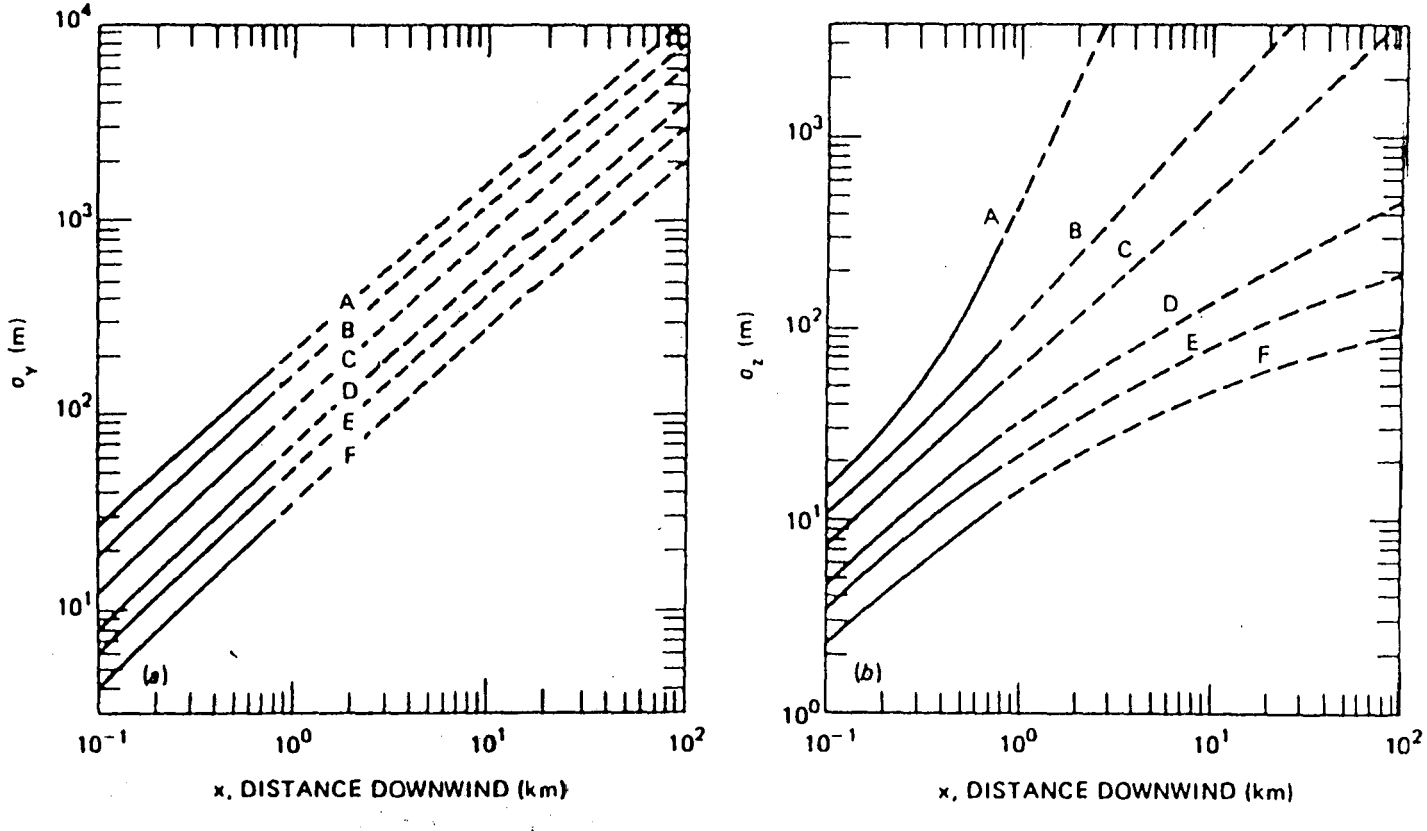


Fig. 2-3 Curves of σ_y and σ_z for Pasquill's turbulence types based on Pasquill. See also Gifford, Slade, and Turner.

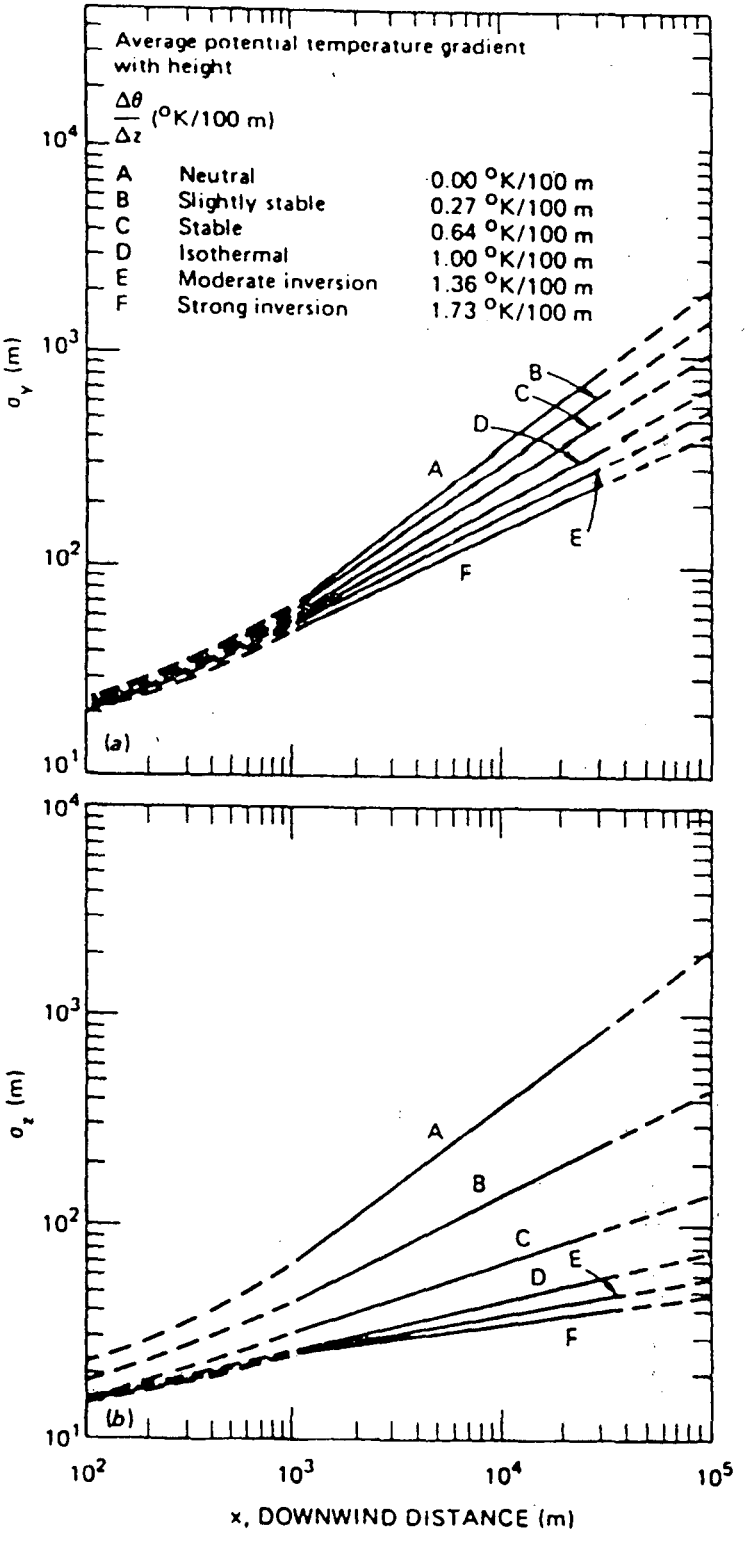


Fig. 2.4 Curves of σ_y and σ_z for TVA data from Carpenter et al. Average potential temperature gradients with height refer to plume height.

Table 2.2 Meteorological Conditions Defining Pasquill Turbulence Types

A: Extremely unstable conditions
B: Moderately unstable conditions
C: Slightly unstable conditions
D: Neutral conditions*
E: Slightly stable conditions
F: Moderately stable conditions

Surface wind speed, m/sec	Day time insolation			Nighttime conditions	
	Strong	Moderate	Slight	Thin overcast or ≥4/8 cloudiness†	≤3/8 cloudiness
<2	A	A - B	B		
2	A - B	B	C	E	F
4	B	B - C	C	D	E
6	C	C - D	D	D	D
>6	C	D	D	D	D

*Applicable to heavy overcast day or night.

†The degree of cloudiness is defined as that fraction of the sky above the local apparent horizon that is covered by clouds.

schemes, reflect different diffusion data base and, to a certain extent, refer to different applied problems, and thus these schemes are expected to differ from each other. Comparison of Fig. 2.2 to Fig. 2.4 shows major disagreement; curves do not have the same shape. The PG curves of σ_z have larger values and more sharply increasing upward curvature with distance for unstable conditions and conversely for stable conditions, although the difference in that case less pronounced. PG curves of σ_y are slightly steeper than the BNL curves for all stability conditions but more so for stable. The TVA curves differ from both the BNL and the PG curves. Not only are the shape of the TVA curves rather different, particularly for shorter distances, but also the range of atmospheric stability conditions encountered for these elevated plumes is much narrower and includes no unstable conditions at plume height. This is in contrast to the near surface level stability conditions encountered for releases near ground (Gifford, 1976)

It was Briggs(1973) who resolved this problem to some extent and gave analytical formulas for σ_y and σ_z. Briggs combined the P-G, TVA, and BNL curves using theoretical formulas for asymptotic limits, to obtain the set of recommended formulas given in Table 2.3. The P-G curves and BNL curves are based on different type of data base and according to Briggs, the diffusion of a plume from such an elevated source(TVA) is quite different from that of passive diffusion from a ground level source(i.e, P-G curves).

Table 2.3 Formulas Recommended by Briggs (1973) for $\sigma_y(x)$ and $\sigma_z(x)$ $(10^2 < x < 10^4 m)$

Pasquill type	σ_y, m	σ_z, m
	Open-Country Conditions	
A	$0.22x(1+0.0001x)^{-1/2}$	$0.20x$
B	$0.16x(1+0.0001x)^{-1/2}$	$0.12x$
C	$0.11x(1+0.0001x)^{-1/2}$	$0.08x(1+0.0002x)^{-1/2}$
D	$0.08x(1+0.0001x)^{-1/2}$	$0.06x(1+0.0015x)^{-1/2}$
E	$0.06x(1+0.0001x)^{-1/2}$	$0.03x(1+0.0003x)^{-1}$
F	$0.04x(1+0.0001x)^{-1/2}$	$0.016x(1+0.0003x)^{-1}$
	Urban Conditions	
A–B	$0.32x(1+0.0004x)^{-1/2}$	$0.24x(1+0.001x)^{1/2}$
C	$0.22x(1+0.0004x)^{-1/2}$	$0.20x$
D	$0.16x(1+0.0004x)^{-1/2}$	$0.14x(1+0.0003x)^{-1/2}$
E–F	$0.11x(1+0.0004x)^{-1/2}$	$0.08x(1+0.00015x)^{-1/2}$

As Briggs interpolation formulas incorporate data from different types of plume behaviour, source heights and for different downwind distances, so they would agree with PG curves given by Gifford (1961) and Turner (1970) in the range 100m <x< 10,000m, except the curves for σ_z for A and B stabilities. For other than small distances, TVA and BNL curves agree reasonably well with one another and, except for A and B conditions, with PG curves at about 10km. For very large distances TVA curves are applied. Briggs interpolation formulae apply upto 10km. and could be extended to 20km or 30 km, although Briggs himself did not recommended this. Power law formulae of the type $\sigma_y = ax^b$ and $\sigma_z = cx^d$ have been proposed by many workers (for example, Montgomery, 1973, Smith, 1968). A general limitation of all these results is that no single power law can fit diffusion data over all down wind distance ranges.

For the Gaussian plume model, which can be easily programmed and used in the present work, it is preferable to have analytical formulae for σ_y and σ_z as a function of downwind distance rather than sigma curves presented graphically. Also the original PG curves used widely are based on ground level source data and for distances upto 800m only while Briggs formulae combined various sets of data as discussed earlier. Gifford (1976) while reviewing various sigma schemes recommended Briggs interpolation formulae because of its divergent data base.

Table -2.4

Pasquill stability categories as a function of Net Radiation Index and Wind Speed
1 Knot = 0.515 m/s

Wind Speed (Knots)	Net Radiation Index (NR)						
	4	3	2	1	0	-1	-2
0,1	1	1	2	3	4	6	7
2,3	1	2	2	3	4	6	7
4,5	1	2	3	4	4	5	6
6	2	2	3	4	4	5	6
7	2	2	3	4	4	4	5
8,9	2	3	3	4	4	4	5
10	3	3	4	4	4	4	5
11	3	3	4	4	4	4	4
12	3	4	4	4	4	4	4

1 = Highly unstable

2 = Moderately unstable

3 = Slightly unstable

4 = Neutral

5 = Slightly stable

6 = Moderately stable

7 = Highly stable

In this manual stability classification has been made according to Turner (1964)

Determination of stability classes:

If turbulence observations are not available, the σ_y and σ_z must be estimated by an empirical techniques such as the Pasquill- Gifford (1961) curves for different stability classes or by analytical formulae given by Briggs giving separate equations for different stability classes ranging from A (very unstable) to F (stable). These classes are based on cloudiness, surface wind speed and insolation.

The most widely used stability classification scheme was defined and developed by Pasquill (1961) and was modified slightly by Turner (1967). Table 2.2 contains the criteria for Pasquill's six stability classes, which are based on five classes of surface wind speed, three classes of daytime insolation, and two classes of nighttime cloudiness.

Turner (1964) added an additional stability class on the stable side making seven stability classes ranging from A (very unstable) to G (very stable). Table 2.4 gives stability classes as a function of wind speed and net radiation. The net radiation index in this table ranges from 4, highest positive net radiation (directed towards ground) to -2, highest negative net-radiation (directed away from earth). To derive the stability class, following procedure is followed (Padmanabhamurthy, 1988)

1. For day or nighttime

If cloud amount= 8 oktas

cloud height <2000 meters

Then NR = 0

2. For night time (defined as period from one hour before sun set to one hour after sunrise)

a) If cloud amount <= 3 oktas

cloud height = any value

Then NR = -2

b) If cloud amount >3 oktas

cloud height = any value

Then NR = -1

3. For day time

a) If cloud amount <=4

cloud height = any value

Then NR (net radiation) is calculated from the table.2.5

TABLE 2.5

Insolation as a function of solar altitude(Turner, 1964)

SOLAR ALTITUDE	NR
$60^0 < \alpha$	4
$35^0 < \alpha <= 60^0$	3
$15^0 < \alpha <= 35^0$	2
$\alpha <= 15^0$	1

b) If cloud amount > 4 .

cloud height < 2000m.

Then NR is calculated from Table 2.6 given below.

TABLE 2.6

SOLAR ALTITUDE	NR
$60^0 < \alpha$	2
$35^0 < \alpha <= 60^0$	1
$15^0 < \alpha <= 35^0$	1

$\alpha <= 15^0$ 1

c) If cloud amount > 4

cloud height >= 2000m. and < 5000m.

Then NR is calculated from table 2.7 given below:

TABLE 2.7

SOLAR ALTITUDE	NR
$60^0 < \alpha$	3
$35^0 < \alpha <= 60^0$	2
$15^0 < \alpha <= 35^0$	1
$\alpha <= 15^0$	1

The procedure for determining stability classification mentioned above requires solar altitude as the primary input apart from other meteorological variables during day time. Day time is defined as the period between one hour after sunrise and one hour before sunset taking into account the lag in sensible heat exchange between earth's surface and atmosphere.

For a given geographical location, time of time of year and time of day, solar altitude is calculated from the equation:

$$\sin\alpha = \sin\beta \sin\phi + \cos\phi \cos\beta \cos T \quad \ldots \quad (2.8)$$

where

α = solar elevation or altitude

β = Declination of the sun

ϕ = Geographical latitude.

T = Solar hour angle counted from midday in terms of local apparent time.

Declination of the Sun and the Geographical latitude is found out from Astronomical Tables. For calculating Hour angle, true solar time is calculated by the equation.

$$T_{(time)} = I_{Hour} + T_c + E_t \quad . \ . \ . \ . \quad (2.9)$$

where

$T_{(time)}$ = True solar time

I_{Hour} = Civil time

T_c = Longitude correction (four minutes for every degree)

E_t = variable local apparent time.

If $(T-12) < 0$ then Hour angle $= (T+12) * 15^0$

and if $(T-12) >=$ then Hour angle $= (T-12) * 15^0$

PLUME RISE DETERMINATION:

Determination of effective stack height i.e, physical stack height plus plume height, is a vital step while estimating concentration of pollutants from a source as a function of downwind distance. High emission velocity and high temperature of the effluents than the ambient air at the stack top enhances the effective stack height above the physical stack height. The rise of such emissions above their source height often accounts for a significant reduction in related ground level concentrations.

There is no dearth of plume-rise formulae in the literature, and the selection of one is complicated by the fact that no one formula can apply to all situations. Moses and Storm (1961) have made a comparative study of some formulae and commented that "there is no one formula which is outstanding in

all respects . Accuracy of plumerise equations is difficult to specify in broad terms. A rise equation developed from data of a given site or group of sites may give different values from those based on other sites. There may be variations between equations of different investigators for the same set of data due to differences in interpretations and emphasis. Two equations of different functional forms may give identical calculations for one set of input data and quite different for another. But regardless of potential inaccuracies, good results can be obtained with judicious application of plume-rise equations.

The main factors which affect the plumerise are heat content of effluent gases, stack exit velocity, wind speed and atmospheric stability. The former two factors lead to buoyancy and momentum in the plume and induce rate of rise. As plume rises, ambient air entrains into plume mass and effect of buoyancy and momentum diminishes and plume picks up horizontal momentum from entrained air which causes the plume to bend over and rise with a diminishing angle of inclination, except when the wind is so light that the plume rise vertically.

When a plume is trapped by an inversion layer (temperature of air increases with height) as is the case in coastal region where IBL separates unstable or neutral air mass below it from a stable air mass above it, plume rises upto the inversion layer and then it ceases to rise because it has entrained enough through the cooler air to make it denser and so downmixing of plume takes place. However penetration of an inversion layer occurs if the plume has enough heat content to

remain warmer than the air above the inversion.

Early attempt for estimating plumerise was made by Holland (Storm, 1976). In his formula he separately accounted for the momentum and buoyancy contribution to rise on the basis of experimental data on jets in laboratory and field data from TVA power plants. Bringfelt (1968,1969) covered various field data of the literature in addition to data from many plumes in Sweden. Briggs (1969,1971,1972) gave the famous "2/3 LAW" taking into account the buoyancy effect. This is a relatively simple formula which predicts that near the stack, the rise of a hot, buoyant plume is proportional to the reciprocal of wind speed, to the one-third power of the distance downwind. Carpenter et al.(1971) and Montgomery et al.(1972) used data from TVA coal-burning power-plants to give TVA models. Carpenter et al. gave a similar equation to that of Briggs with a difference in the value of constant factor while the later gave separate equations for three stability conditions.

In the literature there are a number of other formulae, to name a few Fay et al., Moses and Carson , CONCAWE formula, Whaley's formula, Lucas formula, Morton et al. formula, ASME equations and many others. All these formulae mentioned above are considered by Padmanabhamurthy and Gupta (1980) in their comparative study of plume rise formulae and concluded that Lucas formula is close to Briggs model at low wind speed and TVA model at higher wind speeds and a slightly modified Lucas formula yields reasonable results under the conditions obtainable at Delhi,

Mathura and Agra region. Guldberg (1975), after an extensive comparison of plume rise formulae, concluded that Briggs model predicts best the observed plume rise during periods of low wind speeds and TVA model suggested by Montgomery et al. (1972) at higher wind speeds.

Briggs (1971) compared a number of plumerise formulae (Holland, Moses and Carson, Lucas etc.) and concluded that simple "2/3 LAW" gives good agreement with the data mentioned. Guldberg (1975) also compared various plume rise formulae and came to conclusion that both Briggs "2/3 law" and TVA model perform well in making prediction of final plumerise. Anfossi (1985) also compared data from five TVA steam plants and with prediction of Briggs model and concluded that Briggs model predicts plume height with a good average accuracy.

Even though the "2/3 law" overestimates the plume-rise when applied to industrial size boilers and stacks as shown by Rittmann(1982) it is suggested that in absence of a particular preference, Briggs equations should be applied. This is suggested in view of the wide range of field data on which they are based and the simple theoretical foundation which is in agreement with others. In the present study Briggs formulae are used which are discussed below.

BRIGGS PLUME RISE FORMULAE:

Plume-rise dh(x) vs. distance x is given as:

a) For unstable and Neutral condition:

$$dh(x) = c_1 F^{1/3} u^{-1} x^{2/3} \quad \text{for } x <= x^* \qquad \ldots . \qquad (2.10)$$

where

c_1=1.6 as suggested by Briggs

$F = g/(\pi c_p \rho T)$ Q_H is buoyancy flux parameter($m^4 s^{-3}$)

u = wind speed (m/s)

c_p =specific heat at constant pressure(cal/g K)

ρ = density of air (gm/m^3)

T = air temperature(K)

Q_H =heat emission(cal/sec)

and $dh(x) = 1.6\ F^{1/3}/u\ (x^*)^{2/3}\ [2/5+16/25\ x/x^*$

$+11/5\ x^2/(x^*)^2]/(1+4/5\ x/x^*)^2$ for $x>x^*$ . . (2.11)

Here

$x^* = 2.16\ F^{2/5}\ H^{3/5}$ (H<305m.) . . . . (2.12)

$x^* = 67\ F^{2/5}$ (H>305m.) . . . . (2.13)

where H is physical stack height.

b) For stable condition:

Plume-rise through stable ground layer may lose all their buoyancy and level off at some height above the stack.

