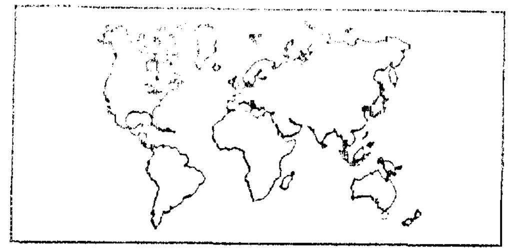
Environmental Assessment/Analysis Reports



Report E0071

India - Bombay Sewage Disposal Project

EA Category A

2 of 4

Environmental Assessment

January 1995

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FINAL REPORT

BOMBAY SEWAGE DISPOSAL PROJECT

MARINE OUTFALLS

SPONSOR

MUNICIPAL CORPORATION OF GREATER BOMBAY

National Environmental Engineering Research Institute

January 1995

FOREWORD

The Municipal Corporation of Greater Bombay (MCGB) is in the process of implementing wastewater treatment and disposal schemes with the World Bank assistance. These schemes are planned under the Bombay Sewage Disposal Project and envisage disposal of preliminary treated sewage from Colaba, Bandra and Worli service areas into the Arabian Sea by marine outfalls, treated wastewaters from aerated lagoons at Versova and Malad into Malad Creek, and from aerated lagoons at Bhandup and Ghatkopar into Thana Creek.

The implementation of the proposed facilities is expected to significantly improve the beach environment and coastal water quality in and around Bombay. The large scale construction activities, however, have potential adverse environmental impacts.

The MCGB retained the National Environmental Engineering Research Institute (NEERI), in September 1991, for assessing the potential impacts of the construction and operation of the proposed facilities. The primary objective of the study was to delineate an Environmental Management Plan to enhance the beneficial impacts and mitigate the adverse impacts of the project.

The first report on the study **Environmental Management Plan for Bombay Sewage Disposal Project (Issues & Approach)**, submitted to the MCGB in January 1992, delineated the major issues and outlined the approach towards development of Environmental Management Plan. This report presents the Environmental Management Plan for marine outfalls after exhaustive data collection, mathematical modelling, and analyses of various predictive scenarios for different outfall lengths.

The cooperation and assistance rendered by Er. I.C. Gandhi, Deputy Municipal Commissioner; Er. M.K. Gokhale, Deputy Municipal Commissioner (Retd.); and other staff of MCGB in the preparation of this report is gratefully acknowledged. The contributions made by the Binnie & Partners and World Bank towards the review of the draft report are sincerely appreciated. Thanks are also due to the officials of a number of agencies who readily furnished the information necessary for the study.

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January, 1995

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EXECUTIVE SUMMARY

1. Bombay is the hub of commercial and industrial activities and has witnessed a rapid growth during past few decades. According to 1991 census, 9.93 million persons reside within the municipal limits of Greater Bombay which has a land area of 603 sq. kilometers.

2. The infrastructural development, however, has not kept pace with the growth of population. As a result, the city suffers from shortage of all basic amenities including housing, water supply, sanitation and transport. Amongst these, sanitation is perhaps the most neglected sector. Out of approximately 1500 mld, only a miniscule proportion 22.5 mld (1.5%) of municipal wastewater generated in the city receives treatment before disposal to adjoining coastal and creek regions. Discharge of such large quantity of untreated sewage into the coastal environment has resulted in widespread impairment of coastal water quality.

BOMBAY SEWAGE DISPOSAL PROJECT

3. The first integrated wastewater management scheme for the city was planned in 1970. The scheme envisaged disposal of screened wastewater from entire Bombay municipal area through two submarine outfalls at Worli and Bandra.

4. The plan, since then has undergone many revisions. The most recent - Development Plan III, divides the Bombay municipal region into seven drainage areas. The plan provides for disposal of wastewater after preliminary treatment through marine outfalls at Colaba, Worli and Bandra into coastal sea. For the remaining four drainage zones treatment in aerated lagoons is proposed before effluent disposal into the adjacent creeks (Figure 3.1).

THE PROPOSED FACILITIES

Marine Outfalls

5. For construction of the two proposed 3 kilometer long outfall at Worli and Bandra, are under consideration. The headworks for the outfalls will comprise influent pumping station; preliminary treatment facilities comprising coarse and fine screens and grit removal; and effluent pumping station to provide the motive force for wastewater disposal against the tide. The outfall design details are presented in Table 4.5.

NEED FOR PRESENT STUDY

6. The present study has been undertaken in keeping with the World Bank policy and procedure for the environmental assessment of Bank lending operations

with respect to Bombay Sewage Disposal Project-Development Plan III. Procedures as listed under Operational Directive 4.01 have been followed during the assessment. The study also meets the requirements of State of Maharashtra and Government of India for environmental clearance of development projects.

OBJECTIVES OF ENVIRONMENTAL ASSESSMENT

7. The primary objective of the environmental assessment study has been to ascertain if the proposed facilities are adequate to provide the desired benefits and if not, what modifications in the form of higher degree of treatment and/or increase in outfall lengths would be necessary. As the project involves large scale construction activities, the study also aimed at assessment of the potential negative impacts during the construction of the project and delineation of necessary mitigatory measures.

ENVIRONMENTAL STANDARDS

8. Environment (Protection) Act, 1986 vests in Central Government, the powers to lay down standards for environment protection. Central and State Pollution Control Boards are responsible for compliance of these standards. The Boards, based on local conditions, have power to stipulate more stringent location specific standards.

9. For protection of coastal water quality, two standards apply in India. The first of these standards is in the form of receiving water quality and is based on best designated use of the water body such as for bathing, fishing or navigation. Pertinent details of this standards (IS 7967-1976) are provided in Table 3. The creek and coastal waters used for recreational purposes or fishing, accordingly, should always have biochemical oxygen demand (BOD) less than 5.0 mg/l, total coliforms not more than 1000/100 ml and dissolved oxygen (DO) more than 3.0 mg/l.

10. The second standard is in the form of effluent standards for discharges into marine coastal area. Accordingly to the standards has summarised in Table 4, effluents with BOD and suspended solids of 100 mg/l each and ammoniacal nitrogen upto 50 mg/l can be discharged into the creeks.

11. No effluent standard, however, has been stipulated for coastal discharges through marine outfalls. In the absence of such standard, Maharashtra Pollution Control Board (MPCB) has given consent to MCGB for discharging treated/untreated sewage subject to compliance of receiving water quality standard for coastal waters viz. total coliform counts less than 1000 /100 ml. Since the outfall discharges on their movement towards the coast can pollute the beaches etc., it has been further stipulated by MPCB that compliance with

the receiving water standards shall be measured at 1 kilometer from the coastline**.

METHODOLOGY FOR ENVIRONMENTAL ASSESSMENT

12. In order to assess improvement in coastal water quality, its existing status was determined through elaborate field surveys. The surveys were conducted during winter of 1991 and summer of of 1992.

13. To predict the post-project environmental conditions in terms of dissolved oxygen, BOD and total Coliforms, mathematical models were used to simulate initial dilution and advective- dispersion processes. These models were calibrated for local environmental conditions through insitu and laboratory experiments.

14. For processes involving more complex interactions such as nutrient enrichment, bioaccumulation and ecological transformations, the approach of observation at and inference from the regions which have been receiving similar wastewater discharges over a long period was adopted.

15. For estimation of construction phase impacts, field investigations on ambient air quality, noise levels, coastal water quality, meteorology, sources of noise and air pollution during construction were conducted. Ground vibration data for blasting operations during earlier constructions at Bombay were also collected to determine the safe limits for such operations.

16. The overall inferences of the environmental assessment were used to examine the efficacy of proposed schemes in achieving the desired environmental benefits. The findings of the study were also used to identify additional data requirements for evaluating the options for upgrading the proposed schemes.

EXISTING ENVIRONMENTAL STATUS

17. The primary impacts of the present wastewater discharges are manifested in terms of poor water quality in many regions along with the West coast. Higher levels of pollution are observed during the ebb tide in comparison to the flood tide. Observations on bacterial quality along the coast show frequent occurrence of total coliforms concentrations between 10^4 to 10^5 per 100 ml for about one third of the 24 kilometer long coastline.

18. Observations on dissolved oxygen levels (DO), an indicator of general health of water body, indicate that about 5 kilometers of the coast are highly polluted. These regions are near the mouth of Malad and Mahim creeks through which large quantities of wastewater reach the coast (more than 50 percent of total discharges on the West coast of the city). During the low tide dissolved oxygen levels in these regions invariably fall to less than 2 mg/l indicating severe stress on ecosystem.

** Refered as 'reference line' in remaining of the reports

19. Concentrations of Biological Oxygen Demand (BOD) at the reference line are generally low (less than 5 mg/l) indicating considerable dilution and decay before the pollutants reach the reference line. Ammonia-N levels are in the range of mildly polluted waters whereas phosphates are close to levels observed in clean sea.

20. The nutrient levels in sediments are observed to be higher during winter than summer. These levels, however, are similar in polluted and clean regions and therefore do not indicate accumulation of nutrients in sediments due to sewage discharges.

21. Amongst the phytoplankton, considerable occurrence of indicator groups like Cyanophyceae have been found in many regions which also show higher pollution in terms of physico-chemical and bacterial parameters. This observation also signifies contamination of coastal waters due to organic pollutants.

22. The analysis, however, does not indicate any significant contamination due to toxic inorganics (metals) or organics in water or in sediment samples. The possible explanation for these observations lies in the low levels of metals and toxic organics observed in the wastewater.

23. Among the three prominent beaches Juhu beach is most scenic and is also relatively least polluted. Dadar and Girgaum beaches are highly polluted due to their proximity to wastewater discharges.

24. Poor water quality conditions exist in Mahim Creek which discharges wastewaters near Bandra coast. The anerobic conditions of Mahim Creek during the low tide, cause odorous conditions in their immediate vicinity creating serious aesthetic problem.

25. Ambient air quality analysis at the Worli and Bandra outfall sites was carried out for assessment of construction phase impacts. The results indicate that present air quality in terms of Suspended Particulate Matter (SPM), NO_2 and SO_2 at both sites fall within Indian Standards for ambient air quality.

ENVIRONMENTAL IMPACTS OF PROPOSED PROJECT

Construction Phase Impacts

26. The major construction phase activities are blasting, tunneling, and material transfer at the sites of Worli and Bandra headworks. Tunneling under the sea bed and disposal of excavated muck, will be additional major tasks. The prominent impacts of these activities are vibrations due to blasting, rise in ambient noise levels, impairment of air quality near the construction sites, and impaired water quality due to the trenching on the sea bed.

27. No adverse impacts on nearby structures due to blasting would occur if charge sizes are restricted to 4.5 and 5.4 kg at Worli and Bandra respectively. Safe peak particle velocities of 20 mm/sec for concrete structures and 8 mm/sec for poor structures have been considered.

28. Calculations for noise levels in vicinity of construction site reveal that the levels would be in the range of 57-61 dBA at Worli and 62-67 dBA at Bandra at the nearest sensitive locations from the sites.

29. During the construction activities at outfall headworks, marginal increase in air borne pollutants such as NOx, and SO_2 is expected. However, due to land-sea breeze their dispersion would be very high.

30. The construction of the outfall would not have any significant impact on the coastal water quality, as tunnelling will take place at about 50-70 meters below the seabed. For such construction the disposal of excavated muck, generated at a rate of about 500 tons per day for about 15 months, entails disposal. The excavated muck will be composed of tuff and basalt. This material will be used for reclamation of additional land near Bandra outfall headworks.

31. Coastal waters along a short length of the alignment of each outfall will experience certain water quality impairment during the construction of the diffuser sections. The impairment will be caused due to the suspension of seabed material during the bearing operations for diffuser sections. The area of impact will, however, approximately a 1 kilometer wide region near the point of construction. There will be thus, increase in the turbidity during the construction of the diffuser section. The impact, however, will be of very short duration and of low intensity. Due to the high background turbidity in the sea off Bombay's coast.

32. No adverse impact of outfall construction on fishing interests in the region, except of some navigational constraints, is expected. Some localized water

quality impacts due to the spillage of fuel and oils used for operation of construction machinery and barges etc. may occur. These will have to be minimized with good house keeping and vigilance. These impacts will however be transient and marginal.

Operation Phase Impacts

33. The impacts associated with operation of marine outfalls are essentially beneficial and expected to considerably improve the coastal and beach environment. The most prominent impact, in this context, would be considerable improvement in physico-chemical quality of coastal waters.

34. Construction of 3 km long outfalls at Worli and Bandra will fully eliminate the dissolved oxygen depletion which presently occurs during the low tide near Mahim coast. Reduction in nutrient loading along with improvement in DO will considerably improve the ecological health of near shore waters in the region. These improvements will contribute towards elimination of odour nuisance, enhancement of beach aesthetics and water use.

35. The discharge of wastewater through marine outfalls will not cause environmentally adverse conditions, such as low dissolved oxygen or high nutrient concentration in the water column, even in the vicinity of outfalls, as the expected initial dilution is more than 50 times during most of the tidal cycle. For such periods, the dissolved oxygen levels near the outfall diffuser section will be more than 4 mg/l and BOD levels less than 3 mg/l. However, if peak dry weather flow coincides with the tidal slack period, BOD levels of upto 20 mg/l are probable in immediate vicinity of outfalls. The probability of such occurrence is less than 0.01. This concentration, however, will fall below 5 mg/l soon after the tidal currents re-establish and would not have appreciable influence on DO.

36. Observations on the west coast and in immediate vicinity of Colaba outfall (a small outfall in operation since 1988), discharging sewage into east coast, indicate no significant accumulation of organic matter, nutrients or metals in the sediments. Since similar dilution and coastal currents are expected near the diffuser section of proposed outfalls, no significant adverse impact on sediment quality are expected. Due to low levels of metals and trace organics in the sewage, their concentrations in the water column or sediments in the vicinity of outfalls will also remain close to the ambient levels.

37. As the operation of outfalls does not result in impairment of water and sediment quality even near the diffuser section, no adverse effect is expected on marine flora-fauna and the fish yield in the region. Increased fish yield may be obtained in coastal regions near Bandra and Worli due to improved water quality conditions.

38. The 3 kilometer long outfalls, however, are not expected to improve the bacterial quality to the desired levels. Even after commissioning of the outfalls, under adverse meteorological conditions, about 1/3rd of the coast line would remain susceptible to total coliform levels exceeding the stipulated standard by up to 50 times during the non-monsoon. The bacterial counts may reach levels upto 100 times higher than the standard during the monsoon.

39. Under conditions of intense rainfall during monsoon, sewage overflows of the order of 4.0 m^3/s and 3.0 m^3/s for the duration of about 2.5 hours and 4 hours would occur at Worli and Bandra. These spillages will be discharged through the existing outfalls.

40. The evaluation of impacts of sewage overflows, indicates that formation wastefields with high BOD levels and creation of anoxic conditions near the discharge sites. The depletion of oxygen, however, will be gradual and will be confined to a small area. The aquatic fauna, therefore, would be able to move away to areas of higher dissolved oxygen and would not be affected by the spillages. The coastal bacterial contamination due to the spillages, however, would be very high at both locations. These impacts, however, would be transient and the natural assimilation would overcome them within a short period of two or three days.

41. Mahim creek near Bandra outfall and area near Worli outfall will experience anaerobic conditions due to sewage overflow and need to be minimized.

ANALYSIS OF ALTERNATIVES

No Action Scenario

42. The municipal wastewater discharges which are presently estimated at 1500 mld are expected to rise to 2200 mld by the year 2005, the design period of the project. If the proposed schemes are not implemented, the wastewater will continue to reach the coastal regions through the present drainage routes and cause pollution. The existing coastal water quality, exhibits evidence of gross bacterial pollution and high DO depletion in regions near the main wastewater outlets and moderate pollution all along the coast. These levels will rise under no action scenario and the overall coastal water quality including beach water quality will further deteriorate.

Augmentation of Outfalls' Length and Pretreatment

43. As the proposed outfall length and degree of pretreatment are inadequate to comply with the stipulated bacterial standard, alternatives in the form of different combinations of outfall lengths and degrees of treatment (3, 4 and 5 kilometers long outfalls with preliminary, primary and secondary treatment)

were examined. The analyses, although approximate in nature, because of inadequate data on coastal currents, indicate that only 5 kilometer long outfalls with secondary treatment are likely to nearly meet the existing bacterial standards at the reference line.

44. A reduced level of daytime compliance (50 percent during monsoon and 80 percent during non-monsoon), however, is anticipated at the reference line with 5 kilometer long outfalls preceded by preliminary treatment.

MITIGATION PLAN

Construction Phase

45. The potentially adverse impacts of outfall construction are vibrations due to blasting, rise in ambient noise and dust levels. Marginal water quality impairment near the discharge head is also expected option is considered. These impacts can readily be prevented by adherence to good construction and house keeping practices.

Operation Phase

46. Findings of the study indicate that proposed 3 kilometer long outfalls will provide adequate environmental improvement for all parameters except the bacterial quality in the coastal waters. The mitigation plan for the outfalls, therefore, is closely related to the compliance of stipulated bacterial standard which entails that the total coliform counts at the reference line should be less than 1000/ 100 ml at all times.

47. Available data on the coastal currents in the project area is inadequate to provide a firm recommendation on additional outfall length or treatment level for the compliance with the bacterial standard. This information will be available only at the completion of further modelling studies with updated hydrodynamic data. In the present design of outfalls, therefore, provision has been made for their extension beyond 3 kilometers at a later date.

48. The monsoon nearshore spillage, specially at Bandra, may have significant negative impacts on Mahim creek water quality. Necessary design modifications should be carried out to reduce the quantum of spillage.

Environmental Monitoring

49. Regular environmental monitoring should begin immediately and continue during the construction and post-commissioning phases. During the pre-commissioning phase, samples collected from important beaches and seafronts should be analyzed for bacterial contamination and dissolved oxygen. The critical period of the tidal cycle corresponding to elevated pollution levels at sampling locations, first, should be identified by sampling at two hourly interval (only day time hours) for a week. Year long sampling during that period should be undertaken with the frequency of 2 samples per week.

50. Samples at selected locations at the reference line should be collected on alternate days for 15 days, once every year in winter and in summer, to establish a database on existing coastal water quality. The samples should be collected at low tide slack and should be analyzed for relevant physicochemical, biological and bacteriological parameters. Sediment samples should also be collected and analyzed for benthos, nutrients and heavy metals.

51. During the construction phase additional samples, once every week, should be collected near the construction head and analyzed for physicochemical parameters. Visual inspection, once a day, should be conducted to detect any oil leak from offshore construction machinery. Noise and air pollution levels should also be monitored at the construction sites and if required mitigatory actions should be taken to ensure compliance with the standards. Additionally, daily visual inspection of roads and roadsides in the vicinity of the construction site should be undertaken to identify any nuisance that need attention with respect to dust, spill of construction materials or debris etc.

52. Post-commissioning monitoring similar to pre-commissioning period should be undertaken. During this phase, water samples at the beaches and seafronts and locations on reference line situated at North of Worli should be collected during low and high tide slack and at South of Worli at low tide slack.

53. The effluents from grit removal facilities should be regularly analyzed for grit and heavy metals.

Public Participation

54. The survey conducted among the fishing communities and general public residing near the construction sites and beach users reveal lack of

awareness about the project. There is therefore a need for public awareness programme specially among the fishing communities on the West coast which fear that discharges from marine outfalls would adversely affect the fish yield.

55. As the findings of present study show that these apprehensions have no true basis, the first step towards environmental awareness should be to place the assessment report for public discussions among representatives of fishing communities and general public, MCGB officials and local NGOs. The report summary should also be translated in vernacular languages and distributed among fishing societies.

56. A comprehensive awareness programme on the need of the project, major technical and social issues and the environmental benefits should be undertaken through local media. The coverage should include group discussion on TV and radio among panel comprising eminent citizens and officials connected with implementation and environmental assessment of the project.

Institutional Needs

57. Adequate facilities for sampling and analysis should be developed by MCGB for the recommended environmental monitoring. Alternatively, Government and/or private laboratories with adequate infrastructural facilities and expertise should be identified.

58. Training programs at various levels within the MCGB should be conducted on a continuous basis for efficient implementation and effective operation and maintenance. Necessary measures for institutional strengthening towards these objectives are being planned through MCGB's in-house Central Research and Training Centre and the management consultants M/s Tata Consulting Services.

Recommendations

59. As 3 kilometer long outfalls at Worli and Bandra are expected to substantially improve the existing coastal water quality without causing any significant impairment at the discharge site, it is recommended to proceed with their construction as the initial phase of the project. Considering the need for further extension of outfalls for compliance of the bacterial standard, the outfall design should have provisions for such extension.

60. The hydrodynamic data on the region should be strengthened through further field studies to facilitate use of models of higher sophistication to finalize the suitable outfall length-pretreatment option.

61. It is envisaged that the review of present bacterial standard will be necessary to allow a practical management option for the outfalls. In this context, it may be noted that the European Community bathing water directive requires 95 percent compliance of TC count of 10000 / 100 ml, whereas the Florida standard entails 80 percent compliance of 1000 / 100 ml TC levels. These standards apply near the beach. If the effect of the discharge from the 3 km long outfalls is to be compared with international standards, these would allow additional dispersion and decay of the wastefield moving shoreward under the influence of coastal currents.

Chapter 1

INTRODUCTION

Rapid growth of Bombay city over past few decades has given rise to innumerable problems of diverse nature and of significant dimensions. One of the major problems is the deterioration of water quality in creeks and coastal regions around the city, due to more or less unrestricted disposal of large volumes of domestic and industrial wastewaters. Loss of clean recreational beaches and sea fronts, and probable damage to coastal ecosystem are some of the manifestations of such pollution that have caused serious concern to the planners and the residents alike.

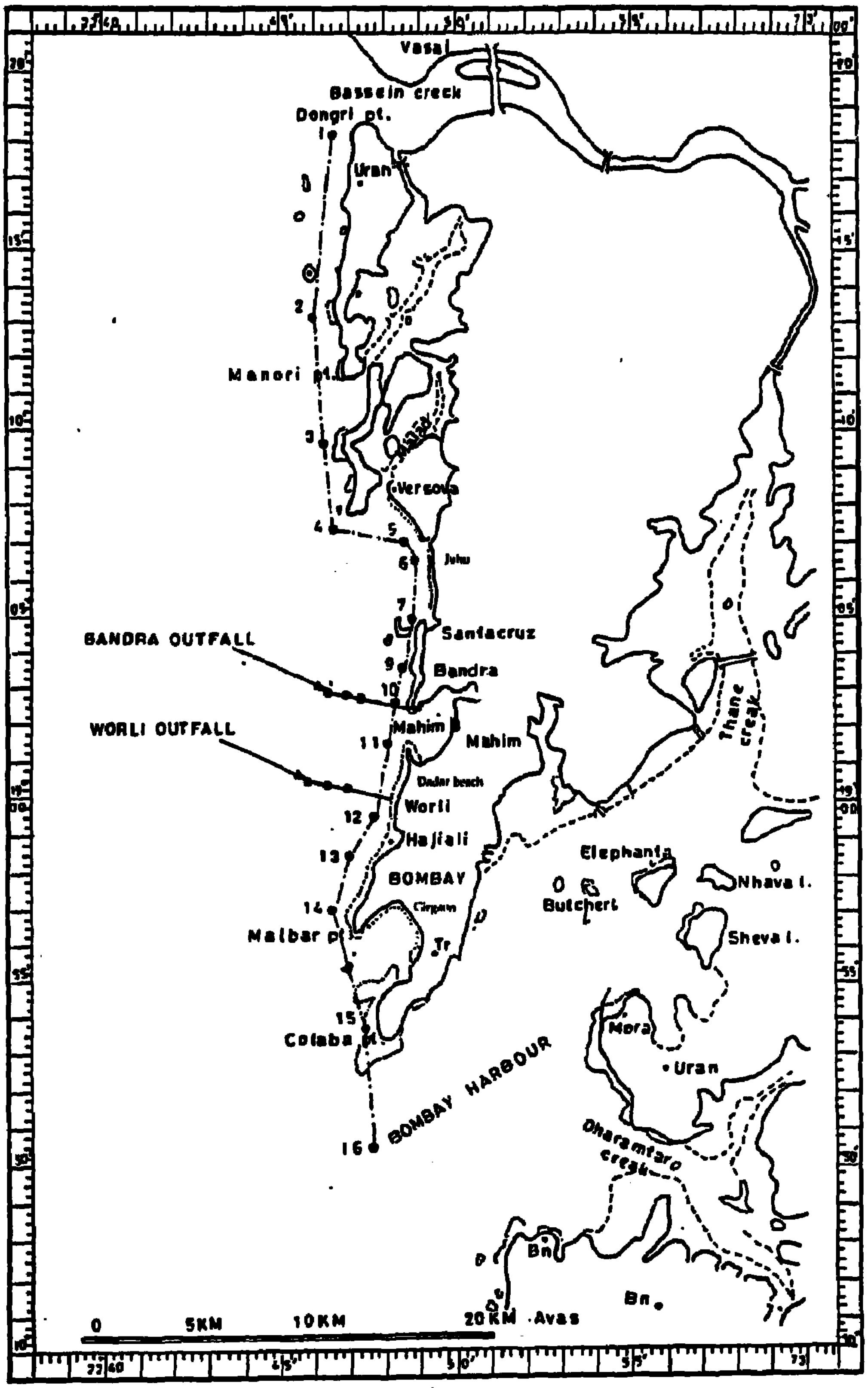
Regardless of the wastewater treatment method, Bombay, being an island city, warrants discharge of the effluents either to Thana creek on the east coast and/or to the Arabian sea on the west coast. In the late seventies, M/s Metcalf & Eddy carried out detailed hydrodynamic and water quality studies in Thana creek and in Arabian sea to examine the impact of such discharges on water quality. These studies indicated the feasibility of discharging the primary treated effluents into the sea through long marine outfalls and secondary treated effluents directly into the creeks. The recommendations of M/s Metcalf & Eddy study culminated in the formulation of Development Plan III of the Bombay Sewage Disposal Project. It comprised construction of primary treatment facilities followed by marine outfalls at Colaba, Worli and Bandra; and four aerated lagoons at Bhandup, Ghatkopar, Malad, and Versova to provide secondary treatment prior to disposal into Malad and Thana creeks (Figure 1.0). The Municipal Corporation of Greater Bombay (MCGB) was to undertake the implementation of these works through a series of large scale co-ordinated pollution abatement programmes.

Before implementing the above measures, MCGB desired to ascertain the environmental impacts of construction and operation of the proposed facilities in keeping with the World Bank policy and procedure for the environmental assessment of Bank lending operations. In September 1991, MCGB retained NEERI to undertake the environmental assessment studies for all wastewater disposal and treatment facilities envisaged under Bombay Sewage Disposal Project. The study also meets the requirements of State of Maharashtra and Government of India for environmental clearance of developmental projects.

1.1 OBJECTIVES

Disposal of untreated/partially treated municipal wastewater could have a variety of impacts on the receiving marine environment. The most prominent of these are the deterioration in bacteriological quality of water, probable build up of nutrients in sea water giving rise to algal blooms under adverse meteorological conditions, and accumulation of metals and trace organics in sediments and benthos through the process of biomagnification. Construction of marine outfalls could also adversely affect the interests of

Figure 1.0 : COASTLINE OF BOMBAY AND OUTFALL ALIGNMENT



fishing communities by reduced fish catch due to increased turbidity, vibrations and restricted access to the fishing region. Several properly planned coastal sewage disposal systems, however, have been instrumental in significant improvements in coastal water quality and beach aesthetics at many parts of the world.

The study, therefore, aims at identification of major environmental impacts of implementation of the planned facilities and delineates environmental management plan to minimise the adverse impacts and to enhance the beneficial impacts.

As the nature and necessary mitigatory measures for majority of impacts, associated with construction and operation of marine outfalls, are significantly different from those of the aerated lagoons, the scope of present report is confined to marine outfalls. The major components of the study are :

* Assessment of existing coastal water quality around Bombay for prediction of impacts of discharges from Worli and Bandra marine outfalls
* Assessment of impacts due to construction of marine outfalls on air, water and socioeconomic components of environment
* Study of wastewater dispersion characteristics in the vicinity of Colaba outfall to evolve basis for developing impact scenarios for Worli and Bandra outfalls
* Assessment of existing near shore water quality at Juhu, Shivaji Park, Worli and Chowpatty for different seasons
* Identification and calibration of mathematical model for initial dilution; dispersion and dieoff of coliforms for relevant coastal regions by laboratory and field investigations
* Prediction of total coliform population at the reference line * for worst case conditions for monsoon and non-monsoon period
* Identification of measures for compliance of water quality standards in the coastal waters by evaluating options of wastewater treatment and outfall length combinations
* Assessment of adverse impacts on aquatic flora and fauna and fishing communities due to operation of outfalls and delineation of mitigatory measures

(*) The water quality standards for protection of best designated use of bathing and recreation in the coastal regions against outfall discharges apply at 1 kilometer seaward distance from the coastline (low water line). This distance is referred as 'reference line' in this report.

1.2 PROJECT PLANNING AND REPORTING SCHEDULE

The project work involved study of coastal and creek regions with different hydrodynamic and water quality characteristics and covered diverse environmental issues. A Preliminary Assessment Report addressing the issues and approaches on the subject was, therefore, first submitted to have a clear idea of future work while delineating environmental management plan for different regions and project implementation phases.

As the assessment of environmental impacts for regions of different hydrodynamic characteristics and water quality response requires separate studies, it was considered appropriate that the project work and reporting be divided into separate segments. The first segment addresses itself to the task of delineation of environmental management plan for marine outfalls in the form of identification of outfalls' lengths to meet coastal bacteriological standards. It was agreed that marine outfall study should be completed by December, 1992.

It was anticipated that marine outfalls and aerated lagoons discharging effluents into Malad creek may have a probable cumulative effect on water quality. The studies on aerated lagoons, therefore, were also divided into two phases. The study related to Malad creek were assigned higher priority and were decided to be undertaken prior to Thana creek studies.

1.3 SALIENT FEATURES OF THE PRELIMINARY ASSESSMENT REPORT

As the study covered diverse environmental issues, it was decided that the approach for conducting the work be first delineated and agreed upon. To this end, a report entitled 'Environmental Management Plan for Bombay Sewage Disposal Project-Issues and Approach' (Preliminary Assessment Report) was submitted. The report presented an overview of Bombay Sewage Disposal Project, highlighted the environmental issues associated with project implementation and described the approach to resolve them.

The report provided a description of the major events related to Bombay Sewage Disposal Project chronologically and methodology for studying the issues relating to the construction and operation of the facilities under the first phase of Development Plan III. The issues discussed in the report covered water quality aspects, socioeconomic aspects, solid waste disposal, air quality impacts, odour and aerosol spread and specific construction phase impacts. The report also presented a critical review of the available environmental quality and related data, the likely environmental benefits and adverse impacts of the project.

Based on the general experience on the impacts of marine outfalls on coastal water quality and a qualitative assessment of probable impacts at Bombay, it was envisaged that implementation of the project shall contribute towards an all round improvement of water quality in coastal and creek regions around Bombay. Significant positive change in water quality constituents such as microbial contamination, DO, BOD, and nutrients balance was expected.

1.4 ORGANISATION OF THE REPORT

This report addresses issues pertaining to the impacts of construction and operation phase activities of proposed marine outfalls. The report comprises eight chapters which are briefly described below.

Chapter II of the report provides the project setting with brief description on city of Bombay with respect to its growth, geography, climatology, demography and environment. The chapter also summarizes the major environmental problems which need be earnestly addressed for betterment of quality of life of large sections of Bombay population.

Chapter III presents history of 'Bombay Sewage Disposal Project' and the present status of project implementation.

Chapter IV highlights the salient features of marine outfall and its repercussions on the environment and the design features of proposed outfalls.

Chapter V describes the assessment of existing status of the coastal environment, construction sites and neighbouring areas and discusses the socioeconomic implications of the project.

Chapter VI provides an overview of methodology used for prediction of initial dilution and secondary dispersion processes and describes the laboratory and insitu experiments conducted for model calibration.

Chapter VII highlights the details of environmental impact predictions for different management options.

Chapter VIII is the concluding chapter of the report. It details the environmental management plan for construction and operation phases of the project and provides salient features of future monitoring programme in the project area.

Chapter 2
PROJECT SETTING

2.1 PREAMBLE

A small cluster of islands burgeoning into a megapolis sounds incredible. However, this is the story of the growth of Bombay, within a span of about ten decades. Bombay has witnessed unprecedented industrial and commercial growth in this period and has emerged as the industrial capital of India. The industrial growth of the city has accompanied an equally phenomenal rise in population. The infrastructural development, however, could not keep pace with the growing population. This has led to shortage of water supply, lack of proper sanitation, proliferation of slums and inadequate transportation etc.

Urbanisation and industrialisation has also given rise to problems of waste management. Disposal of untreated wastewater into the coastal regions has led to deterioration of water quality in the adjoining areas and poor beach aesthetics. In order to curb the increasing environmental impairment, civic authorities have planned large scale waste management schemes in the city. Construction of marine outfalls to discharge the wastewater deep into sea and thus rationally utilise the assimilative capacity of these regions, is one of such schemes.

As environmentally sound outfall design entails considerations of local coastal environment, socio-economic and other infrastructural conditions, this chapter describes Bombay city, its geological and demographical characteristics and relevant environmental setting.

2.2 BOMBAY: THE CITY, ITS GENESIS AND GROWTH

Bombay, situated at 19°N latitude and 72.8°E longitude was originally a cluster of seven islands of Colaba, Fort, Byculla, Parel, Worli, Matunga and Mahim. Now Greater Bombay is extended upto Mulund and Dahisar. It is no more an island but a sort of peninsula. Its early inhabitants were KOLIS or fishermen. Bombay was a part of the Mauryan Empire (273 -232 BC). It was under the Silara Kings (810 AD – 1260 AD). On Dec. 23, 1534, Bombay was ceded to D Joans III, King of Portugal by Sultan Bahadurshah.

In 1549, the islands of Bombay were handed over in perpetuity to Dr. Pracia da Orfa. In 1625, an Anglo Dutch fleet captured Bombay fort by a surprise attack. They looted the island and left. On June 23, 1661 King Charles II of England married Princess Catherine Le Breganza of Portugal and Island of Bombay was given in dowry to King Charles II. Thus, Bombay went to the British by an alliance of marriage. In 1668, Bombay was handed over to East India Company by a Royal Charter. Sir George Oxender was the first Governor of Bombay.

Decades of development and reclamation resulted in the expansion of the city area to 70.2 sq.km in 1950, to which the area of Bombay Suburban District was added in 1951, bringing a total area of 235 sq. km under Greater Bombay . In 1957, more villages were added and the area increased to 466.3 sq.km.

2.3 GEOGRAPHY

Greater Bombay comprises of the islands of Bombay, Trombay and major parts of Salsette. In the north, the Salsette island is separated from the main land by Bassein Creek on the West, and by Thane creek on the East. The Bandra Creek, on the South of Salsette island separates it from the island of Bombay, while the western margin is further indented by Manori and Malad Creeks (Figure 1.0). The island is bounded on West and South sides by Arabian Sea and has a natural deep water harbour protected by the island of Bombay on the west coast and the main land of Konkan on the east. Bombay is the largest port along the west coast of India.

City of Bombay, on the southern side of Mahim Creek is highly overcrowded with unplanned growth. The suburban development, on the northern side is relatively better planned and is aligned to the two railways, the western and the central, dividing this area into western and eastern suburbs. Suburbs on Central railway comprise the main industrial belt of Bombay. The important industries include paints and varnishes, petrochemicals, pharmaceuticals, miscellaneous chemical products manufacturing, textile manufacturing, machinery and electrical appliances etc.

2.4 REGIONAL GEOLOGY AND STRUCTURE

The regional geological setting of western India and in particular of Bombay, may be termed Deccan Trap as described in both Geology of India chapter XVI pp 275-286 and in Geology of India and Burma chapter XV pp 405-421. The basaltic rocks extend over an area of some 500,000 square kilometers and the thickness of the Deccan Trap may be as much as 2,000 to 3,000 m along the present western margins, where the rocks dip 5-15 degrees to the west; the only sea where the rocks are not effectively horizontal.

The Traps are divided into 3 sub-units; Lower, Middle and Upper Traps. The Bombay area (Upper Traps), is noted for its inter-trappean sedimentary beds, lava flows and ash deposits.

The basaltic rocks have been erupted from vents and along fissures. The individual flows vary between 10 and 30 m thick, although composite flows of a number of smaller units, which are difficult to differentiate can give rise to apparently thicker flow sequences. The lavas can, and often do, show sedimentary -'coercing-downwards' like differentiation within the flows, occasionally giving rise to brecciated deposits. Two major flow formation mechanisms (each of which can be subdivided into two types) are seen although breccias, tuffs and other variations due to minor changes in the magma mineralogy are also noted.

2.5 CLIMATOLOGY

The climate of Bombay is fairly equable with average annual maximum and minimum temperature of 31.4°C and 22.9°C respectively and the average annual maximum and minimum Relative Humidity of 95.7% and 34.0% respectively. The average annual rainfall is around 2000mm occurring mostly during July to September. Strong land and sea breeze effect is observed, particularly during monsoon. Predominant wind directions during monsoon are south-west and west.

2.6 DEMOGRAPHY

In a little over a century, the population of Bombay has almost increased by hundred folds to about 10 million. The rise in population has been caused by large scale migration from various parts of the country on account of better employment opportunities in Bombay. The most commonly spoken languages are Hindi and Marathi. The city of Bombay is divided into 22 wards. The wardwise population for the years has been given in Table 2.1.

Inadequate housing has forced a large number of people in Bombay to reside in slums. According to 1981 census, more than 30% of Bombay's population lived in slum areas. Marine produce was the main source of income for inhabitants of Bombay before it developed into an industrial centre. Though at one time fishing was an important activity, as Bombay grew in size and population the proportion of people involved in fishing has become insignificant. Fishing communities are now confined to a few coastal areas viz., Colaba, Mahim, Trombay, Versova and Worli.

2.7 ENVIRONMENTAL SETTING

Bombay is endowed with a natural harbour, beaches and hill ranges, lakes and river. It was estimated in 1959 that the area of mangrove forests in Bombay and adjacent coastal districts is about 24,870 ha. The revised estimates indicate that the same is around 20,000 ha in 1975.

There are two major forest areas in Bombay. It has few good national parks and a small bird sanctuary that has been preserved. Vegetation cover in Bombay is not very good, however, suburban areas are much greener than the main area of Bombay city.

The mangrove swamps of Bombay are worst affected by human interferences. The principal causes are increasing population pressures and large scale reclamation of mangrove swamp areas for housing, indiscriminate cutting of plants and possibly excessive sewage discharges.

Table 2.1

Comparative Statement of Population Projection made by Various Agencies

Ward	1981 Census	2005 Metcalf & Eddy	1991 Binnie & Partners	2001 BMRDA	2001 Revised Development Plan
A	1,89,367		2,14,000		2,27,616
B	1,46,049	A to E	2,00,000		1,75,122
C	2,48,536	16,35,000	3,17,000		3,12,455
Total	5,83,951	16,35,000	7,31,000	7,58,707	7,15,193
D	4,44,666		6,69,000		5,31,084
E	4,54,490		5,53,000		4,62,876
F	7,93,981	10,36,000	8,25,000		8,46,320
G	9,81,028	8,55,000	10,07,000		8,65,088
Total	26,74,165	18,91,000	28,54,000	26,59,671	27,05,368
Grand Total for City	32,58,117	35,26,000	35,85,000	34,18,378	34,20,561
H	7,24,644	10,38,000	9,97,000		8,11,667
K	9,23,354	11,24,000	11,02,000		13,17,892
Total	16,47,998	21,62,000	20,99,000	20,06,654	21,29,559
L	4,33,571	5,64,000	4,22,000		4,10,068
M	5,67,625	6,42,000	5,60,000		5,13,135
N	8,73,323	9,10,000	8,25,000		10,83,895
Total	18,74,510	21,16,000	18,07,000	19,84,192	20,07,098
P	6,63,246	7,60,000	8,93,000		8,80,033
R	5,61,338	4,85,000	6,56,000		11,11,333
Total	12,24,584	12,45,000	15,49,000	14,79,340	19,91,366
T	2,22,114	4,13,000	3,00,000	3,02,165	3,23,943
Total Population	82,27,332	94,62,000	93,40,000	91,90,729	98,72,527

2.8 MAJOR ENVIRONMENTAL CONCERNS

The environmental problems in Bombay have been caused due to high population pressure and intensive industrial and commercial activities within a small physical area. Discharge of large quantum of untreated wastewater into the surrounding coastal regions, formation of pockets of acute air pollution due to industrial and vehicular emissions, inadequate disposal of solid wastes, congested roads and overcrowded trains, noise pollution, encroachment of forest area and open spaces and aesthetic impairment are some of the consequences of Bombay's phenomenal growth. The solution of these problems entails an integrated and well coordinated effort considering the problem as a whole. The wastewater management plan undertaken by Municipal Corporation in the form of Bombay Sewage Disposal Project is an important and positive step towards restoration of environmental quality in and around Bombay.

Chapter 3

BOMBAY SEWAGE DISPOSAL PROJECT

3.1 HISTORY OF THE PROJECT

Wastewater facilities within the city of Bombay, date back to the 1860's following the inauguration of the Vihar Lake scheme to provide Bombay with the first piped water supply. Following a Government Commission report in 1872, the Worli outfall, discharging wastewater to the Arabian Sea, was completed in 1880. Lack of funds, however, prevented the construction of the outfall as initially proposed to discharge below the low water level.

Wastewater facilities within the city continued to expand, and by 1900 all wastewater was directed to Love Grove from where it was pumped to sea through the Worli outfall. Problems of pollution in this area had started to become evident even at this early date.

By 1905,the basis of the present wastewater collection, treatment and disposal system within the city, had been established. Subsequent demands were met by the duplication of sewers, the provision of overflows to relieve surcharging in developed areas, the addition of new sewers in developing areas, the construction of additional facilities at Love Grove, and the construction of new treatment facilities at Banganga, Dharavi and Dadar.

Following the second World War, the rapid increase in population of the city rendered many of the wastewater facilities completely inadequate. To correct this situation extensive relief works were sanctioned in 1948 under the Relief Sewerage Scheme. Unfortunately, because of the length of time taken to complete these works, and because population forecasts prepared in 1948 proved to be far too low, the relief works did little to alleviate the problems.