The maximum rise under such conditions is given by

$dh = 2.9\ (F/us)^{1/3}$ . . . . (2.14)

where

$s = (g/T)(\partial\theta/\partial z)$=stability parameter; $\partial\theta/\partial z$ being the gradient of potential temperature in ambient air [$\partial\theta/\partial z = (\partial T/\partial z) + 5.4^0$F/1000ft.]

Theoretically, a buoyant plume in a neutral or unstable atmosphere will rise indefinitely but in real atmosphere it will eventually lose its identity owing to continuing

diffusion. So under neutral and stable conditions the final plume rise is also given by Briggs for distance $x = 3x^*$. Equation (2.11) is conservatively approximated by using the "2/3 law" upto this distance ($x=3x^*$).So the final plume rise is

$$dh = 1.6\ F^{1/3}/u\ (3\ x^*)^{2/3} \quad . \ . \ . \ . \qquad (2.15)$$

INTERNAL BOUNDARY LAYER HEIGHT

Hanna (1987) gave height of internal boundary layer as a function of downwind distance x.

$$H_T = 0.1\ x \quad ;\ (x <= 2000m.) \quad . \ . \ . \ (2.16)$$

$$H_T = 200m + 0.03\ (x-2000m) \quad ;\ (x > 2000m.) \quad . \ . \ . \ (2.17)$$

Average distance of the plant site from the coast is taken to be 1 km. which is also considered the distance of each stack from coast in absence of actual data. The above equations are modified for the present situation as follows:

$$H_T = 100\ m + 0.1\ x \quad ;\ (x <= 1000m.) \quad . \ . \ . (2.18)$$

$$H_T = 200\ m + 0.03\ (x-1000m.) \quad ;\ (x > 1000m.) \quad . \ . \ . (2.19)$$

CHAPTER III

RESULTS

PART I

Short term (one hour) ground level concentrations down the plume axis for the four representative months for SO_2, Urea, and Ammonia under unstable, and neutral conditions are plotted and presented in Fig. 3.1 through 3.32. Maximum short term concentration (1 hr.) together with month and distance in each case are given in Table 3.1. Maximum ground level concentrations occur under unstable conditions.

TABLE 3.1

S.No.	Pollutants	Maximum Concentration ($\mu g/m^3$) (1 hr.)	(8 hr.)	Distance (m.)	Month
1.	SO_2	139.22	41.77	2500 m.	April
2.	Ammonia	30.93	9.28	1000 m.	October
3.	Urea	4.63	1.39	2000 m.	April

The maximum long term ground level concentrations (24 hour) along with distance and month are given in Table 3.2 below.

TABLE 3.2

S.No.	Pollutants	Max. Concentration ($\mu g/m^3$) (24 hr.)	(8 hr.)	Direction	Distance (m.)	Month
1.	SO_2	11.06	16.59	NW	1000 m.	October
2.	Ammonia	1.20	1.80	NW	1000 m.	October
3.	Urea	0.06	0.09	SW	1000 m.	April

PART II

Short term ground level concentrations taking into account the presence of Internal Boundary Layer (IBL) for SO_2, Ammonia and Urea are plotted along with the concentrations under unstable and neutral conditions in Fig. 3.1 to 3.32. Stacks 1, 2, 3 and 7 for each month satisfy the conditions of Trapping while stacks 4, 5, and 6 satisfy the Fumigation conditions. Concentrations under Fumigation conditions as well as maximum concentration along with stability conditions in each case are presented in Tables 3.3 to 3.6 .

TABLE 3.3

JANUARY

Stack No.	Pollutant	Maximum Concentration ($\mu g/m^3$) (1 hr.)	(8 hr.	Distance (m.)	Diffusion Conditions
1	SO_2	4.74	1.42	500	Unstable
2	SO_2	5.59	1.68	1000	Unstable
3	SO_2	16.65	5.00	2800	Trapping
4	SO_2	476.54	142.96	2200	Fumigation
5	SO_2	580.13	174.04	1100	Fumigation
6(a)	Ammonia	112.84	33.85	700	Fumigation
6(b)	Urea	59.48	17.95	700	Fumigation
7	Ammonia	26.18	7.85	1000	Unstable

TABLE 3.4

APRIL

Stack No.	Pollutant	Maximum Concentration ($\mu g/m^3$) (1 hr.)	(8 hr.	Distance (m.)	Diffusion Conditions
1	SO_2	4.09	1.23	500	Unstable
2	SO_2	5.92	1.78	500	Unstable
3	SO_2	17.71	5.31	1000	Unstable
4	SO_2	446.00	133.80	1600	Fumigation
5	SO_2	470.98	141.29	930	Fumigation
6(a)	Ammonia	91.70	27.50	600	Fumigation
6(b)	Urea	48.34	14.50	600	Fumigation
7	Ammonia	18.14	5.44	1000	Unstable

TABLE 3.5

JULY

Stack No.	Pollutant	Maximum Concentration ($\mu g/m^3$) (1 hr.)	(8 hr.	Distance (m.)	Diffusion Conditions
1	SO_2	3.79	1.14	500	Unstable
2	SO_2	6.30	1.89	500	Unstable
3	SO_2	20.10	6.03	1000	Unstable
4	SO_2	418.65	125.60	1500	Fumigation
5	SO_2	432.74	129.82	900	Fumigation
6(a)	Ammonia	85.41	25.62	570	Fumigation
6(b)	Urea	45.02	13.51	570	Fumigation
7	Ammonia	16.06	4.82	1000	Unstable

TABLE 3.6

OCTOBER

Stack No.	Pollutant	Maximum Concentration ($\mu g/m^3$) (1 hr.)	(8 hr.	Distance (m.)	Diffusion Conditions
1	SO_2	4.91	1.47	500	Unstable
2	SO_2	5.64	1.69	1000	Unstable
3	SO_2	19.56	5.87	2800	Trapping
4	SO_2	522.52	156.76	2300	Fumigation
5	SO_2	592.50	177.75	1300	Fumigation
6(a)	Ammonia	124.49	37.35	740	Fumigation
6(b)	Urea	65.61	19.68	740	Fumigation
7	Ammonia	30.63	9.19	1000	Unstable

AIR QUALITY STANDARDS:

Ambient air quality standards (8 hr.) prescribed by Central Pollution Control Board, India are as follows.

CATEGORY	CONCENTRATION in $\mu g/m^3$	
	SPM	SO_x
Industrial & Mixed use	500	120
Residential & Rural	200	80
Sensitive	100	30

No standards are prescribed for Ammonia and Urea dust.

The computed concentrations, and air quality standards refer to different time domains. In order to make these compatible for comparison purposes the computed concentrations are converted to the same time frame of air quality standards. One hour concentrations can be reduced to 8 hour concentration value by multiplying by a factor 0.3 and 24 hour values can be reduced to 8 hour values by multiplying by a factor 1.5 (Montgomery et al. 1973, Stern 1976).

Fig. 3.1 Short Term G.L.C. – JANUARY (Stack # 1)

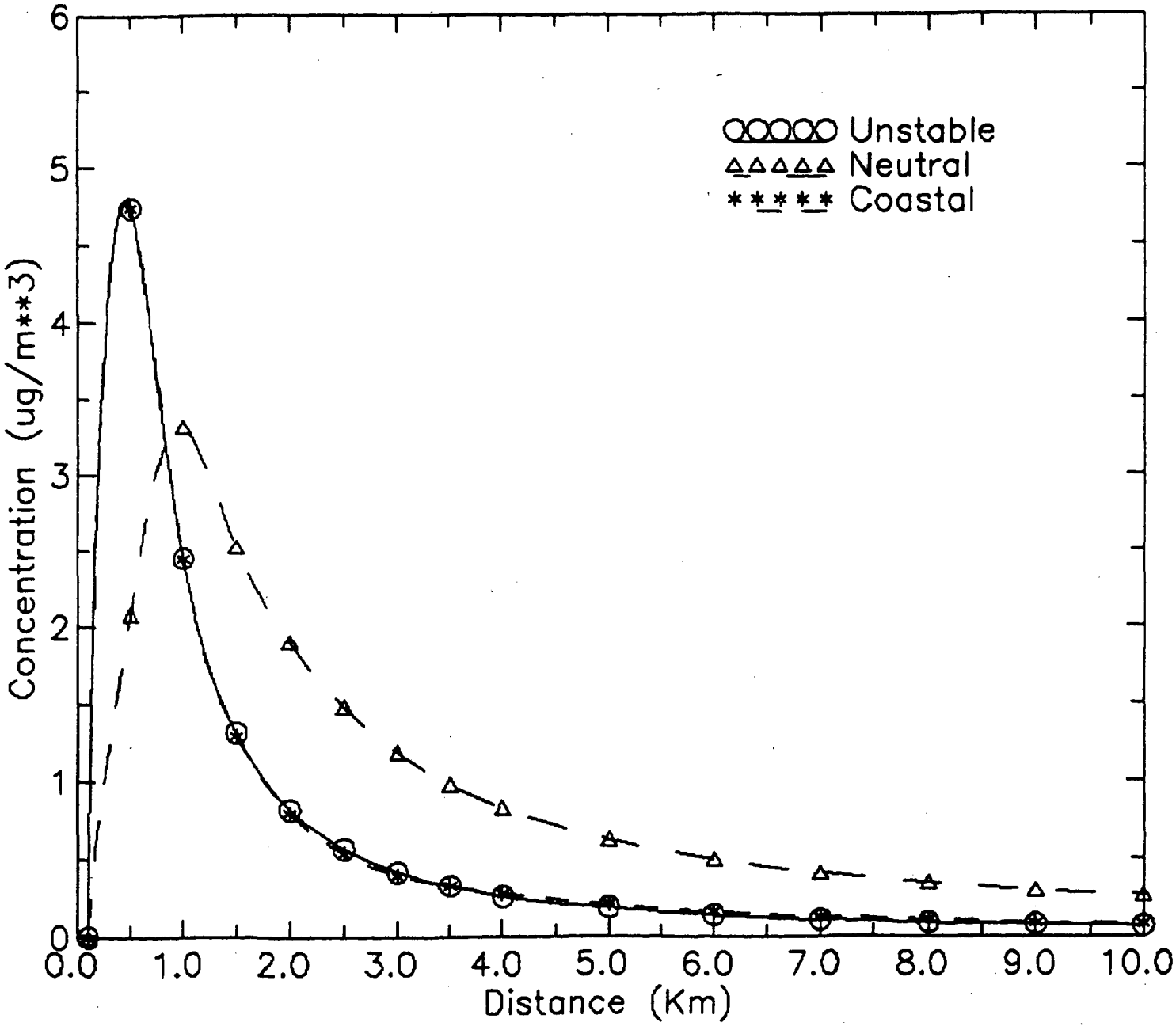


Fig. 3.2 Short Term G.L.C. – JANUARY (Stack # 2)

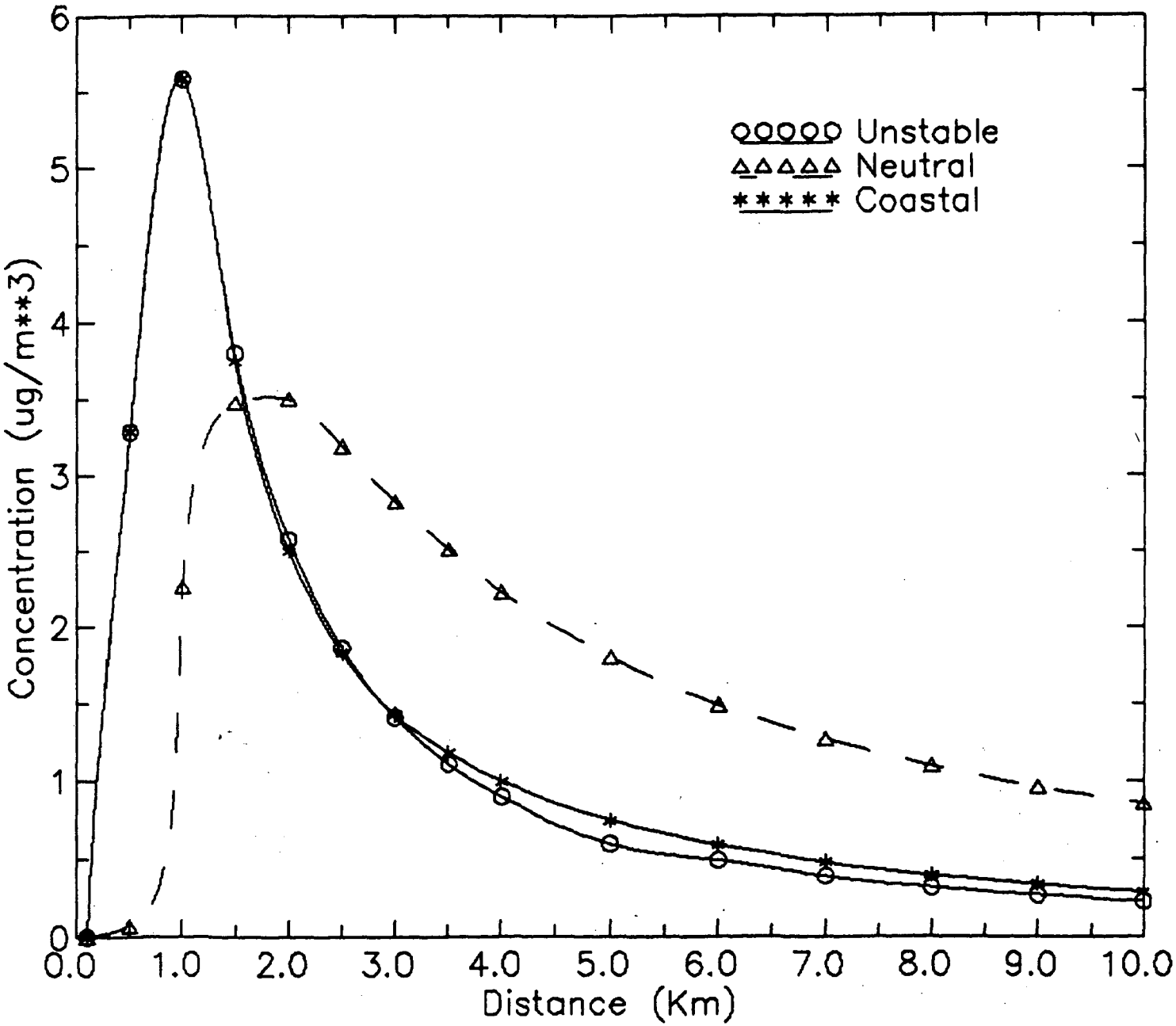


Fig. 3.3 Short Term G.L.C. – JANUARY (Stack # 3)

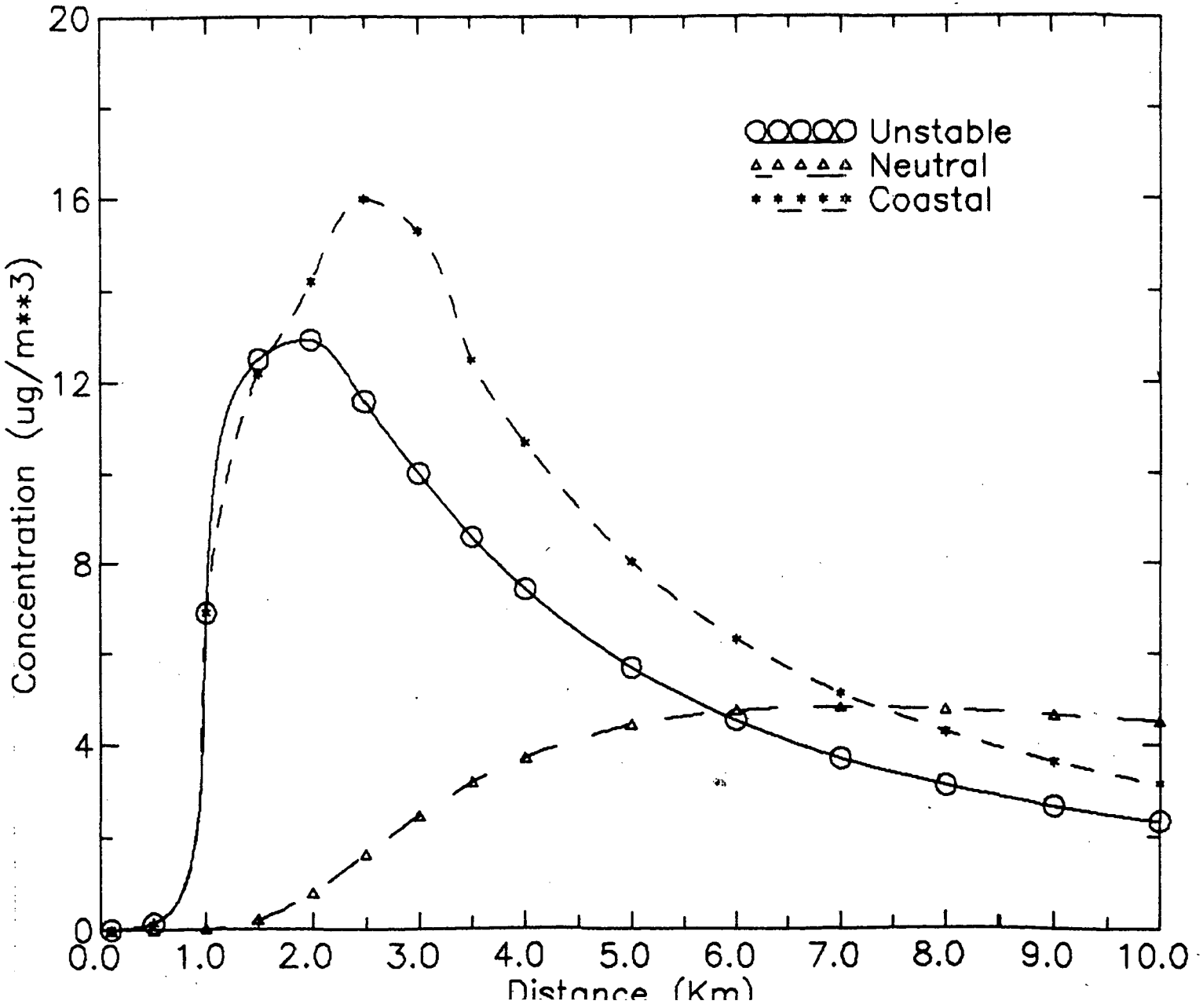


Fig. 3.4 Short Term G.L.C. – JANUARY (Stack # 4)

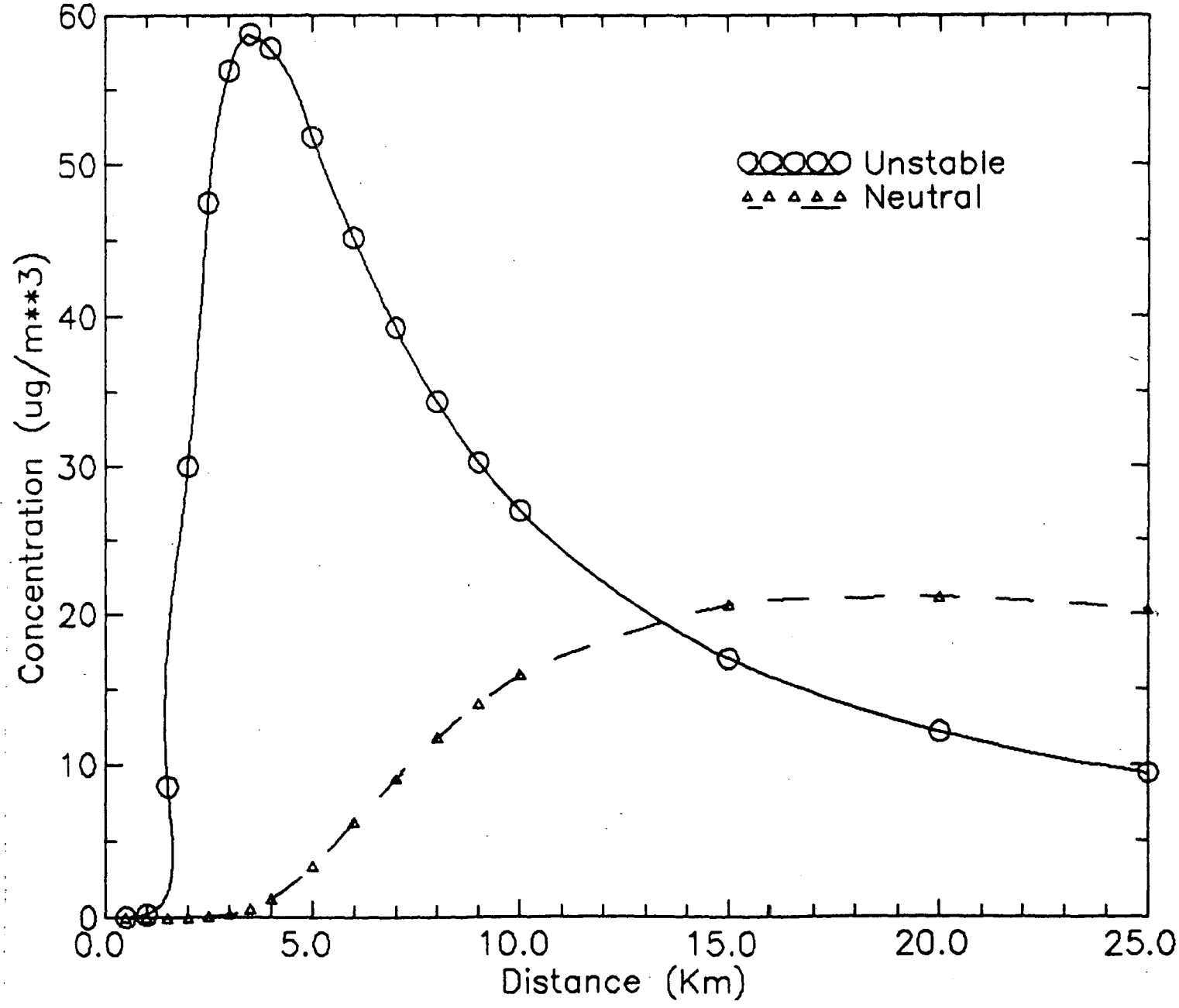


Fig. 3.5 Short Term G.L.C. – JANUARY (Stack # 5)

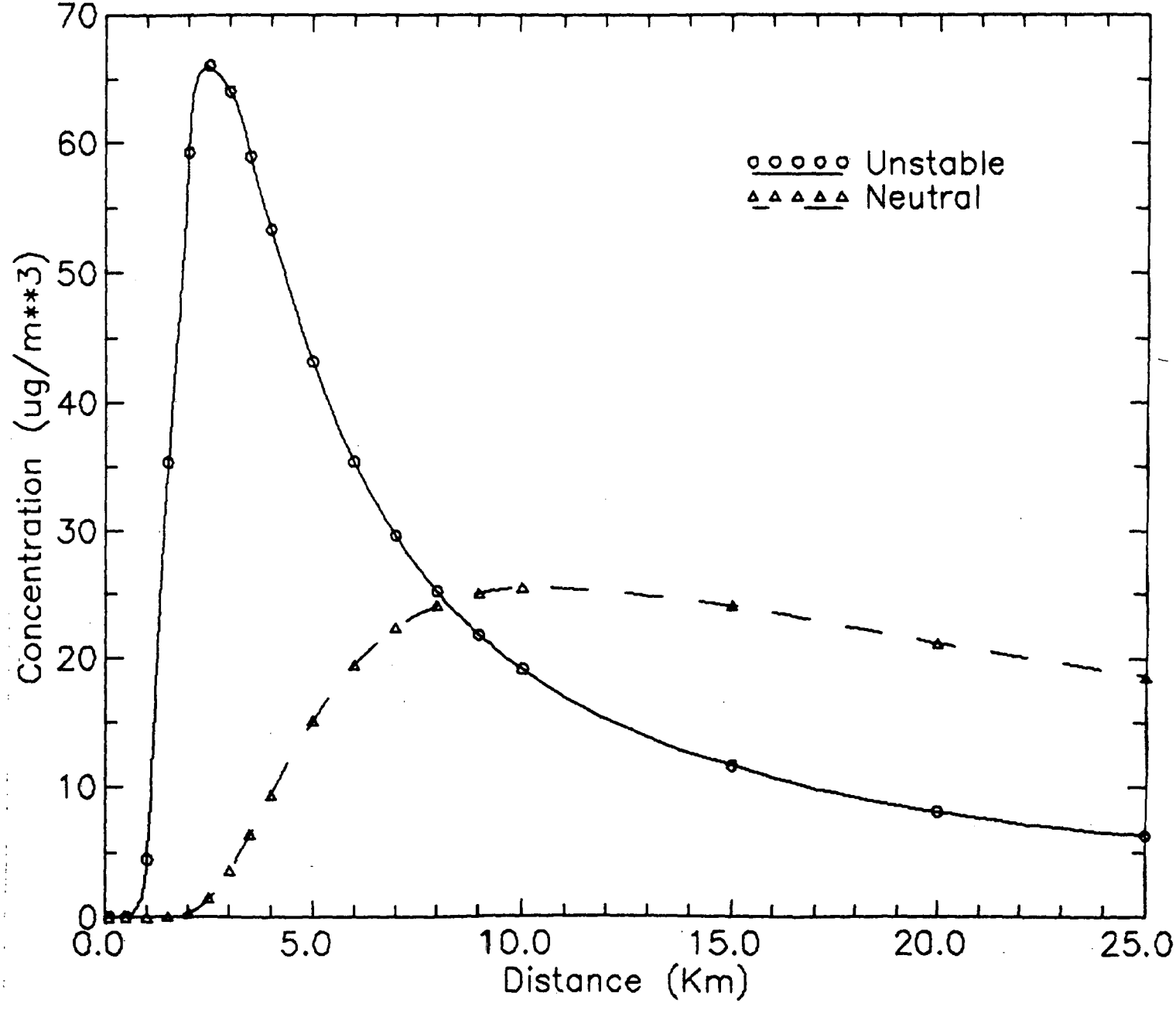


Fig. 3.6 Short Term G.L.C. – JANUARY (Stack # 6) – AMMONIA

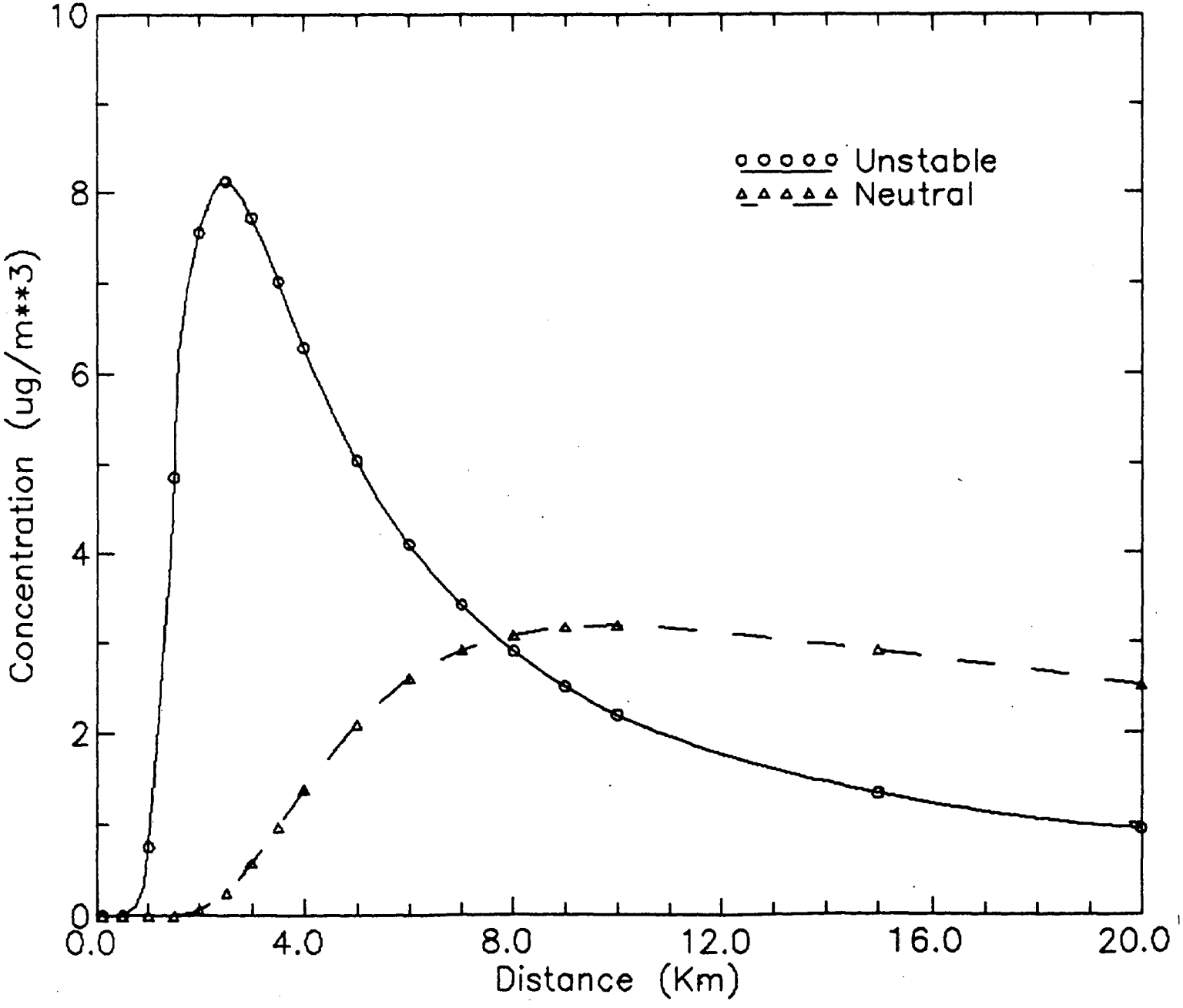


Fig. 3.7 Short Term G.L.C. – JANUARY (Stack # 6) – UREA

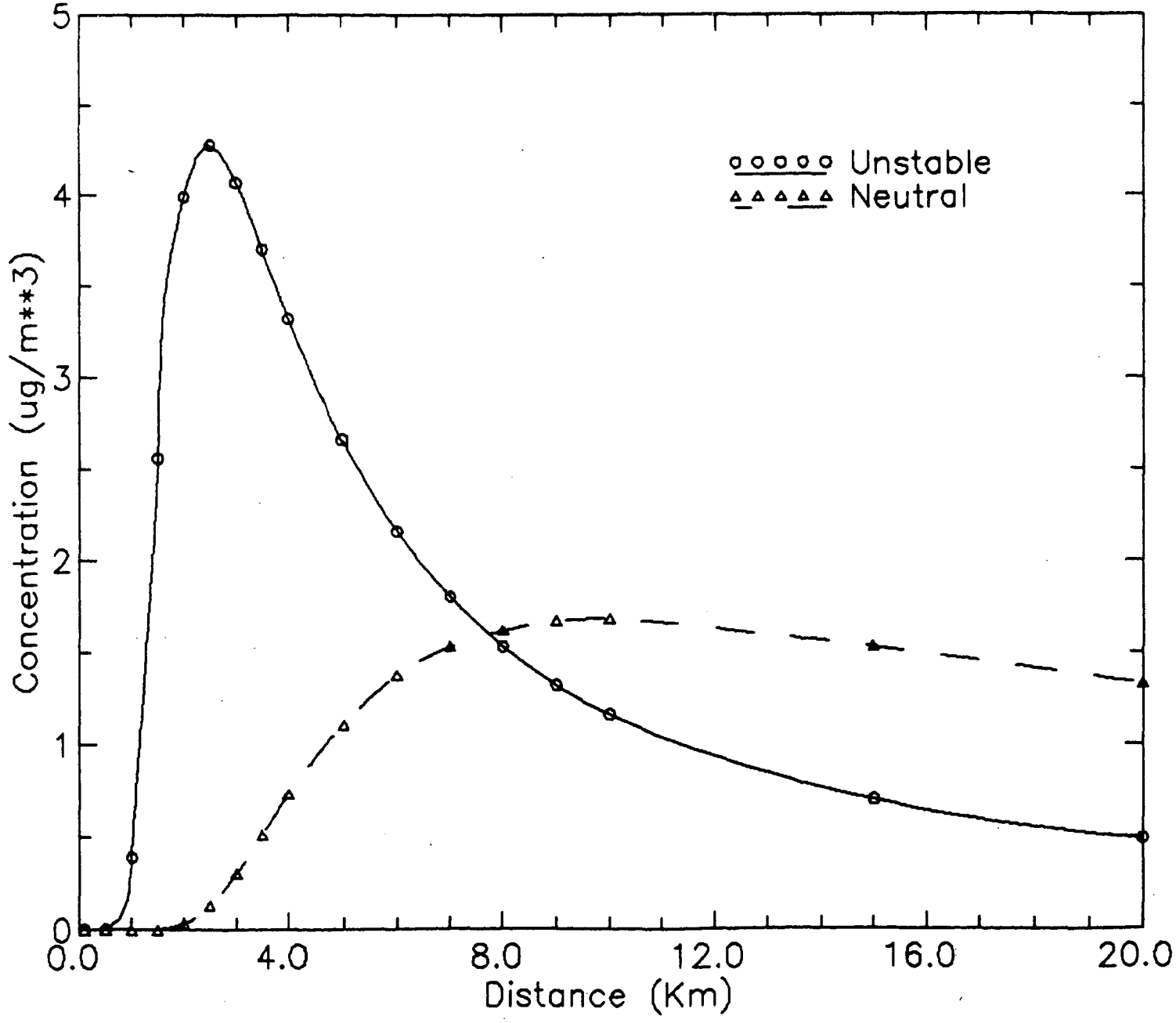


Fig. 3.8 Short Term G.L.C. – JANUARY (Stack # 7) – AMMONIA

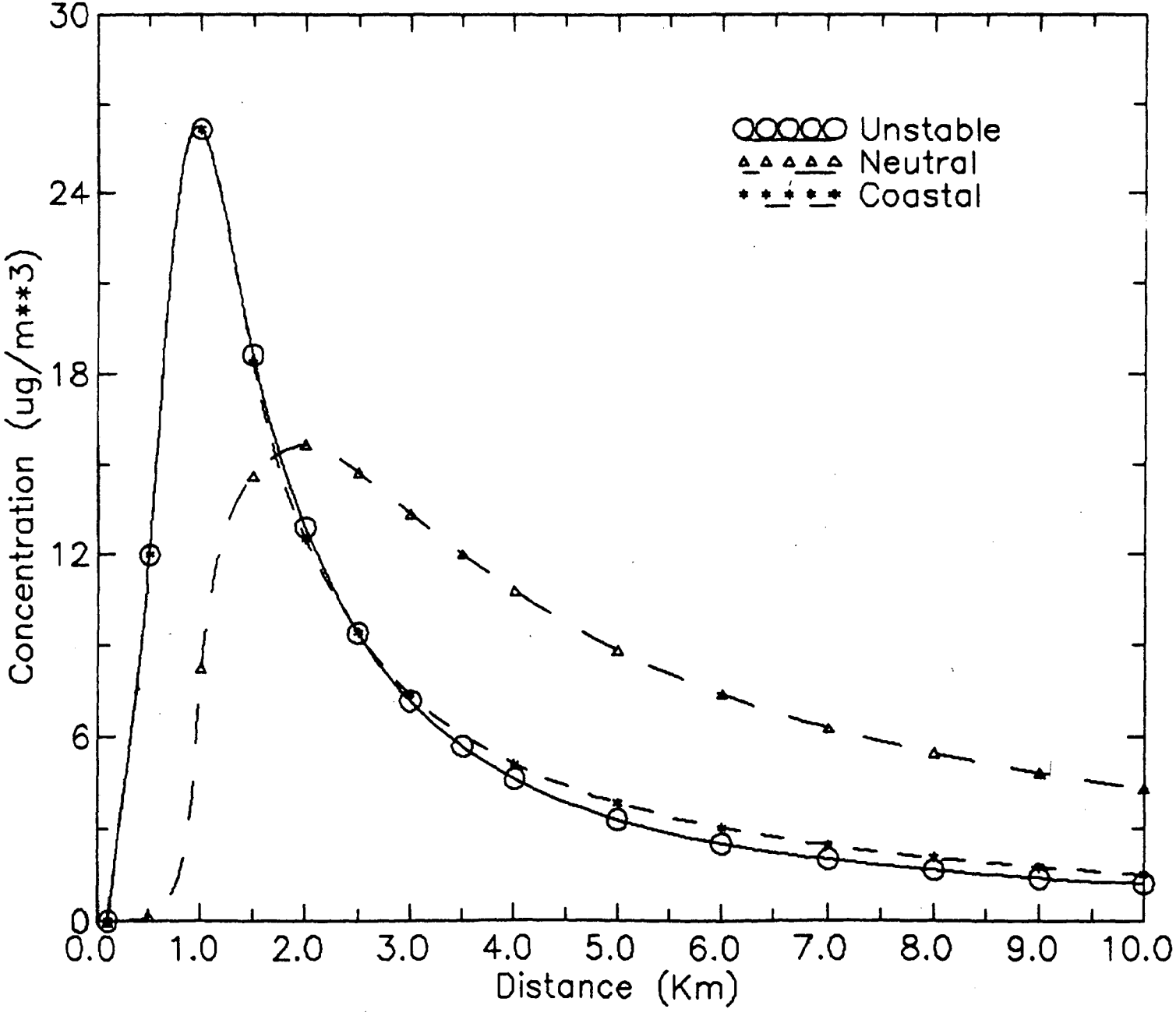


Fig. 3.9 Short Term G.L.C. – APRIL (Stack # 1)

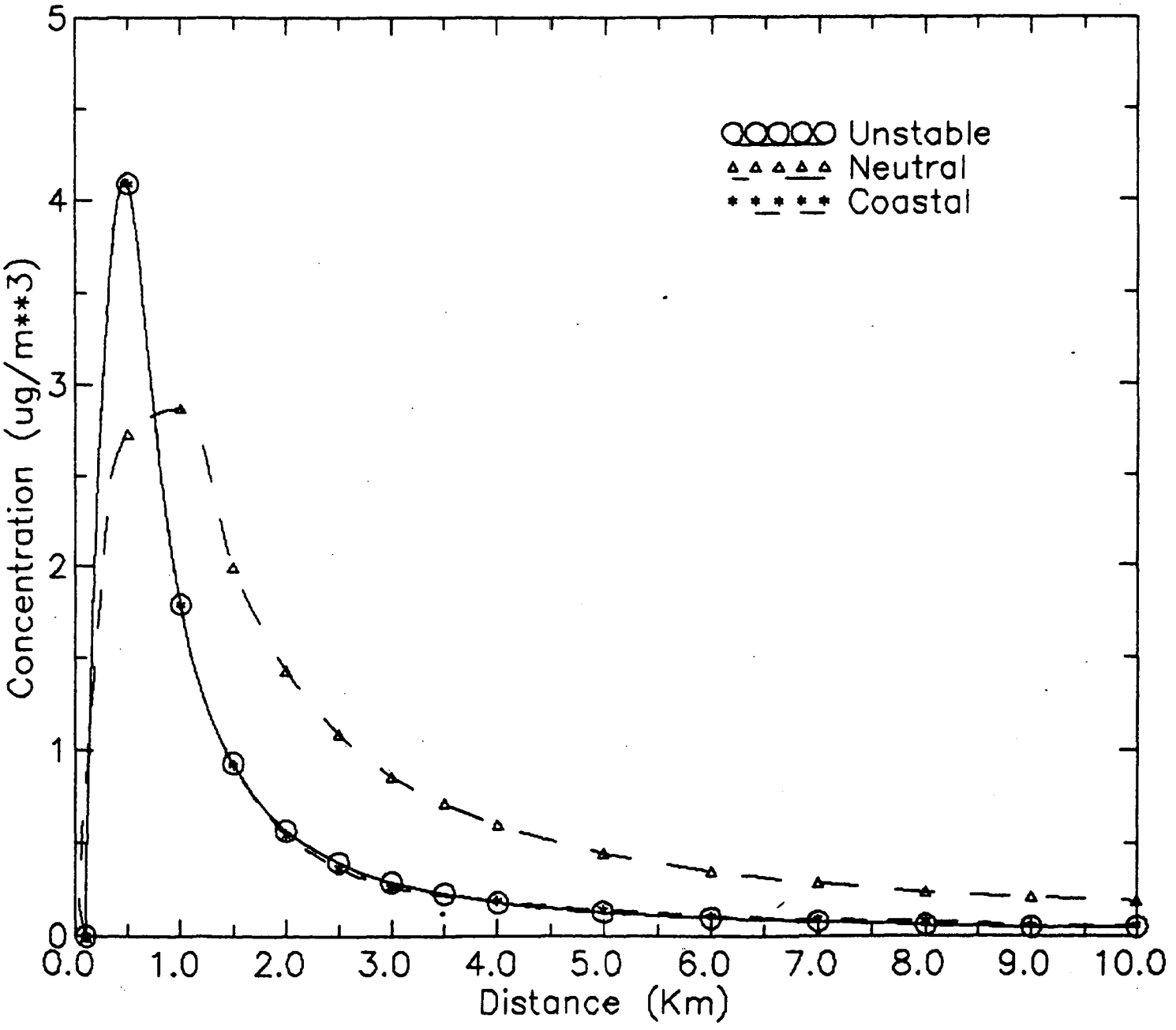


Fig. 3.10 Short Term G.L.C. – APRIL (Stack # 2)