In 1950, the Municipal Corporation boundary was extended to include what are now Wards H,K,L,M,N, and part of P Ward. The boundary was further extended in 1957 to its present position. Wastewater facilities within these suburbs and extended suburbs were very limited during that period.

A High Level Committee of Experts (appointed by the Municipal Corporation) to advise on water supplies and wastewater facilities for the Greater Bombay area, submitted its report in 1963. This report made recommendations for expansion and upgrading of the wastewater facilities within the city and the suburbs to meet the demands of wastewater flows expected from population projected for 1981.

Although some minor improvements were carried out; the collection, treatment, and disposal facilities continued to be completely inadequate to deal with the increasing quantities of wastewater.

3.2 DEVELOPMENT PLAN I

In May 1970, M/s Binnie & Partners (India) Ltd. were retained to advise on water and wastewater problems in the Greater Bombay area. Their study of the wastewater problems culminated in the preparation of Development Plan I. This plan set out a programme for expansion of existing facilities to meet the demands of the projected population in 1991. The plan recommended disposal of screened wastewater from the entire Greater Bombay area through two marine outfalls at Worli and Bandra.

3.3 DEVELOPMENT PLAN II

On instructions of the Deputy Municipal Commissioner (Special Engineering), an alternate plan for the treatment and disposal of wastewater from the Greater Bombay area as per the projection for 1991 was prepared. This plan was referred to as Development Plan II.

Development Plan II recommended the disposal of screened wastewater from Malabar, Worli, and Mahim Drainage Zones through marine outfalls at Worli and Bandra. Wastewater flow from Chembur Drainage Zone was planned to be treated in plants at Bhandup and Chembur prior to discharge to Thana Creek, and the flow from Marve Zone at a treatment plant at Marve followed by discharge into Malad Creek. In this plan the Dadar treatment plant was to be retained and expanded to meet the needs of Dadar. Sludges from all treatment plants were planned to be discharged to the Arabian Sea through the marine outfalls.

3.4 REVIEW OF DEVELOPMENT PLAN II

The Municipal Corporation proceeded with some of the sewerage proposals contained in Development Plan II, and the detailed design of eight pumping stations and feasibility studies of eleven more pumping stations. However, no work was carried out, on the treatment and disposal aspects of the plan.

Before proceeding with design and construction of facilities to augment the treatment and disposal of wastewater, the Municipal Corporation, in consultation with the International Development Association, decided on a fresh review of the recommendations contained in Development Plan II. To this end the services of M/s Metcalf & Eddy Inc. of Boston, U.S.A. and M/s Environmental Engineering Consultants of Bombay were retained with the view to solve the immediate and mid-term wastewater problems of Bombay.

The prime objectives of the review were :

- To produce a wastewater treatment and disposal plan for Bombay (Development Plan III) for the period through 2005 that would achieve and maintain satisfactory levels of public health and environmental quality

- Determination of the wastewater assimilation capacities of Malad and Thana Creeks and coastal waters around Bombay for their optimal utilization for disposal of municipal wastewater

- To prepare feasibility studies, and preliminary designs and cost estimates for a first-stage programme catering to the wastewater flows for 1981

- To outline further environmental or related studies required for the development of a long-range environmental quality improvement programme

M/s Metcalf and Eddy submitted an Interim Report in 1977 setting out their proposed solution to the problems of treatment and disposal of wastewater generated in the Greater Bombay Area. This proposed solution was subsequently revised in consultation with MCGB engineers and became the basis of Development Plan III.

3.5 DEVELOPMENT PLAN III

Under the Development Plan III, the design period for the wastewater management facilities was extended to the year 2005. Under the scheme, it was envisaged that the sewage generated in the municipal boundaries of city of Bombay shall be treated and disposed into the coastal and creek regions through seven different works.

The drainage zones envisaged in the earlier plan were reorganized to form seven service areas. Provision for the treatment/disposal of entire wastewater generated in an area, was made at the works within that area itself. The physical boundaries of the service areas and location of the treatment/disposal works designated for each of those are presented in Figure 3.1. The salient features of these works are presented in Table 3.1 and summarized below.

Colaba Service Area

Disposal of 41.1 mld by the year 2005 into the Harbour, after 1 hour sedimentation at an expanded and upgraded Colaba Treatment Plant.

Figure 3.1 : Drainage zones and treatment/ disposal schemes

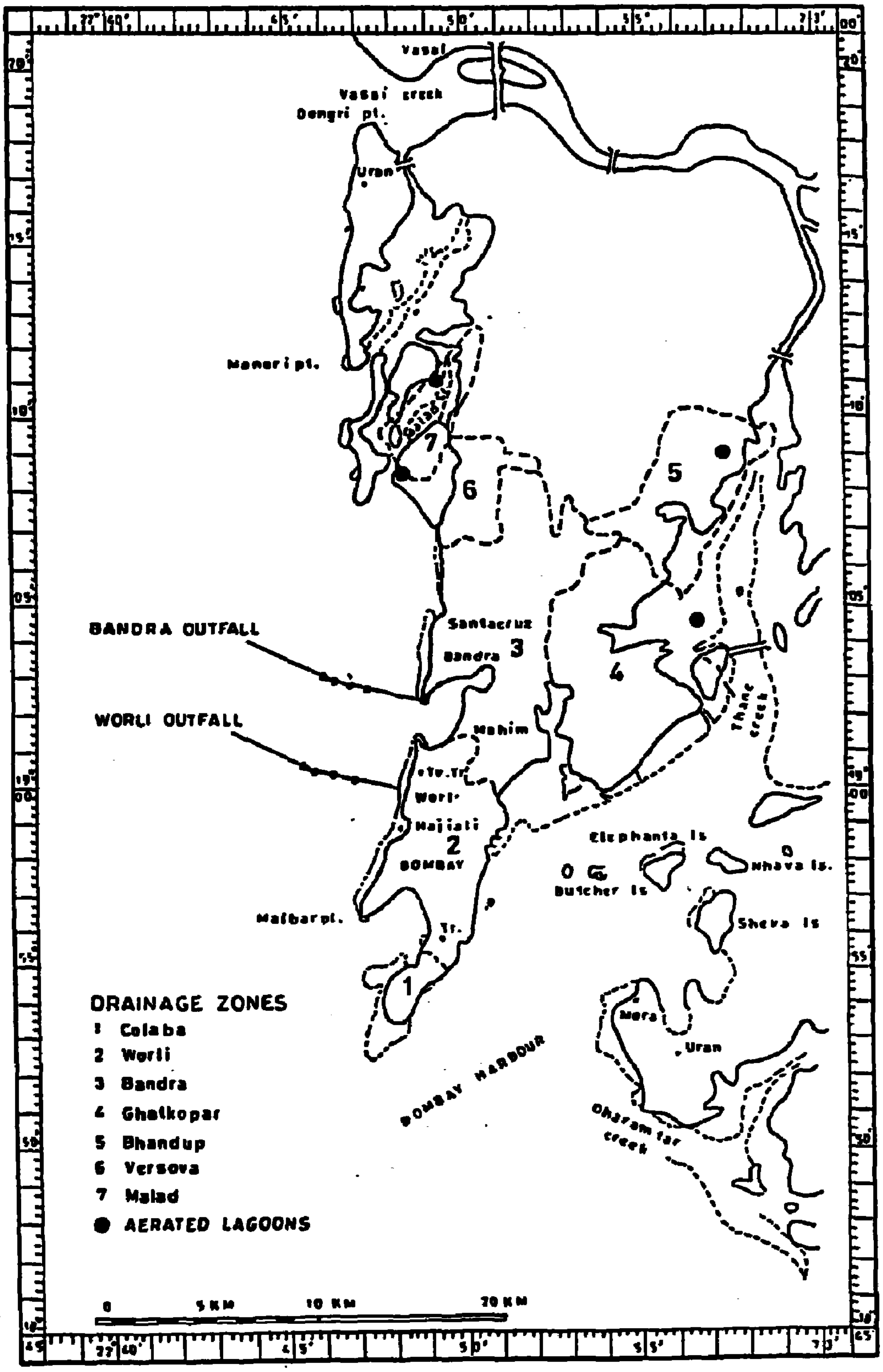


Table 3.1

Wastewater Treatment/ Disposal Facilities
Present Status

Sr. No.	Service Area	Facility	Design Flow (mld)	Present Status
1.	Colaba	Marine outfall	44.40	1.2 km length facility in operation since 1988
2.	Lovegrove	Marine outfall	760	498 m outfall operational since 1990
3.	Ghatkopar	Aerated lagoon	384.71	in planning stage
4.	Bhandup	Aerated lagoon	177.48	in planning stage
5.	Bandra	Marine outfall	796.0	200 m outfall not operational
6.	Versova	Aerated lagoon	178.15	under construction
7.	Malad	Aerated lagoon	233.49	under construction

Love Grove Service Area

The existing treatment plant at Dadar to be retained as a training and research establishment. Provision for expansion and upgradation of facilities to provide secondary treatment for a flow of 22.5 mld, in year 2005.

Wastewater generated within the remainder of Malabar Zone and all of Worli Zone to be conveyed to the Love Grove site for treatment and disposal. Recommended facilities for the design flow in 2005 of 756 mld to comprise screening, grit removal, one-hour sedimentation and chlorination before disposal to the Arabian Sea through a marine outfall. Sludge processing by gravity thickening and vacuum filtration before disposal to landfill sites or application to agricultural land. Screenings and grit from preliminary treatment facilities to be disposed off through landfill.

Bandra Service Area

Disposal of wastewater from the Mahim Zone to the Arabian Sea through an outfall. The design flow of 851 mld to be subjected to screening, grit removal, one-hour sedimentation and chlorination before disposal to the Arabian sea through a marine outfall and diffuser. Processed sludge after gravity thickening and vacuum filtration for landfill or agricultural application. Disposal of screening and grit from preliminary facilities through landfill.

Ghatkopar Service Area

Disposal of wastewater from South Chembur Zone, to the tune of 386 mld in 2005 to Thana Creek after treatment in aerated lagoons at Ghatkopar. Pretreatment to consist of screening and degritting, with provision for disposal of screenings and grit to a landfill. Removal of stabilized sludge from the lagoons required at approximately ten-year intervals. The sludge to be used for land application or landfilling.

Bhandup Service Area

Disposal of wastewater from North Chembur Zone, to the tune of 176 mld in 2005 to Thana Creek after treatment in aerated lagoons at Bhandup. Pretreatment to consist of screening and degritting, with provision for disposal of screenings and grit to a landfill. Removal of stabilized sludge from the lagoons required approximately at ten-year intervals. The sludge to be used for land application or landfilling.

Malad Service Area

Disposal of wastewater from North Marve Zone to the tune of 233 mld in 2005 to Malad Creek after treatment in aerated lagoons situated at Malad. Pretreatment to consist of screening and degritting, with provision for disposal of screenings and grit to a landfill. Removal of stabilized sludge from the lagoons required approximately at ten-year intervals. The sludge to be used for land application and/or for landfilling.

Versova Service Area

Disposal of wastewater from South Marve Zone to the tune of 178 mld in 2005 to Malad Creek after biological treatment in aerated lagoon situated at Versova. Pretreatment to consist of screening and degritting, with provision for disposal of screenings and grit to a landfill. Removal of stabilized sludge from the lagoons required approximately at ten-year intervals. The sludge to be used for land application and/or for landfilling.

Concurrently with the studies by M/s Metcalf and Eddy, MCGB had also authorised Tata Consulting Engineers to investigate the feasibility for upgrading eleven existing pumping stations and to undertake preliminary engineering on eight new stations who submitted the reports on these proposed works in 1978. The service area wise description of these pumping stations is given in Table 3.2.

3.6 FIRST PHASE FACILITIES

In order to reduce initial capital requirements, the Municipal Corporation decided to implement Development Plan III in two phases. Phase I program which was targeted to be completed by 1984 included the following components in addition to upgrading and construction of pumping stations.

- **Colaba treatment works**

  Influent pumping station, screens, aerated grit chambers and 1.1 km long outfall for ultimate disposal in the Bombay Harbour. Design flow 44 mld average DWF.

- **Love Grove treatment works**

  Influent pumping station, screens, aerated grit chamber and a 3 km long outfall for disposal into the Arabian Sea. Design flow 760 mld average DWF.

- **Bandra treatment works**

  Influent pumping station, aerated grit chambers and a 3 km long outfall for disposal to Arabian Sea will be provided at Bandra. Design flow 796 mld average DWF.

  9.0 kms of tunnel to collect sewage from within the Mahim Zone and convey it to the Bandra influent pumping station.

Table 3.2

On Line Pumping Stations
Phase I

Sr. No.	Collection Area	Pumping Station	Ultimate Capacity (App) (mld)
New Pumping Stations			
1.	Colaba	Kitridge Road	22
		N.F. Road	22
2.	Lovegrove	Dadar	220
		Carrol Road	30
3.	Bandra	Kalina	32
		Saki Naka	160
Pumping Stations to be Uprated			
1.	Lovegrove	Jacob Circle	250
		Globe Mill Passage	145
		Tulsi Pipe	170
		Tank Bunder	16
2.	Bandra	Matunga	150
		Wadala	125
		Sion Koliwada	22
		Mahim	120

- **Versova treatment works**

  Influent pumping station, average DWF design flow 132 mld, and screens, aerated grit chambers and aerated lagoons, average DWF design flow 178 mld

  2.93 kms of force main to convey sewage from Pump Station to Aerated Lagoon site.

- **Malad treatment works**

  Influent pumping station (Average Dry weather design flow 280 mld) and screens, aerated grit chambers and aerated lagoons (Average Dry Weather design flow 234 mld)

  2.23 kms of force main to convey sewage from Pump Station to Aerated Lagoon site

- **Ghatkopar treatment Works**

  Influent pumping station, screens, aerated grit chambers and aerated lagoons will be provided at Ghatkopar. Design flow 385 mld average DWF

  2.4 kms of sewer tunnel to collect sewage from the south part of the Chembur Zone and convey it to the Ghatkopar influent pumping station

  0.95 kms of force main to convey sewage from Pump Station to Aerated Lagoon site

- **Bhandup treatment works**

  Influent pumping station, screens, aerated grit chambers and aerated lagoons will be provided at Bhandup. Design flow 178 mld average DWF

  1.15 kms of force main to convey sewage from Pump Station to Aerated Lagoon site

3.7 PRESENT STATUS

Due to techno-economic reasons and logistic constraints, the execution schedule of the first phase facilities has been considerably delayed. The present status of the progress on the planned disposal/treatment facilities has been summarized in Table 3.1.

Regarding the progress of work on the pumping stations, both Kitridge Road and N.F.Road new pumping stations have been commissioned in Colaba service area. In Love Grove service area all pumping stations as envisaged in phase I, except for Jacob Circle pumping station, have been commissioned.

In Bandra service area, among the new pumping stations, Kalina pumping station has been commissioned whereas Saki Naka pumping station is nearing completion. Among the four pumping stations to be upgraded in the area, the work is in different stages of progress and is likely to be completed by 1993 for Mahim and Wadala pumping stations, by 1994 for Sion Koliwada and Matunga pumping stations.

It was observed that the present wastewater flows in Worli and Bandra service areas were considerably less than the projected wastewater flows for the year 1992. Whereas the wastewater flows already reaching the pumping stations at Malad and Versova were considerably higher than the estimates.

In view of the discrepancies among the projected and observed wastewater flows in 1992, revised first order estimates of wastewater flows for year 2001 were provided by Binnie & Partners. The revised estimates for the year 2001 were used as for year 2005 since no schemes for water supply augmentation within this period are currently planned. The revised estimates for the years 1992 and 2005 along with the original estimates of M&E and percent change with respect to those have been presented in Table 3.3. All calculations in this report for assessment of environmental impacts and development of Environmental Management Plan for marine outfalls are based on the revised estimates for year 2005.

Table 3.3

Projected and revised estimates of average dry weather flows (MLD)

Drainage Zones	1992			2005		
	As per Metcalf and Eddy Projections	As calculated from water supply data from H.E's Dept.	Variation	As per Metcalf and Eddy Projections	As calculated from water supply data from H.E's Dept.	Variation
Colaba	37.60	31.78	-15.50	41.10	36.96	-10.07
Lovegrove	687.00	314.85	-54.20	756.90	511.21	-32.46
Bandra	619.00	492.12	-30.70	796.80	552.47	-30.66
Versova	96.59	115.00	19.06	131.30	164.02	24.92
Malad	203.45	193.27	-5.00	280.40	363.84	29.75
Ghatkopar	300.57	235.12	-21.77	386.10	320.59	-17.00
Bhandup	124.84	130.21	4.30	176.10	207.71	18.00
TOTAL	2,069.05	1,449.35		2,563.70	2,156.20	

Chapter 4
MARINE OUTFALLS

4.1 PREAMBLE

The increased urbanization in coastal towns has given rise to environmental problems entailing practical solutions incognizance to the local characteristics. In the coastal towns due to their geological setting and drainage properties, wastewater control through conventional treatment methods has not been a very attractive option. There has been a general tendency to use the available assimilative capacity of the coastal waters for wastewater elimination.

During the earlier times, wastewater management practices in coastal towns resulted in construction of number of short outfalls draining the wastewaters into the shallow portions of sea and creeks. These practices, due to the want of adequate environmental considerations, gave rise to adverse marine environmental conditions, frequently causing foul smelling dirty beaches and contaminated shellfish fields.

The overwhelming economic advantage associated with the use of coastal regions for the waste assimilation, however, always remained an important factor in the wastewater management. For instance, it has been estimated in UK that replacement of sea outfalls by primary and secondary plants would require almost thrice the operating costs per annum (Huntingdon and Rumsey,1987). The practice of using marine outfalls for wastewater disposal therefore continued. The increased awareness of environmental hazards caused by inadequate design of marine outfalls, however, inspired many attempts for enhancing their performance such as pretreatment, improved design of diffusers, and inclusion of hydrodynamic and assimilative processes while deciding the length of outfalls.

These considerations over the course of time brought significant changes in the design and operation of marine outfalls and present day outfalls invariably incorporate technological excellence in the areas of civil, hydraulic, environmental and oceanographic engineering.

4.2 SALIENT FEATURES OF MARINE OUTFALLS

Marine outfalls are essentially piped structures designed with basic objective of carrying the wastewater for higher dispersion into the coastal environment and thus ensuring its safe ultimate disposal. Other essential components of the outfall are the headworks for providing the necessary pumping head for the transport of wastewater and the diffuser section, the mechanism for providing rapid mixing of wastewater after its discharge into the sea. Following sections give a brief description of the essential components of a modern marine outfall.

4.2.1 HEADWORKS

The headworks provide the motive force for the disposal of wastewater against the hydraulic pressures generated through tidal and wave motion in the marine environment. The headworks generally comprise the facilities for functions like receiving sewage from sewage catchment, grit removal, removal or disintegration of sewage solids, provision of pumping station, and for offering primary or higher degree of treatment. The headworks may have some or all the above mentioned functions. A typical layout of modern outfall headworks is given in Figure 4.1.

4.2.2 OUTFALL SECTION

The prime structure in an ocean outfall system is the longitudinal section of the outfall itself and immediately follows the headworks. The outfall that transports wastewater from the land to its disposal point, usually a few thousands of meters from shore in water depths of about 5 to 100 meters, is either laid in a trench in the sea bed or tunneled through the subsea strata.

One of the major design elements of a marine outfall is the outfall profile. This profile, is to a large extent, determined by the method of construction of the outfall and has a strong influence on its hydraulic performance. The ideal profile for most situations commences with a drop shaft to below low tide level and then continues down a seaward slope until it breaks through the sea bed at the start of the diffuser section and discharges the water via short risers (Figure4.2). The advantages of such a profile are the following:

— the intertidal storage in the pipeline is low so the pipe does not fill with salt water on the rising tide;

— the pipeline is always full and not subject to repeatitive emptying and filling;

— salt water intrusion is limited to the seaward end of the pipe;

— there are no high points to accumulate sewage gas; and

— the high drop shaft provides plenty of head to flush out salt water and sediment.

In a tunnel outfall the profile is similar but usually slopes uphill to provide good drainage during construction (Figure4.2). The adverse gradient encourages intruding salt water to flow back to the drop shaft and provides an enormous reservoir for salt water storage. Flushing out the salt and sediment may hence require high velocity flows applied for long durations.

Figure 4.1 : Typical layout of modern outfall headworks

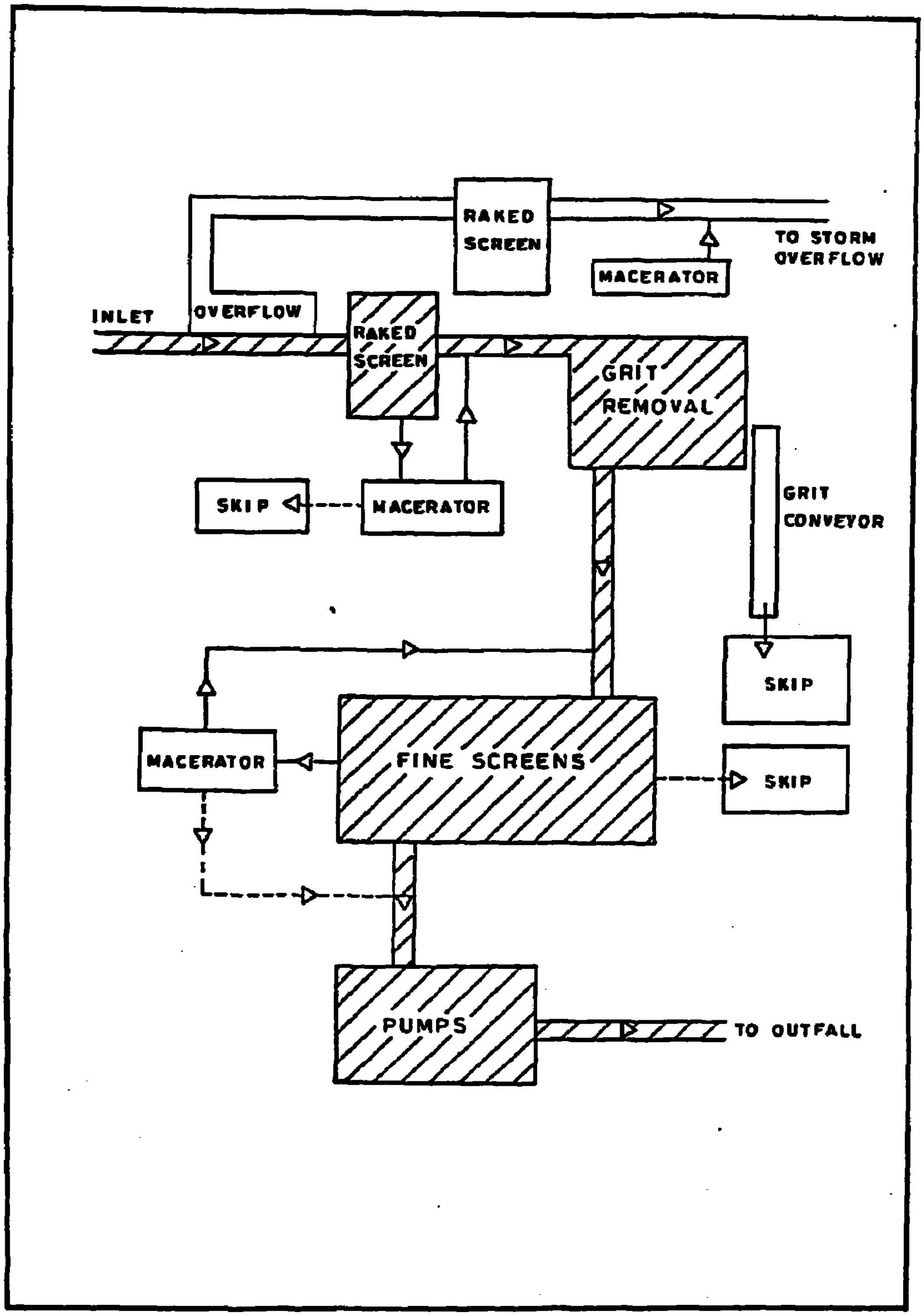
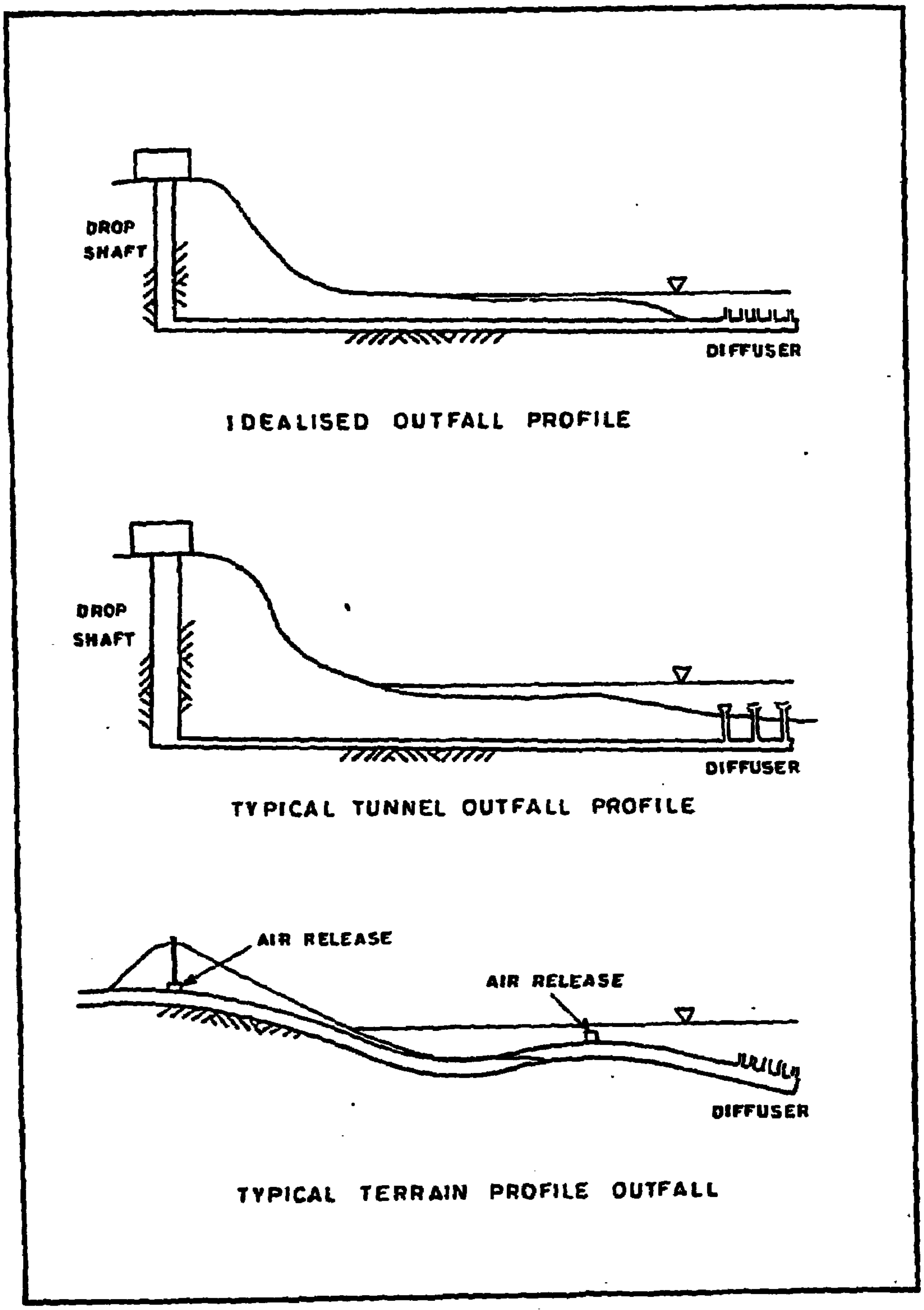


Figure 4.2 : Outfall longitudinal profile



Outfall laid to the profile of the existing terrain (Figure4.2) may experience problems with tidal flow reversal and gas pocket formation. Flow reversal may be dealt with by lowering the onshore section below low water level or by the use of non-return valves. Non-return valves increase the maintenance requirements. The development of gas pockets can be mitigated by control of the sewage septicity, the avoidance of high points in the profile and the use of air valves.

4.2.3 DIFFUSER SECTION

In order to provide better mixing of wastewater in a marine environment, the end section of a marine outfall is provided with a large number of ports or horizontal holes. This end portion of the outfall is known as diffuser section, generally comprising several hundred meters, which plays a crucial role in the dilution of the wastewater.

The main aims of diffuser design are to provide an even flow distribution at peak discharge, so that all the ports achieve a similar initial dilution and adequate secondary dispersion required to meet the environmental water quality standards; to minimise the head loss and to provide adequate flushing to remove sediment, slime and grease, to ensure achievement of long-term design objectives.

In practice, it may be very difficult to achieve these objectives due to wide flow variations, which must be accounted for, and limitations in available head. Under normal dry weather conditions the flow may exhibit significant diurnal variations. The variations become even more extreme where high future flows have been projected.

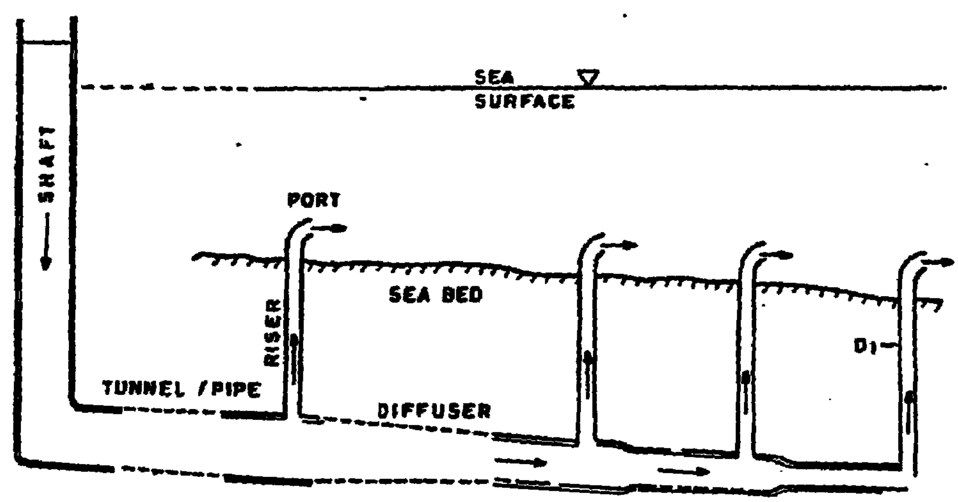
A diffuser designed to pass high flows with a limited head may experience periods of flow reversals at low flows. In the long term, low velocities lead to a build up of slime and sediment which increase the head required to drive the diffuser. The head is increased by the extra friction, the reduction of the pipe cross section and the possible intrusion of saline water due to transient flow and tidal effects. Saline intrusion may bring marine sediments into the diffuser so increasing the potential for blockage.

Modern practice has generally been to taper the diffuser pipe, as the flow reduces towards the seaward end due to port offtake flows. Tapers increase the velocity in the main pipe and assist sediment flushing. A typical tapered diffuser section is shown in Figure 4.3.

4.3 MECHANISM OF WASTEWATER ASSIMILATION

As has been stated earlier, marine disposal of wastewaters has been an attractive option in the coastal towns because of low operating cost of the outfalls to achieve similar degree of treatment or waste assimilation

Figure 4.3 : Typical layout of tapered outfall diffuser section



through the primary or biological treatment. This economic advantage of marine disposal over the treatment options is achieved by using the wastewater assimilative capacity of the coastal sea. The processes which contribute to the assimilation of wastewater, after its release into the marine environment, are those of initial dilution and secondary dispersion.

When the wastewater enters the marine environment from the diffuser, it is buoyant and tends to rise. This effluent, initially travelling horizontally after leaving the diffuser ports, gradually ascends on a more vertical path. The effluent mixes with the ambient sea water under the turbulence induced by the jet flow at the diffuser ports and ambient currents, and gets progressively more and more diluted as it rises towards the surface.

Once the mixed effluent reaches the sea surface or an intermediate equilibrium level, it tends to move with the prevailing currents or spread due to buoyancy effects or dispersion. The latter can be strongly influenced by the prevailing ocean currents which tend to carry the effluent cloud with them in a process known as advection. The spread of an effluent after the initial dilution stage is known as secondary dispersion. During the process of secondary dispersion the effluent also undergoes assimilation as a result of bio-chemical processes.

4.4 ENVIRONMENTAL REPERCUSSIONS

Marine outfalls may impinge on the aquatic environment while being constructed and when operational. The construction of marine outfalls itself is a matter of significant environmental concern and should be subjected to good care and safe and environmentally sound design practices. The offshore construction activities of an outfall can be disruptive to fishing interests. Impacts during construction phase take the form of noise, vibration, contamination (e.g. by oil, litter) and mechanical disturbance of leach and sub-tidal deposits. The latter may result in enhanced turbidity and changes in the profile and texture of the bed which have ecological consequences. Trench construction generally causes a greater impact, and more cause for complaint (from beach users, fishermen and boat users), than does tunnel construction.

Post operational impacts may be of a different nature and are dependent upon the nature of the effluent discharge, the performance of the outfall, and the characteristics of the receiving waters. The impacts are often potentially far more serious than those associated with the construction phase. Effluents comprising readily degradable or volatile substances are unlikely to have widespread or lasting effects if sufficiently diluted and dispersed.

More enduring and extensive impacts can arise from the discharge of depositing solids (which may accumulate following release), or of toxic persistent and bioaccumulable substances such as heavy metals or organohalogens. The disposal of recalcitrant pollutants is yet another potential hazard. It is necessary to control such discharges at source either through waste minimisation by adopting clean technology or by providing treatment for necessary detoxification procedures before their release into the sewer system. Thus, marine outfalls may be used to dispose a wide variety of waste materials, without causing damage to the marine environment, if careful pre-planning, clearly defined quality objectives and continuous long term assessment are undertaken.

An environmentally sound design and careful maintenance and operation of outfall works are thus, obligatory for safeguarding the environment. For instance, in the past, poor design considerations and lack of environmental concerns gave rise to a plethora of short outfalls along the shorelines in coastal towns. This resulted in the deterioration of beaches and near shore waters.

An illustrative example of beneficial impacts of long sea outfalls as against short outfalls is provided in a systematic study of marine outfalls in UK. Impact of four outfalls commissioned in 1971, 1981, 1984 and 1987, was monitored and compared with the impacts of earlier constructed short outfalls. The study revealed that stretches of beach and nearshore waters around long outfalls improved dramatically in quality, while locally unsatisfactory conditions persisted around the old, inadequate short outfalls. These observations strengthen the significance of a proper design approach of long sea outfall and its impact on the local environment.

Present day outfall designs, however, involve careful considerations towards mitigation of the adverse impacts due to wastewater discharges in the coastal environment. Several properly planned outfalls have significantly improved the coastal quality and beach aesthetics in many parts of the world.

4.5 ENVIRONMENTAL SAFEGUARDS

The wastewater discharge from marine outfalls could adversly affect all water uses in the coastal areas. The relevant environmental quality objectives for outfalls therefore call for considerations for protection of these uses and should include the following :

- Protection of marine aquatic life
- Safeguarding of recreational waters
- Avoidance of noticeable slicks and subsurface plumes
- Safeguarding of water quality for industrial use

Environmental safeguards for regulating the beneficial uses of receiving waters against industrial/municipal discharges are achieved through compliance with the environmental standards. For marine outfalls, initial dilution is one of the major factor which reduces the adverse environmental impacts of wastewater discharges. To avoid occurrence of adverse environmental conditions, a minimum initial dilution standard is prescribed in some countries. For example in US, achievement of a minimal initial dilution of 50, at least 50 percent of the times, is obligatory for acceptable operation of marine outfalls. In order to ensure safe bathing water quality at the beaches, more stringent microbiological, physico-chemical and aesthetic standards are used such as the EEC bacteriological standards (Table 4.1).

In India, Environment (Protection) Act, 1986 vests in Central Government, the powers to lay down standards for environment protection. Central and State Pollution Control Boards are responsible for compliance of these standards. The Boards, based on local conditions, have power to stipulate more stringent location specific standards.

For protection of coastal water quality, two standards apply in India. The first of these standards is in the form of receiving water quality and is based on best designated use of the water body such as for bathing, fishing or navigation. Details of these standards (IS:7967-1976) are provided in Table 4.2. The creek and coastal waters used for recreational purposes or fishing, accordingly, should always have BOD less than 5.0 mg/l, total coliforms not more than 1000/100 ml and Dissolved Oxygen more than 3.0 mg/l.

The second standard is in the form of effluent standard for discharges into marine coastal areas (Table 4.3). According to this standard, effluents with BOD and suspended solids of 100 mg/l each and ammoniacal nitrogen upto 50 mg/l can be discharged into the creeks.

No effluent standard, however, has been stipulated for coastal discharges through marine outfalls. In the absence of such standard, Maharashtra Pollution Control Board (MPCB) has given consent to MCGB for discharging treated/untreated sewage subject to compliance of receiving water quality standard for coastal waters. Since the outfall discharges on their movement towards the coast can pollute the beaches etc., it has been further stipulated that the receiving water standards shall apply at the reference line.

4.6 PROPOSED MARINE OUTFALLS AT BOMBAY

The service zones of Worli and Bandra contribute about 50 percent of the total wastewater generated in the municipal region of Bombay. Wastewater from these zones is proposed to be discharged into the coastal waters on the west coast of Bombay through two 3 km long marine outfalls. These

Table 4.1
EEC Bacteriological Standards for Bathing Waters*

Parameter	Guideline (% of Sample)	Limit (%)	Sampling Frequency
Total Coliforms/100 ml	500 (80)	10,000 (95)	Every 2 Weeks
Fecal Coliforms/100 ml	100 (80)	2,000 (95)	Every 2 Weeks
Fecal Streptococci/100 ml	100 (90)	—	Daily

* *Gunnerson (1988)*

Table 4.2 : Tolerance limits for water quality after receiving discharges (IS: 7967 - 1976)*

Sl. No. (1)	Characteristics (2)	Tolerance limits for Bathing, Recreation, Commercial Fish Culture and Salt Manufacture (3)
1.	Colour and odour	No noticeable colour or offensive odour
2.	Floating material	No visible floating matter of sewage or industrial waste origin
3.	Suspended solids	No visible suspended solids of sewage or industrial waste origin
4.	pH value	6.5 to 8.5
5.	Free ammonia (as N), mg/1, Max	1.2
6.	Phenolic compounds (as C_6H_5OH), mg/1, Max	0.1
7.	Dissolved oxygen, Min	40 percent saturation value or 3 mg/1 whichever is higher
8.	Biochemical oxygen demand (5 days at 20°C), mg/1, Max	5.0
9.	Coliform Bacteria, MPN index per 100 ml, Max	1,000

* Abridged

Table 4.3 : General standards for discharge of effluents

Sl. No.	Parameter	Standards Marine Coastal Areas
1.	Supsended solids, mg/1, Max	100
2.	pH value	5.5 to 9.0
3.	Temperature, °C, Max	45 at the point of discharge
4.	Oil and grease mg/1, Max	20
5.	Total residual chorine	1.0
6.	Ammoniacal nitrogen (as N), mg/1, Max	50
7.	Total Kjeldahl nitrogen (as N0, mg/1, Max	100
8.	Free ammonia as (NH_3), mg/1, Max	5.0
9.	Biochemical oxygen demand (5 days at 20°C), Max	100
10.	Chemical oxygen demand, mg/1, Max	250

* Abridged

outfalls are proposed to be situated at Worli and Bandra with an inclination of 290°N. The outfall alignment with the coast is shown in Figure 1.0.

4.6.1 PROJECT HISTORY

The Worli and Bandra sewage outfalls were designed to be constructed of 3.5m diameter reinforced concrete spigot and socket pipes laid in a sea bed trench. The outfalls were to be laid 3 km out to sea and were to discharge screened sewage at up to 24 m^3/s at Worli and $20m^3/s$ at Bandra. The discharge would not have met local or international environmental standards so primary treatment and chlorination were to be added later. Recently, serious reservations have been expressed about the potential dangers of discharging chlorinated sewage to the sea and of transport and storage of chlorine within the city. Also effective chlorination of primary treated sewage would have entailed large inputs of chlorine making the whole process impractical due to high cost.

Construction of the outfalls started in 1984 and outfalls were laid in the sea upto 498m at Worli and 209m at Bandra. The contractor stopped work in 1987 claiming that outfalls could not be constructed as designed. Many pipes had been cast but not laid and trench excavation had been undertaken. The contractor offered to complete the work using a different design with the pre-stressed concrete pipes in 34m lengths and supported in a trench on large diameter bored piles.

An appraisal of the design was carried out by Binnie & Partners following cessation of construction. A review was made of the original reinforced concrete pipe design and the reasons why the contractor was unable to complete the contract. It was concluded that the outfalls could be constructed with reinforced concrete pipes provided the work was undertaken by a contractor who had experience of building this type of design and who mobilized the necessary plant for dredging trenches and casting, handling and jointing pipes.

In addition to reviewing the original design an appraisal was also made of the contractor's design. Binnie & Partners reported in April 1988 that, with some reservations, they were generally satisfied that the outfalls could be completed using the contractor's design. They concluded, however, that it was probable that an alternative design could be constructed at a much lower cost.

4.6.2 RECOMMENDATIONS OF BINNIE AND PARTNERS

Following the discussion of draft and supplementary reports of Binnie and

Partner's in March 1990 and further review of the options, it was recommended that :

a) Tender documents should be prepared for the two preferred outfall designs (RC pipe and tunnel)

b) Both outfall would need to be 7 to 8 km long to achieve international environmental standards without pretreatment of the sewage.

c) As funds are unlikely to be available at present to construct outfalls to this length, phasing could be adopted. Phase I for both outfalls should consist of 3 km long outfalls which could be extended later.

d) Land should be reserved at Bandra and Worli to allow for primary treatment at a later stage either as an alternative to extending the outfall or in addition to extension.

MCGB therefore, decided to accept Binnie & Partners recommendation and ordered that two revised designs, reinforced concrete pipes and tunnel should be developed. To yield information for the tunnel design some of the boreholes to be sunk as part of a detailed site information programme were deepened. The boreholes were sunk to a depth relevant to a tunnel extending 3 km into the sea.