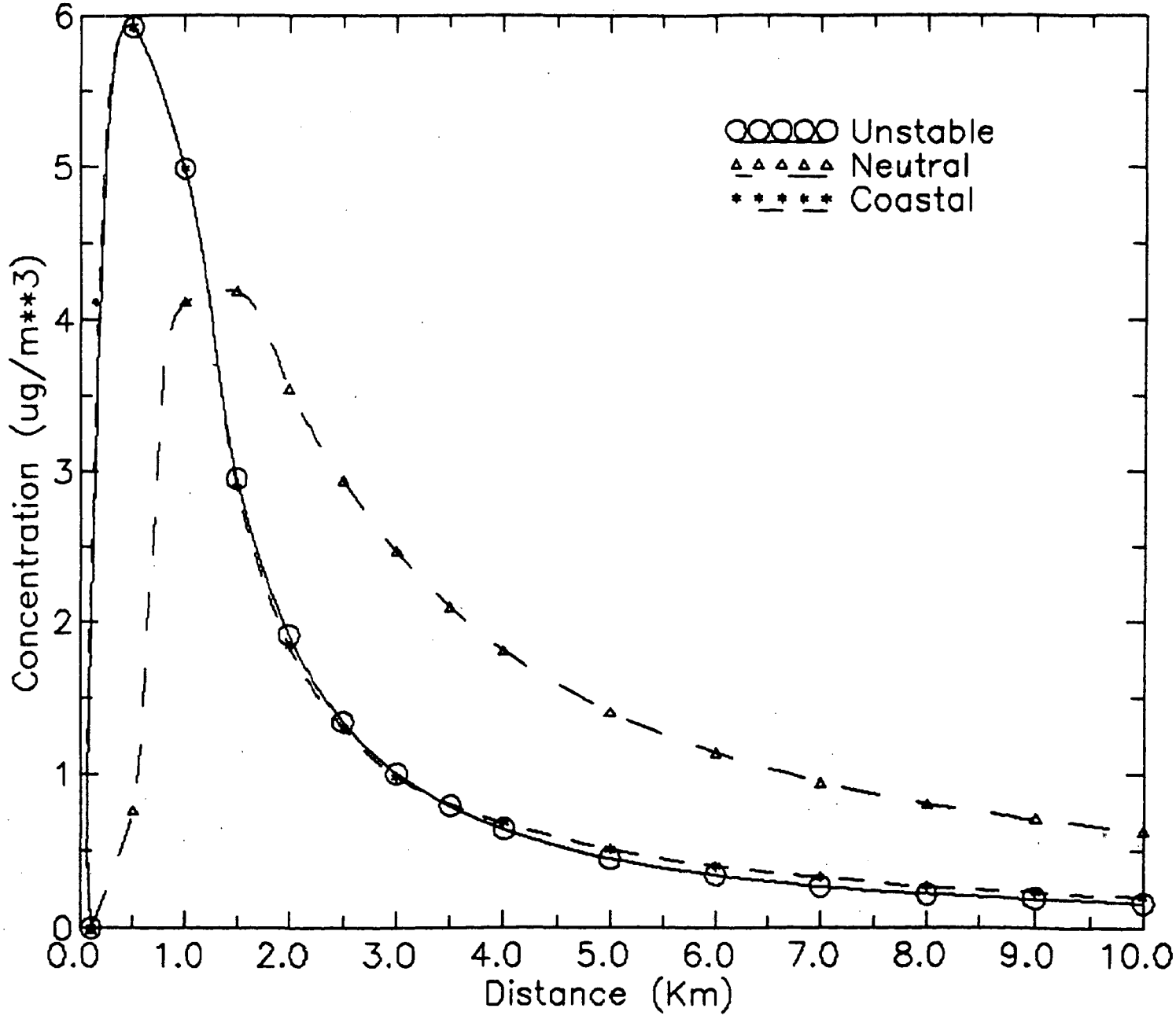


Fig. 3.11 Short Term G.L.C. – APRIL (Stack # 3)

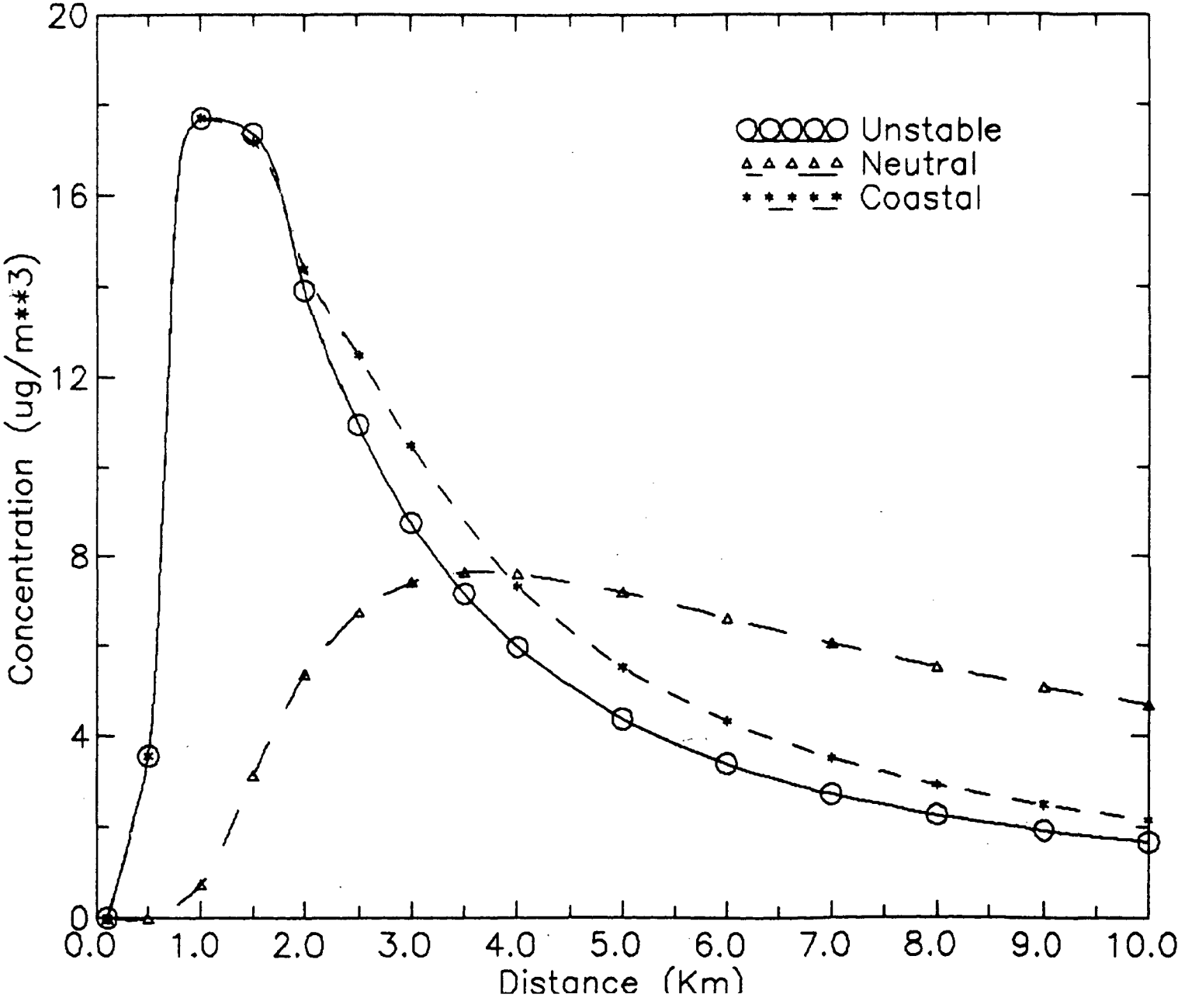


Fig. 3.12 Short Term G.L.C. – APRIL (Stack # 4)

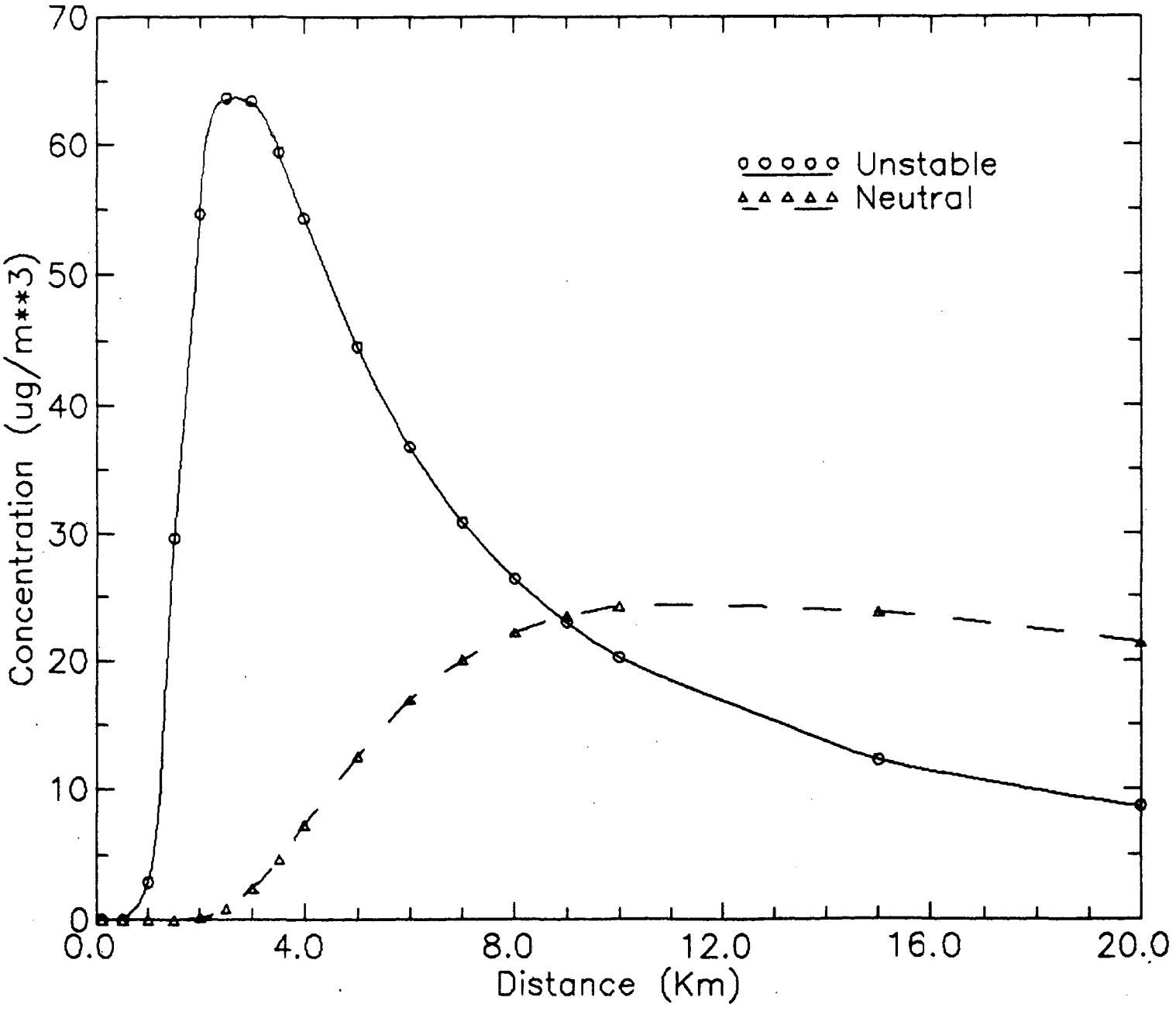


Fig. 3.13 Short Term G.L.C. – APRIL (Stack # 5)

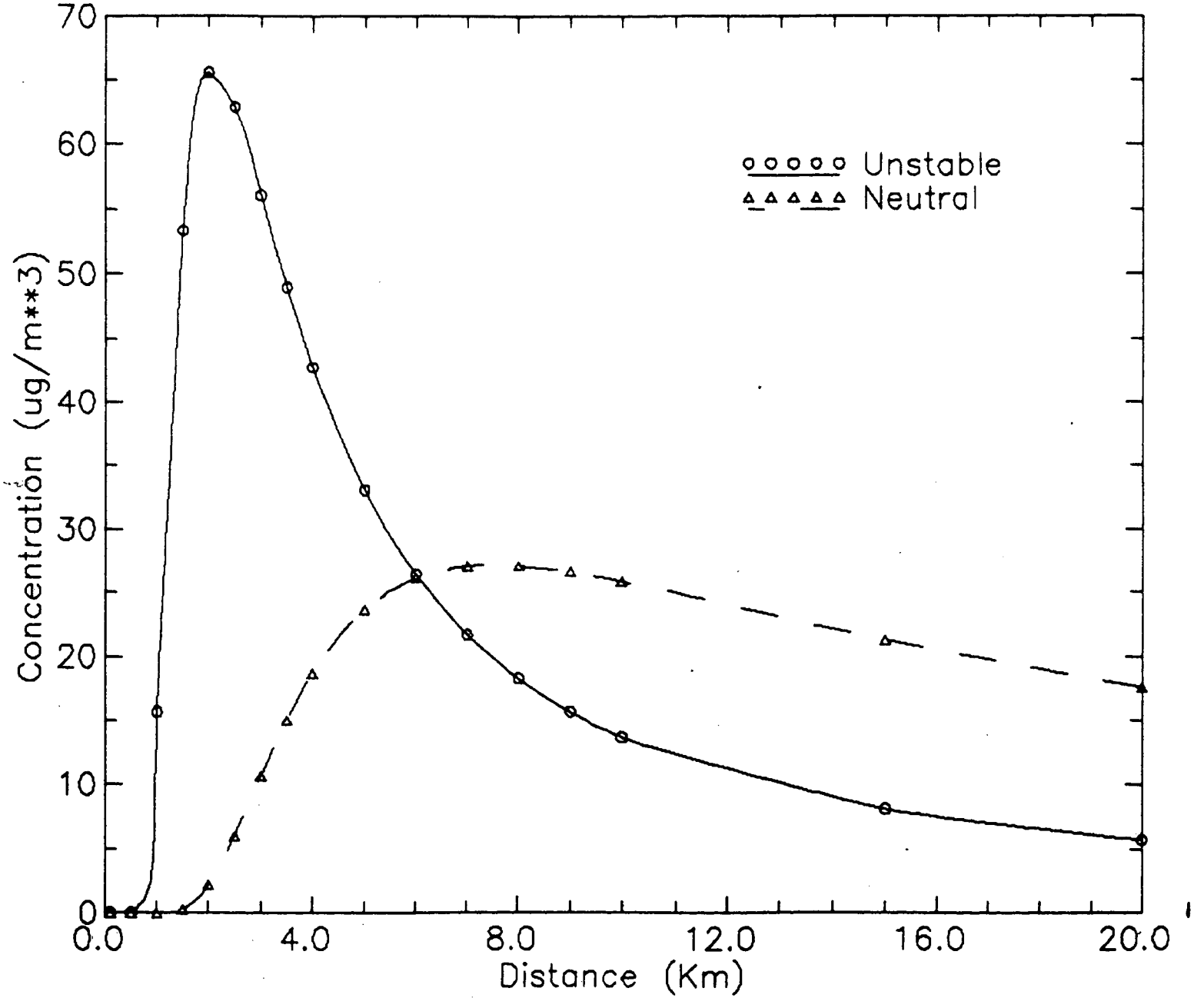


Fig. 3.14 Short Term G.L.C. – APRIL (Stack # 6) – AMMONIA

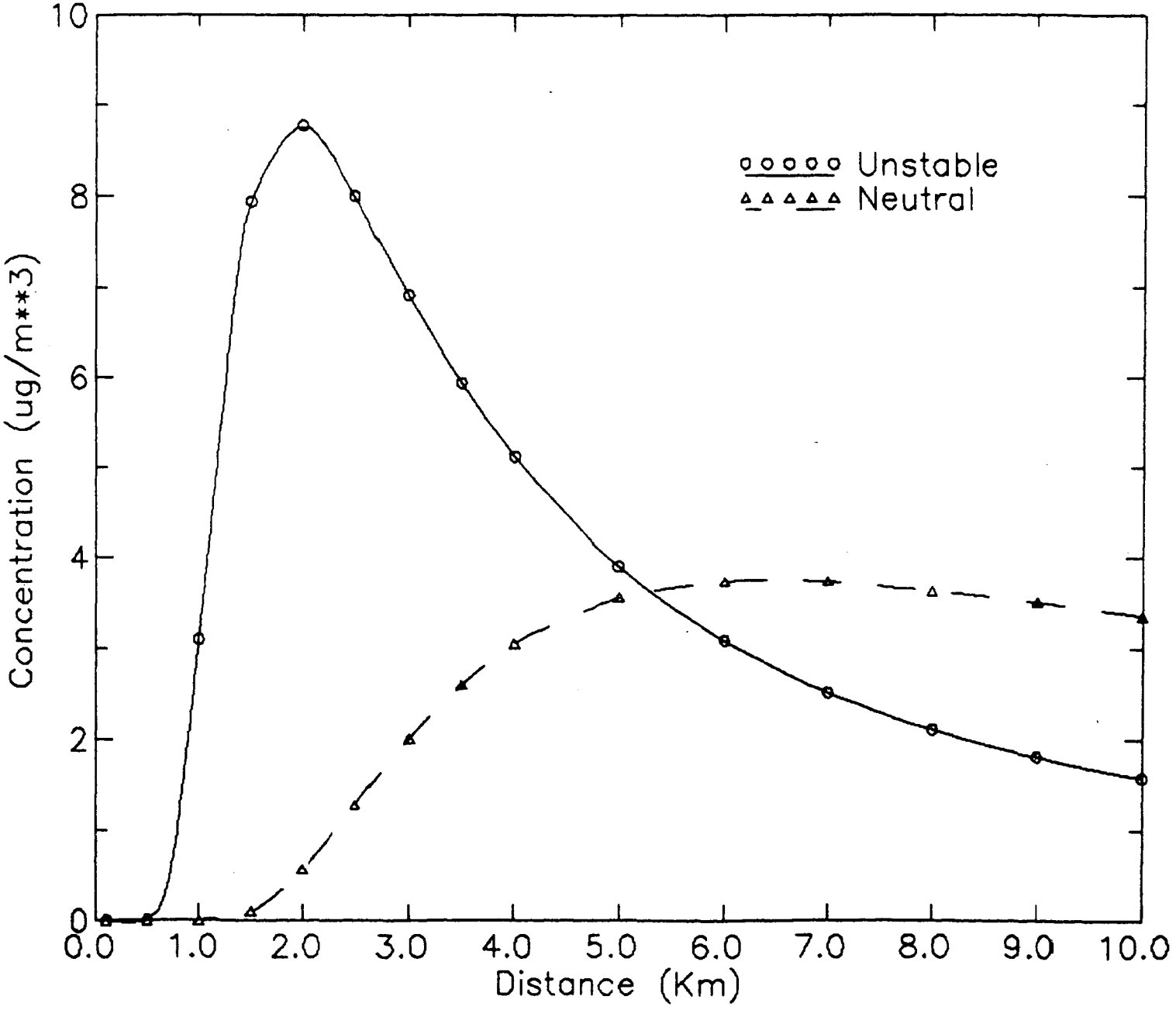


Fig. 3.15 Short Term G.L.C. – APRIL (Stack # 6) – UREA

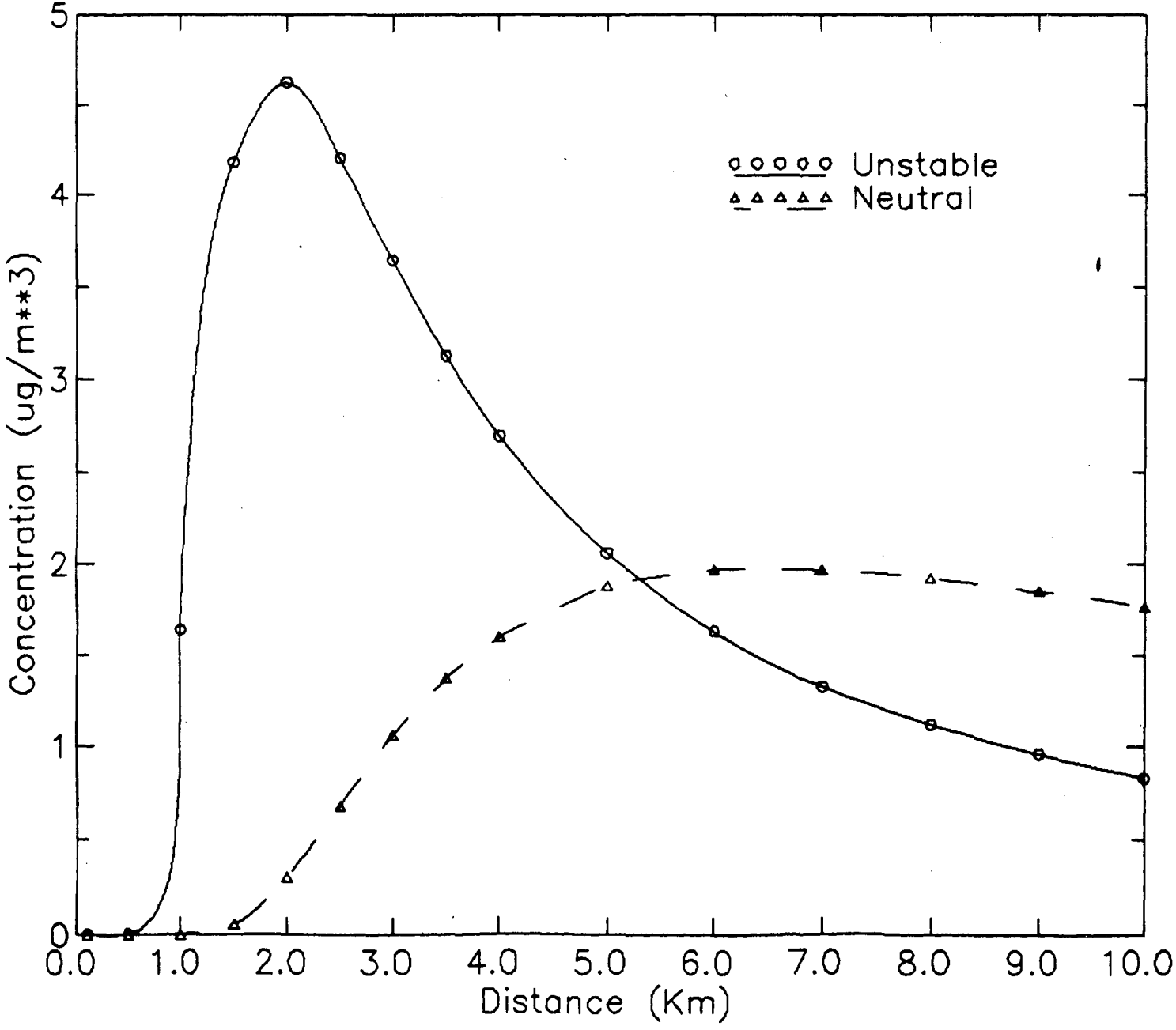


Fig. 3.16 Short Term G.L.C. – APRIL (Stack # 7) – AMMONIA

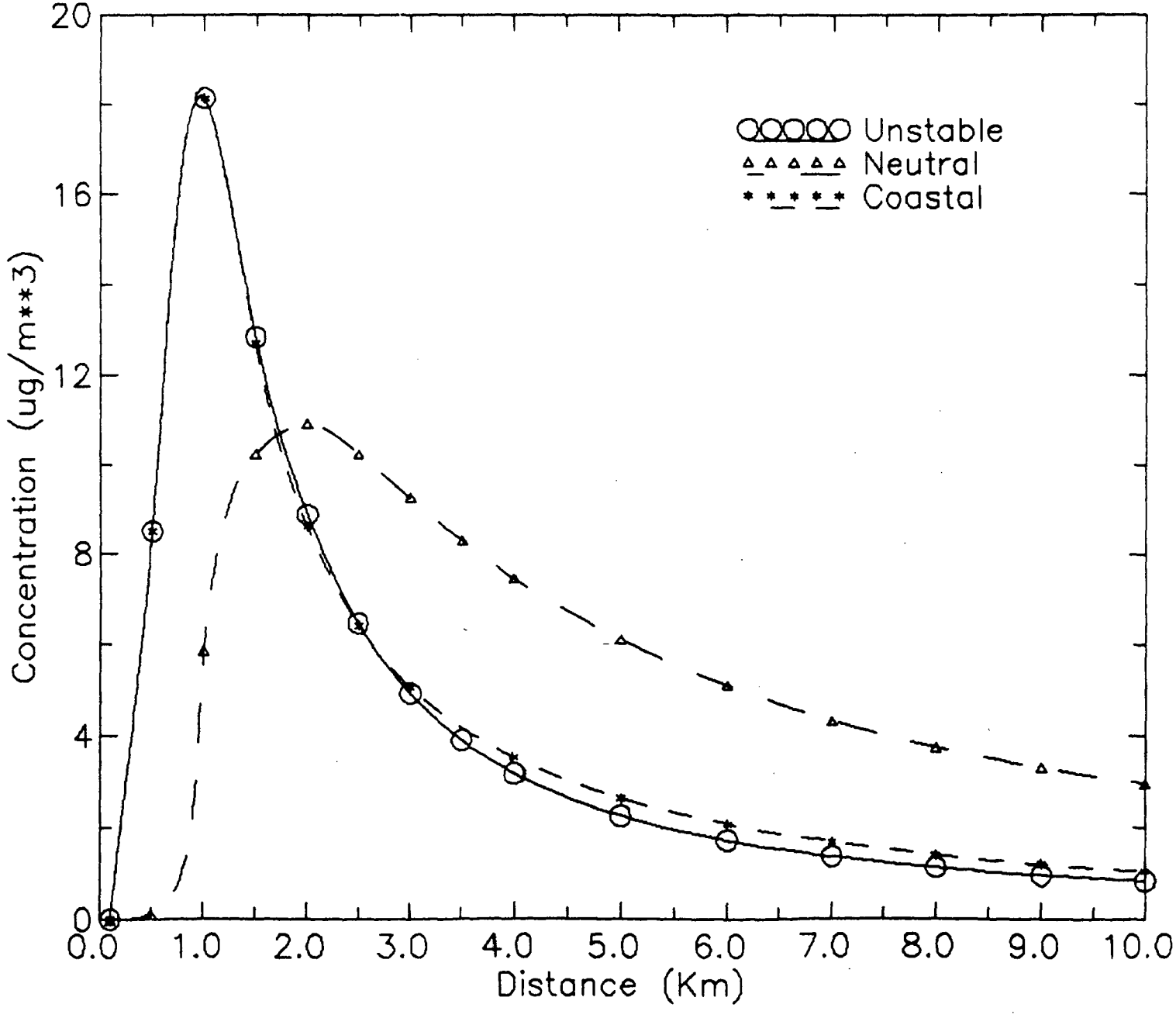


Fig. 3.17 Short Term G.L.C. – JULY (Stack # 1)

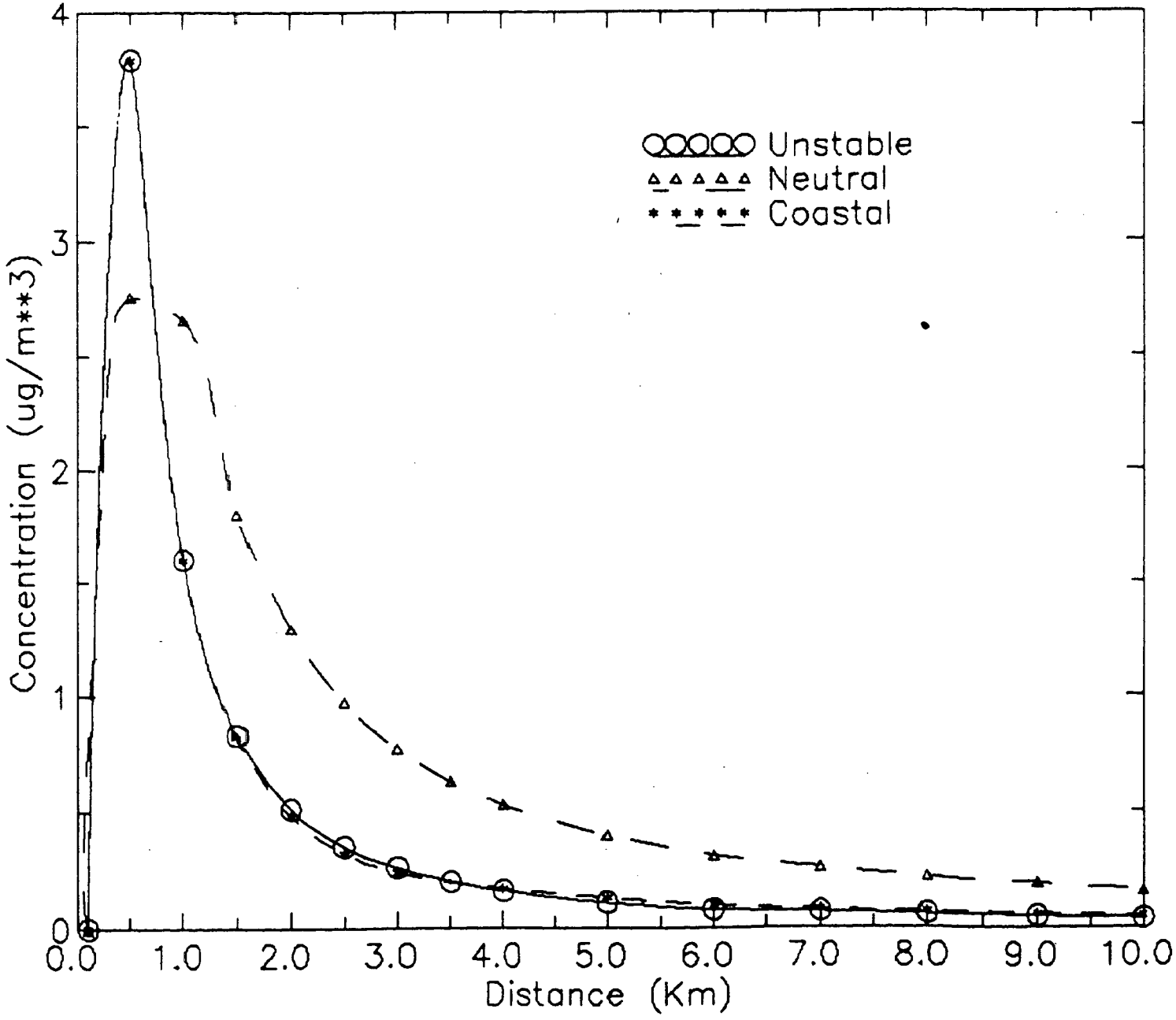


Fig. 3.18 Short Term G.L.C. – JULY (Stack # 2)

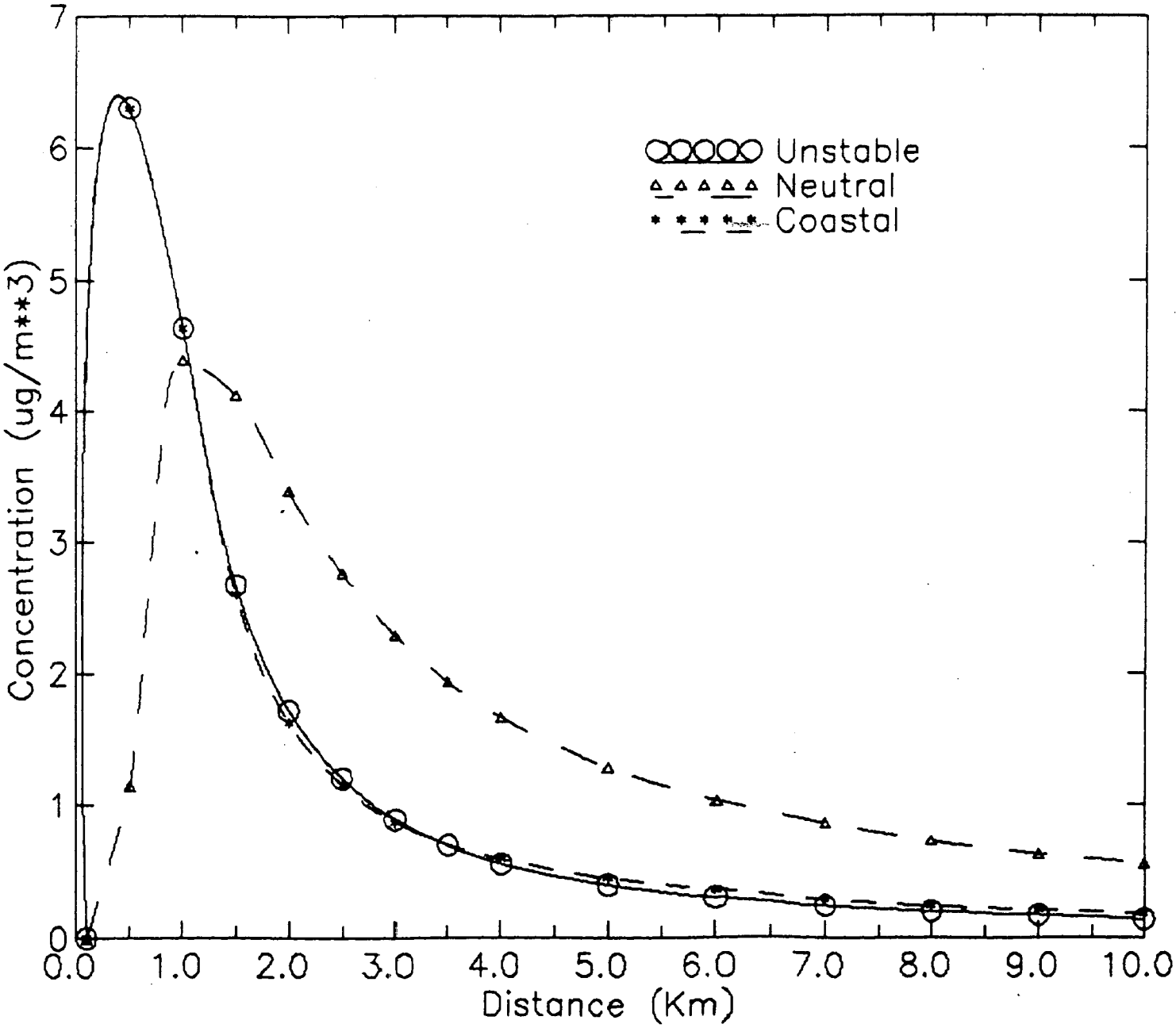


Fig. 3.19 Short Term G.L.C. – JULY (Stack # 3)

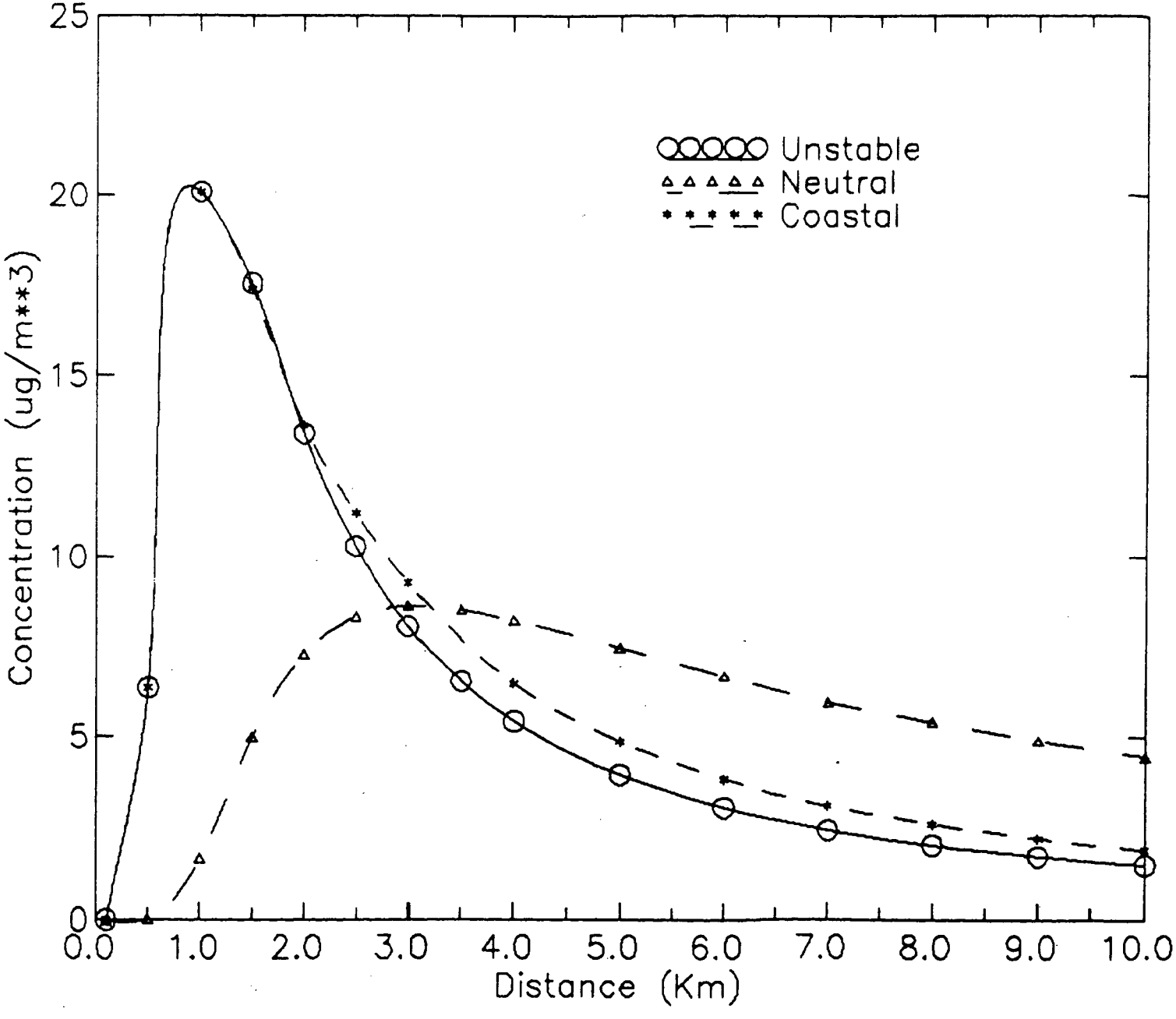


Fig. 3.20 Short Term G.L.C.– JULY (Stack #4)

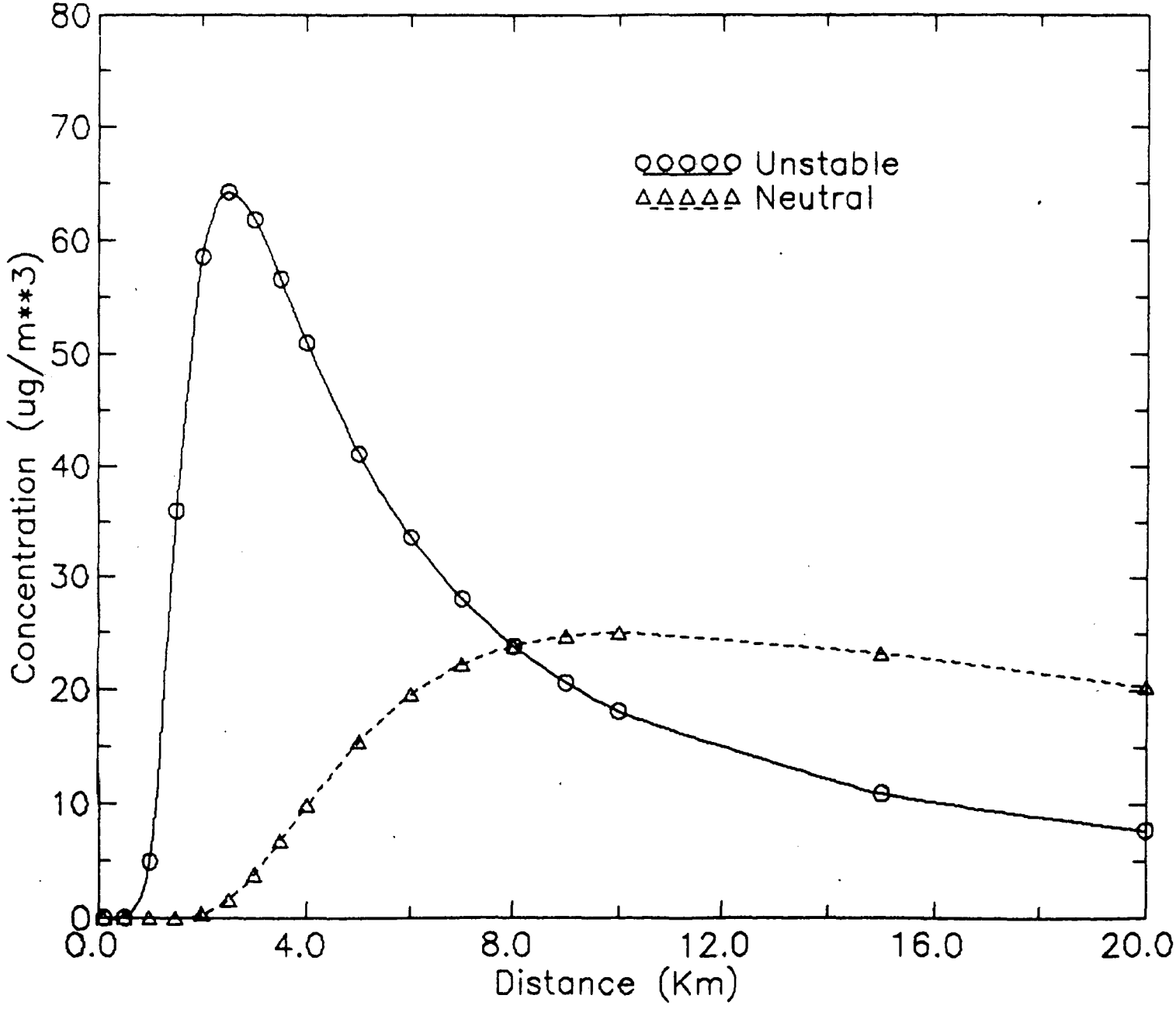


Fig.3.21Short Term G.L.C.– JULY (Stack #5)