A considerable number of 3.5 m internal diameter pipes had been manufactured under the previous contract. It was desirable to try and use these in the new works. Hence it was considered appropriate to investigate hydraulic designs and operational regimes that would allow the adoption of 3.5 m internal diameter conduits for both the tunnel and the pipe design*.

Following section describes the designs and criteria used in the development of the selected designs.

4.6.3 DESIGN OF OUTFALLS

The last 250 m seaward end of the outfall comprises the diffuser section. Sewage is discharge from risers which carry sewage from the tunnel to the sea bed. Each riser terminates in a discharge structure equipped with ten individual ports equally distributed around the periphery of the structure. The diameter of the main barrel reduces in steps to maintain adequate sediment transport capacity under the reduced flows. The velocities that are achieved in the main and reduced diameter barrel are sufficient during at least part of the daily cycle to ensure no permanent deposition of sediment. The riser discharge structures have been designed to reduce the risk of sea water intrusion once commissioning is complete.

* The environmental study was initiated in 1991 and covered both pipe and tunnel outfall options. At its completion, the environmental clearance for its implementation was obtained from Government of India for either option and tenders were invited for both options. After tender evaluation, option of tunnel outfalls has been selected.

4.6.4 ALIGNMENT

The tunnels have a curved alignment from shafts at the landward end and then follow a straight line, close to the alignment investigated, to diffuser location. The alignment of the main outfall portion thus is 290 degrees North (Figure 4.4). The vertical alignment of the tunnels is a steady upward gradient to seaward.

4.6.5 SEWAGE FLOWS

To prevent sedimentation in the tunnels the outfalls have been designed to allow the velocities to be developed as necessary for the transfer of sediment without siltation. This design can accommodate most of the wet weather flows expected in the year 2005. Under abnormal wet weather conditions storm overflow will come into operation but this will only occur during the monsoon season. Table 4.4. shows if the headworks which have already been built are modified the maximum carrying capacity of the outfalls can be increased.

The number and size of ports has been determined from considerations of the minimum outfalls flows in year 1997, the commissioning flows and a need to maintain the Densimetric Froude No. not less than 3.0 at the minimum flows. The design adopted comprises 10 ports per riser, varying from 210 to 375 mm diameter which is consider to be large enough to allow grease balls to escape freely which otherwise could block discharge ports.

The salient design parameters for Worli and Bandra outfalls are presented in Table 4.5.

4.7 CONSTRUCTION

4.7.1 OUTFALL OPTIONS

In order to assess the most appropriate method for completing the outfalls, careful consideration has been given to five methods of constructing the outfalls :

i reinforced concrete pipe construction (similar to the previous design);

ii piled outfall using prestressed concrete pipes;

Table 4.4

Design Sewage flows as per Metcalf and Eddy Projections*

	Design flows in year 2005			
	Worli		Bandra	
	(mld)	(m^3/ s)	(mld)	(m^3/ s)
Minimum flow	378.5	4.4	398.4	4.6
Average dry weather flow	756.9	8.8	796.8	9.2
Peak dry weather flow	1456.1	16.9	1506.6	17.4
Peak wet weather flows	2075.1	24.0	1763.8	22.0

* *Metcalf and Eddy Report (1984).*

Fig 4.4 : **Outfalls alignment at Bandra and Worli**

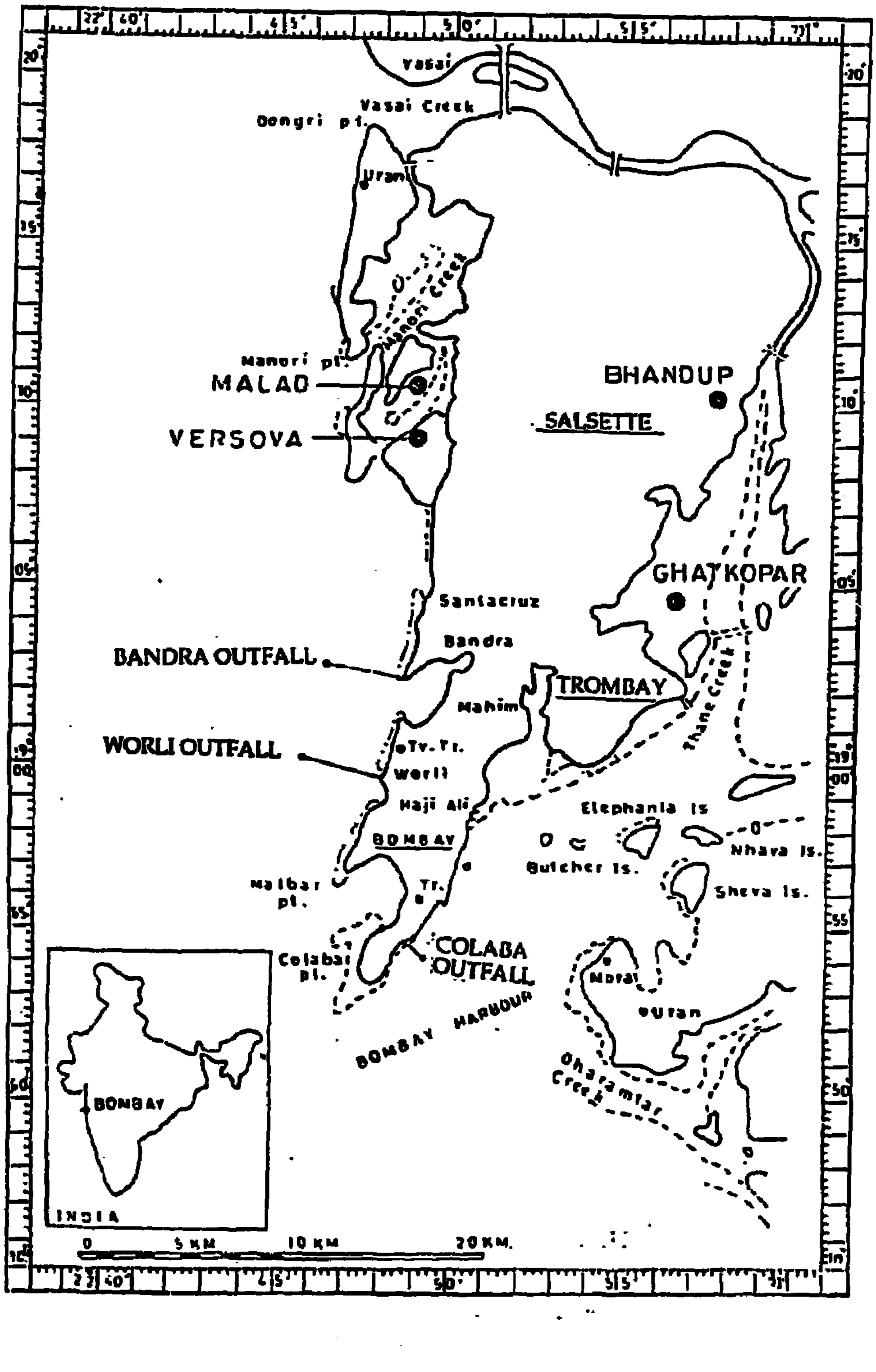


Table 4.5

Design specifications of proposed outfalls

			Worli	Bandra
			Tunnel	Tunnel
(a)	Length of outfall	km	3.44	3.79
(b)	Diameter	m	3.5	3.5
(c)	Length of diffuser	m	250	250
(d)	Loss coeff at entry to outfall	m	0.5	0.5
(e)	Centerline depth of diffuser to MSL	m	17.48	46.38
(f)	Diffuser bed slope		0	0
(g)	No. of risers		10	10
(h)	Riser head		10 ports per riser	10 ports per riser
(i)	Riser diameter	m	1.0	1.0
(j)	Water depth at Ch 3000 m from sea bed to MSL	m	10.0	8.0
(k)	Roughness k, low flow	m	0.006	0.006
	high flow	m	0.002	0.002
(l)	Loss coeff in riser bend and multiport	m	5.0	5.0
(m)	Effluent density	kg/m^3	1002	1002
(n)	Seawater density	kg/m^3	1024	1024
(o)	Ambient current, minimum	m/s	0.07	0.21
	average	m/s	0.31	0.40
	maximum	m/s	0.74	0.72
(p)	Discharge (year 2005)	m^3/s		
	Peak WWF		24.0	22.0
	Average DWF		16.9	17.4
	Minimum DWF		4.4	4.6
(q)	Discharge (75% of year 2005)	m^3/s		
	Peak WWF		18.0	15.3
	Peak DWF		12.67	13.05
	Average DMF		6.6	6.9
	Minimum DWF		3.3	3.45
(r)	Available design head at pumping station		7.12	6.78

* *Metcalf and Eddy Report (1984);*

iii bottom pulled steel pipes;

iv immersed tubes;

v tunnels

The RC pipe design would be similar to the original design and would, so far as possible, use the pipes already cast. However, it has been found necessary to lower the profile of the pipelines and to provide larger and greater quantities of rock armour in order to secure the outfalls against damage by large waves.

The piled outfall is the design proposed by the previous contractors.
For the bottom pulled steel pipe design it was assumed that three pipes of 2.3 m diameter would be laid; this being close to the largest size of pipe ever previously used for bottom pull construction. A greater number of smaller diameter pipes could be laid but such an arrangement would alter the hydraulic characteristics of the outfall and will be more expensive.

The immersed tube design was added to those originally proposed, as providing a design which would not require heavy rock armouring to give stability, and which would increase the number of contractors with the necessary experience to tender.

For the tunnel design, access shafts would be constructed close to the shore line and the tunnels would be bored through basalt, breccia and tuff. The depth of the tunnel would be sufficient to ensure that it would be in competent rock for its full length. The riser would be constructed by boring down from the sea bed to point adjacent to the tunnel and connecting to the tunnel by short adits.

The bottom pull and piled outfall design were not been recommended for technical and financial reasons. Acceptable designs recommended were RC pipes, immersed tubes and tunnels and the immersed tubes was subsequently discounted because of constraints, imposed by the site and local fishing activities on constructions.

4.7.2 TUNNEL OUTFALL

Tunnel construction was found to be economical for larger size outfalls (greater than 1.6 m diameter) where the geology is suitable.

In Bombay one tunnel of similar size has been constructed and two more are planned for transfer of water. The water tunnels are at similar depths to an outfall tunnel and are below the water table. Some short-term ingress of water has been experienced as surrounding rock has been drained by tunnelling. Beneath the sea any water passage to the sea bed could tap a large source of water so special measures such as probe drilling ahead of the tunnel heading and ground and water bearing rock. These techniques have been adopted previously for tunnel under the sea. Most under sea tunnels have been constructed for transport purposes but an outfall tunnel has the advantage that it can be placed well below sea bed level whereas transport tunnel are generally kept as high as possible to avoid excessively long approach sections. The tunnel would be concrete-lined to reduce total ground water seepage to give permanent support to the excavation as construction proceeds, and to improve hydraulic capacity.

Tunnel construction.

The site investigation which was carried out provided information for the design of both seabed and tunnel outfalls. From the information available form the drill holes, tunnel excavation will be through either the relatively strong basalt, or the weaker fresh volcanic tuffs and breccias.

Before tunnelling can start, an access shaft a about 8.5 m diameter needs to be excavated both Worli and Bandra to a minimum depth of about 75 m. The shaft would be used for access to the tunnelling face and for removal of muck. After construction the shaft would act as the inlet to the tunnel outfall. As it is a permanent part of the finished outfall the shaft would be concrete-lined and incorporates a sump for drainage purposes during construction. The sump would also be used should the tunnel requires future dewatering as part of maintenance programme.

Access to some tunnel is provided by the construction a relatively step downward sloping tunnel to meet the main tunnel. This is know as a drift. Removal of muck from the a drift is done by winching the muck wagons up this slops, instead of the usual vertical lift with a crane. One advantage of this method is that a forward advance of say 300 m is made before the tunnel proper starts. However, this technique is not preferred by many tunneling contractors and we have assumed in this reports that conventional vertical shafts will be used, because of the lack of space at the sites for such a drift.

The depth of the shaft will depend on the back slope in the tunnel. Tunnellers prefer such a slope to be about 1 in 200. This provides efficient drainage of any water ingress (back to the shaft sump) without causing gradient difficulties for the locomotives.

The tunnels would be formed in both basalt and tuffs. The drill and blast method of excavation could be used but overbreak would be considerably more than with a tunnel boring machine (TBM), and the permeability of the surrounding rock would be increased. The initially sound tuff cores, from the site investigation drill holes, degenerate on exposure to air into a softer material and 'disc' and therefore any such material in the tunnel excavation must be sealed as soon as possible. Thus, segmental tunnel lining will be either follow closely behind the tunnel face or the rock surface will be sprayed with gunite concrete as temporary seal.

The use of TBM instead of drill and blast method of excavation is preferable in these conditions because precast concrete tunnel segments can be installed as permanent lining in the relatively smooth bore left behind by the TBM. The segments themselves can be installed to provide a smooth bore and although not used before in India, these 'one-pass' type segments could be precast.

The main advantage of precast segmental linings, apart from rapid support to the excavation, is that the time taken for construction of the tunnel is reduced. A further advantage is that quality of the concrete segments can be carefully controlled in the factory conditions whereas with slip forming, or in situ concrete, honeycombing and cold joints can occur. Based on performance in the Bombay Water Supply Project, excavation rates using a TBM are expected to be 250 m/month.

A tunnel lining would also ensure good long-term hydraulic performance. Because of the corrosive environment, cast iron and steel linings are not suitable. The relatively advanced and unproven linings available now would also not be suitable where proven reliability over many years is required. The linings will therefore be precast concrete segments.

A lining of precast segments installed behind the TBM provides early support to the tunnel walls as well as a savings in construction time. The TBM will have to be dismantled on completion of excavation in order to get it back to the access shaft through the now smaller diameter lined tunnel. TBMs will however can be designed to be dismantled easily for removal from restricted access.

The tunnel has been designed to be extended as a later date, this will be done by sinking or shaft at sea over a branch tunnel to be constructed in the first phase of the work upstream of the diffuser section. The seaward shaft would be constructed by sinking an 8.5 m diameter caisson in the sea at approximately 2700 m from the shore. This shaft, which could become permanent structure would have several advantages :

- as a recovery point
- as a marker to shipping of the outfall position
- as access and vent shaft for any tunnel maintenance

To facilitate working over the seaward shaft and artificial island would be created around the caisson. This incorporate a breakwater and a safe anchorage for supply and personnel vessels. After of extension the island would be retained to protect the shaft

Diffuser

The diffuser section of the main barrel will be 250 m long and will have a gradual reduction in the internal cross-sectional area to maintain velocities and equalize discharges along the diffuser section. The diffuser of each outfall will have 10 vertical riser shafts 1.0 m finished diameter which would be drilled from a jack-up barge to a depth just below the tunnel invert. The riser will be drilled in advance of tunnel excavation and offset from the tunnel alignment. After the tunnel is complete, cross-adits will be excavated to the riser shafts and connection made to link the risers with the tunnel. At the top each riser a 10 port discharge structure will be installed for dispersion of the effluent.

The first activity by the contractor will be to locate, transport and install one or possibly two tunnel boring machines of suitable diameter (say 4.1 m bore). Twelve months have been allowed for this activity, during which establishment and construction of the access shafts will be carried out. Because precast segmental lining is to be used, a precasting yard must also be established during this period.

Six months for access shaft construction has been allowed with a permissible three month overrun. For the outfall shafts, insitu lining will be placed possibly as the shaft is excavated and this may result in some time saving.

From then on tunnelling proper starts and a rate 250 m/month the tunnels should take about one year to excavate. The contractors has been given the options to work simultaneously or consecutively with identical resources at both sites.

Drilling and installation of the risers is programmed for the first calm winter season or possibly the first two season. The installation of the risers from a jack-up barge is estimated to take up to 6 months for each outfall.

The tunnel lining method would have a major effect on the completion date. It has been suggested that a precast concrete segmental lining be installed behind the TBM for both speed and early support of the tunnel sides.

Opening the discharge ports and commissioning the outfall can only be done after completion of the tunnel, risers cross-adits as the tunnel will flood during this activities. This work demands a time period of two months.

The commissioning of the Bandra outfalls can only commence when the Bandra Pumping Station and WWTF is commissioned. It is planned that the pumping station WWTF and outfalls will be commissioned in about 1999. The Worli WWTF and pumping station are already commissioned and discharging through 500 m of 3.5 m diameter concrete pipe constructed under earlier contract. As soon as Worli outfall is complete it can be commissioned. For this reason if the outfalls are to be constructed consecutively then the first outfall to be constructed will be that at Worli.

4.8 INFERENCE

In the present time marine outfalls provide a cost effective and efficient alternative method of wastewater management for coastal towns. Such disposal, however, has a number of environmental repercussions. While constructing the marine outfalls, it is necessary that the associated environmental impacts are carefully evaluated and brought to acceptable levels through the outfall design features which mitigate the detrimental environmental impacts. Reliable estimates of factors governing the assimilation of wastewater discharged through marine outfalls such as initial dilution and secondary dispersion, therefore, are critical inputs for selecting an environmentally sound outfall design.

Chapter 5

EXISTING ENVIRONMENTAL CONDITIONS AND FINDINGS

5.1 PREAMBLE

The wastewater drainage area of Bombay comprises of seven service areas. Wastewater from four of these areas viz. Worli, Bandra, Malad and Versova reaches the west coast either through direct discharges into the coastal regions or through other surface water bodies such as Malad Creek and Mahim Bay . The total wastewater thus reaching the western coast is about 60 percent of the wastewater generated in the region. The remaining wastewater is discharged into Thana creek on the east coast of Bombay through a marine outfall at Colaba and direct discharges in Bhandup and Ghatkopar portions of the creek.

Disposal of such large quantities of wastewater, specially along the west coast, has given rise to many regions of prominent impairment of aquatic environment. For improving the coastal water quality, the proposed marine outfalls at Worli and Bandra are being designed to carry and dispose the average dry weather wastewater flows of about 512 and 552 mld respectively, upto a distance of 3 kilometers into the sea. Although, diversion of such large quantities of sewage away from the coast is expected to alleviate pollution stress on nearshore regions, some negative impacts of these diversions into hitherto cleaner regions are inevitable. The project implementation also envisages large scale construction either in the form of 3 km long tunnel or pipe outfalls. These activities may also have adverse environmental impacts.

An environmental assessment involves study of all environmental issues related to the project activities and their alternatives with the objective to identify and mitigate the associated negative impacts. The first step in such analysis is to determine the existing environmental conditions with special emphasis on those parameters which are expected to be significantly altered by the project. The present chapter describes the scope, methodology and findings of the field studies undertaken towards such determination.

5.2 SCOPE OF FIELD STUDIES

Both the construction and operation of marine outfalls are expected to have significant environmental impacts. Vibrations due to blasting, water pollution at the construction head, and air and noise pollution at the headworks are the major construction phase impacts of the project. Evaluation and mitigation of these impacts entail considerations of effect of blasting operations on surrounding structures, air and noise pollution due to operation of construction machinery and vehicles, and water quality impacts due to the trenching and laying of the outfall sections on the sea bed.

Field investigations on ambient air quality, noise levels, coastal water quality, meteorology, sources of noise and air pollutants during the construction were undertaken to generate requisite data for assessment of construction phase impacts. Also, data on geological features of construction sites, ground vibrations during earlier blasting operations in Bombay, land-use pattern and soil characteristics were also obtained.

The major environmental impacts of the project, however, are those associated with the operation of outfalls and are largely beneficial. Most prominent of these shall be the widespread improvement in the water quality along the west coast owing to diversion of present wastewater discharges away from the coast.

The discharge of diverted wastewater, however, would cause impairment of water and sediment quality near the outfall diffuser section. Microbial contamination of sea water, benthic sediments and shellfish fields are major concerns of such discharges. Under adverse meteorological conditions, the wastefield formed near the diffuser section can also drift shoreward and contaminate large sections of the coastline. Depletion of dissolved oxygen, nutrient enrichment and possible eutrophication are other water quality aspects which entail investigation in the context.

It is also necessary that extent of mixing of industrial discharges with the sewage in the drainage area is investigated, as, such disposal in marine environment could have certain additional impacts due to the presence of potentially hazardous substances. These impacts are reflected in the form of direct toxicity to aquatic life or through biomagnification. The latter could also have health impacts on the human population through consumption of contaminated sea food.

The water quality impacts arising from outfalls' operation are governed by a variety of physico-chemical and biological interactions and are substantially influenced by the ambient coastal hydrodynamic conditions. Due to the dynamic conditions in the sea and complex nature of these interactions, only those transformations which primarily depend on physical processes or simpler bio-chemical processes such as initial dilution, secondary dispersion, microbial decay and sediment deposition are amenable to predictive modelling. For processes involving more complex interactions such as nutrient enrichment, bioacccumulation and ecological transformations, it is necessary to adopt the approach of observation and inference on the regions which have been receiving similar wastewater discharges over a long period.

In view of above, the sampling and data generation on coastal environment had two distinct objectives. One set of activities were undertaken to define the existing water quality and identify the repercussions of sewage discharges through observations on regions that have been receiving such discharges in the past. Other set of data were collected to obtain ambient environmental conditions and local estimates of model coefficients needed for quantitative prediction of the impacts using mathematical models. Sampling and characterisation of raw wastewater in the Worli, Bandra and Colaba service areas were also undertaken during the course of the field studies.

Methodology and findings of the field studies for defining the ambient environmental conditions are described in the following sections. The field monitoring programmes to establish model coefficients for predictive modelling are presented in chapter 6.

5.3 METHODOLOGY AND FINDINGS

5.3.1 AIR QUALITY

To establish the baseline status of air quality near the outfall construction sites at Worli and Bandra, two air monitoring stations were established at each of the sites. Samples for gaseous pollutants viz. NO_2 and SO_2 and suspended particulate matter (SPM) were collected as 8 hourly averages. As winter season is generally considered critical period for air quality, the observations were made during February, 1992. Continuous monitoring for one week was carried out at each site. Concurrent to air quality monitoring, site specific micrometeorological data viz. wind speeds and directions were collected at 8 meters above the ground level through an automatic weather station. The recorded data was used to draw windroses for both the sites.

The windroses for Bandra and Worli sites, presented in Figures 5.1 and 5.2 respectively, indicate similar meteorological conditions in conformity with the climatological normals of the region. The predominant wind direction during this period is from North and North-West with wind speeds below 20 kmph. The calm conditions (wind speed below 1 kmph) prevailed for considerable period (40 and 30 percent respectively for Bandra and Worli) during the observations.

Figure 5.1 : Wind rose at Bandra

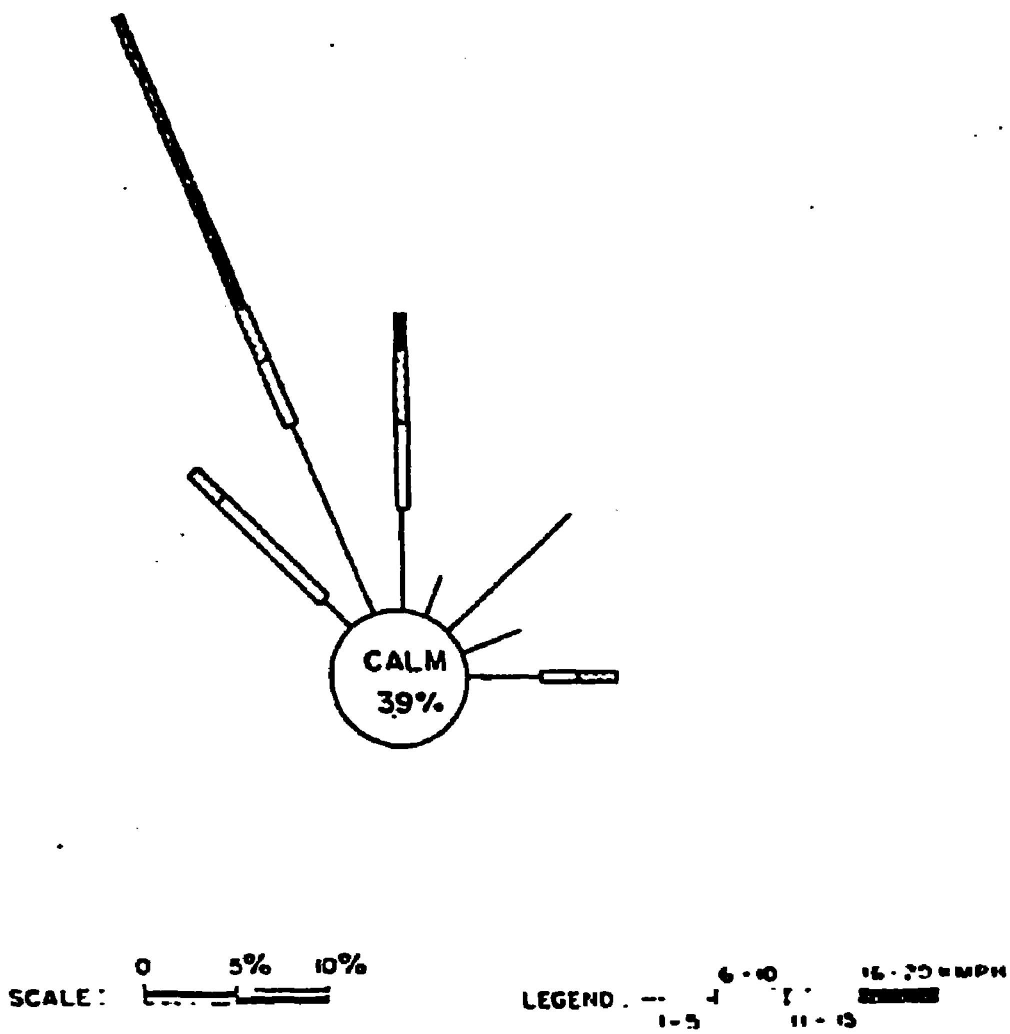
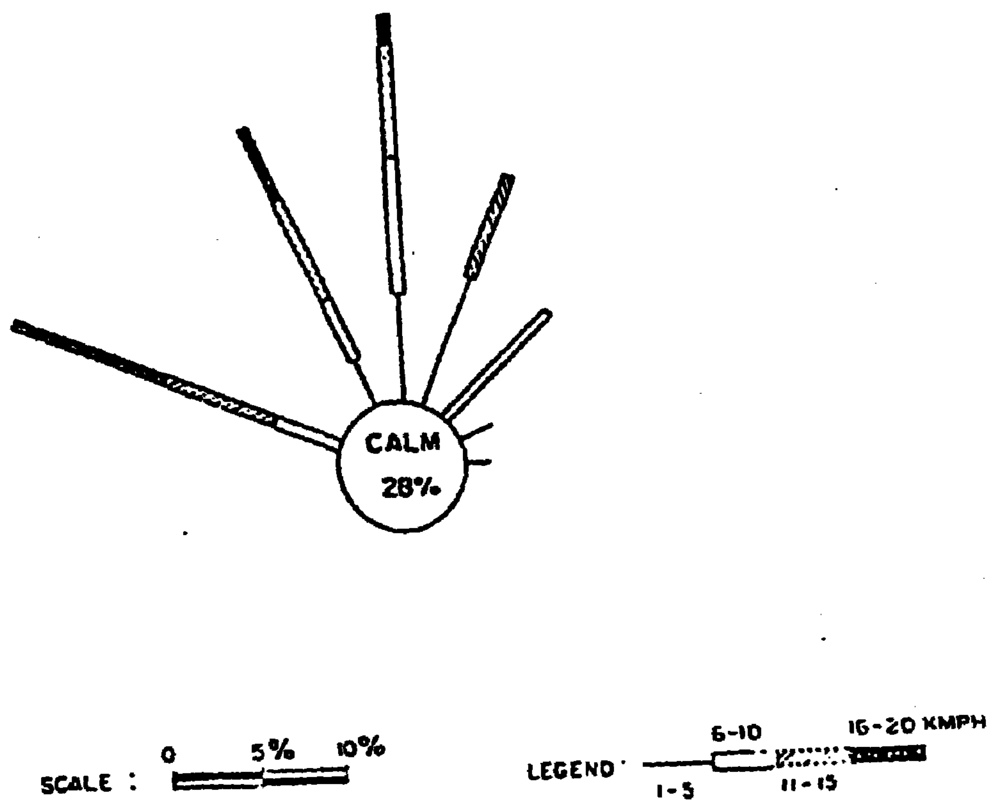


Figure 5.2 : Wind rose at Worli



The statistical observed ambient air quality data at Bandra and Worli is reported in Table A 5.1. The observations indicate that ambient levels of SO_2 and NO_x are higher at Worli in comparison to Bandra whereas particulates are comparable. The higher levels of gaseous pollutants at Worli may be attributed to high vehicular traffic in close proximity to the monitoring sites. It is observed that NO_x levels at Worli (not withstanding limited monitoring) are very close to the ambient standard of 80 $\mu g/m^3$. Indian ambient air quality standards are presented in Table A 5.2.

Air quality monitoring to study spread of bacterial contamination through aerosols and odour due to outfall headworks operation was also conducted. Since the present facilities in operation at Worli are quite similar to finally proposed configuration of screening and degritting units for both the outfalls, monitoring was carried out at Worli wastewater pumping station. For odour determination, hydrogen sulphide (H_2S) levels were monitored by chemical method. Though residents near the Worli outfall site experience some odour, the concentrations recorded through chemical method were below detectable limit. The odour problem, therefore, was studied through individual perception by a panel of observers.

At Worli pumping station, sampling for airborne bacteria was carried out at two locations, one near the grit chamber and the other adjacent to the wet well. Ambient air samples were collected for different intervals through impingers and analysed for total coliforms (TC), fecal coliforms (FC) and fecal streptococci (FS). The results of these analyses, presented in Table A 5.3, indicate that the concentrations of airborne bacteria were generally low but were relatively higher near the grit chambers. This may be attributed to the turbulence in the grit chamber releasing fine aerosols.

Observations on odour indicate that worst situation occurs during the night when the wind velocities are low. Under these conditions due to high atmospheric stability, it appears that the odour causing gases disperse slowly and cause considerable odour nuisance in the down wind directions. Strong odour is experienced at the ground level upto a distance of about 150 m from outlet of grit chambers.

5.3.2 NOISE STUDIES

The objective of field observations on noise levels was to estimate the increase in ambient levels due to construction activities at those residential areas (sensitive zones) which are in close proximity of the proposed sites. At Worli such residential areas are in the form of unauthorised hutments at about 75 m eastward and NEERI premises on the west at about equal distance from the construction site. Whereas, a school is situated at about 75 m northward from the Bandra construction site. The observations, therefore, included measurements on ambient noise levels at headworks sites, these sensitive zones and a few neighbouring areas. In addition, inventory of construction machinery as sources of noise for both pipe and tunnel options was prepared and their operation pattern during the construction was identified.

Highest background noise levels, in the range of 62-71 dBA, were recorded at Worli construction site near the boundary of Lovegrove pumping station. The pumping station is adjacent to a very busy road. Heavy traffic on the road causes considerable noise pollution in the area. Noise levels in near by residential colony were observed in the range of 45-52 dBA and 55-62 dBA in NEERI premises. At Bandra outfall headworks site ambient day time noise levels varied between 35 to 42 dBA. Low noise levels in this area are due to its isolated location. Comparison of the observed noise levels with the Indian standards for urban residential and commercial area (Worli, standard 40-50 dBA), and urban residential area (Bandra, standard 35-45 dBA), indicate that these just about meet the respective standards. Outdoor noise levels in NEERI premises exceed the standards upto about 10 dBA.

To estimate the ground level noise characteristics due to tunnelling, noise levels were observed at Phutka Tank in Matunga, a location where tunnelling operations similar to those expected for outfall tunelling were in progress (90-92 dBA). Similar noise levels were observed during the movement of trolleys provided for transportation of excavated refuse and its transferring through shaft. Noise source characterisation for all other machineries was carried out by measuring noise levels at a distance 2 m away from the source using precision sound level meter (Tables A 5.4 and A 5.5).

5.3.3 LAND USE DATA AND SOIL CHARACTERIZATION

The baseline data on land environment pertains to present landuse pattern in and around outfall sites and properties of the soils. At Bandra, the alignment is expected to cross the shoreline at 300-500 m south of the Hotel Sea Rock. Land use pattern was studied in areas within half a kilometer inward from the shoreline, and about 2 km in the north and north-east directions from the point where the outfall line would take off from the shore. This data is presented in Table A 5.6.

At Worli, an area within half a kilometer of distance from the shoreline, upto 0.8 kms. north from the outfall alignment location i.e. upto the junction of Khan Abdul Gaffar Khan Road and Dr. R.G. Thandani Marg and upto 2.0 kms south from this point has been considered. The present landuse pattern in this region is presented in Table A 5.7.

For determining the soil characteristics near the construction sites, surface soil samples were collected at Bandra and Worli. The procedure for compositing the sample for each location was to collect soil from 4 to 6 points within the area. At Bandra, one composite soil sample was collected from the hillock in front of hotel Sea Rock and other composite samples were collected from road side areas north and south of the hotel. Physical, chemical and cation exchange properties of these soils are presented in Tables A 5.8 to A 5.10.The analysis indicates that soils at Bandra are loamy sands and those on the road sides at Worli are loams. All these soils are light with moderate porosities. The road side samples exhibit highly saline nature and near neutral pH may be due to the absence of soluble carbonates.

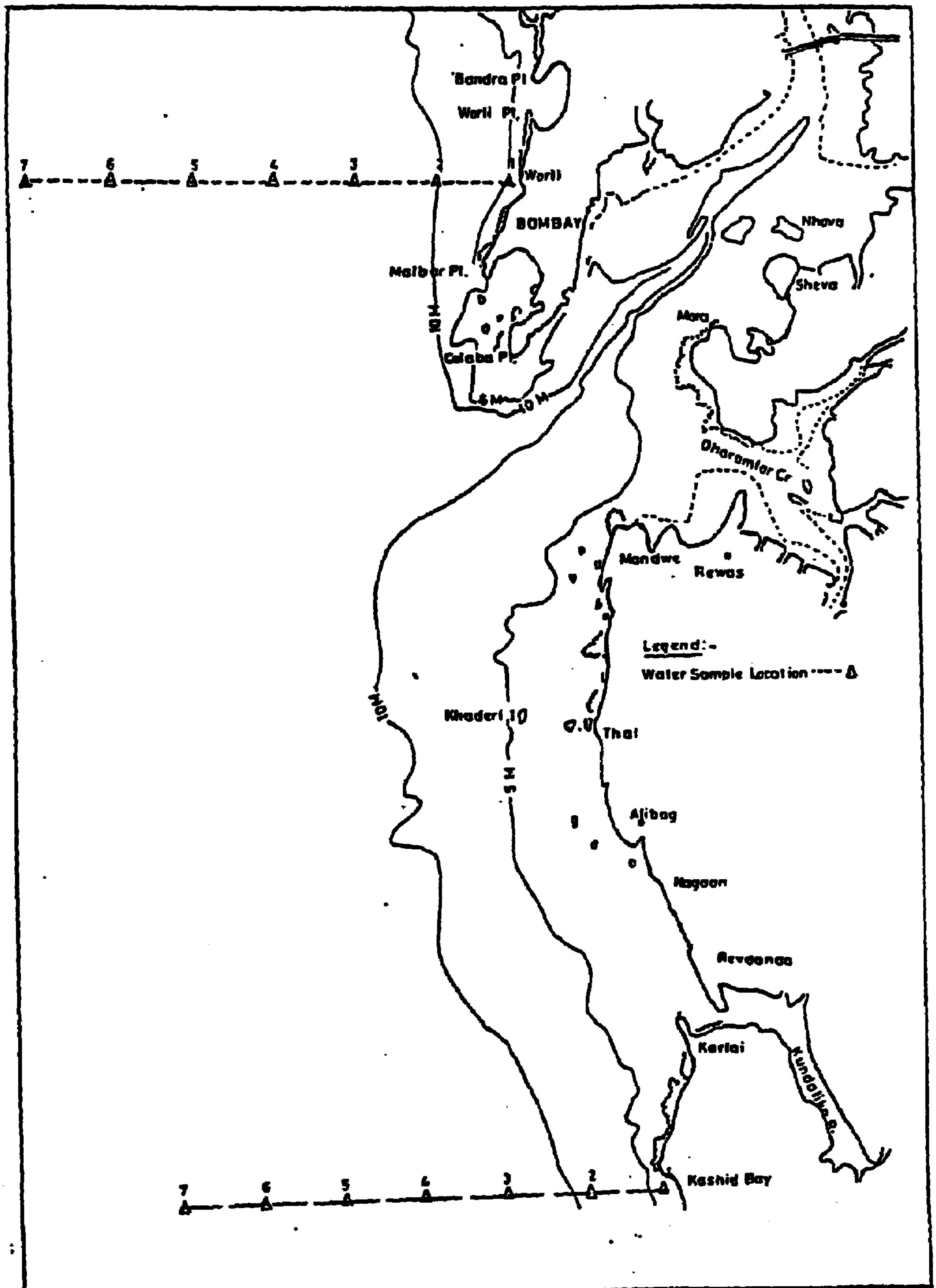
The soils at Worli are also saline, though less in comparison to those collected from Bandra and exhibit neutral pH. The Cation Exchange properties of the soils (Table A 5.10) also suggest that soils at Bandra, including the one sampled at hillock, possess higher content of exchangeable sodium percentage which may have a bearing on selection of plant species for plantations in these areas.

5.3.4 OCEANIC WATER QUALITY

One of the major objectives of environmental management plan is to identify the measures which should mitigate and restrict the negative impacts of wastewater discharges through marine outfalls and confine those to the acceptable level. Since, the resultant water quality after the discharge shall be a function of wastewater quality as well as the ambient seawater conditions, it is necessary to establish the latter. The coastal waters of Bombay, however, have been receiving wastewater discharges for a long period. It is therefore, probable that the proposed points of discharge are already polluted and do not represent the state of clean seawater quality for quantitative estimate of water quality arising after wastewater discharge through the proposed marine outfalls.

With the objective to define the clean sea water conditions in the coastal regions of Bombay, two sampling programmes were undertaken during the winter of 1991. The sampling stations for these observations were selected perpendicular to the coast at the site of existing Worli outfall and at Kashid Bay about 60 kilometers South of Bombay coast. The alignment of the survey lines is shown in Figure 5.3. During these surveys, samples were collected at every 5 km starting from the coast upto a distance of 30 km in the sea. Surface and middle depth waters were sampled for analysis. It was expected that water quality analysis of these samples will provide a decreasing trend of pollutant concentrations with increasing distance from the coast at Worli (already receiving substantial wastewater

Figure 5.3 : Survey line alignment at Worli and Kashid bay



discharges from the Worli service area) and almost uniform concentrations at Kashid Bay (clean sea coast). Water quality at larger distances at Worli, away from the immediate effects of present discharges, was expected to yield values similar to Kashid Bay depicting clean sea conditions on west coast of Bombay.

The water samples collected during these surveys were analysed for physico-chemical , nutrient and bacteriological parameters (Table A 5.11).The salient observations and interpretations of these analyses are discussed below.

5.3.4.1 PHYSICO-CHEMICAL QUALITY

Concentration verses distance plots for ammoniacal-N, soluble phosphate, dissolved oxygen (DO) and biochemical oxygen demand (BOD) for Worli and Kashid Bay are presented in Figures 5.4 and 5.5. For these parameters conventional methods of analysis as prescribed by Standard Methods (17th edition) have been adopted along with suitable modifications for saline waters. The observations along the transects (Tables A 5.12, A 5.13) indicate higher values for BOD and soluble phosphate in near shore samples at Worli in comparison to Kashid Bay. Also, a noticeable depression in dissolved oxygen level is observed near Worli shore indicating high organic load due to coastal discharges. The near shore ammonia-N levels at Worli and Kashid Bay, however, are comparable.

The water quality parameters present almost uniform profile beyond 5 km distance from shore and show similar concentrations at both regions. Based on these observations, clean sea conditions in the form of these parameters may be defined as presented in Table A 5.14.

5.3.4.2 MICROBIAL QUALITY

Samples for microbial parameters were analysed for TC, FC and FS densities as an index of pollution using the membrane filter procedure. Membrane filter (MF) procedure has several advantages over the routine most probable number (MPN) method, the flexibility in choosing an appropriately large number of test sample portion being the primary one. Besides, the MF procedure provides a direct count of viable and culturable organisms and requires a relatively shorter time for analyses (12-48 hrs) as against the MPN method which requires 24-72 hrs. The ease of handling large number of samples and its sensitivity to detect very few organisms also justifies the choice of MF technique over the routine MPN method for enumeration (APHA, 1989).