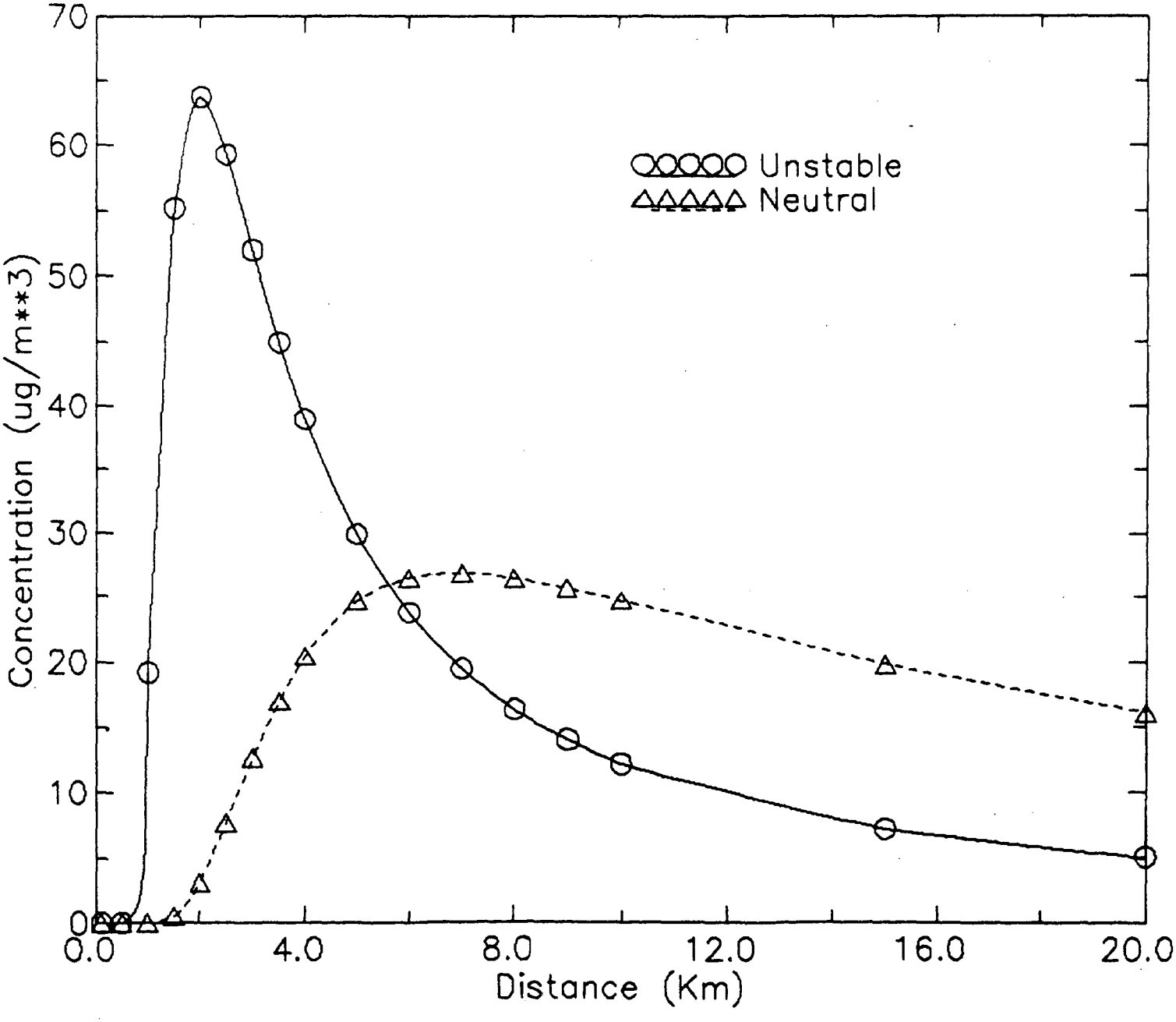


Fig. 3.22 Short Term G.L.C.– JULY (Stack #6) – UREA

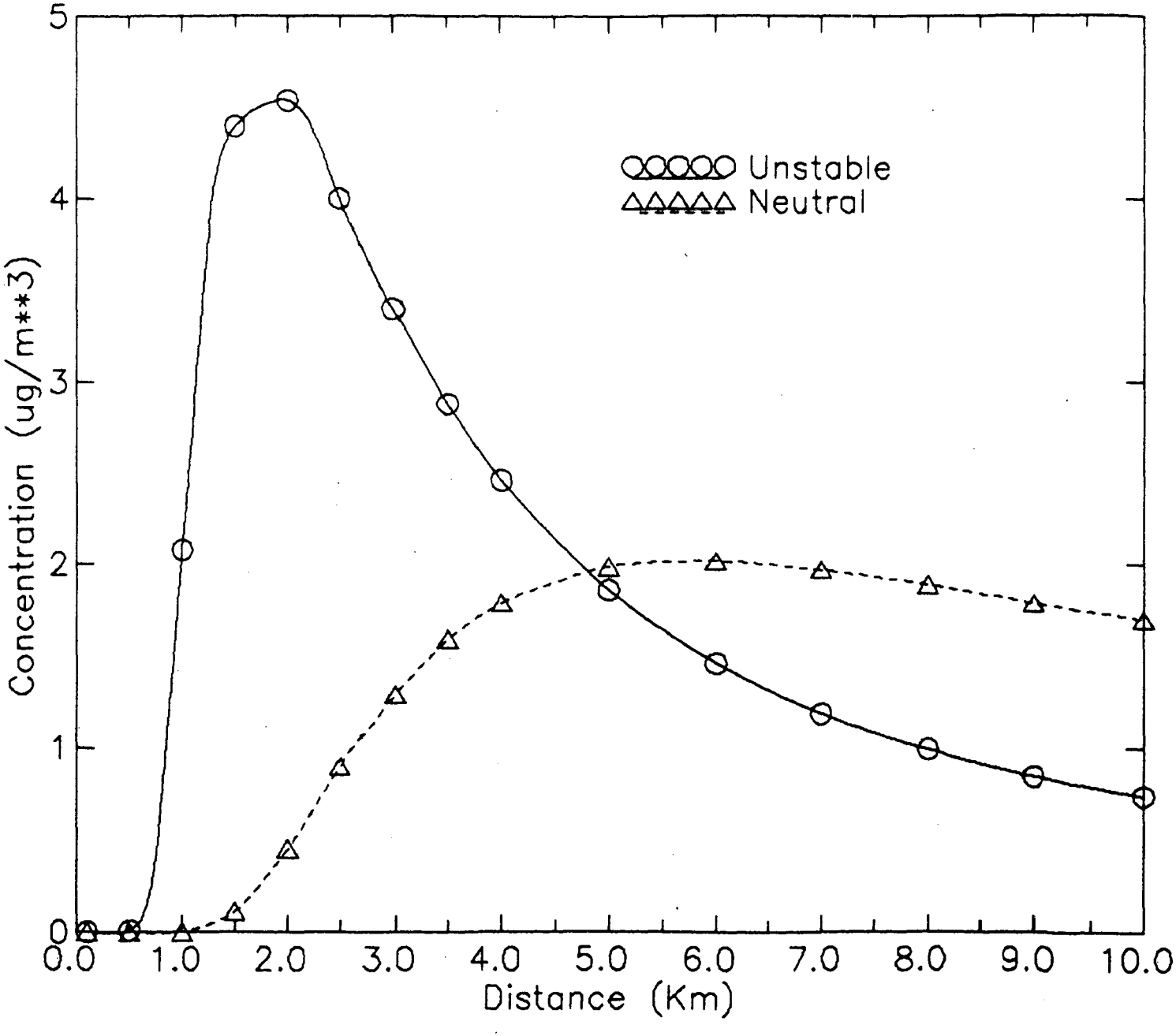


Fig.323 Short Term G.L.C.– JULY (Stack #6) – AMMONIA

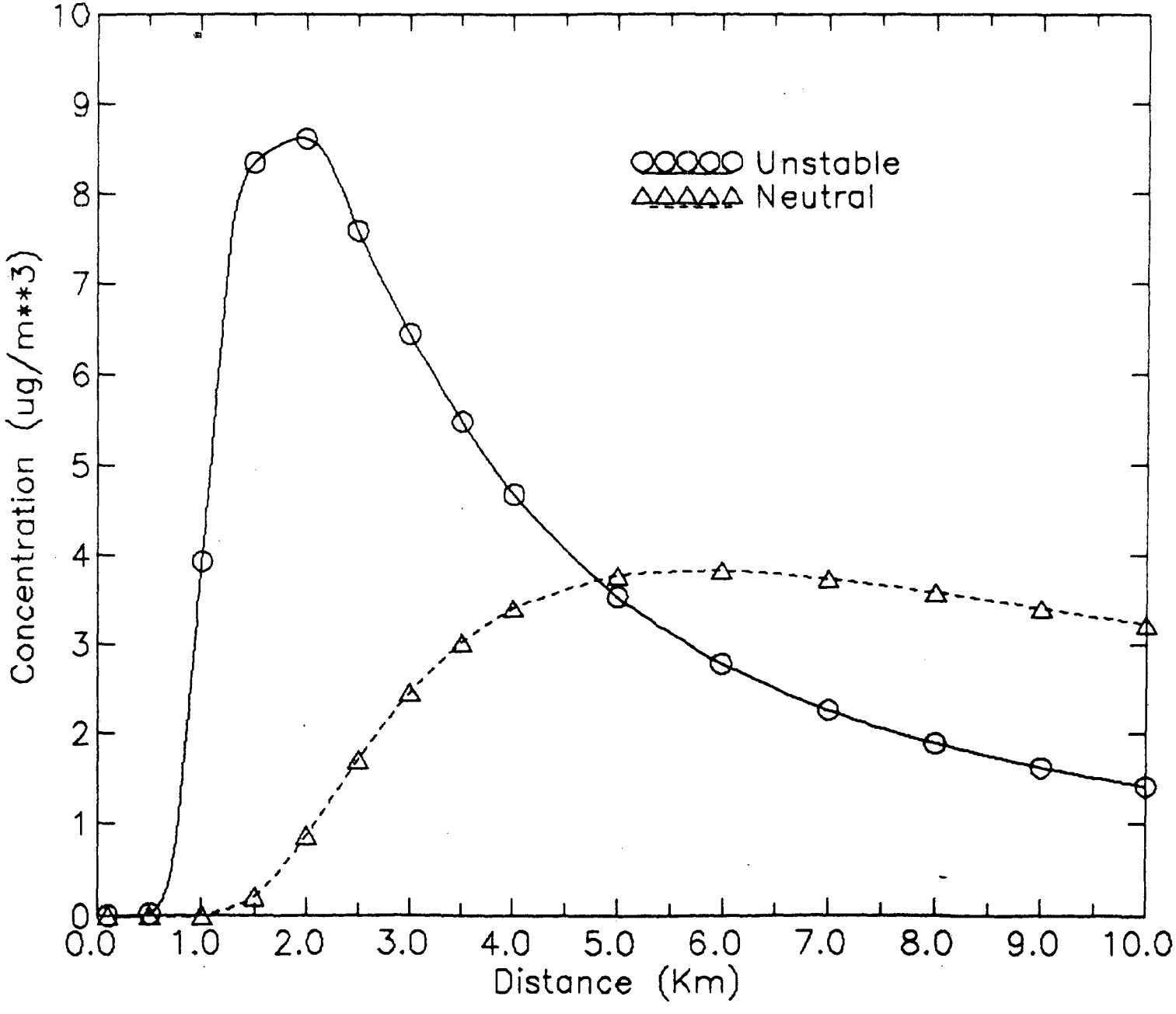


Fig.3.24 Short Term G.L.C.– JULY (Stack #7) – AMMONIA

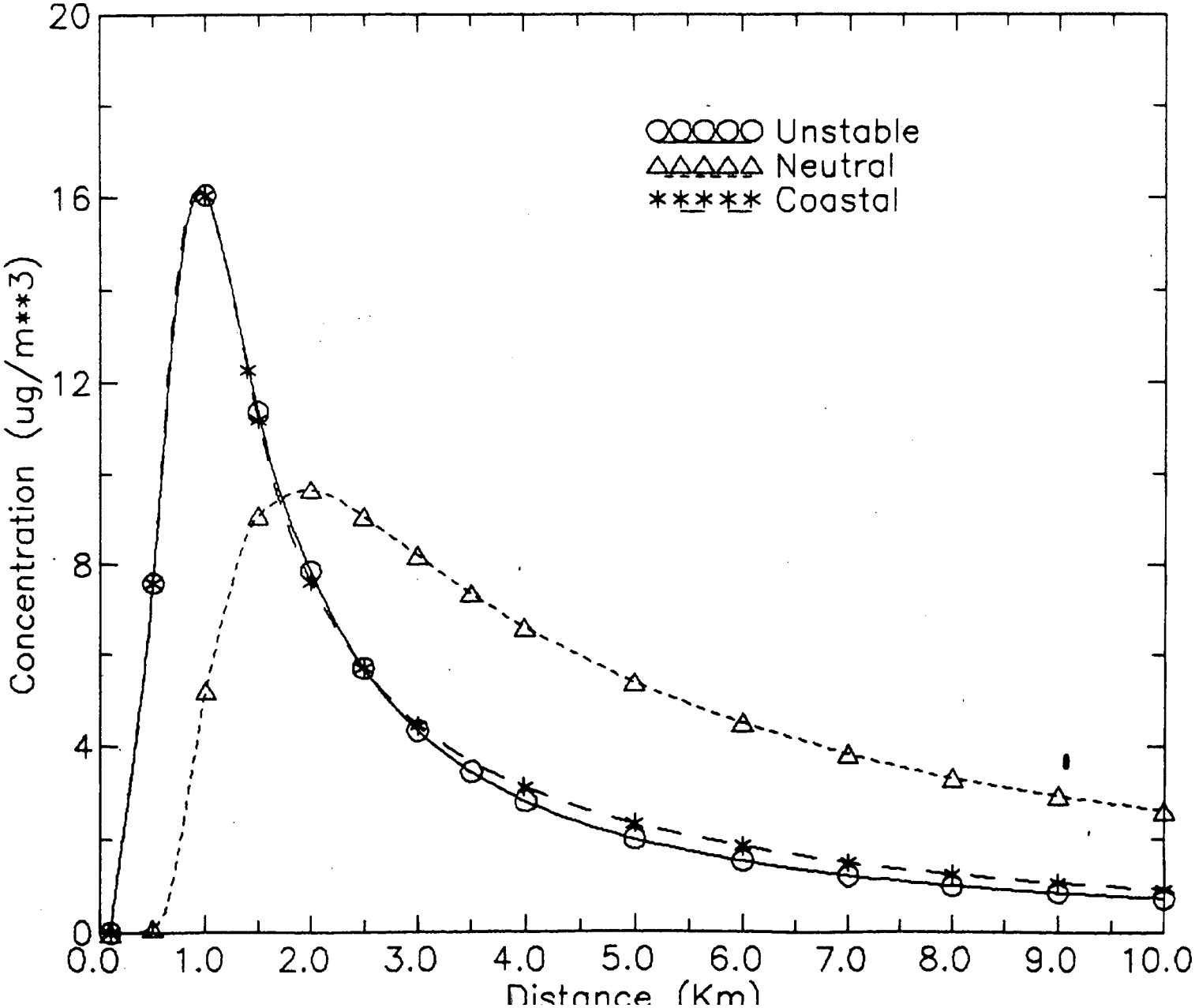


Fig.3.25 Short Term G.L.C.– OCTOBER (stack #1)

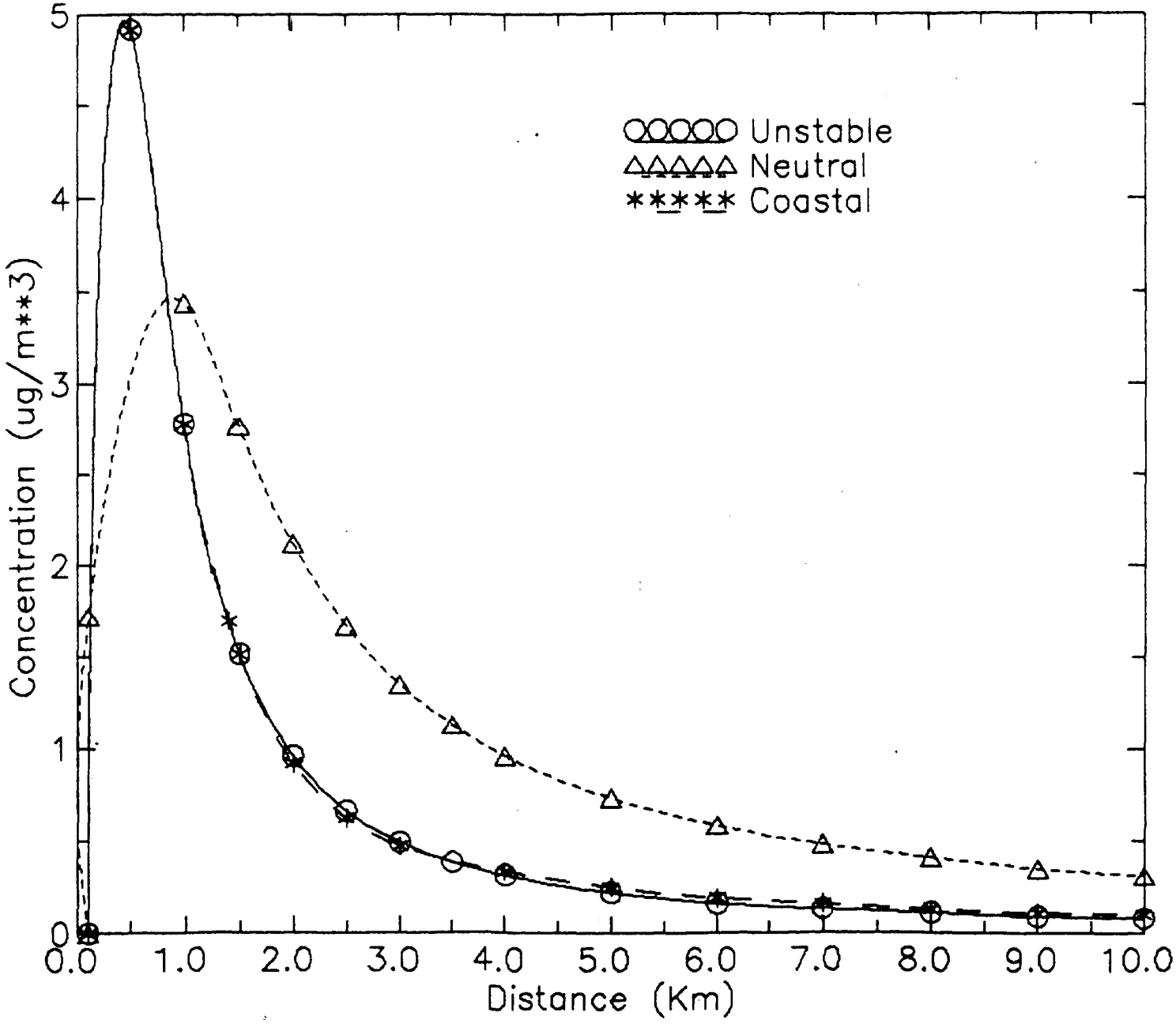


Fig.3.26 Short Term G.L.C.– OCTOBER (stack #2)

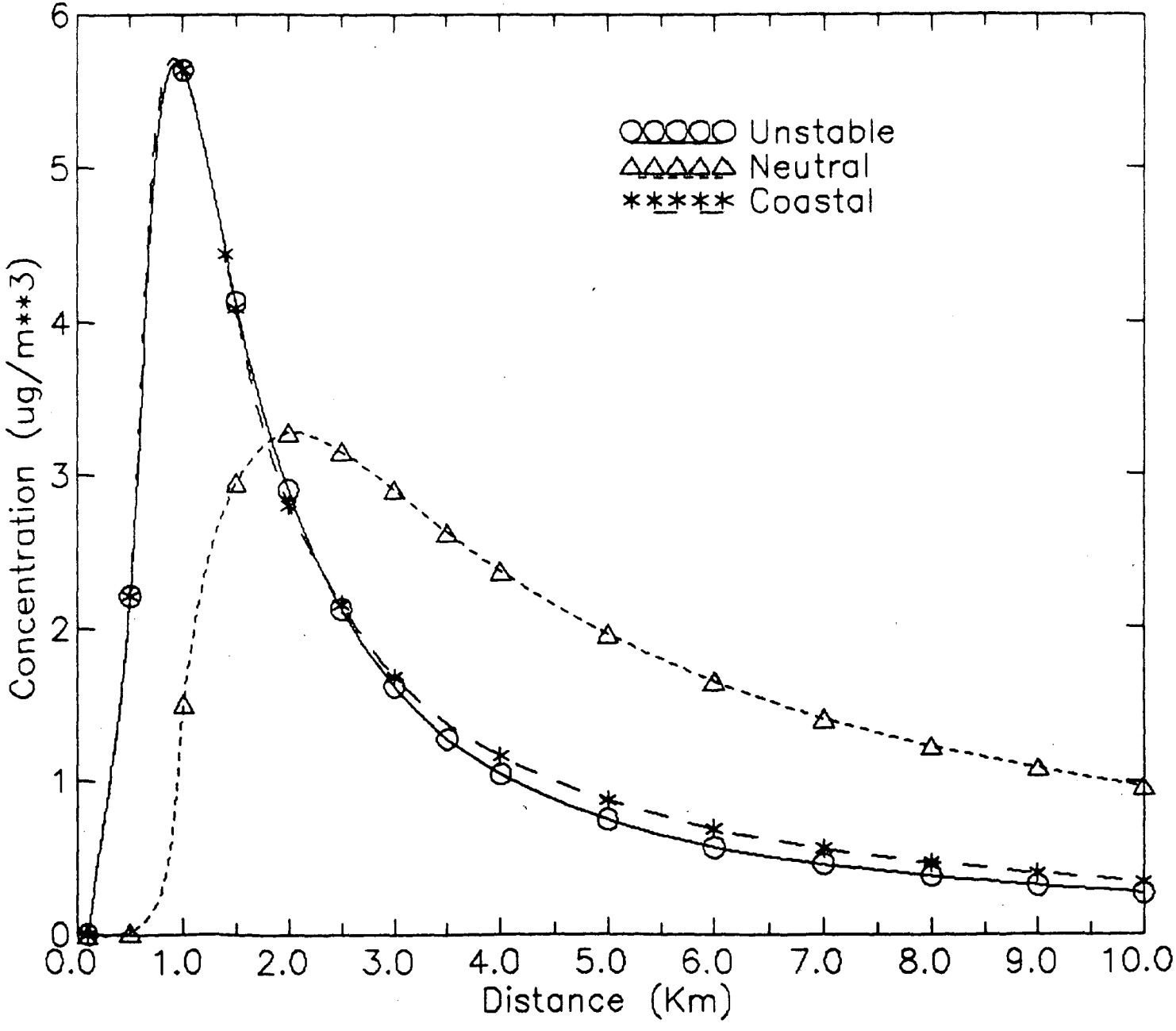


Fig.3.27 Short Term G.L.C.– OCTOBER (stack #3)

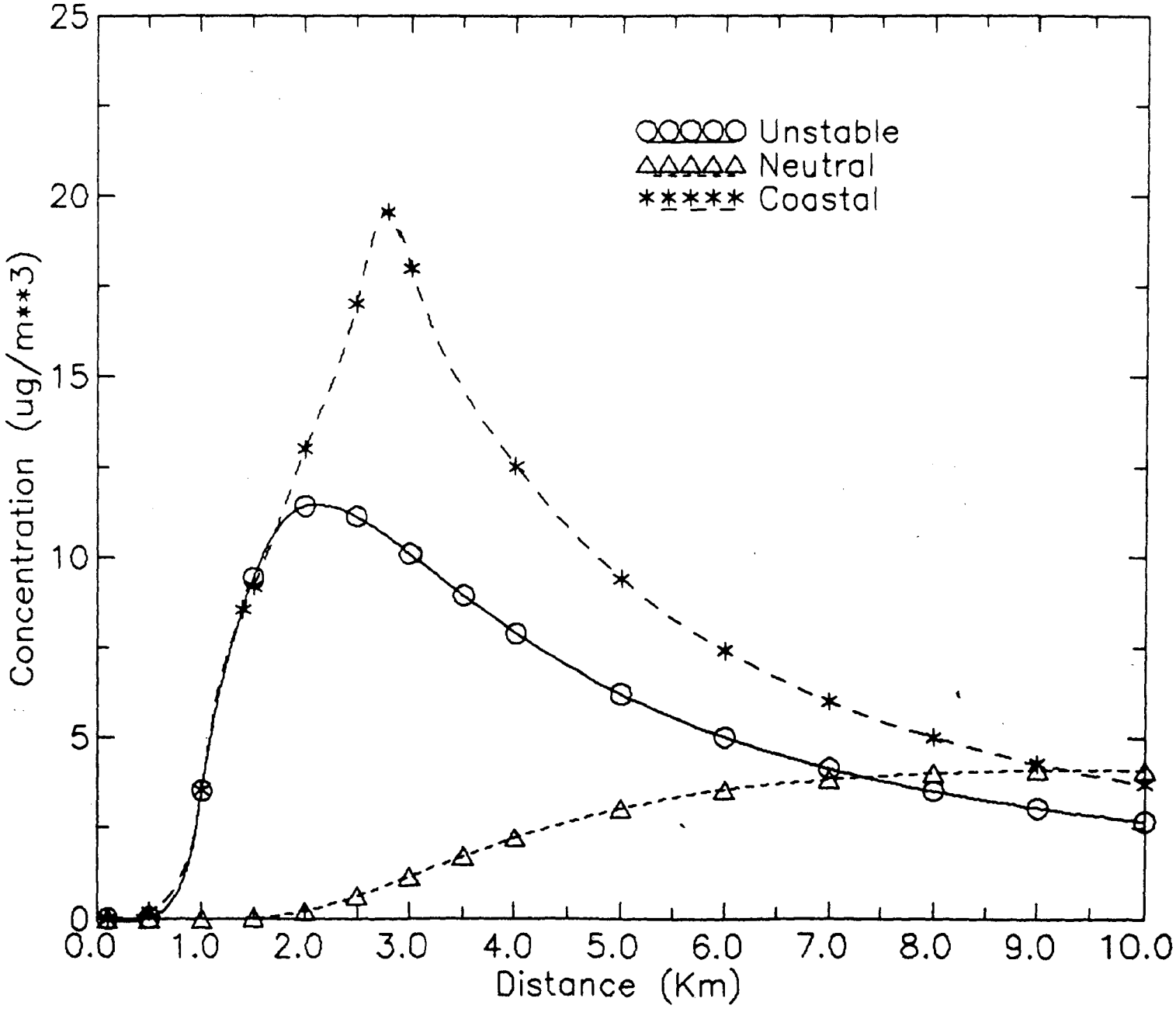


Fig.3.28 Short Term G.L.C.– OCTOBER (stack #4)

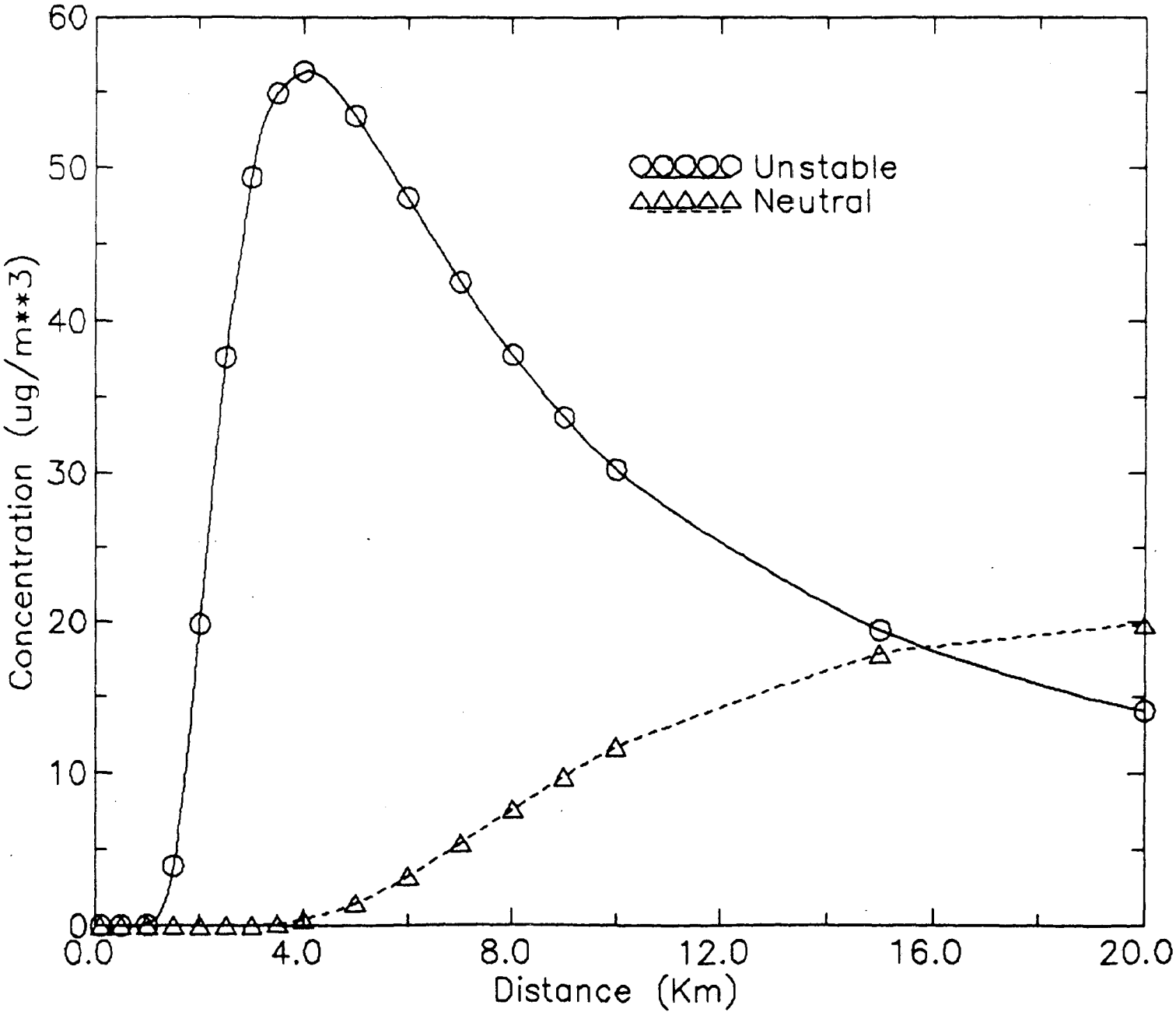


Fig. 3.29 Short Term G.L.C.– OCTOBER (stack #5)

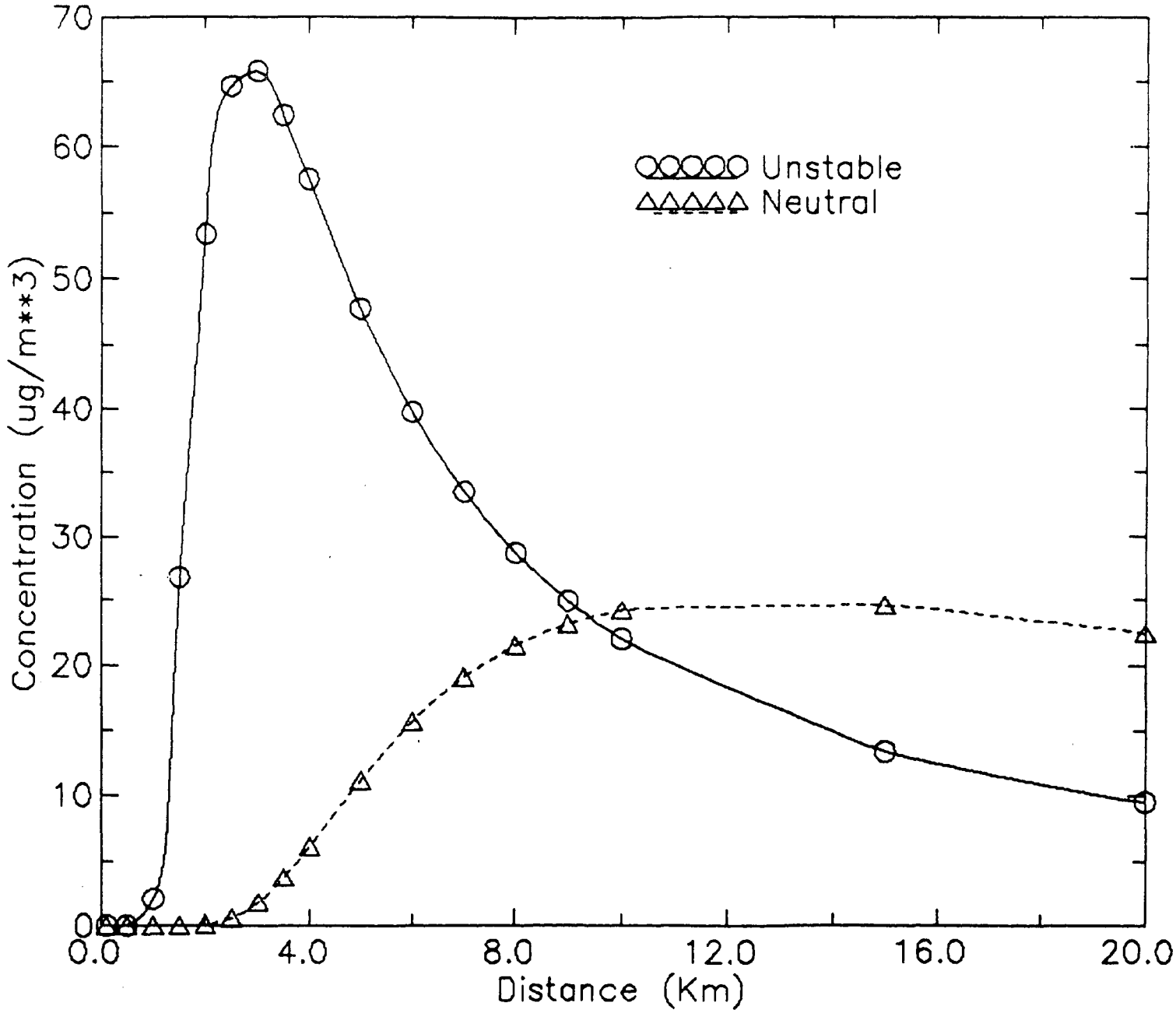


Fig. 3.30 Short Term G.L.C.– OCTOBER (stack #6) – AMMONIA

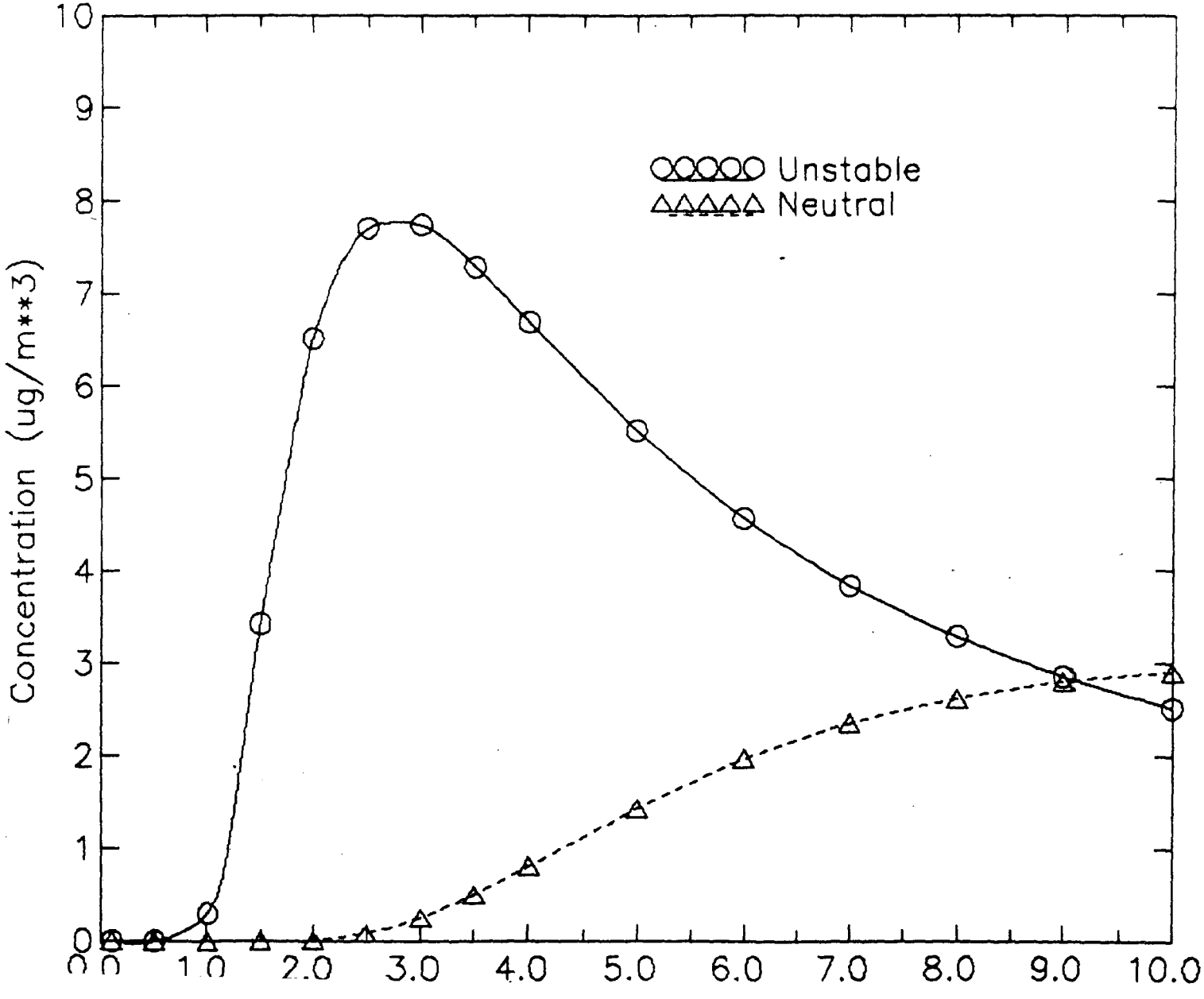


Fig.3.31 Short Term G.L.C.– OCTOBER (stack #6) – UREA

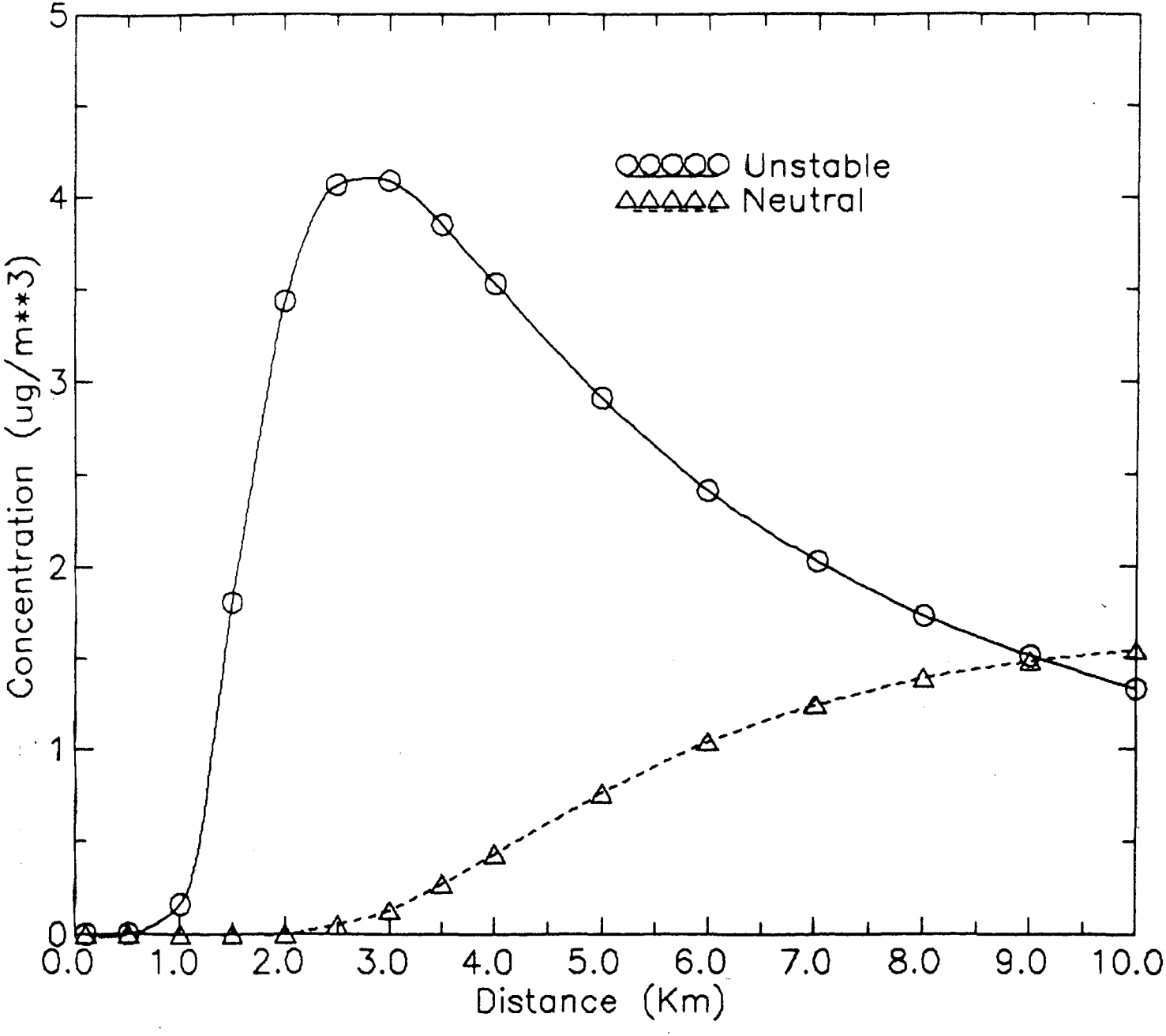
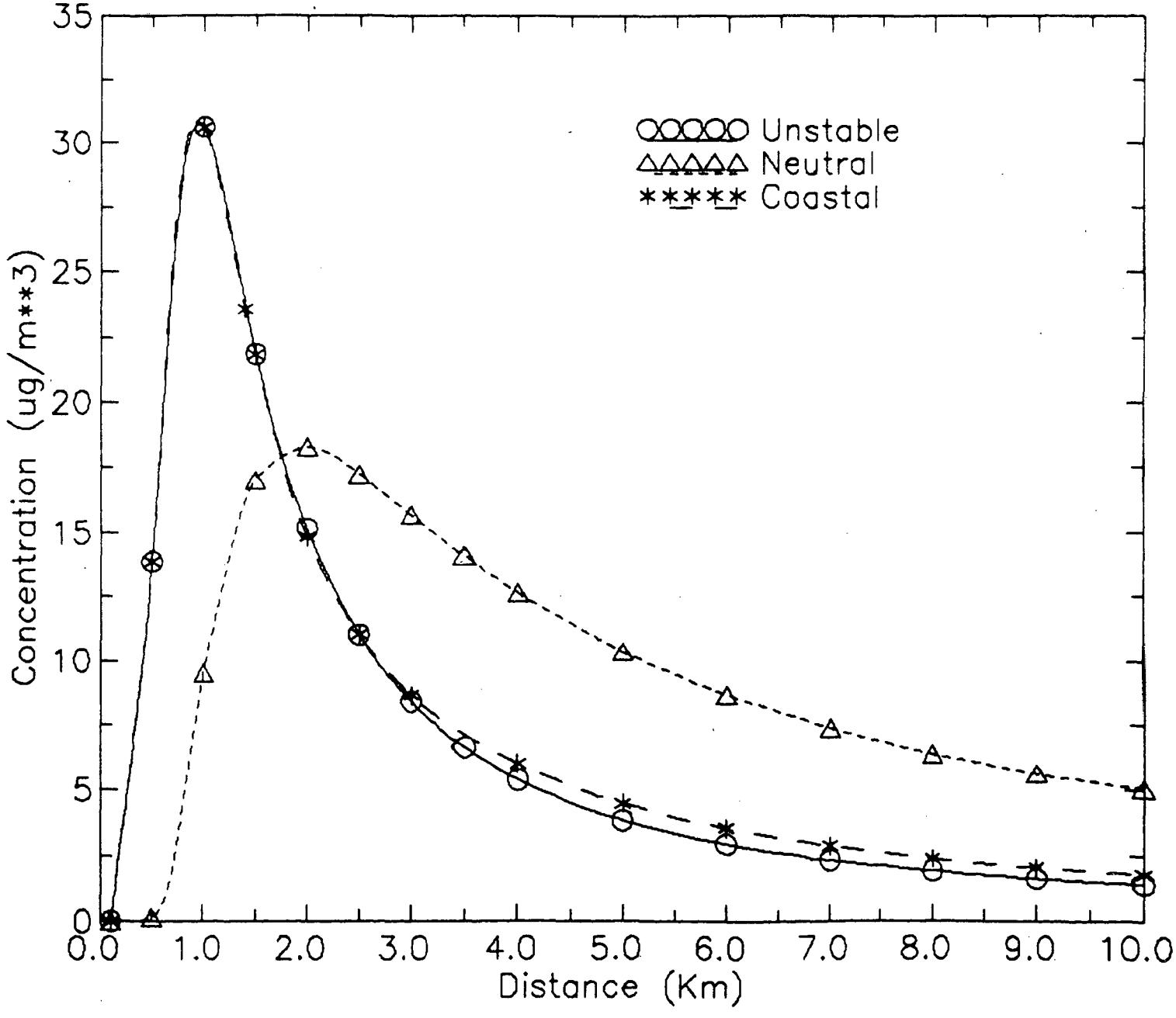


Fig.3.32 Short Term G.L.C.– OCTOBER (stack #7)



CHAPTER IV

DISCUSSION & CONCLUSION

DISCUSSION

In part I of the results, we notice that maximum short term concentrations for SO_2 are well within the prescribed standards of pollution level laid down by Central Pollution Control Board, India for residential areas. No standards are available for Urea and Ammonia. Long term concentrations also are well under the limits for SO_2.