Figure 5.4 : Chemical quality of water at Worli upto 30 kms

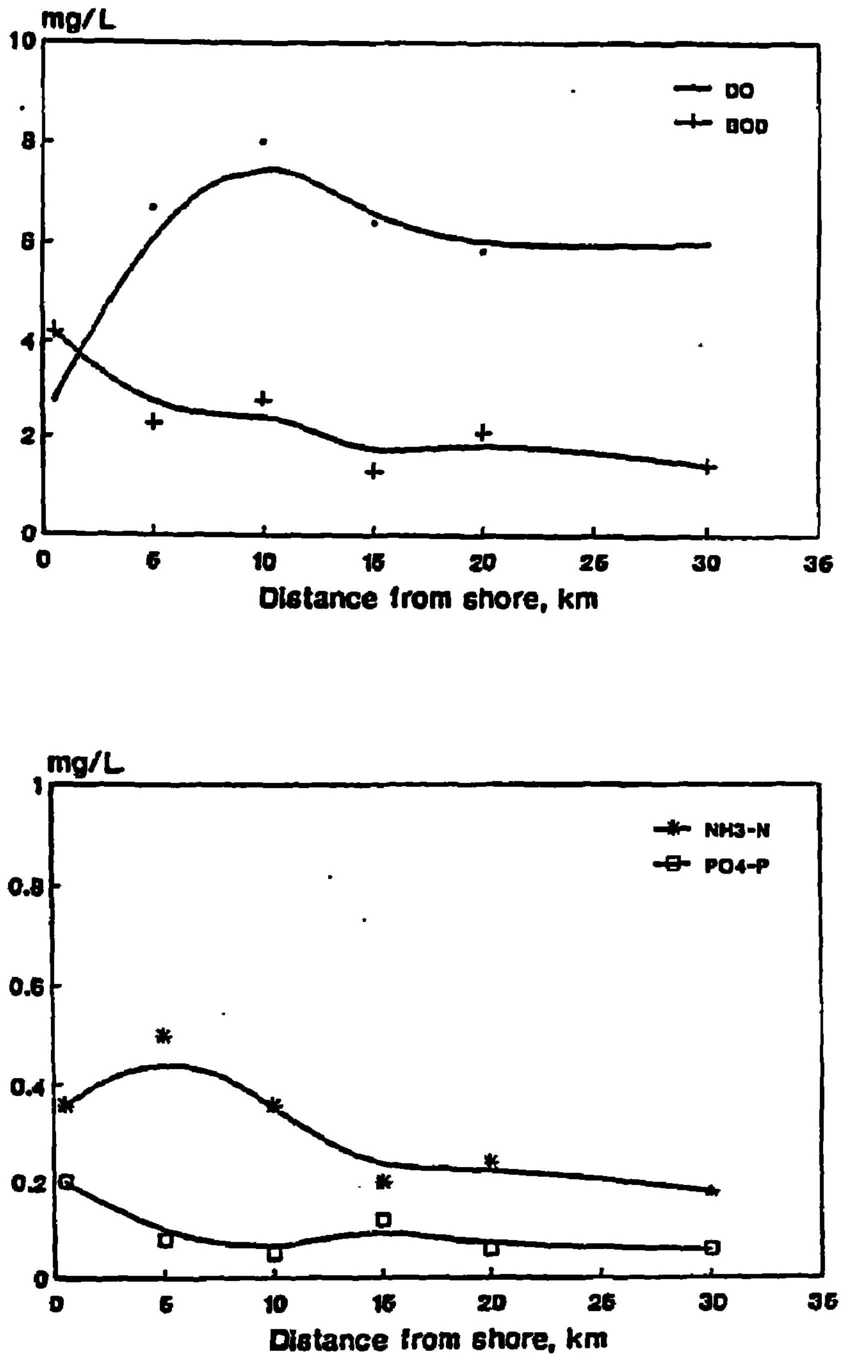
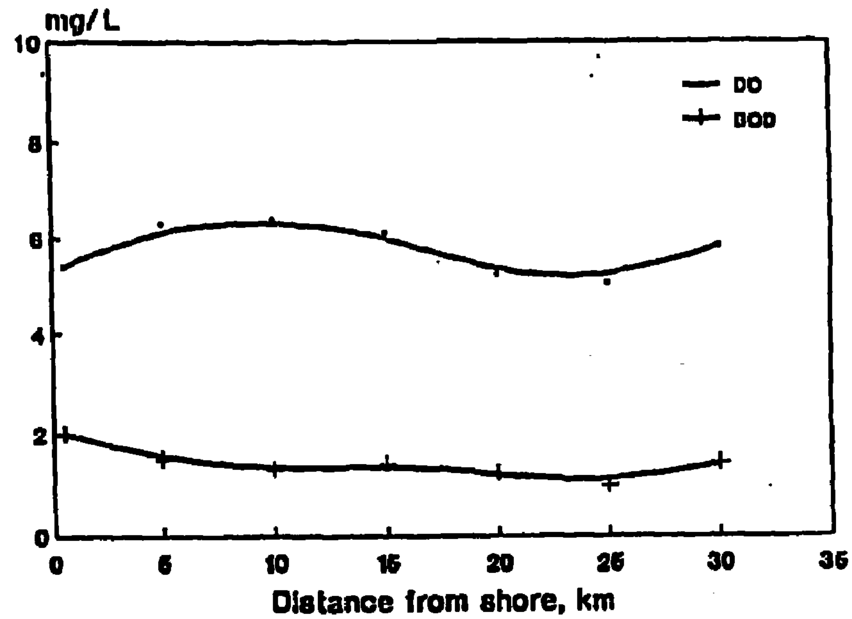
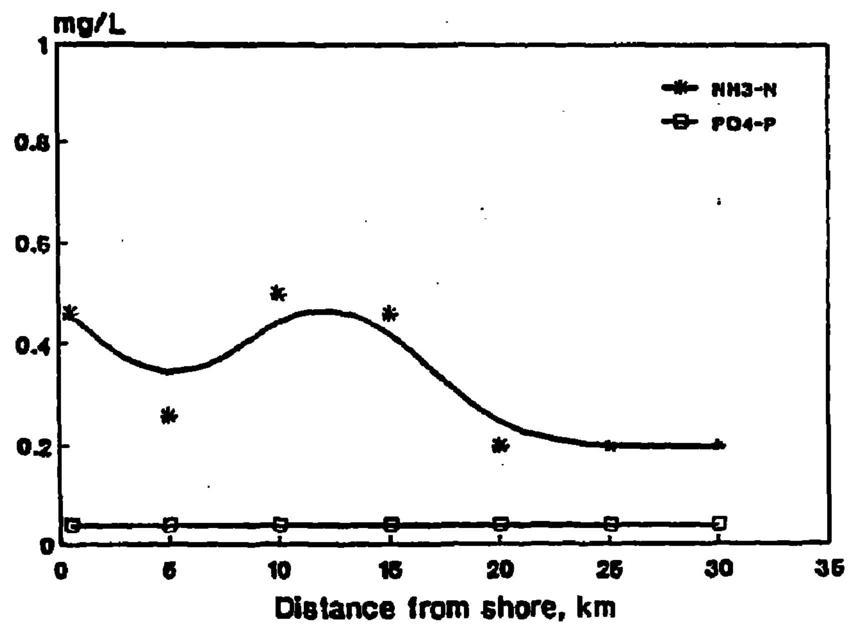


Figure 5.5 : Chemical quality of water at Kashid upto 30 kms





The sea water samples were collected in sterile bottles and transported to the laboratory in ice. Requisite dilutions of the original sample were made using sterile seawater. Appropriate aliquots of diluted/undiluted sample were filtered and the membrane filter papers placed on respective media. Plates were incubated at 37°C (TC,FS) and 44.5°C (FC) respectively. Only those plates exhibiting typical colony counts between 20 and 100 were counted.

Surface samples collected along the 30 km line at Worli showed that the numbers of TC, FC and FS tend to decrease with the increase in seaward distance (Figure 5.6). In the aphotic zone, represented by the mid-depth region, the presence of higher numbers of TC were observed, while FC and FS were very few.

At Kashid Bay, the surface samples exhibit a general trend of similar TC counts while FC and FS counts tend to decrease with increasing seaward distance (Figure 5.7). In the aphotic region bacteriological quality is similar, as seen in the case of surface samples.

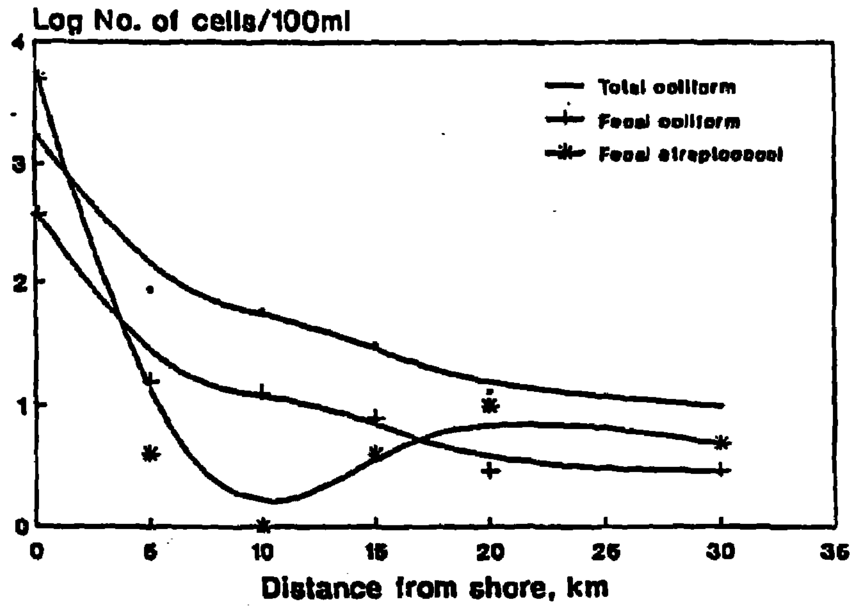
The clean sea region (beyond 20 km), may therefore be characterised by the presence of few TC and scant occurrence of FC and FS respectively. Based on these observations and very high count of these organisms in domestic wastewater, clean sea microbial quality for generation of future scenarios has been taken as zero count of microorganisms of sewage origin.

5.3.5 COASTAL WATER QUALITY

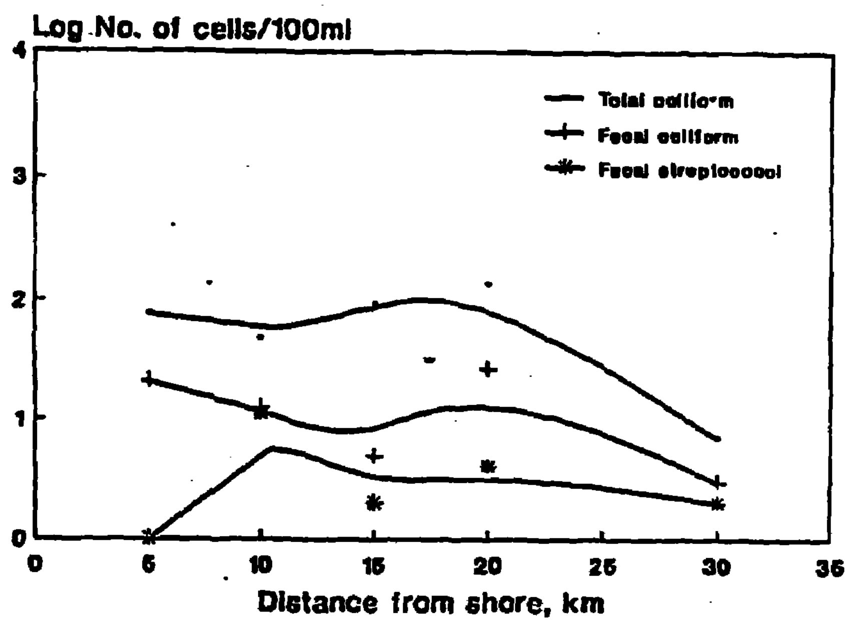
The coastal water system receiving domestic discharges has a highly variable and dynamic character. It is intimately related with diurnal tidal variations which themselves are governed by the lunar cycle; wind and meteorological conditions; and also with the variations of wastewater flows and characteristics. A meticulous and well planned water quality programme with capacity to account for these variations, therefore, is necessary to arrive at a reasonable quantitative estimate of coastal water quality.

Also, as the coastal water quality is expected to differ with the proximity of wastewater discharge points. It is, therefore, necessary that the sampling should cover the entire coastline receiving such discharges. The programme should also have a robust element of comparison between low and high tide water quality and should be extensive enough to eliminate the random fluctuations in measurements. The programme should also bring out the differences or similarities of water quality among the prominent seasons. The high cost and involved logistics of a coastal monitoring programme, however, are the practical constraints which also need consideration while planning the surveys.

Figure 5.6 : Bacteriological quality of water at Worli upto 30 kms

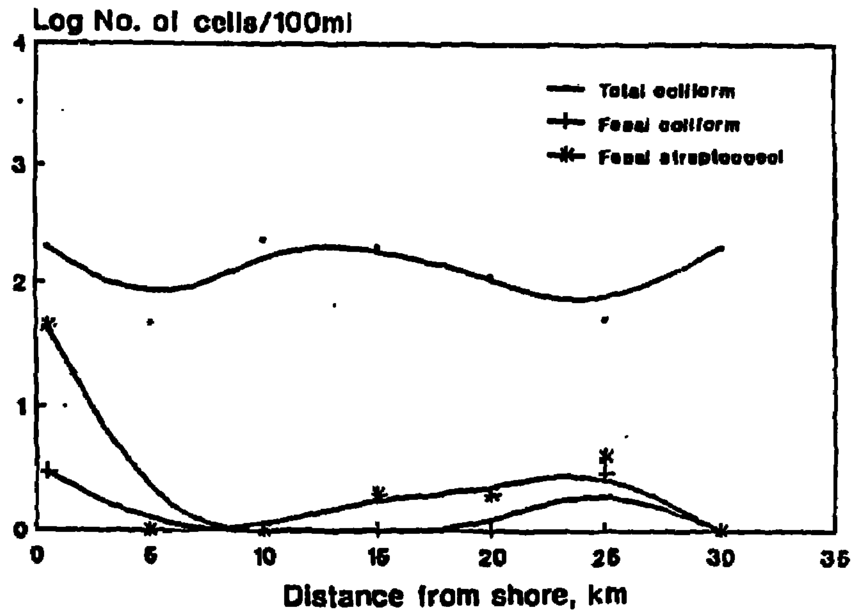


Surface waters

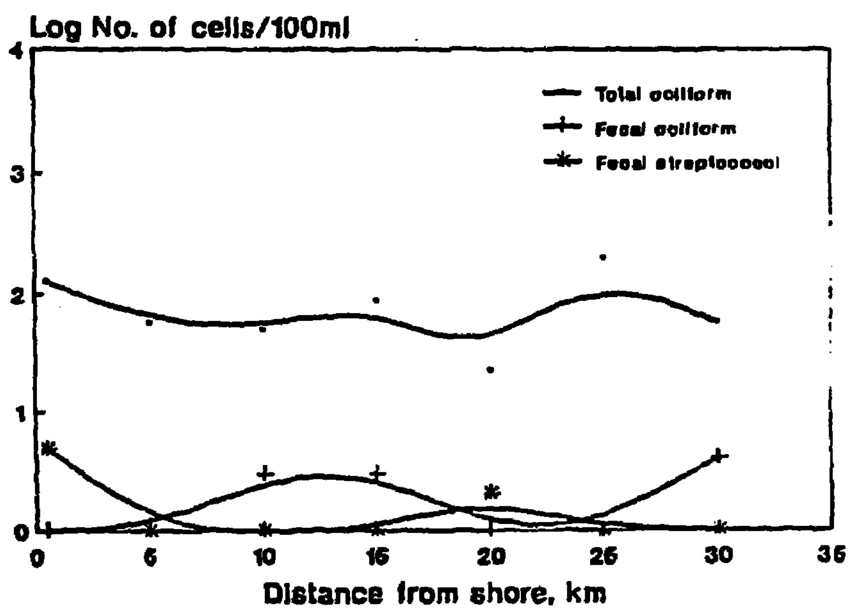


Aphotic region

Figure 5.7 : Bacteriological quality of water at Kashid upto 30 kms



Surface waters



Aphotic region

In view of above, it was decided that for establishing the existing water quality status in the coastal region near Bombay the water quality programme should have following features :

- It should cover the entire coast line receiving major wastewater discharges,
- Water quality samples should be collected at both high tide and low tide slack on all sampling days and
- The programme should have sufficient spread to cover both neap and spring tide conditions and should be adequate to apply statistical methods for analysis.

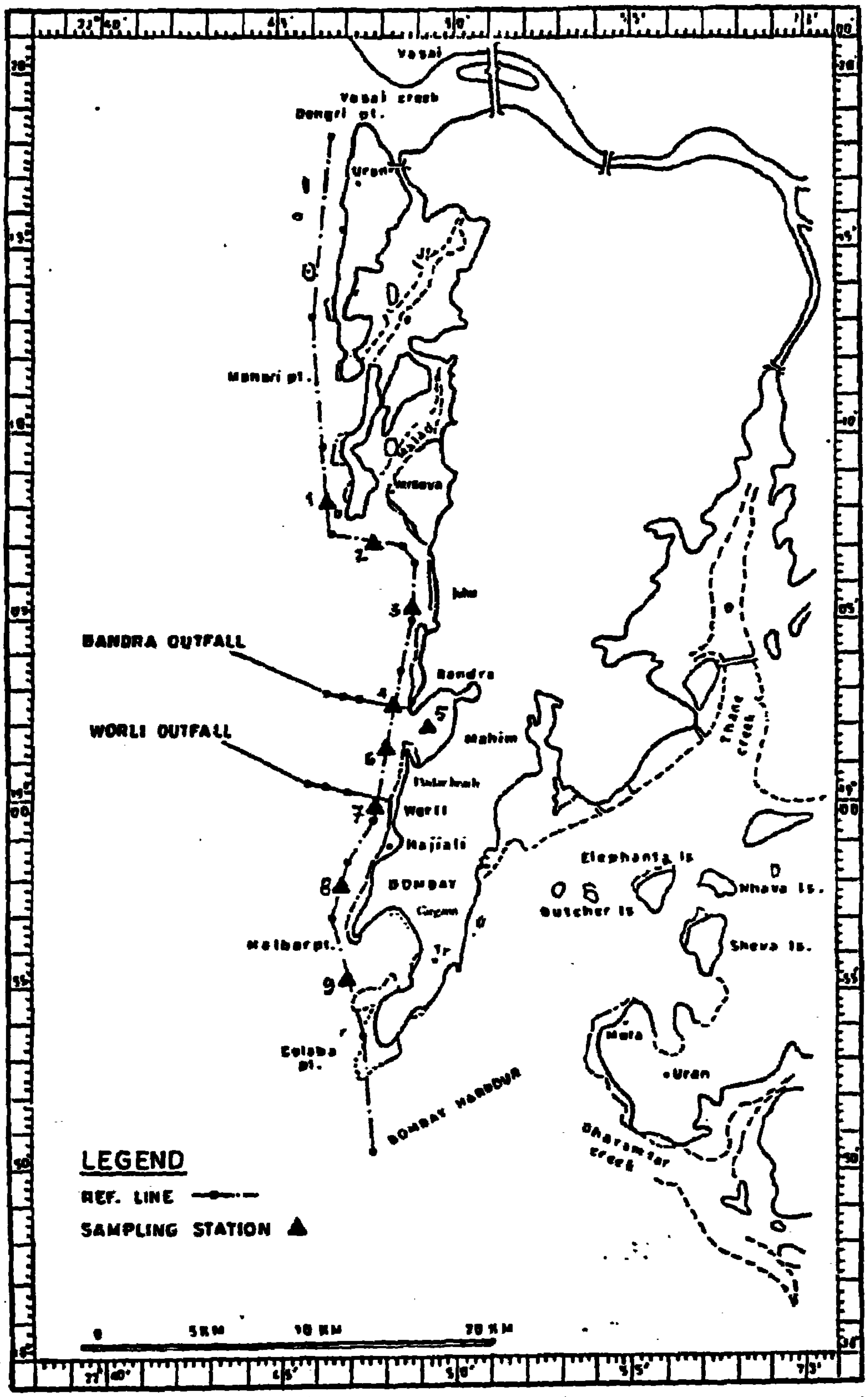
Salient features of coastal water quality survey

With above considerations the coastal water quality programme at reference line was organised. The selection of one kilometer seaward distance for coastal sampling primarily was governed by the fact that the microbial water quality standards prescribed by Maharashtra Pollution Control Board (MPCB) for the compliance of marine outfalls performance were at similar distance. The one kilometer distance also appears to provide sufficient dilution for dampening the large water quality fluctuations expected in immediate vicinity of coastal discharges. Minimum water depth requirement for vessel navigation during the low tide has also been one of the considerations in selection of monitoring stations.

The coastal sampling covered a longitudinal distance of about 24 kilometers between Madh island on north to Girgaum Chowpati to the south. Over this distance a total number of 9 sampling stations were selected covering the prominent sources of present coastal discharges as well as probable cleaner regions. The sampling programme was conducted in the month of December 91 and April 92 providing the estimates for winter and premonsoon seasons. During this survey water samples on five days both for low and high tide were collected. Sufficient number of sampling vessels were deployed on each day to cover all sampling stations at identical period of tidal cycle (within 30 minutes of low and high tide slack water). The water quality survey was spread over a period of about 10 days in each season with sampling on alternate days. The location of sampling stations is presented in Figure 5.8.

The analysis covered estimation for physico-chemical, heavy metals, microbial and biological characteristics of water samples. The details of parameters analysed are presented in Table A 5.15. Although, physico-chemical, microbial and biological parameters, all, jointly define the state

Figure 5.8 : Sampling stations for water quality Monitoring at reference line



of coastal water quality, the difference in nature and precision of analysis for these parameters necessitates independent methodology of interpretation. The following sections, therefore, deal separately with different parameters. Finally the integrated interpretation is also provided.

5.3.5.1 PHYSICO-CHEMICAL WATER QUALITY

The survey for determination of physico-chemical characteristics of coastal waters comprising two seasons of winter and premonsoon resulted in a fairly good number of samples for each of eight water quality parameters. The results for five major pollutants were subjected to rigorous statistical analyses for identification of major pollution parameters, necessary for future long term monitoring both before and after commissioning of marine outfalls.

Stastistical analysis

As the first step in statistical analysis, the worst season and tide conditions were identified for all quality parameters at each sampling locations. It was assumed that the observations followed normal distribution while performing the statistical analysis. For such identification all four sets of water quality conditions viz., low tide winter (ltw), high tide winter (htw), low tide summer (lts) and high tide summer (hts) were retained separately. The sets of ltw and htw, ltw and lts , htw and hts and lts and hts were tested for the null hypothesis of equality of means against alternate hypothesis of one being larger than the other with a level of significance of 0.02. The samples were first tested for the equality of variance using F statistic. For the samples with equal variance, t-statistic for small sample size for testing difference between two means was applied. The null hypothesis of equality of two means was tested against the alternate hypothesis of one being greater than the other with a level of significance of 0.05. For sets with unequal variance Smith Satterthwaite test (Miller and Freund, 1987) was used in a similar fashion

The outcome of these tests enabled identification of those combinations of tide and seasons which gave rise to highest state of pollution in the coastal waters. If the pollution level during such combination of tide and season were similar, the data sets were combined to yield a larger set of representative water quality data for the sampling location. The data for worst state of pollution at each location was compared with similar set of data at all other locations with the objective to identify the most polluted regions due to the discharges along the coastline. The results of such analyses are summarised in Tables A 5.16 and A 5.17. The results provide a comparison for each of these parameters among all sampling points based on the complete set of statistically similar data (indicative of worst pollution) at respective stations. Objective of these analyses was to delineate the coast line into cleaner, moderately polluted and polluted zones for different parameters. The mean values of observed values at each station are also provided in these Tables as an indication of average level of pollution at these points.

Interpretations

The statistical analysis of observed data for comparison of existing water quality among the sampling locations presents an interesting picture. For ammonical-N, nitrates and BOD, no statistically significant difference is observed in the worst case water quality at any of the sampling stations and the values are generally low for nitrates and BOD. The comparison of DO concentration, however, indicates a clear segregation of the coast line into regions of near saturation (4 mg/l), mildly depleted (2 - 4 mg/l) and highly depleted oxygen levels (<2 mg/1). According to dissolved oxygen data, sampling station station 1 facing Mudh island, station 3 facing Juhu beach, station 4 facing Girgaum Chowpati indicate cleaner coastal regions. Sampling stations number 2 facing Malad Creek mouth and station 5 facing Mahim Bay indicate highly depleted DO regions, whereas the rest of the sampling stations indicate a moderate level of DO depletion. The DO depletion was more prominent at low tide slack period. The DO level of less than 2 mg/l on many ocassions were observed during such periods at the polluted stations specially during the low tides (Figure 5.9).

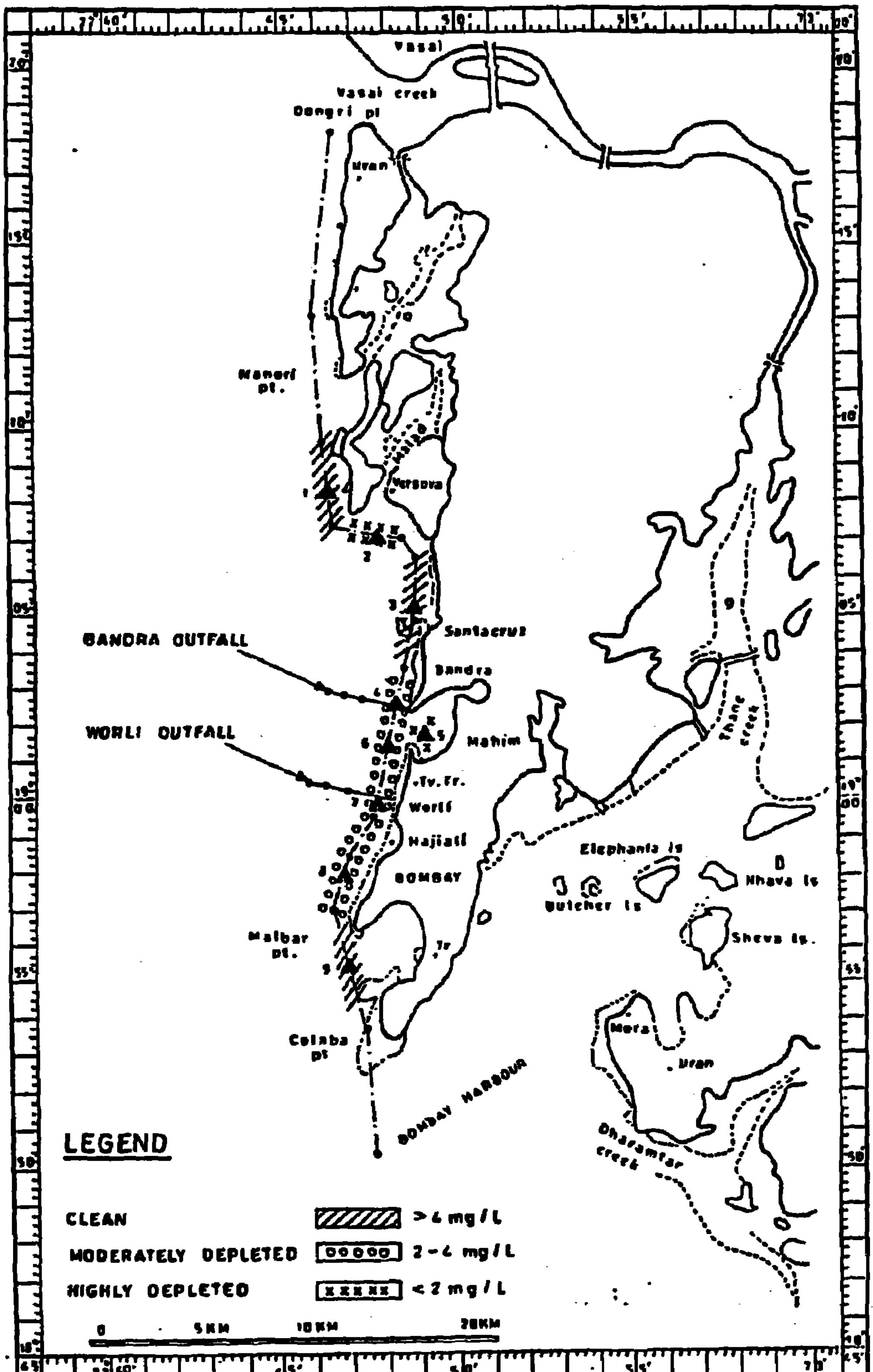
The soluble phosphate levels which are important from the point of view of algal growth are mostly below 0.1 mg/l at all stations except for stations 2 and 5. At stations 2 and 5 these values occassionally exceed 0.20 mg/l indicating significant organic pollution. The regions of higher soluble phosphates thus coincide with areas of low DO. Ammonical-N concentrations, however, exhibit elevated levels typical of polluted coastal waters all along the coast.

The concentration of heavy metals analysed as total metals along 1 km reference line (Table A 5.18) indicate higher ranges than those reported for global background ocean waters (Goldberg, 1963). However, the values observed do not indicate significant industrial pollution as the observations follow the related trace abundance pattern observed in the soils in the region. If the comparison of metal concentrations with potable water standards is considered as an indicator of absence of metal pollution, most of the observations are within such standards.

5.3.5.2 BACTERIOLOGICAL QUALITY

The bacteriological quality of coastal waters was analysed in terms of TC, FC and FS. The enumeration was done using Membrane Filter Technique

Figure 5.9 : Present DO levels at reference line



as described in Standard Methods (APHA, 1989). As has been mentioned earlier, the existing standards in India for bacteriological quality in the marine environment are in the form of bathing standards for beach water quality (Section 4.5, Table 4.4). For marine outfalls special location-specific standards have been prescribed at Bombay. These require the number of total coliforms at one kilometer seaward distance from the coast to be within 1000/100ml at all times. As fecal coliforms and fecal streptococci have also been considered as indicators suggesting contamination of fecal origin, it was thought desirable to evaluate the bacteriological quality in terms of these organisms also.

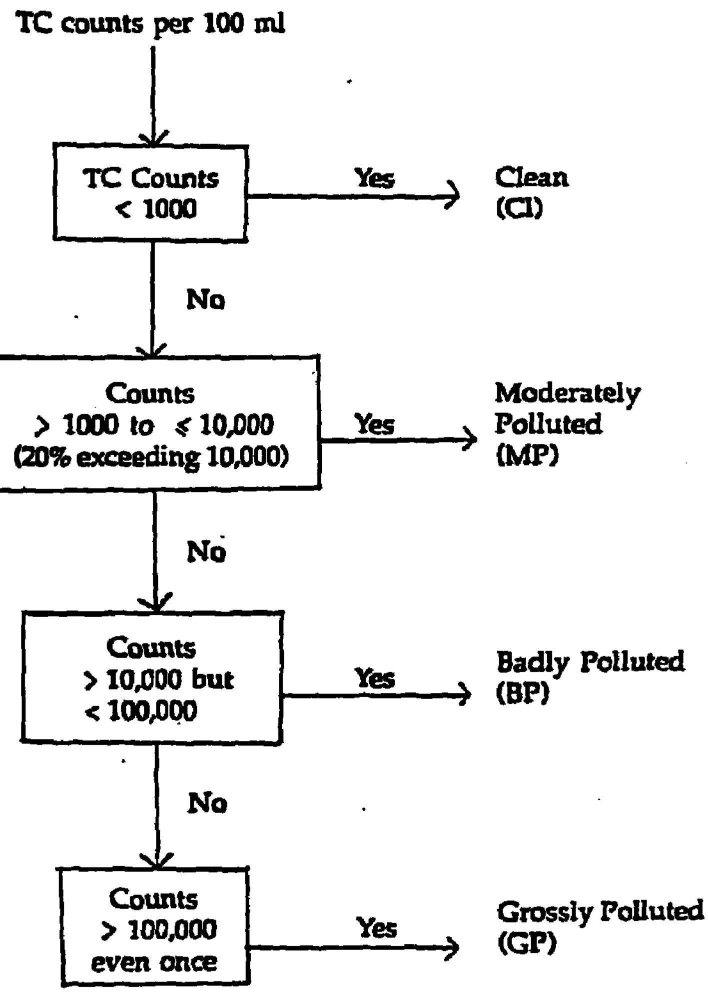
Interpretation

The data on bacteriological analysis indicates a large variation of microbial counts for all parameters at almost all sampling stations. For instance, the range of TC values for the point near the mouth of Malad creek which receives a large quantity of untreated wastewater was observed to be between 200 and more than 100,000 per 100 ml for low tide conditions in the winter. Similar wide differences were observed for FC and FS (Tables A 5.19 and A 5.20). For a point in close proximity of a major wastewater outlet along the Bombay coast, such variation in the bacterial levels even for similar tidal conditions indicate a highly dynamic and variable water quality system and underscores the need for larger data sets for adequate interpretations as has been attempted in the course of this study.

Due to the wide range of variations in the bacteriological quality, the results at sampling locations were compared for possible interrelations among different tidal and seasonal conditions, by categorising the observations as ranges rather than comparing their absolute individual values. The quality attribute to a sampling location, therefore, was classified into four categories designating different degree of pollution. The sampling locations where none of the observed TC counts exceeded 1000/100 ml were designated as clean stations. If a sampling station exhibited the violation of 1000/100 ml criteria for TC it was termed as moderately polluted station provided not more than 20 percent observations exceeded 10000 counts / 100 ml. If more than 20 percent samples violated the limit of 10000 counts /100 ml, it was termed as badly polluted station. Any violation of a limit of 100,000 counts / 100 ml was designated as indication of grossly polluted region. The categorisation of sampling stations on above basis has been summarised in Table 5.21.

It was observed that the bacterial quality of coastal waters generally indicated a degree of pollution one order higher during the low tide in comparison to the high tide. Considering the fact that the coastal region has two creeks with distinct outward wastewater flow during the ebb tide

Table 5.21 : Categorization of sampling stations based on standards



with influences over coastal currents even beyond one kilometer seaward distance, the observation appears justified. This also entails that the low tide and high tide bacterial quality be interpreted separately.

High tide bacterial quality

For interpretation of enumeration results, the frequency distributions in terms of TC for summer and winter high tide conditions at all nine sampling stations along the coast line were derived (Table A 5.22). Following which the sampling stations were graded into the categories of clean (Cl), moderately polluted (MP), badly polluted (BP) and grossly polluted (GP) regions based on earlier defined methodology (Table A 5.23).

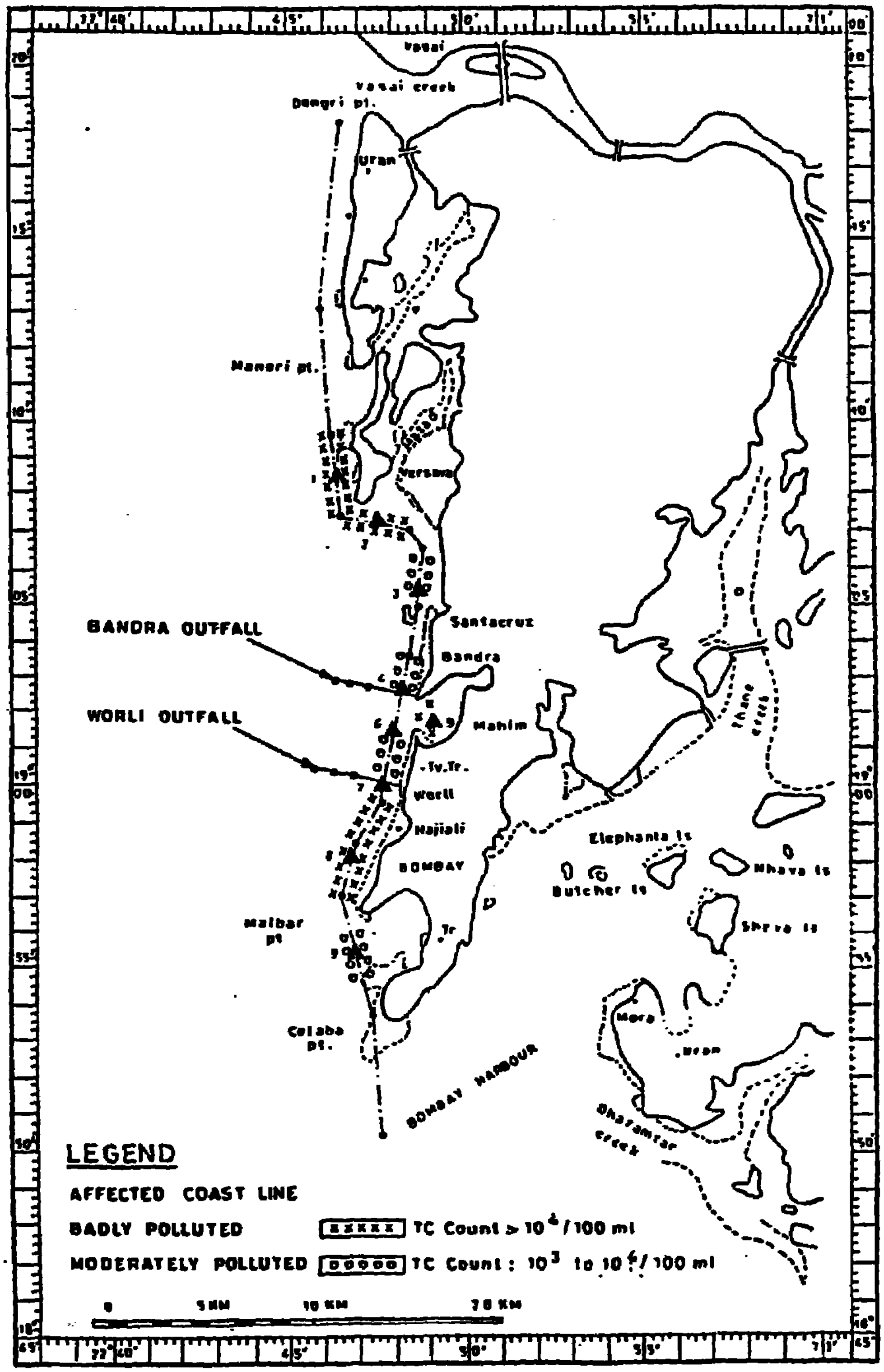
The stations 2,4,6,8, and 9 were moderately polluted during winter and summer seasons suggesting very little effect of seasonal variation, (Table A 5.23) Station 5 was badly polluted in both seasons. However, stations 1,3, and 7 showed a seasonal shift from winter to summer towards improved quality either from moderately polluted to cleaner or badly polluted to moderately polluted conditions. Such shift may be due to bactericidal effect of higher insolation in summer.

Low tide bacterial quality

Majority of the sampling stations show same low tide bacteriological quality during summer and winter (Table A 5.24). Stations 1 and 8, however, show improvement from badly polluted quality during the winter to moderately polluted quality in summer (Table A 5.23). Although station 2 is categorised as grossly polluted in summer and badly polluted in winter, it may be considered as a borderline case since only one sample out of five exhibited counts exceeding 100,000 per 100 ml in summer. In the context of variations in bacteriological quality with tide, stations 4,5,6 and 9 exhibit similar bacterial quality under high and low tide. The other stations were observed to be more polluted during low tide than during high tide. The existing bacteriological quality status at the coast line during the low tide in winter is shown in Figure 5.10.

These results comprehensively suggest that the lowest bacteriological quality is observed during the low tide condition. It may, therefore, be underscored that a surveillance monitoring programme, until the wastewaters are completely diverted, be targeted to delineate the low tide water quality status. After the diversion the monitoring strategy should focus on advection and dispersion of pollutants.

Figure 5.10 : Present microbial quality at reference line



5.3.5.3 BIOLOGICAL PARAMETERS

Phytoplankton

The analysis of data on phytoplankton counts at the nine stations along the reference line shows a general trend of increased productivity during summer in comparison with winter (Table A 5.25 through A 5.29). This may be attributed to higher insolation during summer. The observations also exhibit inter-tidal variation with the low tide counts being generally higher than the high tide counts which may be attributed to suspension of benthic algae in the shallow waters.

The observed summer counts at stations south of Mahim bay occassionlly exceed 10^3/100 ml and indicate mildy eutrophic conditions. Bacillariophyceae group has been found the dominant group of algae. Their percent occurence increases during the high tide indicating the influx of fresh sea water into the region. Among other algal groups, considerable occurrance of indicator groups such as Euglenophyceae, Chlorophyceae and Cyanophyceae have been observed in many regions which also show higher pollution in terms of physio-chemical and bacterial parameters.

Zooplankton

The results of the zooplankton analysis at the sampling stations are presented in Table A 5.30 throughA 5.33. The numbers of zooplakton exhibit a seasonal variation, the winter values being higher than the summer. The higher counts may be associated with increased reproduction rates for most of the zooplankton during the winter. This also may have a bearing on lower phytoplankton counts observed during the winter at some of the stations.

5.3.6 BEACH WATER QUALITY

Visiting beaches for recreation is one of the greatest attraction for the citizens of Bombay. Beach water quality is desirable to be safe and relatively free from objectionable contaminants so that harmful effects can be avoided during bathing or contact water sports.

Four frequently visited beaches viz., Girgaum, Worli, Dadar and Juhu were selected for water quality monitoring. Water samples were collected for evaluation of physico-chemical, bacteriological and other biological parameters. Sampling was done for five days during both winter and summer. During the sampling programme influence of tidal variations on water quality could not be considered due to logistic difficulties in collecting the samples during the full tidal cycle.

5.3.6.1 PHYSICO-CHEMICAL PARAMETERS

The results of physico-chemical analysis are presented in Tables A 5.34 and A 5.35. Beach waters were characterised by high turbidity which exceeded 30 NTU at many occassions. During winter, the DO values at Girgaum ranged from 2.7 to 4.7 mg/l whereas higher DO concentration was observed during summer ranging from 5.1 to 6.5 mg/l. Similar trend was observed at Worli and Dadar. However, Juhu showed higher DO during winter than during summer.

BOD values were less than 10 mg/l at all times during winter in all the beach water samples. Significant fluctuations were observed in BOD values during summer. Dadar showed higher BOD values in the range of 2.0-37.0 mg/l. The BOD levels frequently exceeded the tolerance limit of 5 mg/l for coastal receiving waters (Table A5.35). Nutrients like ammoniacal-N and soluble phosphate did not show much variation during winter whereas significant variation was observed in summer. Results of heavy metal analysis for total metals indicate the concentration levels comparable to standards for potable water for most of metals (Table A 5.36). However, chromium levels in few samples were observed above 0.2 mg/l.

5.3.6.2 BACTERIAL QUALITY

Examination of bacteriological quality of beach waters is of prime concern for public health reasons. Though a significant correlation of the infections caused due to contact with polluted waters has not been established, the possible risks associated, have provided the basis for delineating standards for bathing waters in the various developed and developing countries. In the Indian context, receiving water quality standard based on the best designated use, for bathing, fishing and navigation have been prescribed which specify 1000 total coliform CFU (colony forming units) per 100 ml at all times. Beach water samples have been assessed on the basis of this criterion.

Water samples were collected for five successive days during winter and summer and analysed for TC by the membrane filter technique.

Results and interpretation

Due to the variations in observed counts, it was imperative to categorise the observations into ranges rather than comparing the absolute values while evaluating the water quality. Four ranges were specified for each beach water sample and frequency distribution of number of samples exhibiting counts in those ranges was identified. If a sampling location exhibited the TC counts lower than the stipulated limit of 1000

CFU/100ml at all times, it was designated as clean station. The stations exhibiting TC counts in the range of 1000 - 10,000 per 100 ml, with less than 20% of samples exceeding 10,000/100 ml, were designated as moderately polluted (MP). Sampling locations showing TC counts in the range of 10,000-100,000 per 100 ml were assigned to the badly polluted (BP) category, while those showing TC counts greater than 100,000 per 100 ml at any time, were assigned the grossly polluted (GP) status.

The results of frequency distribution of samples at the four beach locations are given in Table A 5.37 for summer and winter TC counts. It is inferred from the observed data that similar quality status exist in both the seasons. None of the beach locations were found to be 'clean' as none of the samples during both seasons showed counts within the prescribed level. Girgaum and Worli remained grossly polluted during both summer and winter. However, Juhu and Dadar were observed to be more polluted during summer than during winter.