In part II of the results where unique features of coastal site are considered partially, we notice that for stacks 1, 2, 3 and 7 trapping conditions are satisfied and for the rest of stacks conditions of fumigation are being satisfied.

Carpenter et al. (1971) found in their field experiment on TVA power plant that the nonuniform conditions of trapping and fumigation are more critical than the uniform coning conditions of plume and they reported that for high stacks maximum ground level concentration caused by fumigation and trapping conditions are higher than those of the coning plume by factors 2.4 and 3.3 respectively.

For the stacks where trapping occurs, the maximum concentration under these conditions is not as high as expected according to the above generalized and widely accepted assumptions. Actually in some cases, concentrations under trapping

are same as those under unstable conditions. Stacks 1,2 and 7 in all the four months, the concentrations computed under unstable (c) condition are found to be nearly same as that under trapping when modified method is used for coastal terrain. Although for stack 3 in the month of January and October the concentrations under trapping are somewhat higher than those under unstable conditions they are less than the expected concentrations under trapping for a flat terrain. Thus we can say that for the coastal site, generalized assumptions applicable on a flat terrain are not found satisfactory. THe reason for such unexpected low estimation of concentrations under trapping can be accounted by the presence of certain features at a coastal site as discussed below.

Trapping occurs when there exists a stable layer with unstable atmospheric layer below it. The plume emitted into the unstable layer may intersect the stable layer at some down-wind distance and plume gets entrained into the stable layer causing downmixing of plume. This phenomenon is explained in detail in chapter II. For plain terrain with no coastal effect, the existence of such stable layer is associated with the assumption that the stable layer height h_t from the ground remains constant at any downwind distance x. However, for a coastal site, the case is different. The stable layer which is actually the Internal Boundary Layer (IBL) height H_T is variable with distance x as given by Hanna's equations. In the former case ,the height h_t of stable layer at a distance x_t where the plume upper edge touches the stable layer and at a distance $2x_t$ where maximum concentration under trapping is assumed to occur, is same while

for a coastal site the height (H_T) of IBL at distance $2x_t$ is much higher than that at a distance x_t. This increase in IBL height effectively increases the area for plume diffusion in vertical direction and thus results in reduced the ground level concentration. Thus we can say that the effect of variable IBL height is to negate the effect of trapping on the ground level concentration at a coastal site.

For stacks 4, 5 and 6 where conditions for fumigation are satisfied, the computed concentrations are alarmlingly higher than those expected. Even for a single stack the concentrations have exceeded the safe limits laid down by Central Pollution Control Board. For example in the month of October for stacks 4 and 5 short term (8 hr. average) concentrations are 156.76 $\mu g/m^3$ and 177.75 $\mu g/m^3$ respectively. Similar is the case for other months and other stacks.

This unique and entirely different behavior found at the coastal site can be associated with the fact that here the fumigation is of entirely different nature from that of inversion breakup fumigation, the downwind distance x_F for maximum concentration is simply the product of the time t_F by wind velocity U. The time t_F is the time taken by the originally stable plume to diffuse to ground level as it is enveloped by the increasing non-stable layer. Equations for determining t_F are given by Turner (1970), Pooler (1965) and several others. However at a coastal site the distance of maximum concentration x_F depends entirely on the nature of variation of IBL height with downwind distance x in accordance with Hanna's equations for IBL height

determination.

Lyons and Cole (1973) gave a description of pollutant dispersion from a tall stack, situated on the coast, during onshore flow. Estimation of maximum ground level concentration during fumigation is done making use of usual Gaussian dispersion formula with the modification that vertical diffusion height is restricted by IBL height. They also considered losses due to chemical reactions.

Approximation of σ_{yf}, horizontal diffusion coefficient modified for fumigation, is taken same as that considered in the present study. A similar estimate of maximum ground level concentration during fumigation conditions was used by Meroney et al (1975). They estimated very high concentration under continuous shoreline fumigation. In a slightly different approach based on the conservation of mass, the estimated maximum concentration was found to be lesser by a factor of 3 than that estimated by Lyons and Cole (1973). Van Dop (1979) also found that difference between the concentration during fumigation and concentration under neutral conditions becomes considerable only for relatively small stacks.

In the present study the results show very high concentration under fumigation similar to the results obtained by Lyons and Cole (1973) and Meroney (1975) but they are nowhere near the nature of the results obtained by Van Dop (1979). The reason lies with the different nature of IBL height equation and slightly different approach used to estimate concentrations by Van Dop. Van

Dop (1978) assumed that once the pollutants have entered the mixed layer, it is laterally dispersed according to the corresponding stability class of that layer, while in the present study enhanced mixing in fumigation zone is described by introduction of the dispersion parameters σ_{yf}. The above assumption (by Van Dop) will in general result in a considerably lower prediction of maximum surface concentrations than the present case.

As already discussed in chapter I that a slight difference in IBL height estimation may cause serious problems in predicting the ground level fumigation location and hence the location of maximum ground level concentration. The linear relationship between IBL height and x used in the present study and the square root relationship between the two used by Van Dop (1979) might be the cause of such large variation in the nature of values for maximum ground level fumigation concentration. The model given by Hanna (1987) which is used in the present study, is used primarily because its inherent property of not permitting any variation in IBL height with meteorological conditions at a given downwind distance. It can be clearly seen that the simplicity achieved by this model is at the cost of many informations which are required to estimate the actual IBL height such as actual difference in land/sea temperature, overwater stable lapse-rate, surface heat flux over land etc. But on the face of limited choice offered in the present case in absence of most of the important data required for any appropriate estimation of IBL height, as is the case in most of the actual situations due to high cost of monitoring and inaccuracy in measurements, use of

Hanna's model was a justified and clear choice. However, degree of accuracy could have been checked to some extent by actual measurement of IBL, but unfortunately, lack of sufficient detailed information has hindered the verification of model in context of Indian climate. This leaves the scope for further study in this field and then only we may be able to say how appropriate our approach to the estimation of concentration in coastal region is.

CONCLUSION

Simple Guassian approach has been adopted to study the environmental impact of Nagarjuna Fertilizer Plant on the ambient air quality in Kakinada. Hanna's methodology for IBL height calcultion has been incorporated to take into account the coastal effect on diffusion and transportation. Model simulations are made for SO_2, Ammonia and Urea dust. No provisions are made in the model for chemical transformations. As no monitored data is available for comparison, we restrict ourselves to just impact assessment studies.

Short term concentrations are estimated taking into cosideration IBL heights but ignoring the role of wind direction whereas both long term and short term model simulations are made without cosidering coastal effects. For short term model simulations with coastal effects very high concentrations are found for stacks 4, 5 and 6 where fumigation conditions are assumed to be satisfied. Wind roses (Fig. 4.1-4.4) of January and

October suggest frequent occurence of IBL on inland site whereas the converse is true for other two seasonal months. This could lead to higher concentrations for pollutants during winter and postmonsoon months.

As already mentioned, this approach is very preliminary and simplistic in nature. Coastal effects like land/sea breeze and chemical transformation involving sulphate radicals and other important compounds are to be incorporated in the models for better results. Structure of IBL height is to be studied by experimental methods and parameterization based on these results should be incorporated in the future studies.

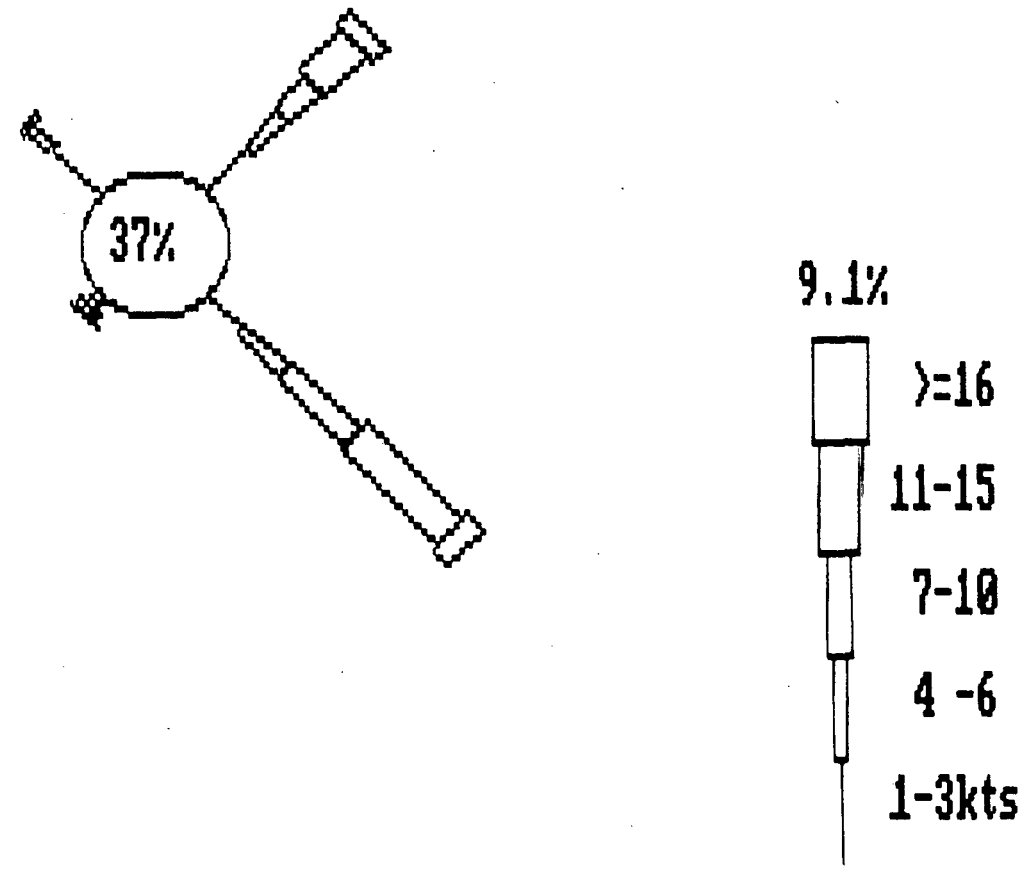


Fig. 4.1 Windrose - January

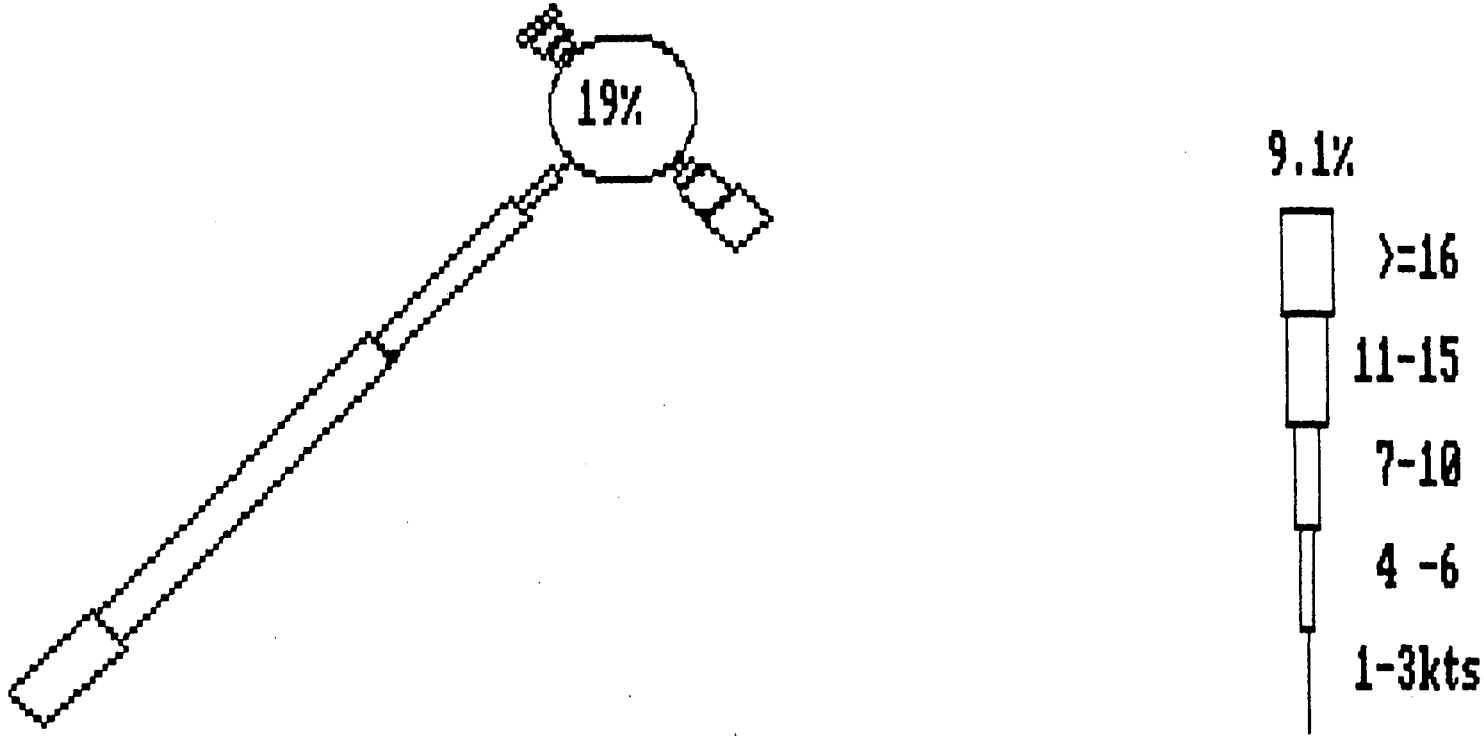


Fig. 4.2 Windrose - April

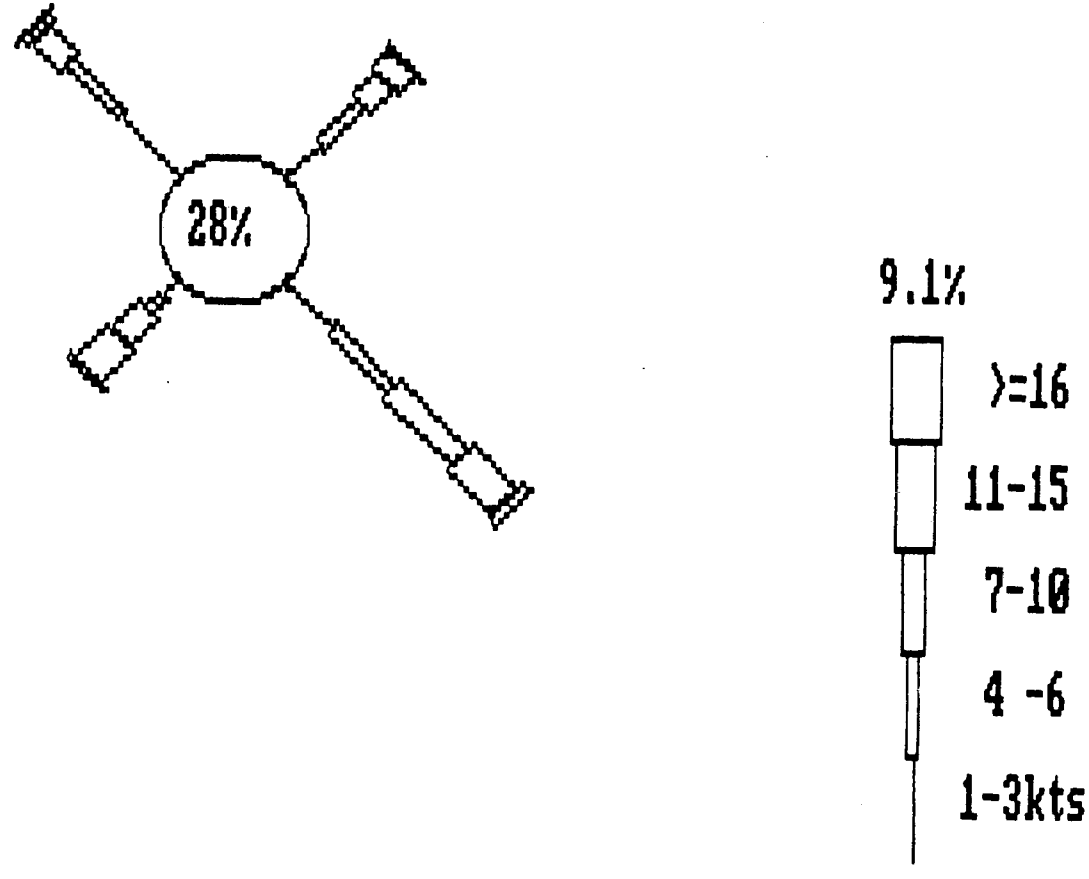


Fig. 4.3 Windrose - October

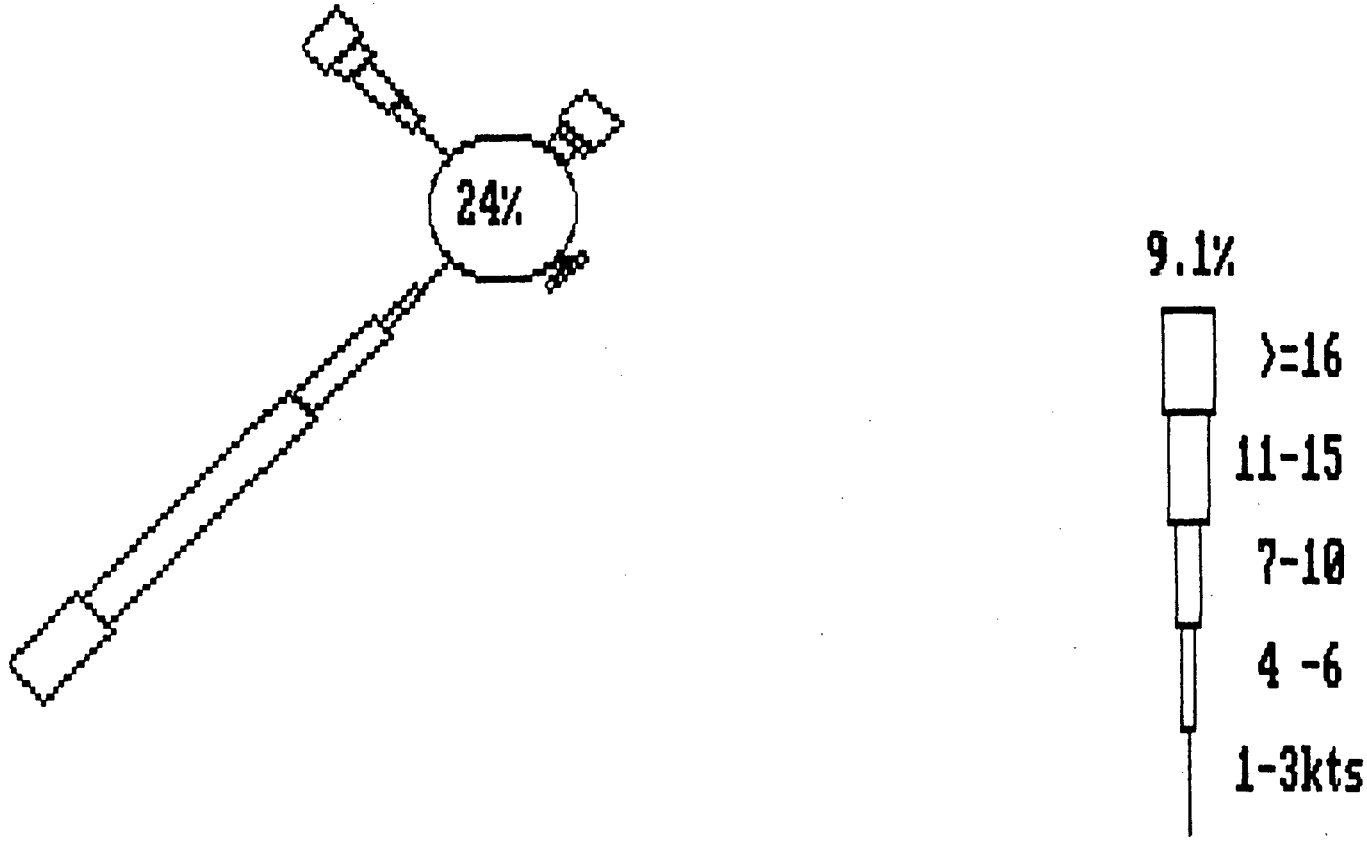


Fig. 4.4 Windrose - July

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