5.3.7 SEDIMENT QUALITY

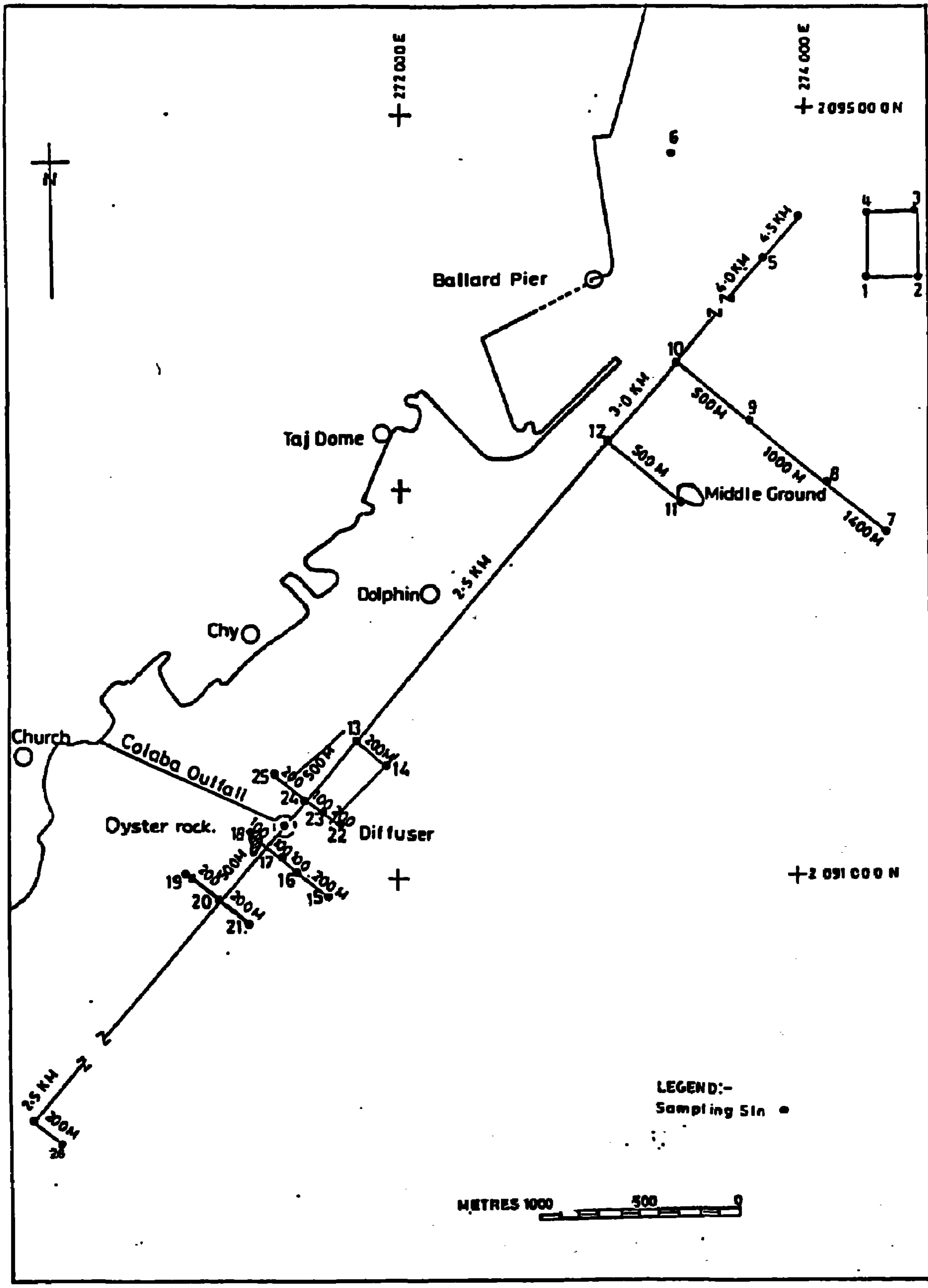
Sediment samples from Worli and Kashid bay at near shore and 30 km points and at all sampling points along the reference line were collected using dredge of 1 kg capacity. With the objective to have an estimate of impacts of sewage discharge on sediment quality, sediments were also collected from the vicinity of existing Colaba outfall. The area selected for sampling and location of sampling stations with respect to Colaba outfall are shown in Figure 5.11.

In order to establish the degree of pollution in the vicinity of outfall diffuser and in the nearby region by comparing with relatively unpolluted regions along the reference line, locations representative of relatively polluted and unpolluted stations were selected for sediment characterization. Therefore, samples from stations 1,2,6,7,9 at reference line and those from regions of Colaba outfall were analysed for nutrient parameters viz., nitrogen and phosphorous and trace metals. In addition, sediments from stations 2 and 5 from reference line and those from stations 18 (immediate vicinity of diffuser), 20 and 13 (500m upstream and downstream) at Colaba (Figure 5.11) were analysed for detergent content. For benthos, samples from reference line stations and those from 30 km line at Worli and Kashid bay were selected.

5.3.7.1 NUTRIENT PARAMETERS

Near shore samples at Worli and Kashid bay exhibited total nitrogen content of 4300 and 3500 mg/kg while the respective 30 km samples showed nitrogen content of 3700 and 2600 mg/kg. Total phosphorous content in near shore samples at Worli and Kashid bay were 2600 mg/kg and 2500 mg/kg and 30 km distance samples exhibited total phosphorous contents of 2000 and 1370 mg/kg. The results of chemical analysis are

Figure 5.11 : Sampling stations near Colaba outfall for sediment quality



Low detergent concentrations indicate absence of their accumulation in the sediments and may be attributed to the lower concentration of detergents in sewage itself (section 5.3.8.1). There may also be a possibility of biodegradation of the detergents in the sediments.

5.3.7.4 BENTHOS OR BOTTOM FAUNA

Benthos are the organisms inhabiting the bottom of an aquatic body. Many of them are sessile, some creep over or burrow in mud of the water body. Distribution of benthic fauna in the sea bottom is a function of temperature, salinity, nature of the bottom deposit and food supply. Depending on the size, the benthos are divided into two groups : a) animals retained on the sieve of 500 μm mesh size termed as macrobenthos, which include bivalves, gastropods, annelid worms and a few bottom-dwelling fishes, and b) animals passing through 500 μm sieve but collected on 45 μm sieve known as meiofauna. The formaminifernas and nematodes are the dominant groups of meiofauna.

Table A 5.46 shows the distribution of Benthic fauna at Worli and Kashid bay regions. Foraminifera was found to be the dominant group in majority of the samples. In samples where foraminiferans were absent, Rotifera, Polychaeta, Copepoda and Stomatopoda were found to be other major groups. At stations along the reference line, Foraminifera was found to be dominant group. The observations were consistent during both winter and summer (Tables A 5.47 and A 5.48).

5.3.8 WASTEWATER QUALITY

Domestic wastewater generated in Bombay city is being discharged into sea through seven service areas namely, Colaba, Worli, Bandra, Ghatkopar, Bhandup, Malad and Versova. Out of these Worli and Bandra drainage zones discharge directly on the west coast. Expected wastewater flows for these zones in the year 2005 are 5.9 m^3/s and 6.4 m^3/s respecticely. Estimation of the impact of these discharges on the receiving marine environment entails their characterisation.

Wastewater samples from above mentioned service areas were collected for physico-chemical and bacteriological analysis. Grab composited samples were collected over a period of 24 hrs. at the interval of 4 hrs. Due to lack of proper flow measuring devices at the pumping stations, flow composited samples could not be collected. The composite wastewater was characterised for physico-chemical, nutrient, trace organics, heavy metal concentrations and microbial quality. Analytical results are presented in Tables A 5.49 through A 5.52.

Observations on TDS, chlorides and sulphates in the wastewater reveal infiltration of sea water at Colaba and Worli pumping stations. The concentrations for other parameters are comparable with normal quality of domestic wastewaters.

Sewage samples from all the pumping stations show very low concentrations of heavy metals. Although their presence in sewage suggests possible influx of industrial wastewaters in to the sewrage system, the observed concentrations are much below the prescribed limits for sewage effluents (IS 2490).

5.3.8.1 TRACE ORGANICS CONTENT

Trace organics constitute compounds like Detergents, Phenols, Polynuclear Aromatic Hydrocarbons (PAH), Pesticides etc. Detergents enter waters and wastewaters mainly by discharge of aqueous and household laundering and other cleansing operations. In environmental waters, the detergent concentration generally is below 0.1 mg/l except in the vicinity of an outfall or other point source of entry (Arthur, 1977).

Sewage samples from 5 pumping stations viz., Colaba, Kharwadi, Malad, Versova and Worli pumping stations were analysed by the Methyl Green method (Moore and Kolbeson, 1956). The detergent contents are quite low and do not show significant variation (Table A 5.53).The highest values were for Colaba and lowest for Versova. Comparison with the Receiving Water Quality Standards for fresh surface water for Alkyl Benzene Sulphate content of 1.0 mg/l reveals that the detergent contents of Bombay's sewage are well within this permissible limit.

5.3.9 SOLID WASTES CHARACTERIZATION

The operation of prelimimary treatment facilities at three outfalls, shall result in the production of screenings and grit wastes. If improperly disposed, these wastes may give rise to foul odour, fly breeding and pollute the near by areas. In addition to attracting flies, poor solid waste disposal practice may also lead to other vermin such as scavenging birds (crows, mynahs), rats and mice and perhaps dogs.

Selection of a proper methodology for disposal of screenings and grit is governed by the characteristics of these wastes. The solid wastes generated at the existing facilities were analysed to obtain data on their organic/inorganic content, moisture content, particle size and calorific value, so as to enable the choice of a suitable management option.

Screenings

Samples of screenings were collected from four pumping stations which were analysed for their physico-chemical characteristics. The detailed results are given in Tables A 5.54 and A 5.55. Physical analysis indicates that most of the screenings are not biodegradable and only 15 to 25 % of the screenings are compostable. Average moisture content of the waste ranges from 65.7 to 73.7 % and C/N ratio varies between 19.3 to 22.9%. The screenings are therefore not suitable for composting. The average calorific value is found to be 690.0 Kcal /kg. The low calorific values and high moisture contents of the screenings render them unsuitable for incineration. However, these wastes contain some putrifiable fraction which may decompose and cause odour problems. Screenings should, therefore, be transported as early as possible after collection to disposal site. Observations on heavy metals indicate low concentrations and, therefore, the screenings may be disposed off along with city refuse.

Grit

Grit consists of the solids which are removed from the grit chambers. At the initial stage grit samples were collected from two existing sources namely Colaba and Lovegrove pumping stations. These samples were analysed for particle size and basic physico-chemical characteristics. The results are presented in Tables A 5.56 and A 5.57.

A few grit samples collected from Love Grove treatment plant were also analysed for various particle sizes and heavy metal distribution. The detailed results are given in Tables A 5.58 and A 5.59 respectively. The data indicate that the organic fraction (loss on ignition) decreases with decrease in particle size. Phosphorous and Potassium were also distributed in a similar way. The C/N ratio, however, varied in reverse order. Heavy metal distribution among the variable size grit particulates was more or less uniform and does not show any variation for the metals analysed. The overall concentrations of hevy metals in grit are well below the levels prescribed for their land application (WPCF, 1989).

Presently, most of the solid wastes generated in Bombay are being disposed at locations identified by the MCGB, which have been considered for disposal for screenings and grit. Present estimate from two pumping stations is not more than 1-2 trips of solid wastes generated per day. As this quantity is negligible in comparison to the 3500 tonnes of city refuse generated daily, screenings and grit can be disposed along with it and is not expected to cause any additional impacts.

5.3.10 SOCIO-ECONOMIC STUDIES

Assessment of socio-economic impacts is an integral part of environmental appraisal of any development project. Construction and operation of marine outfalls is likely to have such impacts on the population proximal to the site of outfall, fishing communities and the beach users. Importantly, there are some apprehensions regarding a reduced fish yield due to operation of the outfalls.

To assess the socio-economic impacts of the proposed project an intensive survey was conducted covering all relevant communities. The survey involved a heterogeneous population in terms of income, occupation and several social parameters. It was observed that the affected population groups in the region could be divided into three categories viz. the fishing community, the residents proximal to the site and the beach users.

The survey aimed at collecting information on the baseline socioeconomic status of effected population groups and awareness, opinion and perceptions of the project among fishing communities and beach users.

5.3.10.1 BASELINE STATUS

The important socio-economic parameters which delineate the baseline status of a community are its population characteristics, health status and availability of essential amenities such as housing, water supply and sanitation; and education, medical, communication and recreational facilities. Following sections summarize information collected on these aspects.

Demography

This study refers to the areas in the vicinity of the proposed marine outfalls. The wardwise population of these areas is presented in Table A 5.60.

Bombay by virtue of its being an island city has a large coastline and hence fishing is also a source of livelihood though restricted to a few communities residing along the coastal areas viz., Mahim, Colaba, Versova, Worli and Trombay. Tables A 5.61 through A 5.64 gives details of fishermen population, fishing boats and fishing nets for Greater Bombay, Thana and Raigad districts. The fishing activity in Greater Bombay has been on a smaller scale as compared to that in Thana and Raigad. This is confirmed again by the lesser number of fishing equipment in Greater Bombay as compared to that in Thana and Raigad districts. The fish yield in Greater Bombay is much lower as given in Table A 5.65. The yield of some of the edible species of marine food over the past decade has declined which could be attributed to lack of proper fishing gear and hence due to underfishing in the greater Bombay region.

The fish catch data provided by the Central Marine Fisheries Research Institute (CMFRI) Cochin, shows wide variation (Table A 5.65) which could be due to fluctuations in operation of specific gears in different zones and within quarter of a year.

Health status

Table A 5.66 presents data on the number of patients registered suffering from diarrhea and vomiting due to gastro-enteritis from Kasturba Gandhi hospital which caters to the cases of infectious diseases. The data provides the number of deaths from gastro-enteritis (1981 to 1990). This data excludes cases of infantile diarrhea. It is evident from this data that there is a sharp rise in the number of cases of death resulting from diarrhea during the the monsoon period (July - August).

Table A 5.67 depicts cases and deaths registered from poliomyelitis during the period between 1981 and 1990. Once again it has been observed that cases of poliomyelitis are more prevalent in the monsoon periods.

The increased incidence of gastro-intestinal disorders during monsoon resulting from consumption of non-potable water could be attributed to contamination at the user end. Open defecation in the nearby shore regions which also serve as recreational sites for individuals and children, may also be a cause for some skin and diarrhoeal disorders.

Socioeconomic indicators

As the present study involves various communities, with different occupations and lifestyles, data on pertinent socioeconomic indicators like literacy, demography, employment, provision of medical, educational, transportation and communication facilities; power consumption etc. were collected and are presented in Table A 5.68.

5.3.10.2 PRELIMINARY FIELD SURVEY

Several visits were conducted to the proposed sites for marine outfalls and the neighboring areas to conduct the survey. Information was generated through questionnaires as well as personal interviews. In order to include diverse groups of the population and to make the survey more comprehensive, three different questionnaires were prepared for the three major population groups viz the fishing community, beach users and residents living in the neighborhood of the proposed project sites.

The survey addressed to the following issues:

i. Onsite environmental conditions

ii. General community structure with special reference to occupation

iii. General and environmental problems

iv. Sensitive issues

v. Environmental awareness and opinion of the community with reference to the proposed project.

Residential Areas

For residential areas about 50 to 100 persons were interviewed at each location. The subjects were generally co-operative. The responses however were overwhelmingly similar on their awareness of Bombay Sewage Disposal project and other relevant environmental issues. Despite the small sample size, in view of the general similarity of responses, it may be considered that a representative view has emerged on socio-economic aspects of the project through this survey. The salient findings of the survey for residential areas of Bandra, Worli and Colaba are as follows:

a. Bandra

The settlement near the Mahim bay road bridge where sewage pumping station is presently located, has 30-40 pucca dwellings which are about 75 years old which have recently increased by about 500 huts. The total population of this settlement is nearly 5000 with majority of them being fishermen. Basic amenities in this settlement are poor.

People in this area complained of persistent offensive smell due to uncontrolled discharge of wastewater. The odour intensifies during low tides. This odour problem causes discomfort and nausea to the local inhabitants.

Fish catch from Mahim bay has dwindled considerably in last 10 years. Fishermen of the area attributed this to discharge of wastewater. At present there are only 125 small boats operating at Mahim Bunder.

Awareness about the proposed marine outfalls construction among the fishermen is rather meagre. However, fishermen referred to earlier work involving laying of pipes for marine outfalls.

The sensitive issue here appears to be laying of pipeline. The fishermen feel that their opinion should be sought as, according to them, this exercise has some linkage with fish catch and if not properly done it may interfere with the fishing activities.

b. Worli

The settlements close to the site are of two types : MCGB Quarters and Worli village, Koliwada on either side of the drain discharging sewage into the sea. Occupants of the MCGB colony are mostly MCGB employees whereas those at the village are mostly fishermen besides labourers, residing in Kutcha houses.

Survey among the MCGB Colony brought out the following facts :

* Significant discomforts experienced by the occupants during earlier blasting operation in 1985-86 for the construction of marine outfalls at Worli. The main objection was the loud noise and vibrations causing damage to the buildings. Blasting in odd hours viz. 0600 hrs and 1200 hrs causing inconvenience and discomfort were other objections raised by the dwellers. Occupants suggested that suitable time for blasting in future would be 1200 hrs to 1500 hrs.

* The blasting work also resulted in dust problem

* Sea water enters the premises through drains during high tide and emits offensive odour.

* In general there is a persistent obnoxious odour of fish in the area which intensifies during the morning hours. It was expressed that intensity of odour has reduced in the past 3-4 years.

* Residents of the Worli village also expressed inconvenience and discomfort caused due to persistent odour nuisance which is more predominant in monsoon causing health discomforts viz. headache and nausea. In this village awareness about the proposed work appears to be rather low.

c. Colaba

It was felt that observation of the existing conditions at the Colaba outfalls may provide guidelines in formulating Environmental Management Plan for the proposed marine outfalls at Bandra and Worli. The Sassoon Dock area was visited and following observations were recorded :

* Fish catch from the nearby areas has considerably reduced in past 10 years. But this was not attributed only to sewage discharge. The contributing factors according to fishermen are increase in number of trawlers; extensive fishing leading to exhaustion of breeding stock; and inability of small boats to go into deep waters. The fishing nets were observed near the outfall point also.

* Fish catch is higher in monsoon period may be due to spawning

* Sewage odour in the area is not much, however fishy odour persists

* Those interviewed in this area are not aware of the Bombay Sewage Disposal Project.

Beaches

Although Greater Bombay has a large coastline, it is mostly rocky. The city therefore has only three important beaches namely, Girgaon Chowpati, Dadar and Juhu. The city of Bombay like many other metro cities in the world faces problems like overcrowding, shortage of other basic amenities including those for recreation, housing etc. These beaches, therefore serve as an important source of open space for recreational activities like walking, strolling, picnics and other water sports. Housing problems in Bombay have led to the proliferation of slums along the coastline near the creeks and beaches. With in sufficient sanitation facilities, defecation in such open areas has been commonly practised, leading to beach water contamination and poor beach aesthetics.

Relevant observations pertaining to each beach were recorded and are presented below :

a. Juhu

The beach is very scenic and a beautiful one. Though this beach is located in the suburbs, the number of visitors has increased considerably over a period of time which may be attributed to increasing population in the suburbs and non-availability of alternate recreational facilities. Spot interviews were conducted on a random sample of visitors. The information so obtained revealed following significant observations :

* Barring 20% of the respondents, all others were residents of Bombay and indicated that they visited the beach regularly.

* 70% of the respondents indicated their liking and preference for this beach.

* 60% of the respondents felt the beach is very crowded and they attributed it to litter disposal (40%), sewage disposal (10%) and other causes such as hawkers spoiling the beach quality, animal dung etc.

* Only 22% respondents were aware about the Bombay Sewage Project. They opined that the project would result in improvement of the beach environment in general. Improvement in water quality has been indicated by a negligible section of the respondents (3%).

b. Dadar

This beach is located in a rather densely populated residential area of the city. The residents comprise of largely working class people of middle to upper middle income group. There are not many open parks and gardens for a leisure walk. The sidewalks cannot be used much for jogging and leisure walk as they are crowded with vendors. The traffic is very heavy on the streets. Hence the beach serves as a the main open space for a lot of recreational activities of people of all age groups. The stretch of this beach is not as long as Juhu or Chowpati, however, it attracts a lot of visitors and is fairly crowded. Unlike Juhu, there is definite deterioration in the beach quality due to its nearness to Mahim bay discharging the wastewater generated in Bandra service area into the coast. Besides this, factories in the local area discharge their wastes into the sewage drains in the area, as expressed by regular visitors to the beach.

Salient features pointed out by the beach users during the spot visit and interviews on random sample basis are :

* Most of the respondents were residents of Bombay (92%).

* 90% of the respondents attributed their visit to the beach due to preference for the beach, nearly 50% mentioned the closeness from their residence.

* As regards environment on the beach 60% felt it to be good. 15% were unable to give any specific opinion.

* According to 40% of the respondents, the beach was crowded whereas 60% do not think so.

* 75% of the respondents thought the beach to be aesthetically dirty. According to them this was due to sewage disposal (50%, litter disposal (40%), 10% of the respondents were noncommittal.

* Awareness about the Bombay Sewage Disposal Project is much better (50%) and this can be attributed to the construction site at Bandra which can be visibly seen from the beach.

* As regards the opinion about the possible impact of the project with reference to improvement in beach environment, water quality and aesthetics, 70% of the respondents were unable to opine and only 20% expressed that impacts will be positive.

  However, it was generally expressed that MCGB should improve the beach quality for the benefit of the tax payers.

c. **Chowpati**

The expanse of the beach has been reduced considerably due to installation of various food stalls and small shops on the beach. This has adversely affected its beauty and has led to unaesthetic, unhygienic and dirty conditions on the beach.

The other alarming situation on the beach is the discharge of the sewage effluent at some distance towards Walkeshwar side which can be visibly seen.

A random survey of the beach users brought forth following salient observations :

* Most of the respondents were residents of Bombay (85%).

* The beach was reported to be having a good environment by almost all the respondents. However, this cannot be attributed to the cleanliness of the beach because as many as 70% respondents said the beach to be dirty. The reason for the beach to be called as 'good' appears to be its popularity due to its location in the heart of the city as well as its usage since long.

* Awareness about the Bombay Sewage Disposal Project appeared to be rather poor. But from amongst those who knew about the project 30% felt that the project would improve the beach quality with improvement in water quality and aesthetics.

5.4 CONCLUSIONS

The present wastewater discharges have resulted in poor water quality in many regions along the west coast. Higher levels of pollution are observed during the ebb tide in comparison to the flood tide. Observations on bacterial quality along the coast show frequent occurrence of total coliform concentrations between 10^4 to 10^5 per 100 ml for about one third of the 24 kilometer long coastline. Only about 25 percent of the total observations show compliance with the present bacterial standard. Bacterial quality of water at four main beaches at Bombay also reveals moderate to high levels of pollution.

Observations on dissolved oxygen levels (DO), indicate that about 5 kilometers of the coast are highly polluted. These regions are near mouths of Malad and Mahim creeks, through which large quantities of wastewater reach the coast (more than 50 percent of total discharges on the West coast of the city). During the low tide dissolved oxygen levels in these regions invariably fall to less than 2 mg/l indicating severe stress on ecosystem. An additional length of about 8 kilometers exhibits moderate oxygen depletion during the low tides, the dissolved oxygen levels occasionally falling to less than 4 mg/l. Only about 10 kilometers of the coast line exhibits acceptable levels of dissolved oxygen.

Concentrations of Biological Oxygen Demand (BOD) at the reference line are generally low (less than 5 mg/l) indicating considerable dilution and decay before the pollutants reach the reference line. Ammonia-N levels are in the range of mildly polluted coastal waters whereas phosphates are close to levels observed in clean sea.

The nutrient levels in sediments are observed to be higher during winter than summer. These levels, however, are similar in polluted and clean regions and therefore do not indicate accumulation of nutrients in sediments due to sewage discharges.

Amongst the phytoplankton, considerable occurrence of indicator groups like Cyanophyceae have been found in many regions which also show higher pollution in terms of physico-chemical and bacterial parameters. This observation also signifies contamination of coastal waters due to organic pollutants.

The analysis, however, does not indicate any significant contamination due to toxic inorganics (metals) or organics in water or in sediment samples. The possible explanation for these observations lies in the low levels of metals and toxic organics observed in the wastewater. The sediment and water samples, even from those regions which exhibit higher bacterial contamination and low DO, do not show significant variations in trace organic/inorganics concentrations when compared with the levels from clean regions.

Three beaches along the west coast of Bombay attract a large number of visitors. The results of spot interviews with the beach users indicate that though many of the users are frequent visitors to the respective beaches, they avoid bathing and swimming due to poor quality of beach waters.

Air quality analyses at Worli and Bandra outfall sites indicate that present air quality in terms of SPM,NO_2 and SO_2 at both sites fall within Indian standards for ambient air quality. The values for Worli, however, suggest that lower assimilative capacity is available in the region for further discharge of pollutants. Similarly, observations on noise levels at Worli slightly exceed the upper threshold limit prescribed for urban residential/commercial areas.

Chapter 6

MATHEMATICAL MODELLING

6.1 PREAMBLE

Like all developmental projects, construction and operation of marine outfalls can have a variety of environmental impacts. The most prominent and lasting of these impacts occur during the operational phase of the outfalls and are manifested as alterations in ambient water and sediment quality. A number of factors including catchment characteristics and sewage flows, headworks processes, outfalls and diffuser hydraulic characteristics, mixing, dispersive and assimilative characteristics of the receiving waters determine the extent and intensity of these impacts. The range of such impacts is restricted mainly to the coastal sea roughly equivalent to the length of tidal excursion in the region.

Quantitative assessment of the impacts on ambient water and sediment quality is an integral part of outfall design. Since, the wastewater discharged into marine environment is diluted, dispersed and advected through the ambient currents and turbulent mixing caused by the diffuser mechanism of the outfall itself, considerations of these factors in association with simpler assimilative processes, provide an adequate framework for their assessment.

Construction activities associated with the outfalls may also have potentially adverse environmental impacts which entail mitigation. Ground vibrations due to blasting operations and noise and air pollution near the construction sites due to operation of construction machinery and vehicles are the major construction impacts which can be forecasted through mathematical models.

6.2 ROLE OF MATHEMATICAL MODELS

Due to inherently dynamic character of even simpler marine interactions, mathematical modelling provides the best tool for their analysis. These models attempt to simulate the physico-chemical and biological processes which occur in the marine environment and determine the fate of the discharged pollutants. Mathematical models invariably take recourse to simplified assumptions while simulating these processes but perhaps are the only practical method for their quantification.

The secondary and tertiary impacts on aquatic environment such as pollutant build-up in sediments, benthic and aquatic fauna through adsorption and bioaccumulation and impacts of nutrient enrichment on aquatic flora involve far more complex multispecies-multicomponent interactions. Mathematical models, without extensive data support, have little role to play in simulating these processes. The inherent uncertainties in the prediction of these parameters through mathematical models also underscore the desirability of adopting a qualitative approach for assessing these impacts.

For coastal processes, therefore, the main thrust of the modelling efforts in this study has been to simulate the processes of initial dilution and secondary dispersion. The possible impacts of secondary and tertiary nature have been studied through observations of those regions of the coastline which have been receiving the sewage discharges over a significantly long time and could be expected to provide indication of long term effect of such discharges on coastal ecosystem.

For construction phase vibrational impacts, regression models developed from in situ observations and for noise impacts, models considering propagation of hemispherical sound wave through homogeneous media have been used.

Before its use in field application, a mathematical model to be used, in practice entails its calibration and verification. The remaining parts of this chapter detail the models used in this study and discuss the experiments and data collection programmes undertaken for their calibration and verification. Special emphasis has been given to the models for simulation of coastal processes due to their overriding importance in deciding the outfall lengths and diffuser section design for compliance of coastal bacterial quality standards.

6.3 SELECTION OF MODELS FOR COASTAL PROCESSES

After discharge from outfalls into the marine environment, wastewater discharges undergo two distinct processes. The first is known as initial dilution and occurs under the mixing created by ambient and jet induced turbulence and the effluent buoyancy. During this process the wastewater discharged through the diffuser ports rises to the surface from its discharge point near the sea bed. Wastewater mixing with the surrounding sea water during this phase, which lasts only for a few minutes, is quite vigorous and causes rapid dilution of wastewater, often, over a range of 50 to over 1000 times subject to the depth of release and ambient conditions. The region of initial dilution is termed as near field region. The process of initial dilution is considered terminated either when the mixed wastewater reaches the water surface or when the mixed plume becomes stable at some intermediate water depth and levels out parallel to the surface establishing the wastefield.

The established wastefield tends to drift with the ocean currents in a region often called far field and the process is termed as advection. During advection, the wastefield continues to undergo the processes of spreading, mixing and decay which reduce the pollutant concentration in the wastefield. The overall effect of these processes is termed as secondary dispersion. The assimilative processes such as microbial decay, carbonaceous BOD removal and reaeration etc. also play significant roles during the processes of secondary dispersion. Although, pollutant concentration reduction during the secondary dispersion occurs at a much slower rate in comparison to the initial dilution, it generally lasts for much longer. As a result the secondary dispersion may play a more important role in wastefield dissipation than initial dilution. The factors governing secondary dispersion, therefore, entail special attention while evaluating the impacts of marine outfalls. Finally, exchange rates on continental shelf scales and biological and chemical decay processes determine the long term building of contaminants.

6.3.1 INITIAL DILUTION MODEL

The dilution obtainable with a diffuser is primarily a function of the discharge, the effluent buoyancy, the depth of water and the ambient current. The initial dilution may be further influenced by the angle of discharge, port size, jet velocity and stratification of the receiving water.

In the still water case, the water over the outfall is considered stationery and the initial dilution creates a buoyant surface field, which flows away from the outfall due to buoyant spreading or marginally small currents. The effect of the ambient current fundamentally changes the initial dilution and therefore, the still and moving water cases must be considered separately. For initial dilution dominant parameters are discharge, buoyancy, depth and ambient current.

The effect of discharging the effluent into moving water is to create forced entrainment of the effluent in the sea water and hence increase the dilution. The most commonly used prediction for initial dilution (in UK) is given by Agg (1978). This formula was based on the results from six field experiments carried out on UK sea outfal's where initial dilutions were measured under a variety of tidal conditions.

Work by Bennett (1983), Bettess and Munro (1981) and at WRc showed that the moving water equation by Agg (1978) should be regarded as approximate and typically underestimates the dilution obtained in the field. For this reason WRc have recently reworked the field and laboratory data of the above authors (Lee and Neville-Jones (1986) and interpreted it using a length scale analysis. This analysis is similar to that used by Wright (1977) and expresses the discharge in terms of buoyancy, volume and momentum fluxes.

For a buoyant jet the jet behaviour is dominated by momentum close to the source and by buoyancy at large distances from the sources. In the case of a jet discharging into an ambient current the length scale $l = B/U_a$ represents the vertical distance at which the velocity induced by the buoyancy flux B has decayed to the ambient velocity value U. For water column height from diffuser Y << 1 the discharge can be linked to a vertically rising plume in still water but advected by the ambient velocity. This is termed as the Buoyancy Dominated Near Field (BDNF) an example of which is shown in Figure 6.1, where CL is the centre line of the plume. For Y >> 1 the jet is significantly bent over and the current dominated flow behaviour is termed as the Buoyancy Dominated Far Field (BDFF), in Figure 6.2.

The analysis of the field data in above studies using this technique has suggested the following correlations for the minimum surface dilution of a horizontal buoyant jet in crossflow:

BDNF :
$$S_m = \frac{0.31\, B^{1/3} H^{5/3}}{Q} \quad \text{for} \quad H < \frac{5B}{U_a^3} \qquad .....6.1$$

BDFF :
$$S_m = \frac{0.32\, U_a H^2}{Q} \quad \text{for} \quad H > \frac{5B}{U_a^3} \qquad .....6.2$$

Where, B = buoyancy flux of effluent discharge

$= Q\, g\, (\rho_a - \rho_d) / \rho_a$

and,

U_a = ambient current speed
H = water depth from point of discharge to free surface
Q = flow from each port of the diffuser
ρ_a = ambient water density
ρ_d = effluent density at point of discharge
g = acceleration due to gravity

The data available in above works was insufficient to produce similar equations for discharges into a coflowing current. The recent literature indicates that dilution in co-flowing current would be greater than in cross-flowing current. However, the difference is generally not significant and the above equations may be used to give a reasonable prediction for a coflowing current.

Figure 6.1 : Effluent plume in the buoyancy dominated near field

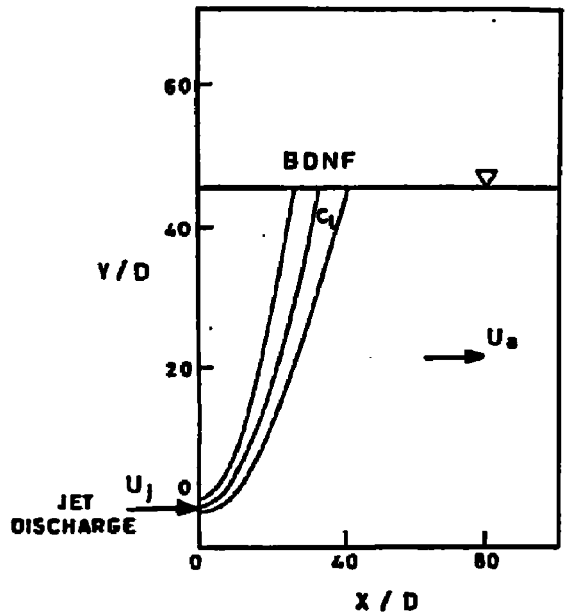
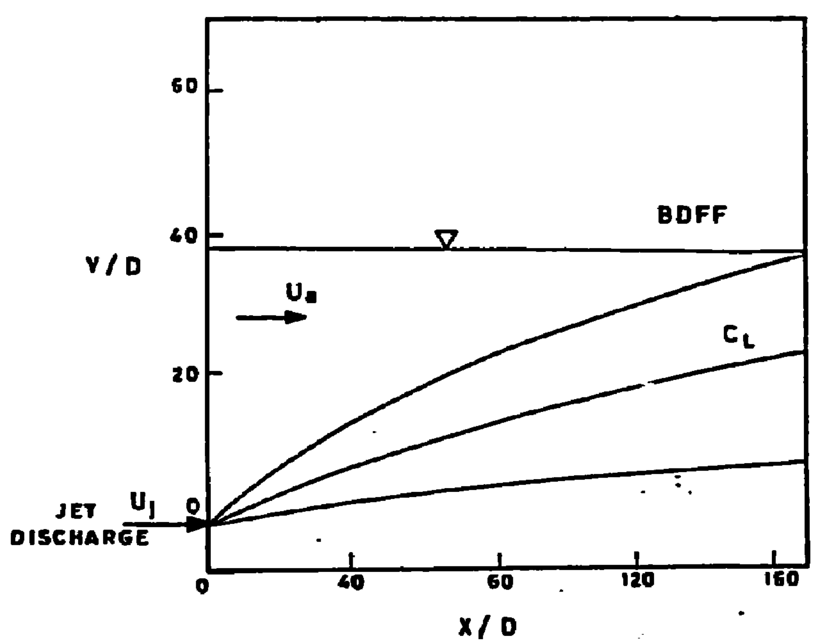


Figure 6.2 : Effluent plume in the buoyancy dominated far field



The dilutions obtained are minimum initial dilutions which are lower than the average dilutions. Average dilutions are obtained by multiplying the minimum dilution by a factor of 1.41 (Brooks, 1973) and are of most interest in secondary dispersion.

The mass continuity equation 2 should be used to check the reduction in dilution due to plume merging and as an overall check on dilution prediction. This checks that there is adequate water passing over the diffuser length to obtain the predicted dilution.

$$S_{max} = \frac{Q_a}{Q_j} = \frac{U_a bh}{NU_j \pi D^2/4} \qquad \text{..... 6.3}$$

Where,

S_{max} = maximum initial dilution for a long diffuser
Q_a = discharge of ambient sea water over the diffuser length
b = length of diffuser
Q_j = sum of the port discharges
U_j = jet velocity of discharge
h = depth of the effluent field, typically taken as 0.5H for the BDFF case
N = number of ports
D = port diameter

Moving water plume geometry

The size of the plume in moving water increases as results of the increased dilution. Presently there is limited experimental data available on plume geometry in moving water and most of the mathematical model predictions neglect the dynamic interaction of the plume with the free surface. However, it can be shown that for the BDNF case the plume width is similar to the still water case and for the BDFF the plume width considerably increases, as presented in Figures 6.1 and 6.2 respectively. For plume geometry in moving water when $U_a/U_j \leq 0.2$, the following relations are useful :

$$W = 0.3\ H \qquad \text{for } \frac{YU_a^3}{B} < 2 \qquad \text{...... 6.4}$$

$$W = 0.5\ H \qquad \text{for } \frac{YU_a^3}{B} > 2 \qquad \text{...... 6.5}$$

Where,

W = plume width (equivalent to h in Equation 6.3)

These equations are based on results of mathematical model predictions and an examination of existing data (Lee and Neville-Jones, 1986) and provide simple solutions for reliable conservative predictions. For greater depths and higher currents the plume width will approach 0.9H.

It is noteworthy that the models described herein for initial dilution calculations, do not consider density stratification of ambient sea water with depth, which can restrict the emergence of the wastefield to the sea surface and significantly reduce the initial dilution.

In fact, the ambient coastal conditions on the West coast of Bombay obviate the need for such considerations. The water depths at the proposed outfall diffuser locations at Worli and Bandra are less than 10 meters and the density profile collected in the region during the earlier studies indicate unstratified conditions even for the winter months. For the critical period of monsoon months when the wastefield is expected to travel at higher speeds due to added wind drag, no vertical stratification is expected.

6.4 FACTORS AFFECTING SECONDARY DISPERSION

Secondary dispersion is the mixing process which distributes the wastewater field in the marine environment and occurs due to :

- advection,
- secondary dilution,
- wind induced drift,
- sedimentation, chemical and biological dispersion, and
- water exchange.

Advection determines the movement of the wastewater field primarily with the ambient currents. Secondary dilution is the process of diluting the effluent following initial dilution, and occurs due to turbulence, eddies and shears induced by the water movement which mixes the wastewater into a progressively increasing volume of sea.

The secondary dilution processes may be impeded by the phenomenon of buoyant spreading. This occurs where the effluent reaching the sea surface forms a lower density surface field which mixes poorly with the sea water. The field's buoyancy causes it to spread out over the sea surface. However, if the difference in density is small this effect does not occur. It has been suggested that it can be ignored if the initial dilution is greater than 1:50 (WRc guidelines, ER209E). Buoyant surface fields are readily dispersed by wind induced turbulence, and hence are only likely to move shoreward as a coherent field, during exceptional weather conditions.

Onshore drift is usually a wind driven mechanism which may drive waterborne bacteria and contaminants towards the shore. The conventional method for the analysis of onshore drift is to assume the problem as horizontal transport of a constant thickness of pollutant travelling shoreward at a rate proportional to the wind speed (Wu,1968).

On release from outfall, certain pollutants may settle out by precipitation or be absorbed on to suspended solids, which may then settle out. Material which remains in the water column,may later be removed by settlement at slack tide, or by biological processes. Consequently contaminants become trapped in sediments. The danger with sediment trapped contaminants is that they may be released into the environment at a later date, due to physical, chemical or biological effects, such as storms agitating the sea bed, dredging, erosion, changes in salinity and changes in distribution of species. At present these processes are poorly understood and more research is required before they can be accurately predicted. Since, normally the concentrations of conservative contaminants in domestic effluents are low, these processes are not expected to be significant in the present application.

Water exchange reduces the concentration of contaminants in the receiving water by an exchange of contaminated and clean water with adjacent water bodies. Water exchange is only significant where the discharge of conservative contaminants is large in comparison to the volume of the receiving waters, so that a progressive build up in the background concentrations may result.

6.5 COMPUTER MODELS FOR SECONDARY DISPERSION

The processes of waste field dilution viz., dispersion, advection and decay require the use of computer models for understanding the complexity of the system. A good degree of realism may be obtained by using a hydrodynamic model to predict the pattern of tidal currents and hence the advection. The predictions should be calibrated and validated from field measurements. Hydrodynamic model output can, therefore, be used in dispersion models, which have been calibrated from dilution, dispersion and decay studies to evaluate the options under a variety of conditions.

As more sophisticated models can prove difficult to calibrate and are usually very costly to run, one should select the simplest model that will provide adequate answers to the problem. The sophistication of the model should also take cognizance of the availability of data for model calibration. Some of the available computer models for secondary dispersion simulation are, Brooks' model, Puff models and two & three-dimensional hydrodynamic models which provide input for dispersion models.

In this study, Brooks' model for prediction of secondary dispersion which may be run from current meter data and onshore drift predictions, has been used. The primary reason for using the Brooks' model had been the lack of data to run models of higher sophistication for the present investigation.

6.5.1 TRANSVERSE DISPERSION IN SEA

As a cloud of pollutants gets advected into the sea, it also undergoes the processes of spreading through the mechanism of dispersion generated by eddies. The eddies that influence the spread of the wastefield about its center are only those that have a scale smaller than the instantaneous size of the wastefield.

But as the size of the wastefield expands, it is apparent that eddies that were at one time considerably larger than the size of the wastefield (and would have been considered as an advective mechanism) become more significant in terms of causing spread of the wastefield about its center. As the wastefield increases in size, there are more and more dispersive eddies which enhance its spread. Thus, one can reason that the diffusion coefficient in the ocean should increase as the scale of the wastefield grows. Because the size of wastefield can be more easily visualized in terms of area than of a pure length scale, it is reasonable to assume that the diffusion coefficient must increase faster than the length scale of the wastefield. Experience suggests that a good relationship to use for diffusion in the open ocean relates the eddy diffusion coefficient ε to the four-thirds power of the length scale of the wastefield. This is expressed as Richardson's Law (Richardson, 1926; Stommel, 1949):

$$\varepsilon = \alpha \, . \, L^{4/3} \qquad \text{..... 6.6}$$

The proportionality coefficient α appearing in equation 6.6 varies significantly with local conditions and ambient turbulence. Due to the increased shear at the water surface its values at the same location can greatly differ for calm or wave environment churned up by a strong local wind. According to Koh and Brooks (1975), data indicate that the approximate range for is 1.5×10^{-4} to 5×10^{-3} $ft^{2/3}$ /s (6.8×10^{-5} - 2.3×10^{-3} $m^{2/3}$ /s). Pearson (1961) suggested $\alpha = 0.001$ $ft^{2/3}$ /s (4.53×10^{-4} $m^{2/3}$ /s).

The presence or absence of shore boundaries also exert an influence on the rate of spread of the wastefield. Richardson's Law is basically only for situations wherein there is unobstructed spread of the wastefield substance. In cases, where the spread of the wastefield is hampered by the presence of a coast, it is more reasonable to consider that the dispersion coefficient increases as the first power of the length scale of the wastefield.

On account of the wide range of α and its dependence on local wave climiate, while predicting secondary dispersion, it is desirable to estimate it through the field experiments for the current regimes representative of critical environmental conditions.

6.5.2 BROOKS' MODEL

The line source model considered by Brooks' (1959) is schematically presented in Figure 6.3. A continuous line discharge of a conservative solute gives rise to a wastefield of initial concentration C_o and width B which enters the current of speed U_a perpendicular to the line of source. As the effluent is swept downstream it spreads laterally due to diffusion and the plume width L(x) increases with distance x from the source. The peak concentration along the centreline $C_{max}(x)$, as a result, decreases with the increasing x.

Beyond the assumption of a constant current speed normal to the line source, Brooks made the following assumptions in solving for the concentration of contaminant at any downstream location.

- Vertical gradient is negligible.
- Mixing in the direction of the current is negligible
- The effluent moves with the current system.
- Mixing in the lateral direction can be described by the diffusion process with variable ε given by

$$\varepsilon = \alpha\, L(x)^{n_o} \qquad \text{..... 6.7}$$

Three different values of the exponent n_o: 0, 1, and 4/3 were considered by Brooks. The first of these corresponds to an assumed constant diffusion coefficient, the second is consistent with a coastline situation discussed earlier, and the latter conforms to Richardson's Law.

6.5.3 MODEL EQUATIONS

Brooks' model focuses on the concentration of the contaminant along the centreline of the plume. The predictions are in the form of centre line concentration of contaminant and the plume width as a function of distance from the source. The distribution of concentration across a cross-section at distance x is taken to be bell-shaped (normal or Gaussian distribution). The ratio of concentration $C_r(x)$ at a crosssectional distance r from the central line at point x, thus, as a function of r/L(x) can be obtained from the curve shown in Figure 6.4 or mathematical expression for Gaussian distribution. L(x), the nominal plume width at x is given by

$$L(x) = 2\sqrt{3}\sigma \qquad \text{..... 6.8}$$

Figure 6.3 : Schematic diagram for Brooks' surface plume model

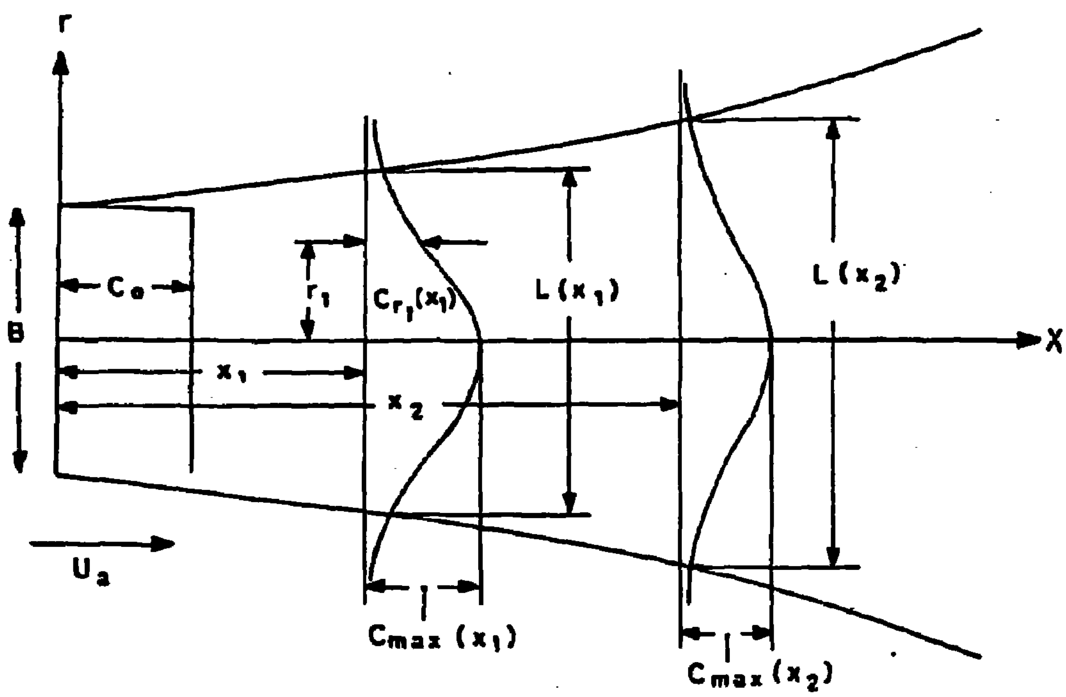
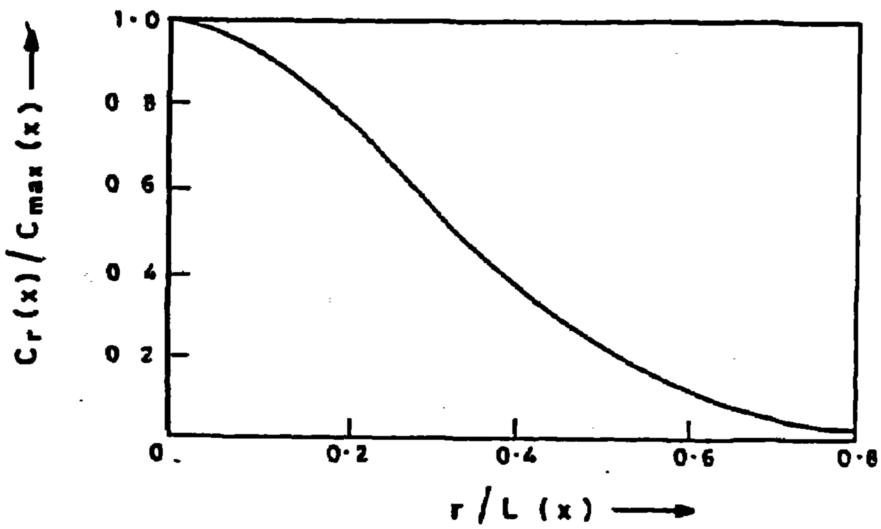


Figure 6.4 : Gaussian distribution for concentration distribution across surface plume



where σ is the standard deviation of the concentration profile at x. Since only 8.3% of a Gaussian distribution lies outside the limits of ±3σ, the use of equation 6.8 is admissible in terms of including the bulk of the contaminant while predicting the concentration at a distance x from the source. The analytical solution obtained by Brooks with the above assumptions have been summarised in Table 6.1.

Brooks' basic model ignores nonconservative substances. Brooks showed, however, that such substances can easily be accommodated assuming a decay equation of the form

$$C(x) = C_{max}(x) \exp(-k_o t) \qquad \text{..... 6.9}$$

The concentration of nonconservative substance can be computed from $C_{max}(x)$ and those across the plume by multiplying by a factor $\exp(-k_o x/u)$. If coliform bacteria are being considered as the nonconservative pollutants, then a design value of k_o can be derived from t_{90} data obtained through laboratory and/or insitu experiments.

6.6 MODELS FOR PREDICTION OF GROUND VIBRATIONS DUE TO UNDERGROUND BLASTING

A part of the chemical energy released during the blast is transmitted to the surrounding geological strata as mechanical energy and propagates through it in the form of an elastic blast wave. The propagation of the elastic blast wave gives rise to oscillatory movement of the ground particles. For the safety of surrounding structure the resulting peak particle velocity must remain within certain safe limits. Prediction of peak particle velocity as a function of charge size, distance from the blast site and characteristics of geological strata, is therefore necessary to establish safe charge sizes for blasting operations. These ground vibration models, therefore generally take the form of regression equations of the following form :

$$V_p = K Q^m R^{-n} \qquad \text{..... 6.10}$$

Where,

V_p = Peak particle velocity in mm/s
Q = Charge size in kilograms
R = Distance from the blast site in meters

and K, m and n are constants which depend upon the geological features of the site and spreading characteristics of the blast wave.

For many regions in Bombay, Central Water and Power Research Station, Pune (CWPRS), over a period of time has collected extensive ground vibration data and for Bandra and Worli segments of Bombay have

Table 6.1 : Analytical solutions of Brooks' Model

Values of n_o	$L(x) / B^*$	C_{max} / C_o
0	$\left[1+2\beta\frac{x}{B}\right]^{1/2}$	$\text{erf}\left\{\left[3/(4\beta\frac{x}{B}\right]^{1/2}\right\}$
1	$\left[1+2\beta\frac{x}{B}\right]$	$\text{erf}\left\{\left[\frac{3}{2}/\left[(1+\beta\frac{x}{B})^2-1\right]\right]^{1/2}\right\}$
4/3	$\left[1+\frac{2}{3}\beta\frac{x}{B}\right]^{3/2}$	$\text{erf}\left\{\left[\frac{3}{2}/\left[(1+\frac{2}{3}\beta\frac{x}{B})^3-1\right]\right]^{1/2}\right\}$

Where, $\text{erf}(a) = \frac{2}{\sqrt{\pi}}\int_0^a e^{-t^2}\,dt$

$\beta = 12\varepsilon_o / uB$

$\varepsilon_o^* = \alpha . B^{n_o}$

* β is initial width of the plume

ε_o dispersion coefficient for plume of width B suggested the following equations to predict peak particle velocity of ground vibrations resulting from shallow underground blasts:

Worli area : $V_p = 1035\ (SD)^{-1.60}$ 6.11

Bandra area : $V_p = 1312\ (SD)^{-1.66}$ 6.12

Where SD is scaled distance (RQ) and, V , R and Q are in mm/sec, meters and kilograms respectively. Equations 6.11 and 6.12 have been used to provide safe blast limits at Bandra and Worli construction site respectively.

6.7 MODELS FOR PREDICTION OF NOISE LEVELS

The sound pressure level generated by a noise source decreases with increasing distance from the source due to wave divergence. For a sound source that can be approximated as a point source located above a flat rigid surface, the radiation pattern is approximately hemispherical and the sound pressure levels at a distance r from a source of sound power level of L_p based on first principles is given by :

$$L_p = L_w - 20 \text{Log}\, r - A_e - 8 \qquad \text{..... 6.13}$$

In equation 6.13 A_e stands for excess attenuation due to atmospheric effects or interaction with objects in the transmission path.

Often, the sound power of the source is not known, but the sound pressure level L_{P_1} at a distance r_1 from the source is known. The sound pressure level L_{P_2} at a distance r_2 from the source can then be calculated from the equation

$$L_{P_1} = L_{P_2} - 20 \text{Log} \frac{r_1}{r_2} - A_{e_{1,2}} \qquad \text{..... 6.14}$$

where $A_{e_{1,2}}$ is the excess attenuation along the path $r_1 - r_2$ between observers 1 and 2. In environmental assessment work, the sound pressure of a source is usually given at a reference distance and equation 6.14 is then used to calculate sound pressure levels at other distances from the source.

Combined effect of all the sources then can be determined at various locations by using the following equation

$$L_{P_{total}} = 10\ \text{Log}\ (\Sigma\ 10^{L_{P_i/10}}) \qquad \text{..... 6.15}$$

where L_{P_i} are noise pressure levels at the point of interest due to N different sources.

6.8 MODEL CALIBRATION AND VERIFICATION

Mathematical models before their use are required to be calibrated and verified through field and laboratory studies. For example In Brooks model transverse dispersion coefficient and microbial decay rates are the model parameters which entail estimation based on field conditions to provide realistic estimates of the phenomenon of secondary dispersion.

Field experiments for model calibration need high degree of precision and coordination. Such experiments may still provide limited information on the system as only a few modes of the system behaviour can be adequately covered. It is, therefore, necessary that the model calibration is obtained as close as possible to the field conditions which are critical from the prediction point of view.

During the course of this work, considerable efforts were made to obtain estimates of transverse dispersion coefficient and microbial decay rates in the coastal water of Bombay under current regimes representing critical movement of wastefield towards the coast. Due to very high cost of insitu experiments and difficulty in conducting the experiments during the night when bacterial die-off is negligible and therefore chances of higher coastal contamination, experiments in laboratory were also conducted simulating the field conditions to the possible extent.

The statistical models used to predict vibrations due to blasting have been derived from the field data and therefore do not require separate effort for their calibration etc. For noise models, excess attenuation in sound pressure levels due to atmospheric effects or interactions with objects in transmission path have been taken based on values reported in literature (Rau and Wooten, 1980).

6.8.1 ESTIMATION OF TRANSVERSE DISPERSION COEFFICIENT

Following the process of initial dilution, secondary dispersion is another major factor for its further dilution during movement of the wastefield towards the coast. In order to provide a good estimate of the probable impact of wastewater discharges through marine outfalls especially in terms of microbial quality near the coast, it is necessary that dispersion coefficients are taken as representative of actual prevailing ambient turbulence. Since the initial dilution estimates indicate good vertical mixing in whole water column and for continuous wastewater discharge from the outfall longitudinal dispersion will have significant effect only near the front edge of advecting wastewater field, estimation of transverse dispersion coefficient acquires special importance in this application.

6.8.1.1 METHODOLOGY

Radio-tracer experiment was designed for Colaba outfall as this unit is fully operational. The Colaba pumping station on an average pumps about 25 mld sewage into the harbour region near the Oyster rock. The outfall is 1100 m in length with a diffuser section of 75 m. In order to estimate the transverse dispersion coefficient a constant radio tracer injection for 3 hours was carried out at the outfall. A total amount of 3.224 curie of Br 82 (half life 36 hours) diluted to 30 liters, was injected at a constant rate of 250 ml/min.

Radio-tracer was injected with sewage flow of around 16.3 m^3 per minute. The injection point was located downstream of the grit chamber before the disposal pumps, providing instant mixing.

The injection was started at 1 hour after low tide slack period once the ambient current field had acquired a distinct inflow pattern. The radiotracer concentrations were observed at different transects. Highly accurate position fixing instruments, which provided the precision of location within 5 meters, were used to fix the points of observation on these transects. A distance of upto 5 kilometers equivalent to time of travel of two hours for the prevailing current conditions was covered. The path of tracer cloud and the transverse plots of tracer concentrations with respect to the centre of the tracer cloud are presented in Figure 6.5.

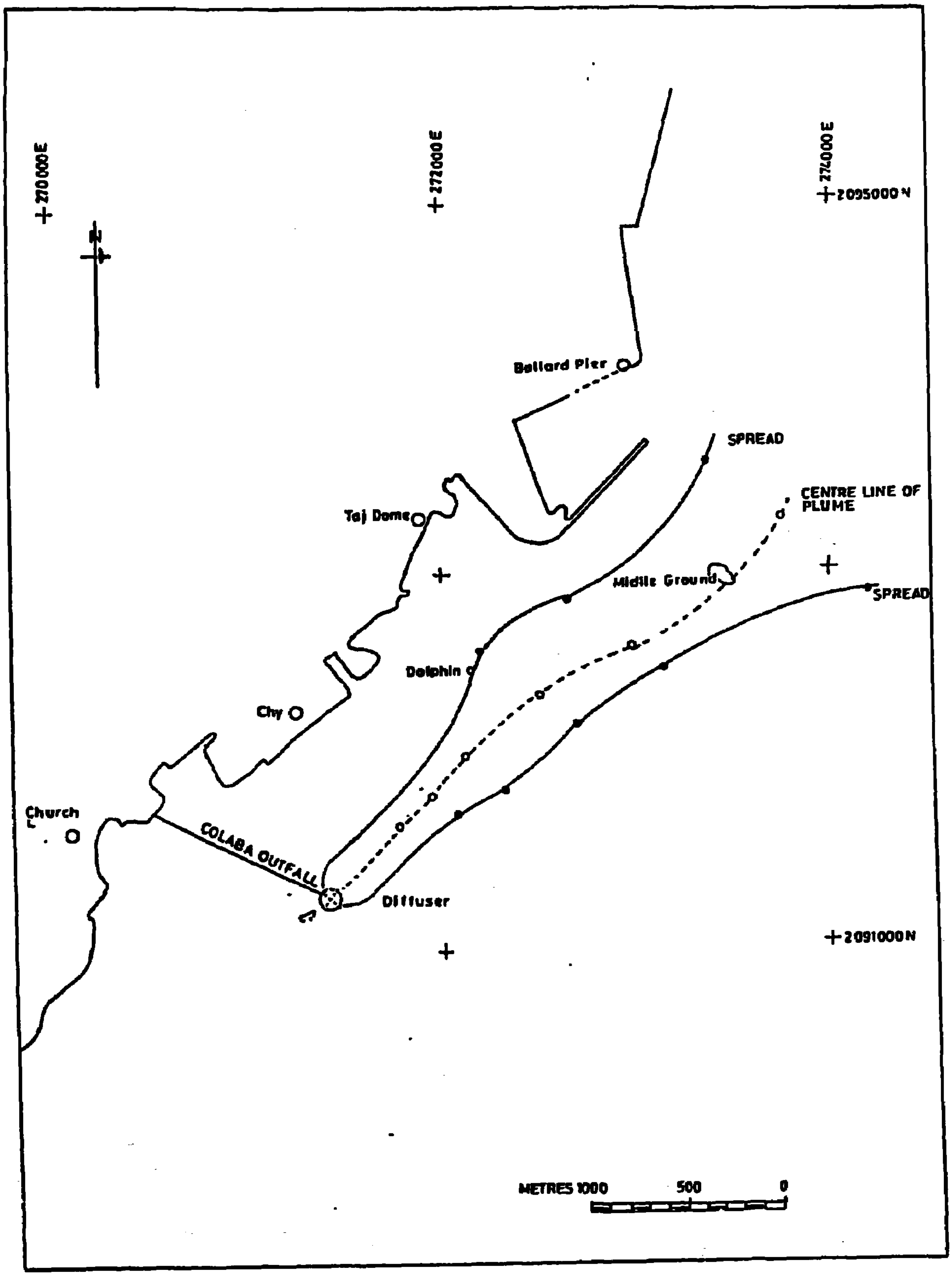
Approximate travel time at the observation transects defined above was estimated from the velocity observations obtained during the preliminary studies. The instantaneous current speeds measured during the tracer experiment varied between 0.9 m/s to 0.65 m/s at different stations. The average speed at the transects during the observations varied between 0.7 m/s to 0.8 m/s.

The observations of tracer concentration were made at the middle length of the tracer cloud for eliminating the effect of longitudinal concentration gradient near front and rear ends of the cloud.

6.8.1.2 SALIENT OBSERVATIONS

As has been stated earlier, the Brook's model used in the study does not consider vertical concentration gradient while modelling the secondary dispersion processes. The model could, therefore, be used to simulate transverse dispersion either in a vertically mixed system or in a vertically stratified system in which the pollutants spread over the ambient water with no vertical mixing. In the field experiment, however, certain degree of vertical mixing was observed.

Figure 6.5 : Path of tracer cloud



The initial thickness of the tracer cloud near the outfall was observed to be about 2 meters which increased to about 4 meters at the 2850m transect indicating a gradual vertical mixing. Due to the model limitation cited above, before using the observations for model calibration, it was necessary to eliminate the effect of such mixing from the observed data set.

The approach adopted, therefore, was to estimate the fraction of tracer mass lost from the top two meters of water column due to vertical mixing and raise the observed values in the same proportion to provide the scenario of complete vertical stratification after initial formation of the tracer cloud. Tracer mass across the complete width of the tracer cloud was, therefore, calculated at each transect and a correction factor was applied to the observed concentration to account for the loss due to vertical mixing.

Observations at 3850m and 4850m transects were not used in data interpretation as the tracer concentrations were observed below 5 times the background values minimum stipulated for interpretation using radio tracer.

With above correction, the observed data sets at 600m, 850m and 1850m were used for model calibration. Observations at 1350m and 2850m were used for model verification. For model calibration and verification average current speed over the period between injection and observation at the respective transects was used. The tracer observations also indicated that the tracer mass followed a trajectory moving away from the shoreline, justifying the use 4/3 of power law for the transverse dispersion.

The value of the proportionality constant in equation 6.8 was obtained by minimising the sum of the squares of difference between the observed and predicted radiotracer concentrations across the width of the cloud at each transect using the method of cubic interpolation. The best fit values for transects at 600m, 850m, and 1850m used for model calibration were obtained as 0.0034 $m^{2/3}$ /s, 0.0029 $m^{2/3}$ /s and 0.0026 $m^{2/3}$ /s respectively. For model verification, therefore, a value of 0.0026 $m^{2/3}$ /s was used at 1500m and 3000m transects. The results of model calibration and model verification are presented in Figures 6.6 a,b,c and 6.7 a,b respectively. The values are slightly higher than the upper limit provided for in literature and may be justified in view of stronger currents measured during the experiment in comparison to normally encountered coastal currents in the region (≅0.4m/s-0.6m/s).

Figure 6.6a : Model calibration results at 600 mts transect

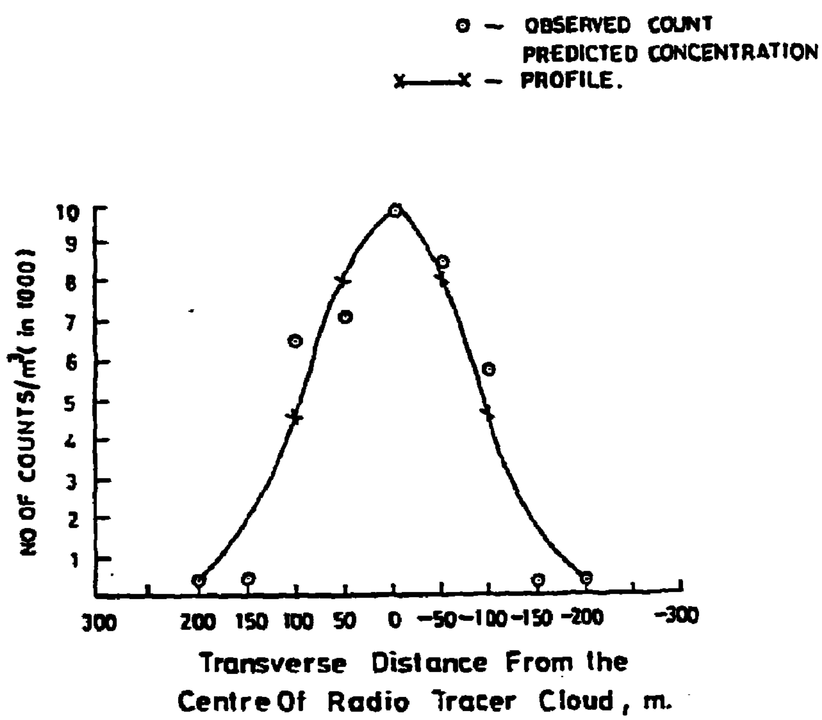
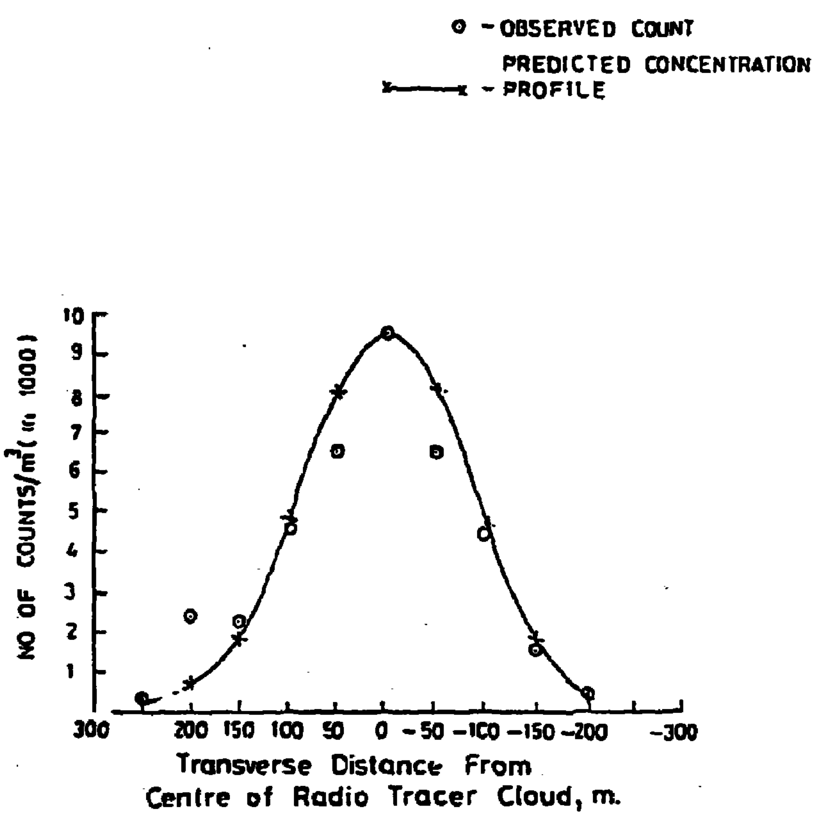


Figure 6.6b : Model calibration results at 850 mts transect



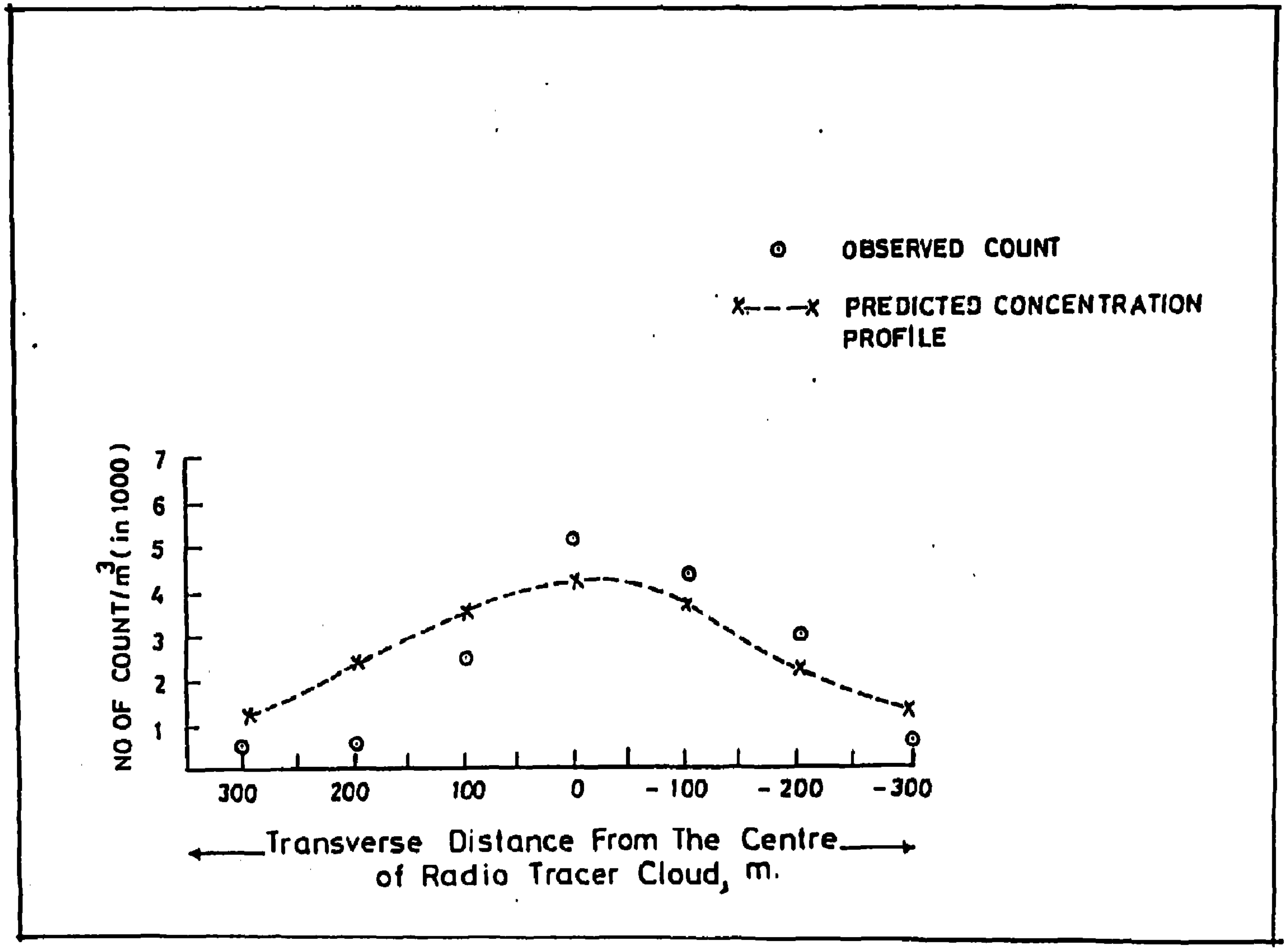


Figure 6.6c : Model calibration results at 1850 mts transect

Figure 6.7a : Model verification results at 1350 mts transect

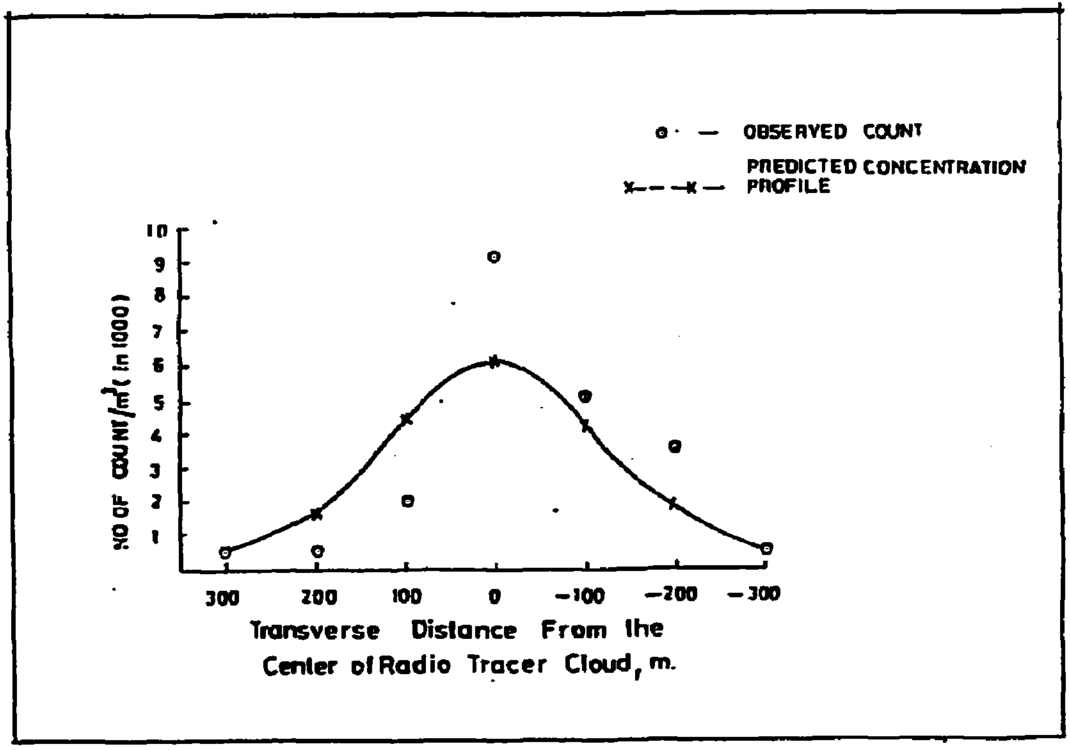
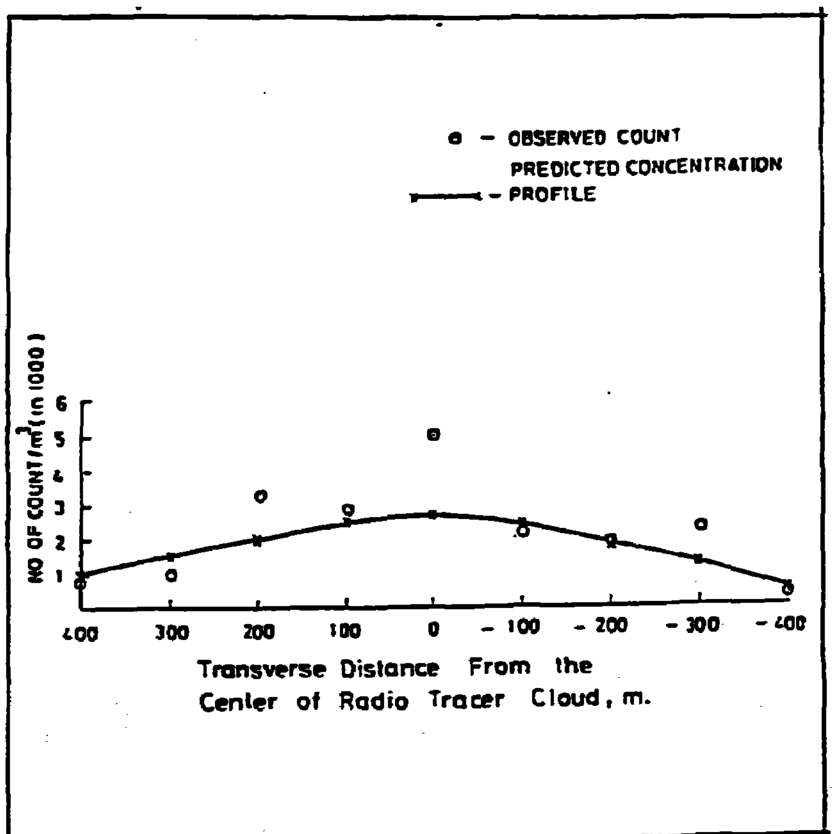


Figure 6.7b : Model verification results at 2850 mts transect



6.8.2 ESTIMATE OF MICROBIAL DECAY RATE

After their release in the marine environment the non-indigenous organisms may either die or enter a dormant phase (viable but non-culturable) or get established as a part of the marine ecosystem. A multitude of the autoecological factors are known to affect the decay/survival of non-indigenous enteric bacteria in seawater. Amongst these, sunlight (Fujioka and Narikawa, 1982; Fujioka et al., 1981; Gameson and Gould, 1975; Gameson et al., 1973), predation (Enzinger and Cooper, 1976; McCambridge and McMeekin, 1981; Mitchell, 1971), salinity (Anderson et al., 1979; Carlucci and Pramer, 1960; Dawe and Penrose, 1978), temperature (Orlob, 1956; Walker and Guarraia, 1975), antibiosis (Aubert et al., 1975; Nusbaum and Garver, 1955), flocculation and sedimentation (Gerba and McLeod, 1976; Mitchell and Chamberlin, 1975; Rittenberg et al., 1958) are the most prominent. Initial dilution of wastewater which determines the nutrient concentration available to microorganisms also plays a role in the decay/inactivation of bacteria in the marine environment.

Sunlight is the most important factor contributing to bacterial decay in sea water. High mortality of coliforms has been observed when exposed to light (Gameson and Saxon, 1967). The sunlight induced sublethal injury has been attributed to both the near UV visible spectrum as well as the UV spectrum. (Kapuscinski and Mitchell, 1981; Pike et al; 1980 Fujioka et al, 1981). Further, the light-induced injured bacteria are more susceptible to predation (Chamberlin and Mitchell, 1978). However, the effect of sunlight is only limited upto the depth of the photic zone. Lower bacterial decay rates, therefore, apply in the aphotic region.

Predation of bacteria is a natural process limiting bacterial numbers in marine ecosystem and may also contribute to non-specific removal of enteric bacteria along with indigenous bacteria. Experimental evidence derived from laboratory studies has shown protozoa (Fenchel, 1982, 1986; Sherr et al, 1983) and polychaetes (Montagna, 1984) as principal predators. Negligible differences in grazing rates were observed during summer and winter (Montagna, 1984) thereby suggesting almost no seasonal influence on predation by these organisms.

Several studies (Nusbaum and Garver, 1955; Burke and Baird, 1931; Aubert et al., 1975) revealed no significant antagonism to enteric bacteria due to normal saline consitutents of sea water. In contradiction to these conclusions, Carlucci and Pramer (1960) found that the survival of Escherichia coli was comparable in natural sea water and in NaCl solutions of equal salinity and generally varied inversely with salt concentration, and also that survival was favoured by more acid conditions (pH 8) in both solutions. In the later study (Carlucci et al.,) artificial sea water was found to be at least as bactericidal as natural sea water.

Another important biotic factor limiting enteric bacteria in the marine environment is antagonism exhibited by marine bacteria and other micro-organisms (Aubert et al., 1975; Orlob, 1956). Though antibioses may be regarded as an intrinsic means of survival of marine bacteria in seawater, it indirectly aids in decreasing the enteric populations. While bacteriophages may be responsible for limiting bacterial numbers in sewage, their importance with respect to seawater environment is questionable and needs attention.

The primary flocculating effects of seawater on sewage will help in further removal of bacteria and other particulate matter. The adsorption of enteric bacteria and sedimentation of sewage particulates is,however, of significance in the region near the outfall. It is probable that wind, wave and current action will interplay to maintain the lighter slow settling particulates in suspension and distribute them throughout the volume of water.

6.8.2.1 LABORATORY SETUP

While previous studies relate to bacteriological decay in shake flasks or diffusion chambers and have been useful in delineating the detrimental effects of individual factors, these studies may not provide estimates of bacterial decay which actually occur in the natural conditions. In this context, a better simulation of field conditions in laboratory was attempted for estimation of net decay of enteric bacteria in this study.

As the depth of the photic zone in the Arabian sea along the Bombay coast was observed to be around 1 meter , the major portion of seawater below the photic zone is not exposed to sunlight. As a result, under dark and diffused light the other factors cited above are likely to play major role in the net decay. The laboratory decay experiments were designed to focus on these aspects.

Nonfiltered clean sea water, collected from 20 kilometers off the Bombay coast was used in the experiments. Experimental setup consisted of cylindrical plastic semi-transparent tank of 200 L capacity fitted with a variable low speed stirrer. From previous studies by Metcalf & Eddy in the coastal regions, minimum initial dilution through the proposed outfalls was estimated to be in the range of about 1:50. Same proportion of dilution was maintained during the decay experiments by inoculating freshly collected sewage. During the experiment the reactor contents were subjected to stirrer-induced mixing, approximately equivalent to the ambient mixing in coastal marine conditions under currents of the order of 0.5 - 0.7 m/s. The first sample was drawn after two minutes of equilibration of sewage with seawater for the analysis. The samples further were drawn at preascertained intervals (ranging from 10 minutes at the beginning of experiment and gradually increasing to to 1 hour by the end of experiment).

6.8.2.2 INFERENCES

The analysis of observations under different light conditions demonstrates a strong relationship of coliforms decay with light. Sunlight appears to be primary factor responsible for their decay. The results of regression analysis of the observations under sunlight, diffused light and dark conditions are presented in Figures 6.8, 6.9 and 6.10. The die-off rate for these conditions is obtained as -1.08 ±0.08, -0.59 ±0.06 and -0.12 ±0.05, respectively. Since unfiltered fresh sea water was used for these experiments, the low die-off rate under darkness suggests negligible effect of biotic components such as predators and antagonistic organisms on bacterial decay. Therefore it may be concluded that maximum enteric decay rates will occur during day time (under bright light) as compared to that during cloudy conditions (diffused light) or during night (no light).

6.9 CONCLUSIONS

Use of mathematical models is necessary for quantification of probable environmental impacts of construction and operation of marine outfalls, especially for bacterial quality at beaches and noise pollution and vibrations near construction sites. Considerations of bacterial contamination at the coastline necessitate use of initial dilution and secondary dispersion models. A wide range of models with different degree of sophistication are available for simulating these processes. In the present application limitations of available data on coastal currents necessitated use of one dimensional steady state model for secondary dispersion. The model coefficients, however, were obtained through field observations.

Statistical models derived from insitu observations and models based on the first principles were used to predict the ground vibrations due to blasting and noise levels due to operation of construction machinery.

Figure 6.8 : Time versus concentration plots for decay experiments performed in full sunlight

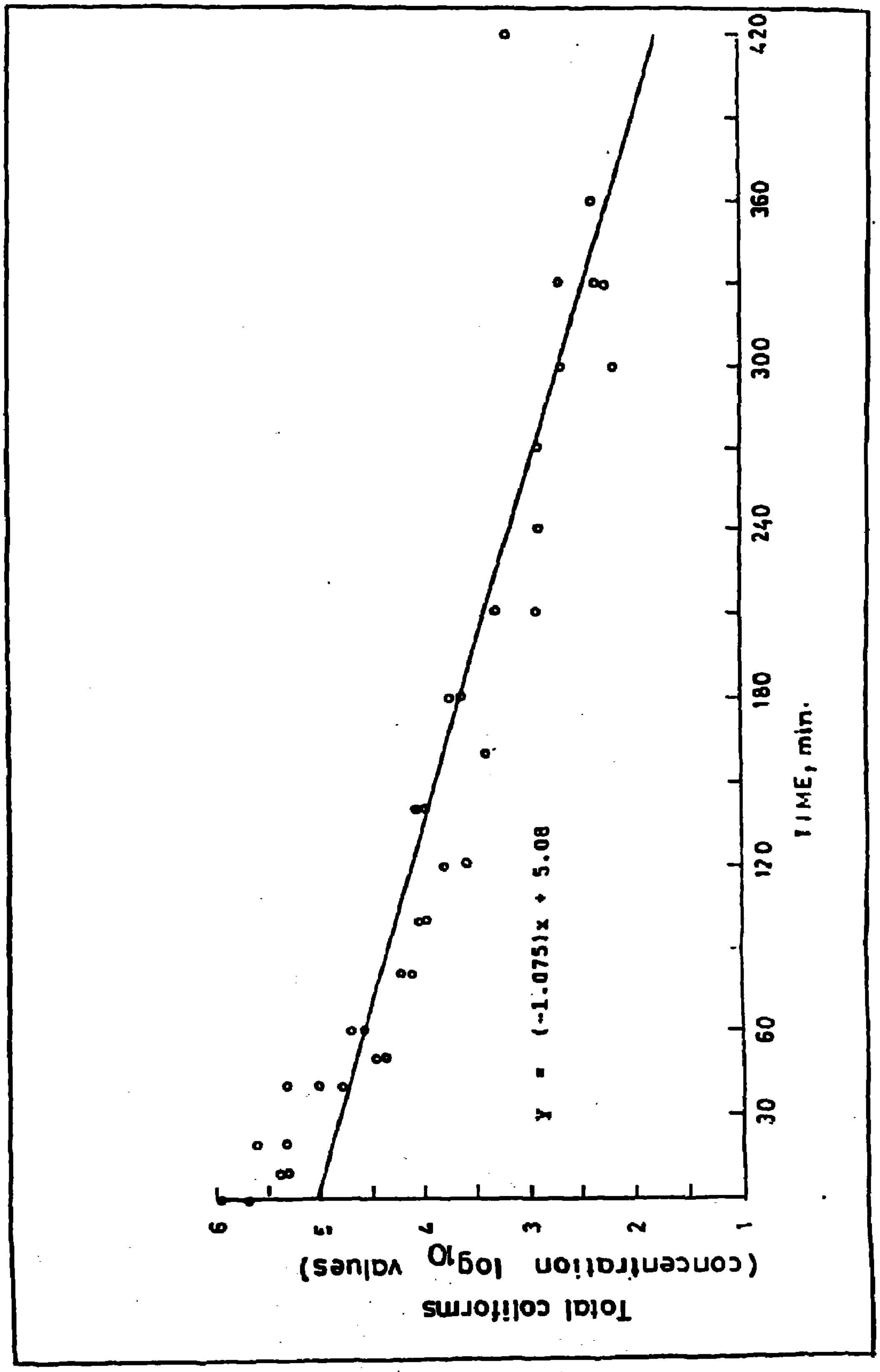


Figure 6.9 : Time versus concentration plots for decay experiments performed in diffused light

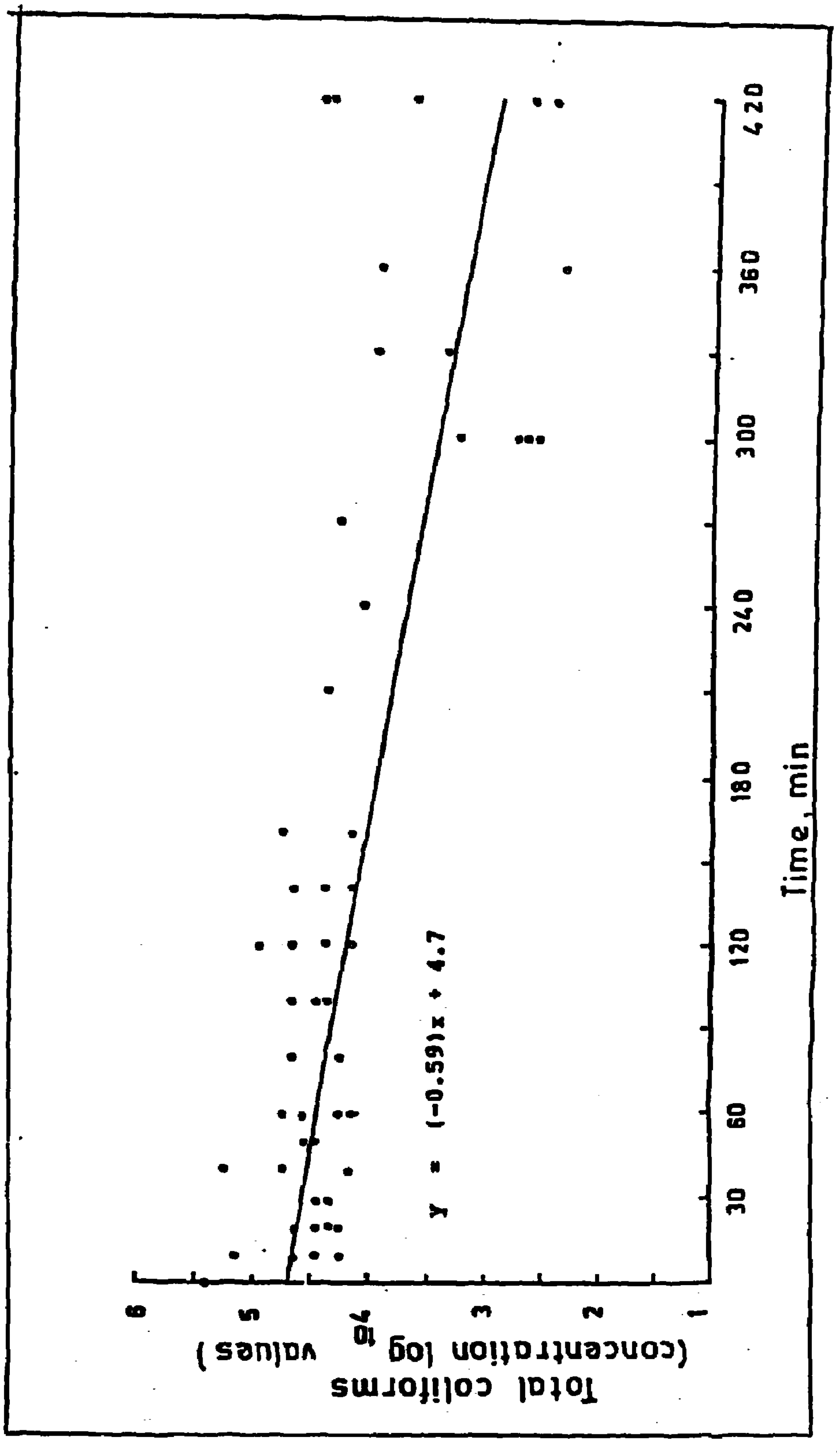
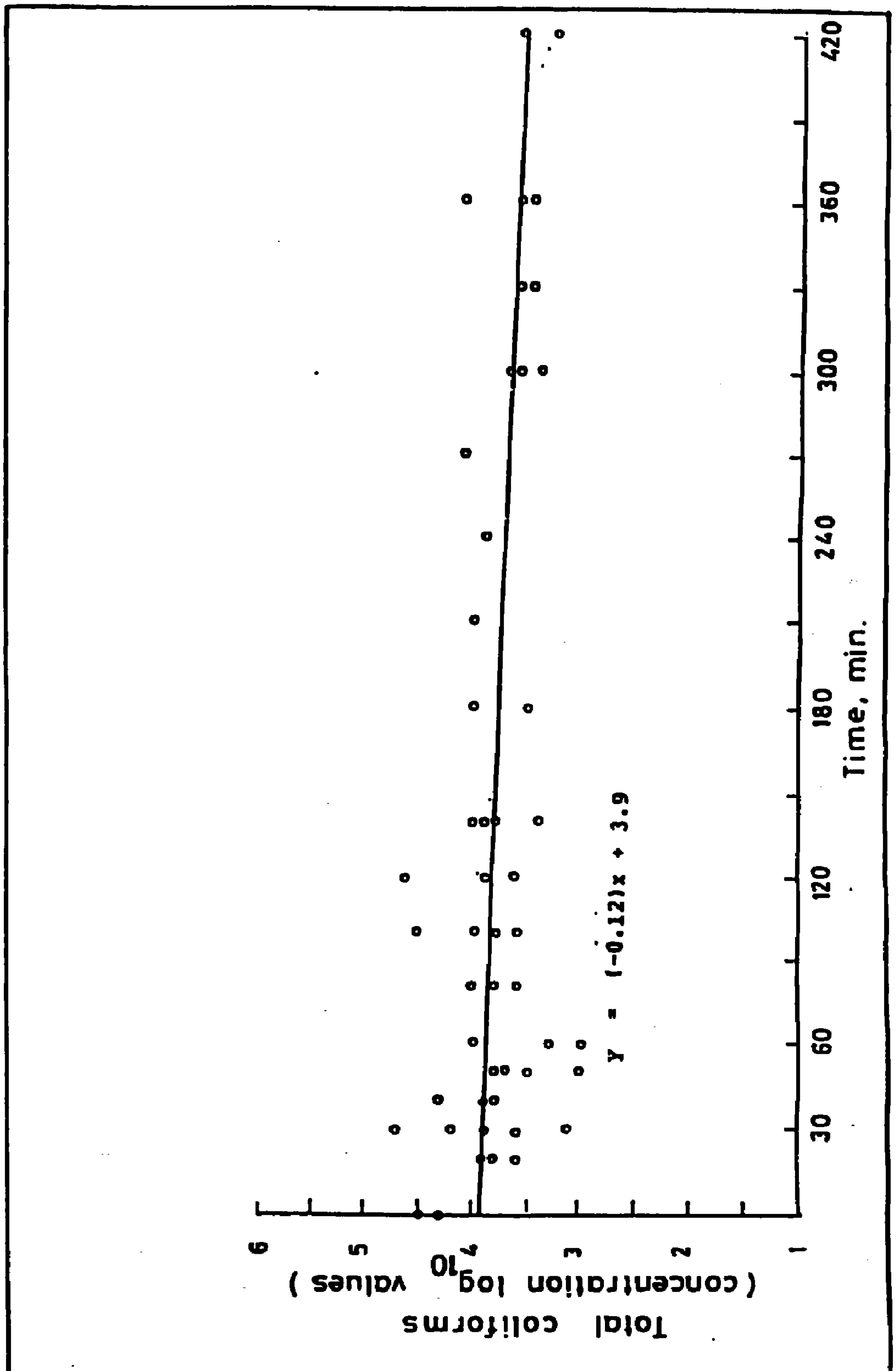


Figure 6.10 : Time versus concentration plots for decay experiments in dark



Chapter 7

PREDICTION OF IMPACTS

7.1 PREAMBLE

The major activities associated with the construction of marine outfalls at Bombay are blasting, tunneling, and material transfer at the sites of Worli and Bandra headworks. Major additional tasks for the outfall construction will be the manufacture of precast concrete lining segment and disposal of excavated muck. The prominent impacts of these activities are vibrations due to blasting, rise in noise levels, impairment of air quality near the construction sites and impaired water quality due to the trenching near the diffuser section.

During the operation of marine outfalls the wastewater, which at present reaches the sea all along Bombay's coastline and causes pollution, will be routed through the outfalls and will discharged at about 3 kilometres away from the coast. The outfall operation, therefore, will reduce nearshore coastal pollution. The diversion of wastewater through the marine outfalls, however, would cause formation of wastefield may have some negative environmental impacts such as low dissolved oxygen in water; and anaerobicity, nutrient enrichment and trace metal accumulation in sediments etc. The wastefield under adverse wind and currents may also drift to the shore and cause bacterial contamination.

Some of the important processes of which govern the primary environmental impacts of construction and operation of marine outfalls can be mathematically modelled. The associated impacts can, therefore, be predicted with a reasonable confidence. Mathematical models for simulation of these processes along with the process of their calibration and verification have been presented in the previous chapter. For estimation of impact of outfall discharges on nutrient enrichment, metal accumulation, fish yield etc., the processes which involve complex environmental interactions, qualitative analysis based on observations on present conditions near the operational Colaba outfall and western coast has been used.

7.2 CONSTRUCTION PHASE IMPACTS

7.2.1 NOISE IMPACTS

For prediction of increase in noise levels at sensitive location near the outfall headworks sites during construcion, data on noise characteristics and operation pattern of construction machine units during different stages of construction were collected (Table A5.5). Site surveys for identification of sensitive locations and ambient noise levels was also conducted. Accordingly, at Worli, NEERI on west and the unauthorised hutments on east both at about 75 m from the construction site; and at Bandra, a school at about 75 m northward from the construction site were identified as the sensitive areas.

The noise characteristics data of construction machinery and observations on an operating tunnel boring machine (similar to those proposed for construction of tunnel outfall), indicated that noise levels could be upto 96 dBA near the generator sets. For noise predictions, for a particular stage of construction, it was assumed that all machine units were in simultaneous operation and were randomly located within a 50m by 50m area at the construction site. Noise predictions were undertaken for both pipe and tunnel outfalls options and were made using the model for hemispherical sound wave propagation. The model results in terms of isopleths of sound pressure level in dBA (A-weighted decibles) are presented in Figures 7.1 and 7.2 for Worli and Bandra, respectively, for the tunnel outfall option. The noise levels for pipe outfall option are about similar to the tunnel outfall.

The results of noise modelling indicate that at the sensitive locations near Worli the noise levels during the operation of construction machineries should be within 57-61 dBA range. These levels are significantly higher than the Indian standard for urban residential and commercial area (40-50 dBA) but are not likely to give rise to community reaction. Additional noise about equal to existing day time noise levels will occur at nearby MCGB colony. This is equivalent to a rise of 3 dBA over the ambient noise levels during the day. The peak day time noise levels at these localities are thus expected to reach 53 to 57 dBA which are just about in the range prescribed by US EPA to avoid outdoor speech interference.

At Bandra, appreciable rise in noise levels over the ambient levels (35 to 42 dBA) is expected. The resultant levels at the sensitive location (school premises) are expected to be in the range of 62-67 dBA which are appreciably higher than Indian standards for urban residential area (Bandra, standard 35-45 dBA) and would certainly require mitigatory measures.

For predicting the noise levels all machine units used in a particular stage of construction were assumed in simultaneous operation, which is unlikely to occur in actual practice. The actual noise levels most of the times are expected to be about 3 dBA lower than those shown in Figures 7.1 and 7.2.

Although the noise levels due to construction activities (with the mitigatory measures) are not expected to cause significant environment

Figure 7.1 : Isopleths showing predicted noise contours during marine outfall construction at Worli

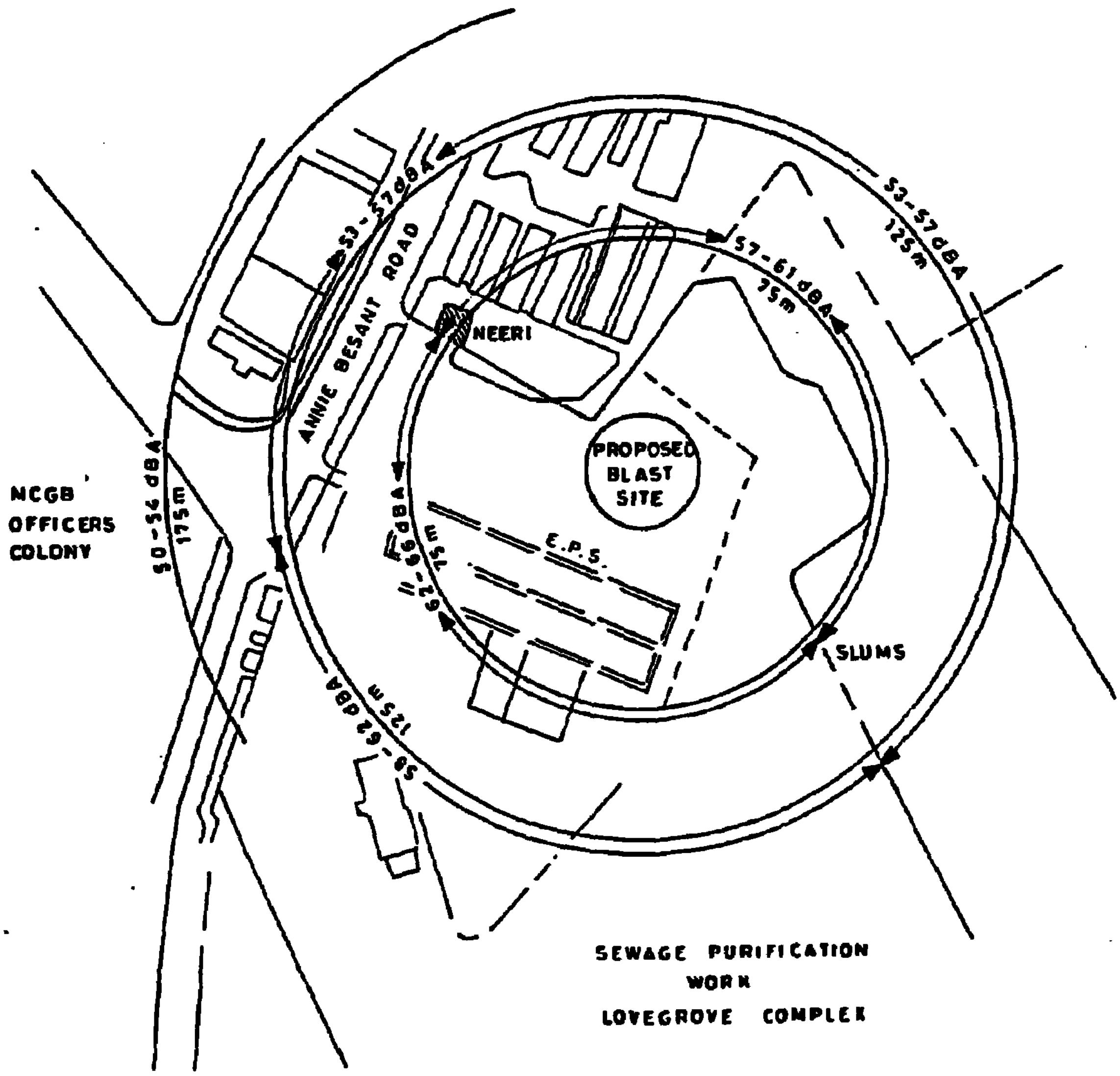
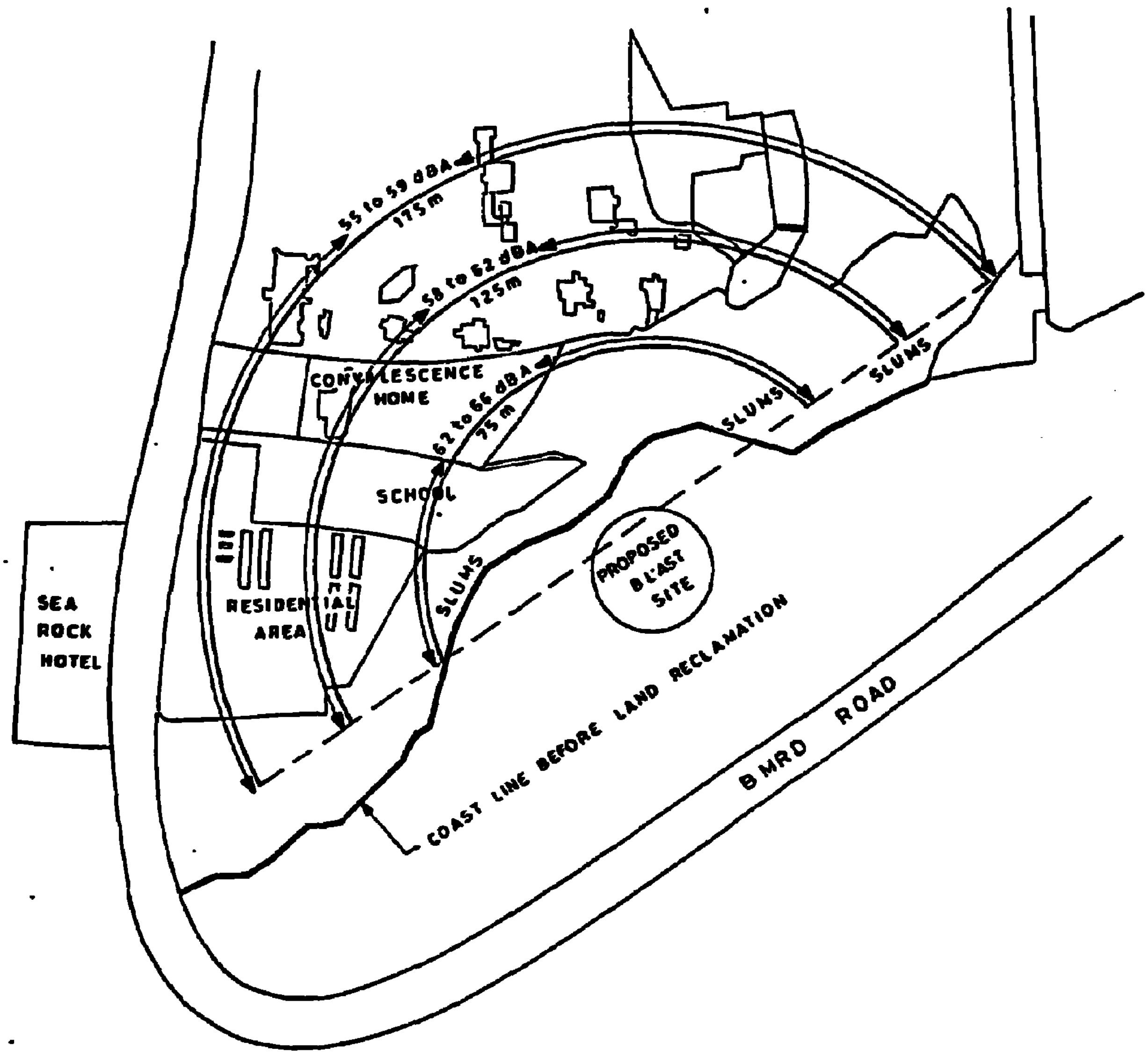


Figure 7.2 : Isopleths showing predicted noise contours during marine outfall construction at Bandra



impacts during the day, these will be very high in comparison to night time standards (which are 10-15 dBA lower than day time standards). It will be, therefore, necessary to restrict all construction activities, including material transfer, within the day hours.(6 AM to 8 PM).

Noise impacts on construction workers

Equivalent sound level averaged over 8 hours, Leq (8 hrs), is used to describe exposure of noise in work places. The damage risk criteria for hearing, as enforced by OSHA (Occupational Safety and Health Administration) and other organizations to reduce hearing loss, stipulates that noise levels upto 90 dBA are acceptable for eight hours exposure (Leq (8 hr.)) per day. Whereas ACGIH (American Conference of Government Industrial Hygienists) proposed an Leq (8 hr.) limit of 85 dBA. Exposure to impulses or impact noise should not exceed 140 dBA (Peak acoustic pressure). Exposure to 10,000 impulses of 120 dBA are permissible per day.

The Director General of Mines Safety in his circular No.DG(Tech)/18 of 1975 has prescribed the noise level in mining occupations (TLV) for workers, in an 8 hour shift period with unprotected ear as 90 dBA or less. Although there are some noise sources which are likely to exceed the limit, they do not produce sound levels above 90 dBA for more than 2-5 hours per shift reducing Leq (8 hr) to be well within the limits.

Heavy machinery drivers and personnel working very near to these machineries are likely to get exposed to higher levels than the prescribed limits if the exposure is continuous and should therefore be provided with protective gear.

7.2.2 IMPACTS OF BLASTING OPERATIONS

The construction of approach shafts for the outfalls entails controlled blasting operations at both Worli and Bandra headworks. Blasting in populated areas could affect the nearby structures due to ground vibrations generated by the propagating elastic blast wave through the geographic strata. Other undesirable impacts of shallow blasting occur due to creation of high air blast intensities (overpressure) in nearby surroundings. High air blast intensities may induce rattling, fright to public, pain and damage to glass windows and even to structures. It has, however, been observed through many field studies that blast sizes which are within safe ground vibrations limits does not cause unduly high air blast intensities.

For evaluating safe blast sizes, statistical models derived from ground vibration data obtained during earlier excavations in Worli and Bandra zones have been used. These models provide the estimate of peak particle velocity of blast induced ground vibrations as a function of charge size and distance from the blast site.

Regarding the safe peak particle velocity of ground vibrations, a limit of 20 mm/sec is internationally accepted. For poorer structures and historical and old monuments, limit of safe ground particle velocity of 8 mm/sec is accepted.(German Standard DIN 4150 part 3, 1986 and Swiss Standard SN 640 312:1978] In the present application, therefore, the safe limits for peak particle velocities for new and old structures have been considered as 20 mm/s and 8 mm/s, respectively. The safe charge sizes for impacts at different distances based on models described earlier have been summarized in Table 1. The closset structures near the blast site at Worli, at a distance of about 25 meters, is an abandoned mill within the presided of Love grow pumping station. The nearest new (concrete) structure is the building which house the effluent pumping station and is also about 25 meters from the blast site. The safe charge size limit for Worli, therefore, is 4.5 kg. At Bandra the nearest unauthorized slums are about 50 meters from the blast site and, therefore, charges upto 5.4 kg can be used.

7.2.3 AIR QUALITY IMPACTS

During the construction activities at outfall headworks, marginal increase in air borne pollutants such as NOx, and SO2 is expected. This rise over the ambient levels, however, will be negligible as the additional emissions from construction (activities will constitute a small fraction of present emissions which are primarily due to autoexhausts. Also, the sites, due to their proximity to the costs, experience strong diurnal land-sea breeze which will blow away and disperse the pollutants effectively. A rise in SPM levels, however, is expected during this stage may exceed the standards for Industrial and mixed localities and may need mitigatory measures. After first stage of construction, most of the work will be done underground.

7.2.4 WATER QUALITY IMPACTS

The construction of the outfalls will not have any significant impacts on the coastal water quality, as tunnelling will take place at about 50-70 meters below the seabed. For such construction the disposal of excavate muck, generated at a rate of about 500 tons per day for about 15 months, entails disposal. The excavated muck will be composed of tuff and basalt. This material will be used for reclamation of additional land near Bandra outfall headworks. Based on physical model studies, Central water and

Table 7.1

Safe Charge Sizes for Blasting at Worli and Bandra

Distance from blast site (m)	Safe blast size in kilograms			
	Worli		Bandra	
	New Structures	Old Structures	New Structures	Old Structures
25	4.5	1.4	4.0	1.3
50	18.0	5.7	16.2	5.4
75	40.5	12.9	36.4	12.1
100	72.0	23.0	64.7	21.5

Power Research Station indicated feasibility of reclamation of 209,400 sq. meters area near the site, out of which about 114,200 sq. meters area has already been reclaimed under their guidance. The additional reclamation will accommodate the full quantity of much (225000 tonnes equivalent to about 50,000 cubic meters) expected to be generated during the construction of both the outfalls.

Coastal waters along a short length of the alignment of each outfall will experience certain water quality impairment during the construction of the diffuser sections. The impairment will be caused due to the suspension of seabed material during excavation of the seabed for the discharge structures. The area of impact will, however, be confined within approximately a 1 kilometer wide region near the point of construction. There will be thus, increase in the turbidity during the construction of the discharge structures. The impact, however, will be of a very short duration and of low intensity due to the high background turbidity in the sea off Bombay's coast.

No adverse impact of outfall construction on fishing interests in the region, is expected. Some localized water quality impact due to the spillage of fuel and oils used for operation of construction machinery and barges etc. may occur at the time of boring for the diffuser sections. These will have to be minimized with good house keeping and vigilance. These impacts will, however, be transient and marginal.

7.3 OPERATIONS PHASE IMPACTS

Bacterial contamination of coastline due to shoreward drift of wastewater discharges and probable negative environmental impacts in the vicinity of outfall diffusers are the primary environmental concerns during the operation of the outfalls. The processes of initial dilution and secondary dispersion of outfall discharges govern the extent of these impacts.

Since ambient currents play a very significant role in both of these processes, the available hydrodynamic data was first analyzed to establish the coastal currents in the region during monsoon and non-monsoon. This was followed by estimates of initial dilution for representative currents for different period of tidal cycle. The advection of wastefield formed after initial dilution was then modelled under the coastal currents and critical winds to determine the critical regions of impact at the reference line as also time of travel from diffuser section, for different management options (combinations of different outfall lengths and land treatment). Secondary dispersion model was then applied for the duration of time of travel to provide the wastefield spread and total coliform counts at the reference line. Dissolved oxygen and BOD levels near the diffusers have been obtained from the initial dilution estimates.

For qualitatively prediction of the impacts of outfall discharges on sediment quality in terms of trace metals and nutrient accumulation and benthos etc., observations on these parameters near Colaba outfall and at the reference line have been used. The basis of these estimates has been the assumption that the dilution achieved near Colaba outfall and at the sections of reference line close to present heavy discharges are comparable or less than the expected dilutions near the diffuser section of the proposed outfalls. Since the outfalls are specially designed to enhance the initial mixing of wastewater with the sea water, such premise should be valid for most part of the tidal cycle. The inference that the impacts of outfall discharges on aquatic components will be similar or less than those observed at reference line near the existing discharges or at Colaba may, therefore, be justifiable. The socio-economic impacts of outfall operation are basically related to fish yield, beach water quality and aesthetics and have been qualitatively estimated from the post outfalls water quality predictions.

7.3.1 ANALYSIS OF DATA ON COASTAL CURRENTS

The only available source of information on the variations of coastal currents with the tidal cycle and offshore winds near the west coast of Bombay are the studies conducted by M&E during June 1976 to September 1977. These studies were conducted in two parts. The first part comprised float studies from Nov. 1970 to June 71 which indicated an elliptical current movement with major axis generally parallel to the coast. The second part was planned to record insitu current meter readings at various stations and concurrent dye and drogue movements using research vessels.

During this study, fishing activities in the area resulted in loss of many of the recording type current meters, by entanglement with fishing nets, rendering much of the current meters data valueless. Current data of longer periods covering many tidal cycles at some observation stations, therefore, could not be collected.

The data collected by Metcalf and Eddy, thus, essentially took the form of dye and drogue plots for different period and tidal conditions for the year 1976-1977 with sparse meteorological and current data during the dye/drogue studies generally lasting for about 24 hours. Based on these observations, Metcalf and Eddy used a value of 0.36 m/s as the average speed of coastal currents. For predicting the bacterial concentrations at the reference line a net drift of 0.075 km/hr for the tidal ellipse was used for the monsoon and non-monsoon periods shoreward wind induced drift of 0.5 km/hr and 0.224 km/hr were used corresponding to the easterly winds of 25 and 10 knots respectively.

Since the basis for concluding the coastal current characteristics was not explicable from the M & E report, it was thought appropriate to interpret the dye and drogue data and associated wind and current meter data independently to arrive at conclusions regarding the coastal current patterns. The data therefore were analysed to provide average tidal current for spring tides for monsoon and non-monsoon (winter) months after eliminating wind effects. For non-monsoon period winter was considered critical because, in winter, lower bacterial decay rates are expected due to lower insolation and ambient temperature. The analysis was confined to spring tide or near spring tide conditions which generate stronger coastal currents and, therefore, can result in a probably faster drift of the wastefield from outfalls towards the coast. Fast travel of the wastefield allows lower decay times for bacterial decay leading to higher contamination levels.

With above objective dye/drogue data for August 1-2,August 17-18 and January 21-22 of M&E report were analysed. The procedure adopted was to read the dye/drogue velocity for each observation interval and vectorially substract the wind induced drift assuming a wind to water surface drag co-efficient of 0.02 (Grace,1978) to obtain the coastal currents without the effect of wind induced current. The wind rose data recorded at Colaba was used for the analysis. The coastal current was calculated for each wind direction and category observed in the wind rose and appropriately weighted for.

The plots of displacement of water parcel with the coastal currents for spring or near spring tide indicate that during the flood and ebb tide a distinct current approximately parallel to the coast establishes in the region. The current pattern (directions) remains stable for about 4.50 hours. For the high tide slack and low tide slack periods an anticlock wise circulation pattern with generally lower current speed is observed. The average speed of coastal currents for each dry/drogue experiment is calculated as the average speed for the period of stable current pattern between the tidal slack periods. The results of these analyses on flood and ebb tide currents for monsoon and non-monsoon are presented in Table 7.2.

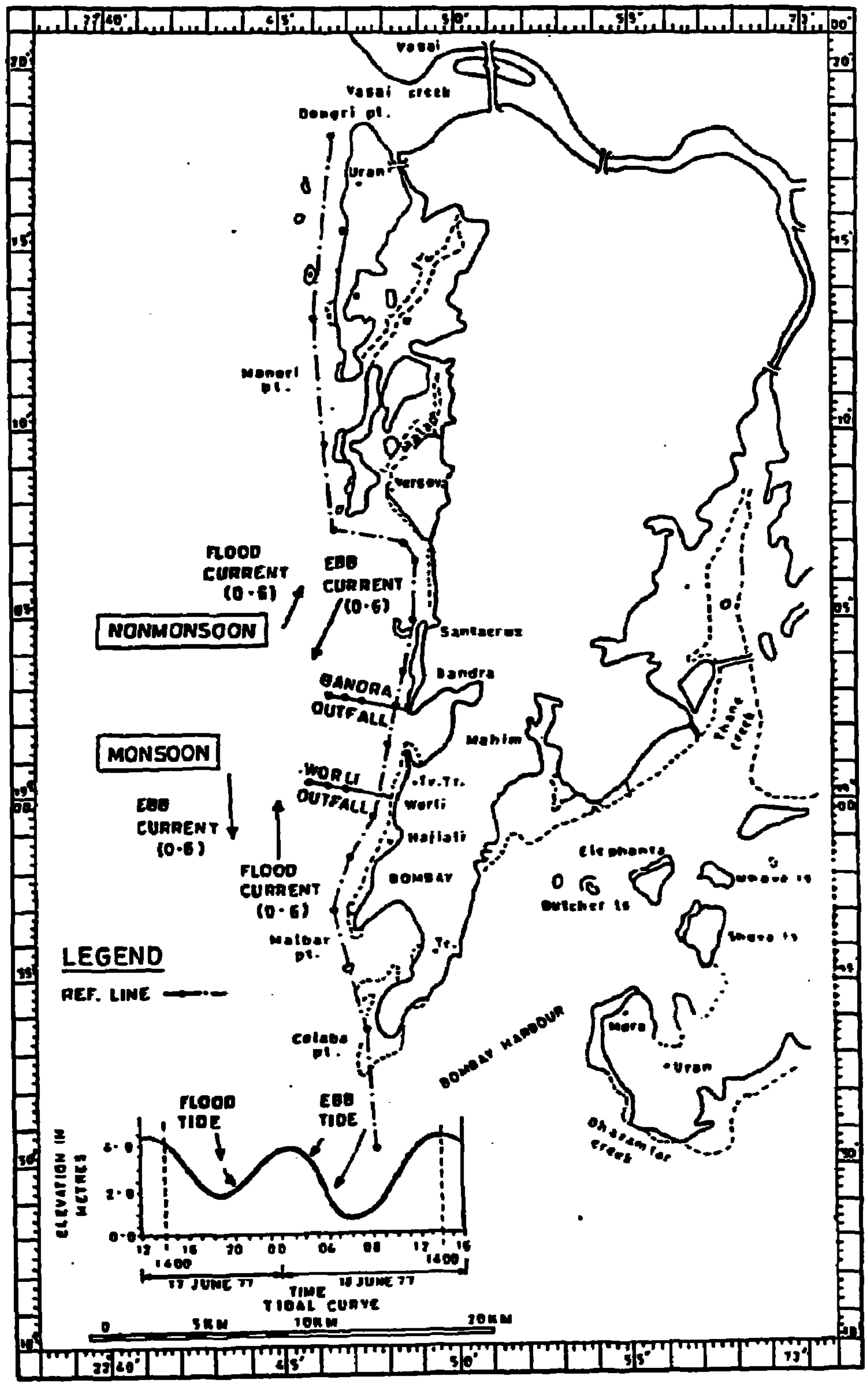
The coastal current speeds for monsoon ebb tide have been taken as 0.5 m/s, the average of speeds derived from above analysis for the three data sets for the month of August. The direction of incoming current in monsoon is taken as 356° corresponding to its maximum inclination towards the coast. The ebb and flood currents used for further analysis in this study are shown in Figure 7.3 in a pictorial form. For simulation of wastefield advection and estimates of initial dilution and secondary dispersion, therefore, for monsoon months flood current of 0.58 m/s coming from 179° and ebb current of 0.5 m/s coming from 356° were

Table 7.2

Tidal currents in coastal region of Bombay

Dye/ drogue study period	Coastal Current			
	Flood Tide Avg. speed, m/ s	Direction (incoming current)	Ebb Tide Avg. speed, m/ s	Direction (incoming current)
August 1-2	0.59	179°N	0.42	356°N
August 17	—	—	0.64	9°N
August 18	—	—	0.43	29°N
January 22-21	0.48	203°N	0.59	22°N

Figure 7.3 : Tidal Current Pattern Along Coast of Bombay



considered. For non-monsoon months, flood and ebb currents of 0.48 m/s from 203° and 0.59 m/s from 22°, respectively, were used. Also, during the period of tidal slack for about 1.5 hours of half tidal cycle, the current field was considered as stagnant and was represented by zero current.

The observations on surface and bottom currents by Metcalf & Eddy during the hydrodynamic survey in the region, do not indicate any significant differences. The current velocities presented above were, therefore, considered uniform over the depth.

7.3.2 PROCEDURE FOR CONSIDERING SHOREWARD MOVEMENT OF THE WASTEFIELD

The wastefield advection, under coastal currents and winds, determines the regions where the wastefield is most likely to reach the coast and the time it takes to travel from the outfall diffusers. As the secondary dispersion processes operate only during this time, considerations of wastefield advection are critical for predicting coastal contamination due to inadequate outfall length or land treatment.

For modelling the wastefield advection, the reference line all along the coastal region of interest was divided into 14 straight line segments (Figure 7.3). The wastefield was then assumed to emanate from the middle of the diffuser section of the outfalls (at 2750 m for 3 kilometers long outfall) and its position was tracked every 5 minutes under the critical currents and winds till it crossed one of these line segments or moved beyond the region of interest. The wastefield position were updated by vectorially adding the displacement during each time step due to tidal and wind induced currents to its earlier position. A wind drag factor of 0.02 was considered in the analysis. The maximum sustained shoreward wind corresponding to critical conditions for monsoon and non-monsoon were considered to be 18 km/hour and 45 km/hour respectively.

It was observed that shoreward movement of the wastefield was intimately related with the tidal cycle. In order to determine the shortest time of travel before the wastefield crosses the reference line, different starting times with respect to the tidal cycle were considered for wastefield movement. The results show that wastefield emanated from the outfalls as the ebb currents get established, reaches earliest to the reference line for monsoon. During the non-monsoon, wastewater released immediately after the flood currents are established reaches the reference line first. It was further observed that the shape of Bombay coast line, plays a significant role in wastefield impact on the coast.

In order to simulate probable cumulative effects of Worli and Bandra outfall discharges, it was observed that under the worst case wind assumption, these discharges do not superpose. Also, under normal wind condition it appears improbable that wastefields from both outfalls shall reach the reference line at the same locations causing superposition. For simulating the cumulative effects, it was thought reasonable to consider that wastefield emanating from one outfall first reaches the other outfall diffuser section at average flood or ebb tide velocity, as applicable for the season. After their superposition, it was assumed that the combined wastefield moves towards the coast under worst case monsoon or non-monsoon wind conditions.

7.3.3 PREDICTION OF INITIAL DILUTION

Ambient currents play a very significant role in initial dilution of outfall discharges. For impacts in the vicinity of diffusers, lowest initial dilution which occurs at the time of weakest ambient currents is critical. Whereas, the initial dilution occurring during the strong shoreward currents is relevant for evaluating the impacts on coastal water quality.

Accordingly, initial dilution estimates for Worli and Bandra were worked out for the minimum and average coastal currents corresponding to spring or near-spring tides during monsoon and non-monsoon period. The revised estimates for peak, average and minimum dry weather wastewater flows were considered while estimating the initial dilutions. The results of the analyses are summarised in Tables 7.3 and 7.4 for Worli and Bandra, respectively.

The tidal currents near Bombay undergo complete reversal in about 6.25 hours and the water depths remain shallow for several kilometers on the coastal continental shelf due to low seabed slope. The tidal currents are, therefore, expected to induce complete vertical mixing in the region. While modelling the impacts at the coast due to secondary dispersion, the initial dilutions for ebb and flood currents have been taken. These estimates imply initial mixing of wastewater with about 90 percent of the water column at diffuser section. The lower initial dilutions during the tidal slack have been considered to estimate water quality impacts near the diffusers. It has been, however, assumed that soon after the development of ebb or flood current, the wastefield formed during the tidal slack gets vertically mixed and the earlier estimates become applicable for further simulation.

Table 7.3

Initial dilution estimates for proposed Worli outfall (3 km long outfall, 504 m long diffuser)

Wastwater discharge M³/ S	Ambient Current		
	Minimum observed 0.07 m/ s	Critical for ebbtide, monsoon and flood tide, non-monsoon (0.50 m/ s)	Critical for floodtide monsoon and ebb tide, non-monsoon (0.60 m/ s)
Peak DWF (11.4)	10	200	240
Average DWF (5.9)	18	380	460
Minimum DWF (3.0)	105	760	910

Table 7.4

Initial dilution estimates for proposed Bandra outfall (3 km long outfall, 506 m long diffuser)

Wastwater discharge M^3/S	Ambient Current		
	Minimum observed 0.07 m/ s	Critical for ebbtide, monsoon and flood tide, non-monsoon (0.50 m/ s)	Critical for floodtide monsoon and ebb tide, non-monsoon (0.60 m/ s)
Peak DWF (12.1)	35	150	180
Average DWF (6.4)	120	280	340
Minimum DWF (3.2)	240	570	680

While examining alternate management options, outfall lengths upto 5 kilometers were considered. Estimates of initial dilution for water depth at 3 kilometers were retained for longer outfall options as due to low sea bed gradient water depths and, therefore, initial dilution is expected to remain in the same range for additional 2 kilometers.

7.3.4 MODEL COEFFICIENTS FOR SECONDARY DISPERSION MODEL

The process of advection of wastefield governs the time for which the primary processes of secondary dispersion to remain active. The extent of the role of these processes in reduction of the the wastefield contaminants' concentration of non-conservative substances is controlled by the coefficients of decay and transverse dispersion. Realistic model predictions of secondary dispersion and their interpretation while delineating the environmental management plan, therefore, warrant judicious selection of these coefficients and an estimate of the sensitivity of model predictions with respect their values.

Decay coefficient for total coliforms

For appropriate selection of the microbial decay coefficient, insitu and laboratory estimates were made. The laboratory experiments were designed to simulate clear sky, cloudy sky and night time conditions to provide estimates for different conditions expected in the field. The decay coefficient for total coliforms was estimated as -1.08 ±0.08, -0.59 ±0.06 and -0.12 ±0.05 per hour for clear sky, cloudy sky and night conditions. The insitu estimate for the surface samples was obtained as -0.5 per hour under sunlight and low light penetration of about 0.5 meter due to high ambient turbidity. Though, the insitu estimate is more prone to errors due to uncertainties and measurement errors inherent in field experiments, the estimated value appears reasonable.

While simulating the decay of microorganisms the Brooks' model multiplies the concentrations obtained through the considerations of purely advective and dispersive processes by a factor providing the reduction due to microbial decay.

As Brooks' model calculates the concentration profile at a given time interval or distance as a function of initial concentration and width of the wastefield, it was not possible to assume different total coliform decay rates operating at top and bottom layers of sea column representing depth related variation in sunlight penetration and obtain the intermediate vertically mixed concentrations while simulating the wastefield.

Therefore, an approach of using a single decay coefficient for total water depth, was adopted. The value of the decay coefficient was obtained by taking a weighted average of higher decay coefficient for top 1 meter and lower decay coefficient for lower water depths in proportion to the respective depths. This approach simulates the field conditions better in comparison to using different decay coefficient for two layers and obtaining the resultant concentrations at the end of simulation by mixing the two regimes.

Following above reasoning, the values of decay coefficients used under different light conditions are presented in Table 7.5.

Transverse dispersion coefficient

The insitu radio-tracer studies gave an estimate of proportionality constant α appearing in Equation 6.6 for transverse dispersion coefficient, as 0.0026 $m^{2/3}$/sec. During the radio-tracer experiment the ambient currents varied between 0.70 m/s to 0.80 m/s whereas the critical ambient flood and ebb currents in the region were estimated in the range of 0.5 to 0.6 m/s. Use of somewhat higher dispersion coefficient than indicated by ambient coastal currents was considered justifiable due to enhanced wave environment in the coastal region which increases the dispersion in the sea. Although during the non-monsoon conditions a comparatively calm wave environment is expected, same estimates for dispersion coefficient were used. An allowance was, however, made for its possible high value while interpreting the results.

7.3.5 ENVIRONMENTAL IMPACTS OF PROPOSED PROJECT

Offshore Impacts

The discharge of wastewater through marine outfalls will not cause environmentally adverse conditions, such as low dissolved oxygen or high nutrient concentration in the water column, even in the vicinity of outfalls, as the expected initial dilution is more than 50 times during most of the tidal cycle. For such periods, the dissolved oxygen levels near the outfall diffuser section will be more than 4 mg/l and BOD levels less than 3 mg/l.

However, if peak dry weather flow coincides with the tidal slack period, BOD levels of upto 20 mg/l are probable in immediate vicinity of outfalls. The probability of such occurrence is less than 0.01. This concentration, however, will fall below 5 mg/l soon after the tidal currents re-establish and would not have appreciable influence on DO.

Table 7.5

Decay coefficients in different light conditions

Simulation conditions	Decay coefficient (per hour)	T_{90} (hours)
Clear sky day (non-monsoon)	- 1.08	2.13
Cloudy day (monsoon)	- 0.59	3.9
Night	- 0.12	19.2

Observations along west coast of Bombay and in immediate vicinity of Colaba outfall (a small outfall in operation since 1988) discharging sewage at east coast, indicate no significant accumulation of organic matter, nutrients or metals in the sediments. Since similar dilution and coastal currents are expected near the diffuser section of proposed outfalls, no significant negative impacts on sediment quality are expected. Due to low levels of metals and trace organics in the sewage, their concentrations in the water column or sediments in the vicinity of outfalls will also remain close to the ambient levels.

As the operation of outfalls does not result in impairment of water and sediment quality even near the diffuser section, no adverse effect is expected on marine flora-fauna and the fish yield in the region.

Nearshore Impacts

The nearshore impacts associated with operation of marine outfalls are essentially beneficial and expected to considerably improve the coastal and beach environment. The most prominent impact, in this context, would be considerable improvement in physico-chemical quality of coastal waters.

Construction of 3 km long outfalls at Worli and Bandra will fully eliminate the dissolved oxygen depletion which presently occurs during the low tide near Mahim coast. Reduction in nutrient loading along with improvement in DO will considerably improve the ecological health of near shore waters in the region. These improvements will contribute towards elimination of odour nuisance, enhancement of beach aesthetics and water use. Increased fish yield may be obtained in coastal regions near Bandra and Worli due to improved water quality conditions.

For estimating the nearshore (at reference line) impacts in terms of bacterial contamination, it is necessary to simulate the wastefield movement and dilution under the processes of advection and dispersion. Table A7.6 presents the results of wastefield advection, under monsoon and non-monsoon conditions, for 3 kilometer long Worli and Bandra outfalls. For these simulations the tidal currents as described in Table 7.2 and maximum persistent shoreward wind for respective seasons have been considered. The results are expressed as the minimum time of travel and the latitude and longitude of the region at which the wastefield crosses the reference line. The critical part of the tidal cycle as well as the average resultant velocity of wastefield advection for the respective simulations are also presented.

The wastefield advection results indicate that for monsoon conditions, wastewater discharge from proposed 3 km Worli and Bandra outfalls may reach the reference line in as little as 60 and 90 minutes, respectively, during the ebb tide. The expected travel time for non-monsoon is 125 minutes for Worli and 145 minutes for Bandra.

The predicted concentrations of total coliforms at reference line were calculated by Brooks' model using these travel times and model coefficients described earlier. The simulations' results for critical monsoon conditions giving centre line wastefield concentration and the approximate length of reference line for which the TC counts remains higher than 1000/100 ml have been presented in Table A7.7. As the bacterial contamination for no treatment option remains very high, results for primary and secondary level land treatments have been also included in the Table A7.7. Impacts of discharges from Worli outfall (which are higher than Bandra due to shorter travel time) have been further analysed for cloudy day and night time conditions. The results for non-monsoon conditions are presented in Table A7.8.

The initial total coliforms count in wastewater has been taken as 7.85×10^7 per 100 ml and water quality scenarios have been generated for peak dry weather flows for year 2005. The total coliform concentration for average dry weather flow are expected to be about half of those for peak dry weather flow. Further, microbial decay rates corresponding to cloudy day time conditions and clear sky day time conditions, respectively, have been used to develop the critical scenarios for monsoon and non-monsoon season as these are the common conditions during the respective seasons.

The results of these analyses indicate that for 3 kilometer long outfalls, under adverse meteorological conditions, about 1/3rd of the reference line could be susceptible to total coliform levels exceeding the stipulated standard by about 100 times during monsoon (Figure 7.4) and upto 50 times during the non-monsoon (Figure 7.5). It is further observed that the bacterial levels at reference line decrease with added treatment but do not approach the stipulated standards even with secondary level land treatment. When compared to existing conditions, 3 kilometers long outfalls are expected to provide a minimum of about two times improvement in levels of bacterial contamination. A similar twofold improvement in terms of extent of polluted stretch is also expected.

The impacts of cumulative effect of outfall discharges on bacterial contamination at the reference line were also analysis. The results indicate that the combined impacts are only about 10 percent more than the impacts of an individual outfall and the conditions causing the superposition of wastefields from two outfalls are expected to rarely occur.

Figure 7.4 : Total Coliform Scenarios for 3 km Long Outfalls (Monsoon)

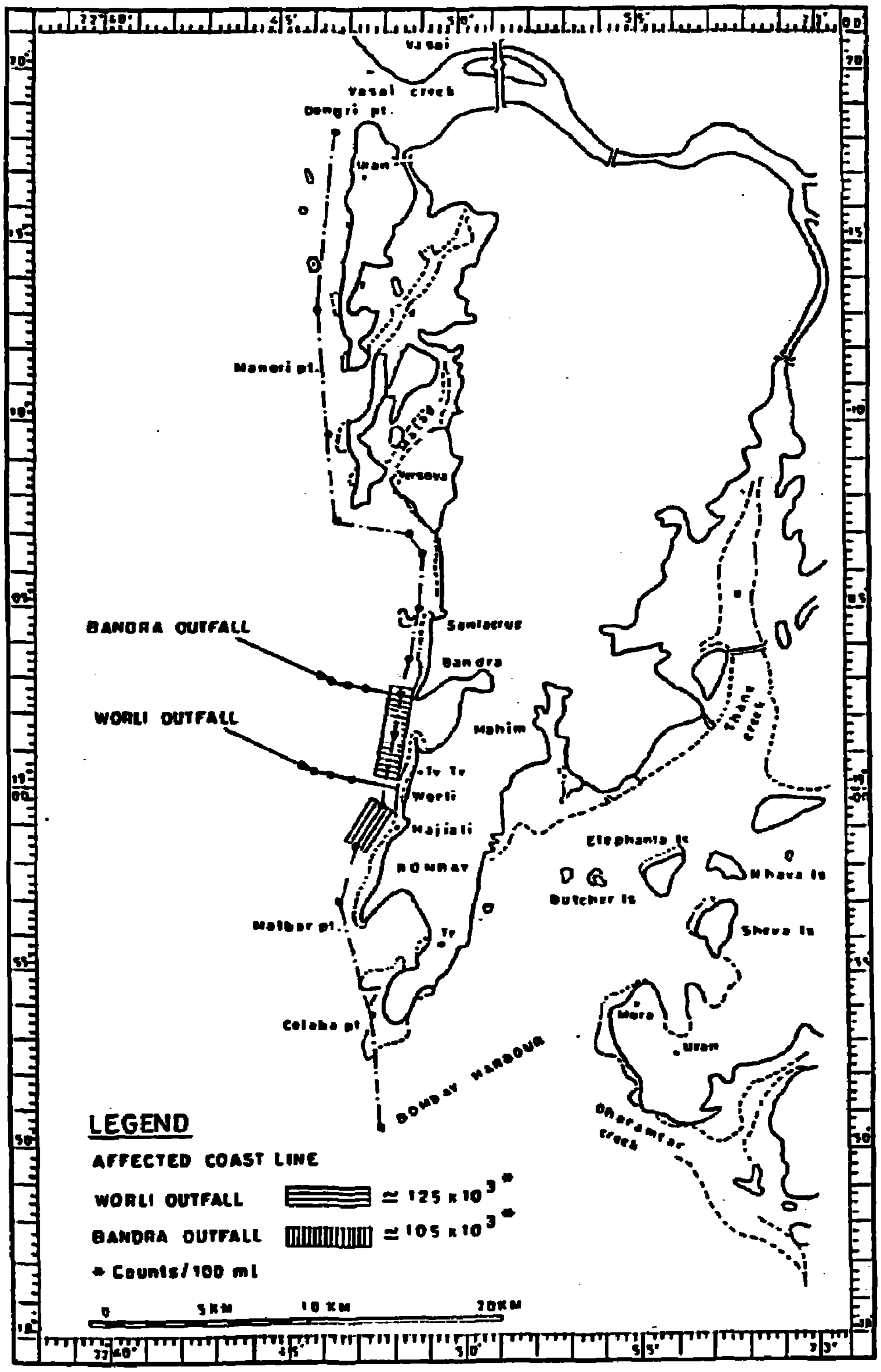
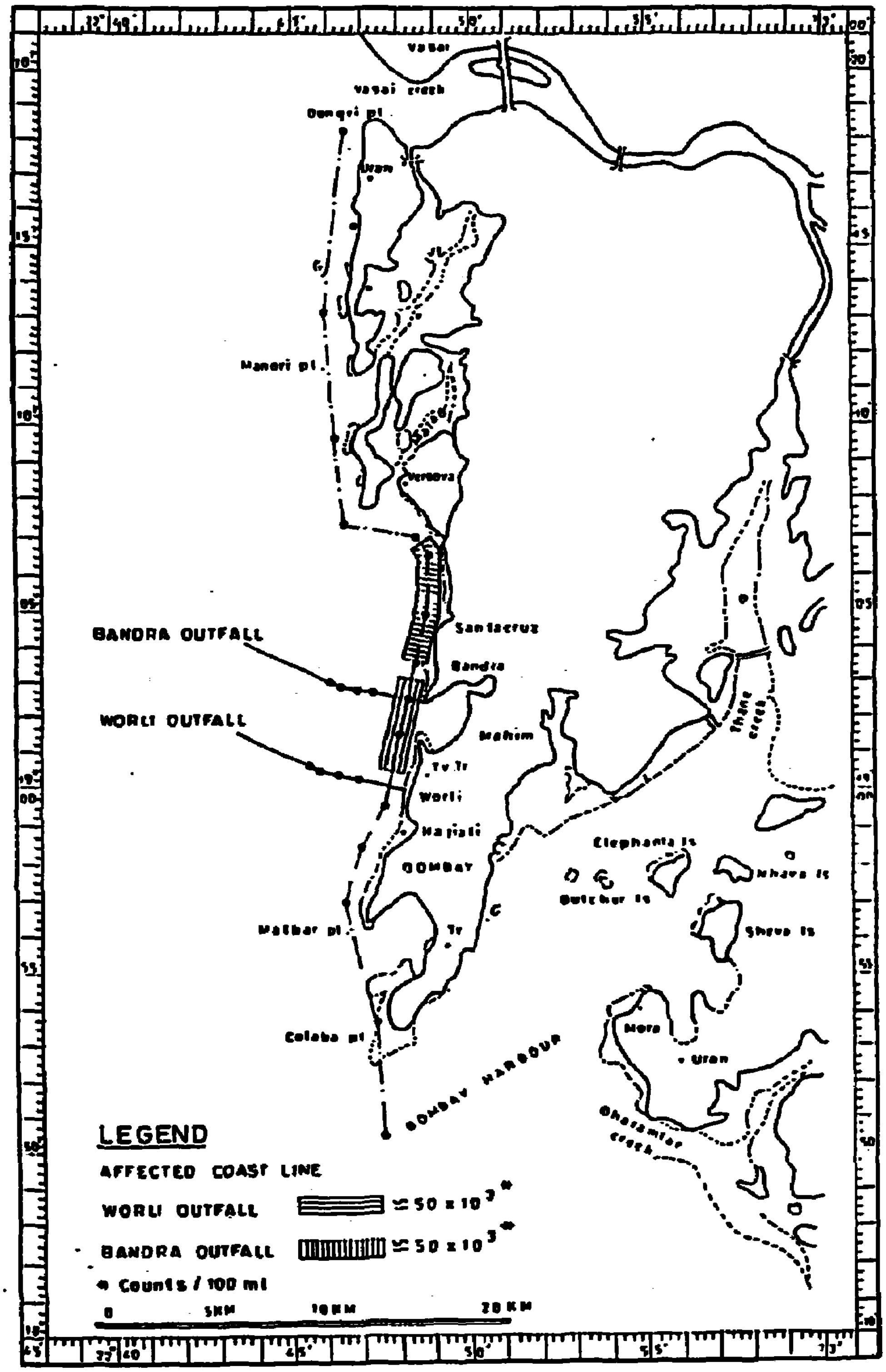


Figure 7.5 : Total Coliform Scenarios for 3 km Long Outfalls (Non-monsoon)



Impacts of sewage overflows during monsoon

The wastewater flow estimates in Worli and Bandra drainage zones indicate appreciable increase during the monsoon. The wet weather flows, during and after heavy showers, have been observed to be about 4 times of average dry weather flows and about 2 times of peak dry weather flows. The analysis of future storm water inflows indicates a rise of 750-900 Mld for Worli and 450-500 Mld for Bandra over the dry weather flows on the days of intense rainfall.

Although the outfalls are designed to flush out the wet weather flows, on a few occasions the peak wet weather flows may exceed the outfall discharge capacity. Under such events, the excess flows will have to be discharged through the bypass mechanism at the outfall headworks. The wastewater spillage, thus caused, would have potential adverse environmental impacts at the near shore coastal regions.

A number of environmental and discharge parameters will govern the actual magnitude of these impacts for a particular overflow. The important factors include the rate of spillage and duration; tidal conditions during the spillage. Due to a number of uncertain variables and lack of adequate data to establish a near shore coastal water quality model, it will be inappropriate to attempt a precise quantification of the near shore water quality impacts due to the storm water flows. A qualitative description of the impacts, however, could be attempted.

The estimates on the quantum and frequency of the sewage overflows by Binnie and Partners indicate that the worst overflows would be of about 4.0 m^3/s and 3.0 m^3/s at Worli and Bandra respectively, for a duration of about 2.5 hours at Worli and 6 hours at Bandra. These over flows will be discharged through the earlier constructed pipe outfalls and the storm water discharge points, therefore, would 500 m and 220 m away from the coast at Worli and Bandra, respectively. The sewage, so discharged will be diluted rainwater, but water quality near discharge points will deteriorate during an overflow. The impacts, however, would be transient and confined to bad weather and periods.

The initial dilution calculations for these discharges indicate that a dilution of about 4 times for Worli and about 1.5 times for Bandra will be available at the discharge locations. Corresponding to a BOD concentration of about 80 mg/l for sewage diluted with storm water, after initial dilution the wastefield BOD at the overflow discharge sites is expected to be about 16 mg/l at Worli and 35 mg/l at Bandra. These BOD concentrations are sufficiently high to completely deplete the dissolved oxygen in the region of advecting wastefield.

The impact of sewage overflows for pipe outfall option will be more pronounced due to the proximity of the sewage overflows to the coast. A discharge at the rate of 3 m^3/s with BOD of 100 mg/l, if coincides with the rising tide, has potential to create anaerobic conditions in large areas within Mahim creek. The conditions can give rise to fish kill in the creek which after commissioning of outfalls is expected to again become rich in aquatic life. Similar occurrence is expected at Worli, though due to smaller duration of sewage overflow and higher dilution in the coastal region, it may occur at a lower scale. The ecological restoration of the Mahim creek may take a few months after the sewage overflow and, therefore, there is a definite need to avoid the sewage overflows if pipe outfall option is selected.

7.4 ANALYSIS OF ALTERNATIVES

The modelling of advection and secondary dispersion processes for proposed outfalls indicate that 3 km long outfalls, even with higher degrees of land treatment, would not achieve the desired bacterial quality at the coast. Although the analysis was restricted to worst case meteorological conditions, the levels of violation of the bacterial standard indicate that the outfall will not provide the required quality even under more probable average weather conditions. It was, therefore, necessary to examine alternatives of longer outfalls with different land treatment levels to achieve better compliance with the stipulated standards. Following section describes the results of such analyses as also the probable impact on water quality if the present coastal discharges are allowed to be continued.

7.4.1 NO ACTION SCENARIO

The municipal wastewater discharges which are presently estimated at 1500 mld are expected to rise to 2200 mld by year 2005, the design period of the project. If the proposed schemes are not implemented, the wastewater will continue to reach the coastal regions through the present drainage routes and cause pollution. The existing coastal water quality, exhibits evidence of gross bacterial pollution and high DO depletion in regions near the main wastewater outlets and moderate pollution all along the coast. These levels will rise under no action scenario and the overall coastal water quality including beach water quality will further deteriorate.

7.4.2 AUGMENTATION OF OUTFALLS' LENGTH AND LAND TREATMENT

As augmentation to the proposed outfalls, alternatives in the form of combinations of longer outfalls and different land treatment (4 and 5 kilometers long outfalls with preliminary, primary and secondary treatment) were examined. The simulations on wastefield advection indicate that the time of travel increases by about 1.5 times if outfall length is increased from 3 km to 4 km and about 2 times if it is increased from 3 km to 5 km (Table A7.9). For 4 and 5 kilometer long outfalls, the bacterial contamination levels at the reference line are presented in Tables A7.10 through A7.14. The results include the cases for monsoon and non-monsoon seasons as also the effect of different degrees of land treatment. The effected coast line and the contamination levels corresponding to the alternatives for extended outfalls are also presented in Figures 7.6 through 7.9. In these figures, B_1, B_2 and B_3 correspond to the scenarios of no treatment (1), primary treatment (2) and secondary treatment (3) levels at Bandra and similarly W_1, W_2 and W_3 correspond to treatment levels at Worli.

It was observed that for non-monsoon season wastefields emanating from 3 and 4 km long outfalls at Bandra take longer time to reach the reference line compared to Worli outfall. The bacterial contamination is also higher for Bandra due to lower initial dilution. Further, for non-monsoon it was not considered necessary to develop the cloudy day time scenarios as such conditions occur sparingly.

The analyses, although approximate in nature, because of inadequate data on coastal currents, indicate that only 5 kilometer long outfalls with secondary treatment are likely to nearly meet the existing bacterial standards at the reference line. A reduced level of daytime compliance (50 percent during monsoon and 80 percent during non-monsoon), however, is anticipated at the reference line with 5 kilometer long outfalls preceded by preliminary treatment.

7.4.3 SENSITIVITY AND PROBABILITY CONSIDERATIONS

The predictive scenarios discussed above have been developed for the worst case wind, current and wastewater discharge conditions. The probability of simultaneous occurrence of these events is less than 0.005. The modelling results, however, depict that bacterial water quality remains below the stipulated standard even if one considers a day time scenario of 5 knots wind from SW, SWW and W, currents half of those for the spring tide and average dry weather wastewater flows. The results indicate that under such or more unfavourable conditions which have a probability of occurrence of about 0.6, for proposed outfalls the total coliform levels at the reference line may exceed the stipulated standards by about 24 times. The wastefield width exceeding coliforms levels of 1000/100ml at the reference line, for such conditions, is expected to be about 4.5 km. The scenario for 5 km long outfall without treatment, however, shows remarkable closeness to the standard viz. highest TC count at centre line of 1100/100 ml.

Figure 7.6 : Total Coliform Scenarios for 4 km Long Outfalls (Monsoon)

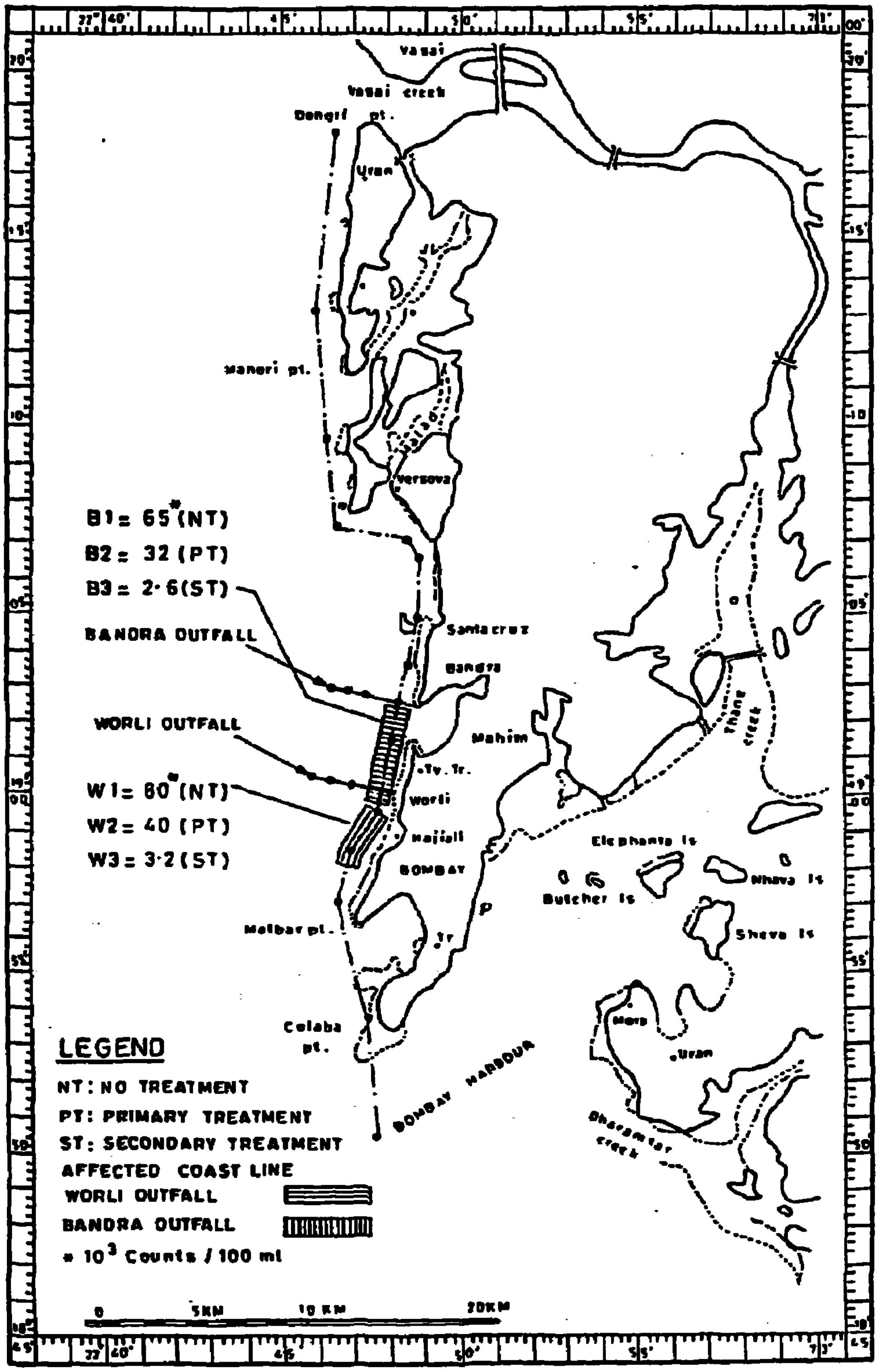


Figure 7.7 : Total Coliform Scenarios for 4 km Long Outfalls (Non-monsoon)

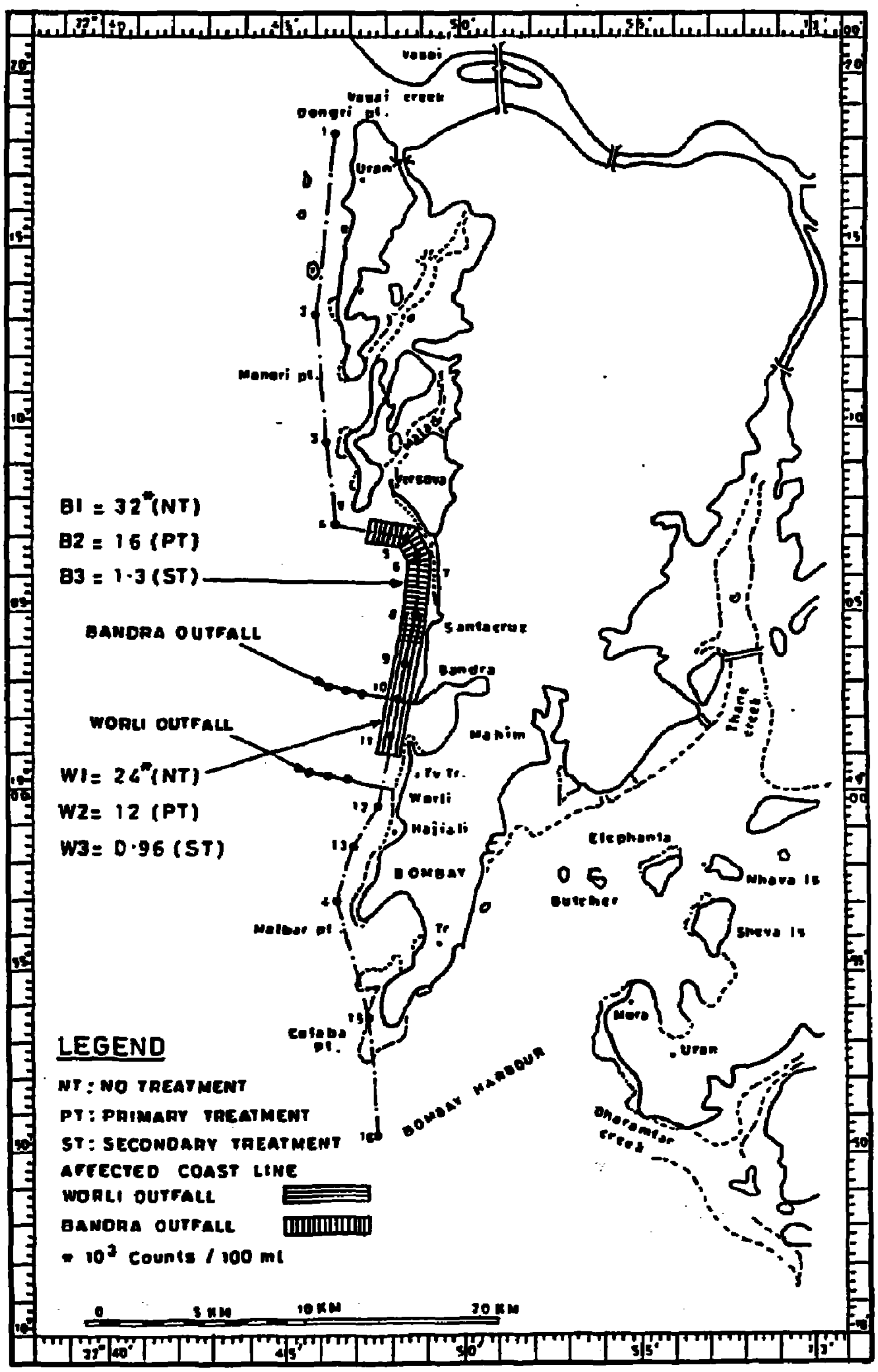


Figure 7.8 : Total Coliform Scenarios for 5 km Long Outfalls (Monsoon)

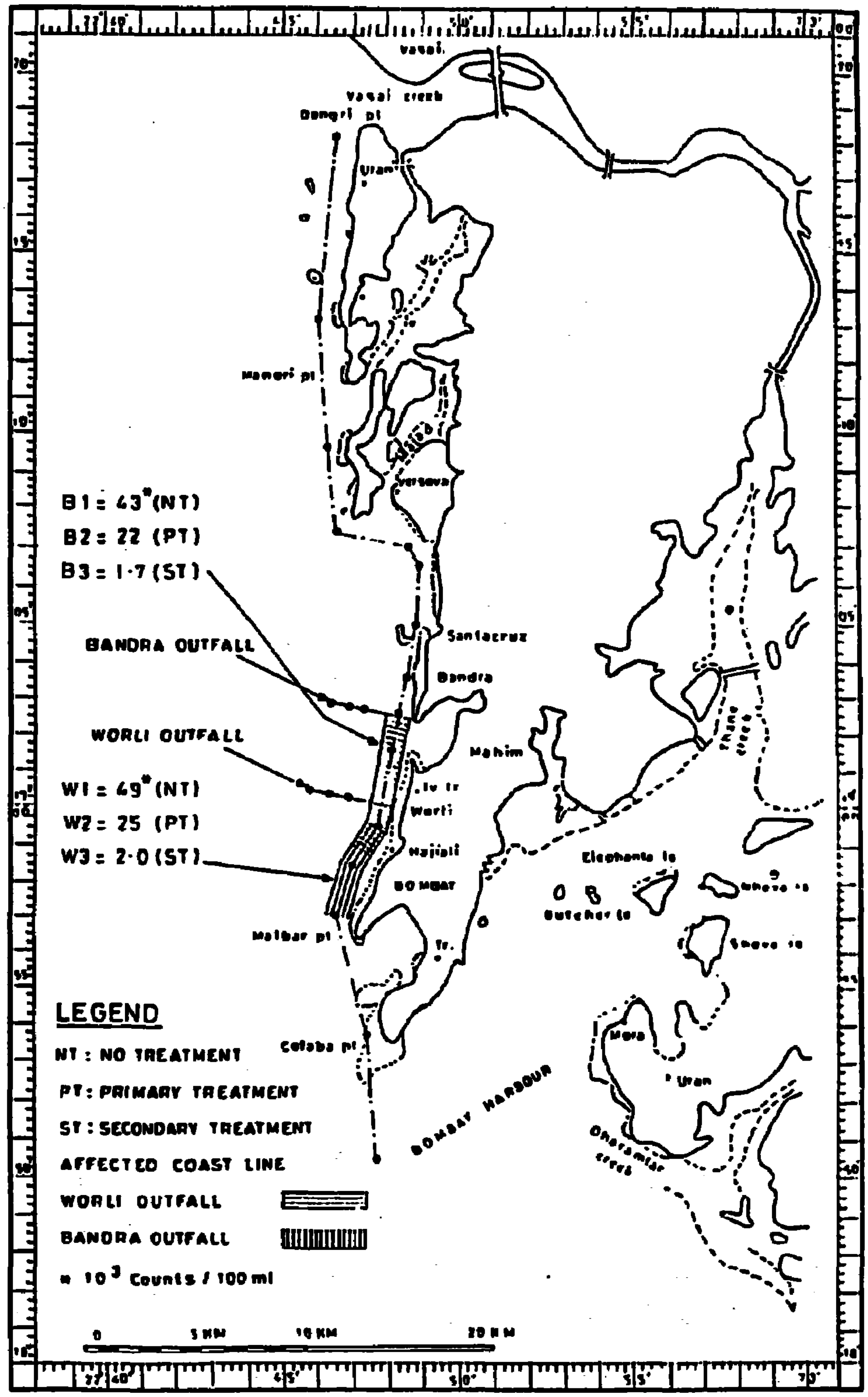
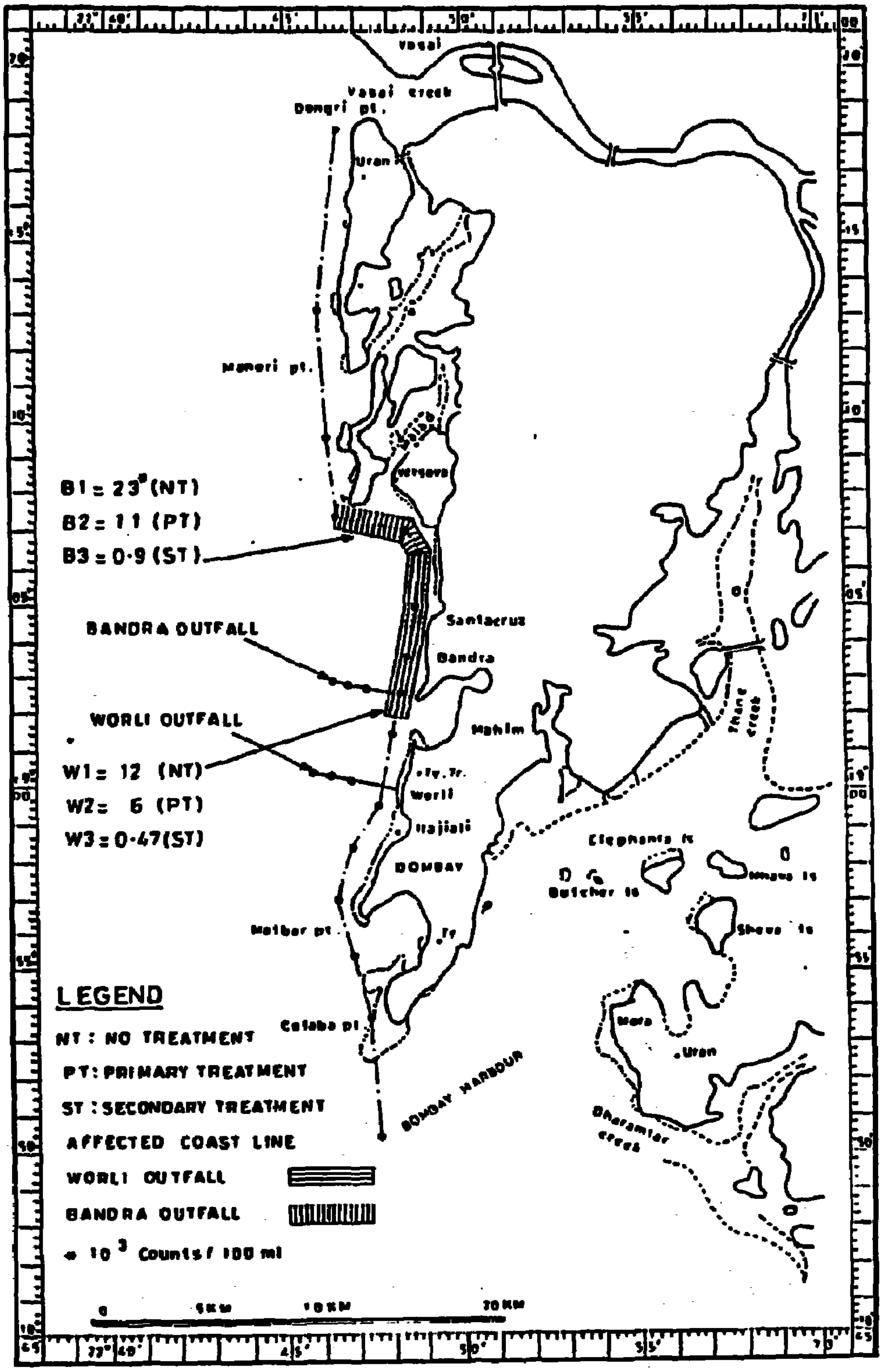


Figure 7.9 : Total Coliform Scenarios for 5 km Long Outfalls (Non-monsoon)



This analysis implies that only 5 km long outfall may have a chance of meeting the stipulated standard for about half of the times (during the day hours) in monsoon. Confirmation of this inference, however, entails more sophisticated modelling effort with additional data on coastal currents. Due to approximate nature of analysis, calculations for Bandra were not carried as similar observations are expected.

Again, due to the need to adopt a simplified and appoximate modelling procedure, a limited sensitivity analysis of model predictions with respect to the model variables was performed. The model results for the 3 kilometre long outfalls do not show a significant change with change in model parameters within their probable range. The model predictions were observed to be most sensitive to variations in coastal currents, specially the direction of the current. This observation emphasises the need for collection of more precise hydrodynamic data on the region to improve the accuracy of model predictions.

7.5 CONCLUSIONS

The implementation of the proposed project of 3 km long marine outfalls at Bandra and Worli is expected to considerably improve the overall water quality and aesthetics of the nearshore region. Also, no significant impairment of offshore water or sediment quality near the outfall diffusers is expected. During the construction of the outfalls moderate increase in the ambient noise and dust levels is probable near the construction sites. The associated blasting operations also require careful monitoring and control to ensure safety of nearby structures.

The proposed 3 kilometre long outfalls, however, are not expected to achieve the desired improvement in bacteriological quality of coastal waters. During the monsoon months, under the influence of strong and sustained westerly winds, total coliforms levels may exceed the stipulated standard by about 50 to 100 times at about one-third of Bombay's coastline. Analyses of alternatives in the form of extended outfall length and land treatment indicate that the desired reduction in coliform concentrations may be achieved with the extension of outfalls upto 5 kilometres and there may still be a need to raise the land treatment from the presently proposed preliminary level.

It is, however, important to emphasise that above analyses has been carried out using the limited field data available on coastal currents in the region. Consequently, the modelling results presented herein are approximate in nature. The conclusions of the study should, therefore, be confirmed/refined by collecting precise and adequate hydrodynamic data for use of sophisticated models before selection of the final management option.

Chapter 8
RECOMMENDATIONS FOR MITIGATION PLAN

8.1 PREAMBLE

Bombay Sewage Disposal Project is one of the most ambitious pollution abatement schemes undertaken in India. As the project envisages disposal of municipal wastewaters through marine outfalls at about 3 kilometers into the sea, considerable improvement in coastal water quality near Bombay is expected on its implementation. The project also has potential of causing some negative environmental impacts due to large scale construction activities and disposal of large volume of wastewater into hitherto clean sea regions.

The environmental assessment study, therefore, was undertaken with the dual objective of ascertaining the adequacy of proposed facilities to provide the desired benefits and to delineate the mitigatory measures for control of the negative environmental impacts. The study indicated that the proposed schemes may not achieve the stipulated coastal bacterial quality and therefore management options of longer outfalls and higher degree of land treatment were also examined. These investigations underscored the need to collect additional data on coastal hydrology to facilitate improved evaluation of these options.

The findings of this study confirm that 3 kilometer long outfalls at Worli and Bandra shall substantially improve the existing coastal water quality without causing any significant impairment at the discharge site. The mitigation plan, therefore, is written with the assumption that, as the first phase of the project, MCGB will proceed with the construction of the proposed outfalls.

It also needs to be emphasized that the review of present bacterial standard will be necessary to allow a practical management option for the outfalls. In this context, it may be noted that the European Community bathing water directive requires 95 percent compliance with TC count of 10,000 / 100 ml, whereas the Florida standard entails 80 percent compliance with 1000 / 100 ml TC levels. Further, these standards apply near the beach and provide additional dispersion and decay of wastefield emanating from a marine outfall and moving shoreward with currents when compared with the Indian standard applicable at 1 km seaward from the coast.

8.2 MITIGATION PLAN

8.2.1 CONSTRUCTION PHASE

The potentially negative impacts of outfall construction are vibration due to blasting and rise in ambient noise and dust levels. Marginal water quality impairment during the construction of diffuser sections is also expected. These impacts can be prevented by adherence to good construction and house keeping practices. Provisions for measures such as conducting the blasting operations under expert supervision, avoidance of unnecessary idling of construction machinery and spillage of fuel and oils and adequate maintenance of construction machinery to ensure efficient and trouble free operation should be made in construction contracts.

Analysis of expected noise levels during construction indicates that some areas in the vicinity of the construction sites may be subjected to noise levels higher than the stipulated standards. It will therefore, be obligatory to confine the noise generating activities to the day hours to avoid sleep disturbance. New well maintained vehicle should be used for muck disposal and material transfer. It may, further, be necessary to construct noise barriers at the construction sites to achieve additional reduction of about 10 dBA.

Provision of water spraying on all haul roads and excavations sites to minimize the dust and development of green belts around the construction sites to minimize the impacts of fugitive emissions and noise and to effect aesthetic improvement should also be made. An inventory of requisite mitigatory measures is provided in Table 8.1. The recommended specifications for the green belts are presented in Table 8.2.

8.2.2 OPERATION PHASE

Findings of the study indicate that proposed 3 kilometer long outfalls will provide adequate environmental improvement for all parameters except the bacterial quality in the coastal waters. The mitigation plan for the outfalls, therefore, is closely related to the compliance of stipulated bacterial standard which entails that the total coliforms counts at the reference line should be less than 1000/100 ml at all times.

Available data on the coastal currents in the project area is inadequate to provide a firm recommendation on additional outfall length or treatment level for the compliance with regard to the bacterial standard. This information will be available only at the completion of further modelling studies with updated hydrodynamic data. The modelling projections with the existing data, however, clearly indicate need for augmenting the proposed 3 kilometer long outfalls either in terms of increased outfalls length or additional land treatment. In the present design of outfalls, therefore provision should be made for their extension beyond 3 kilometres at a latter date.

Table 8.1

Mitigation Plan for Construction and Operational Impacts of Marine Outfalls

Environmental Issues		Action to be Taken	Responsible Entity
A. Construction Phase			
1. Dust contamination at site and on haul roads	(a)	Construction sites and access roads will be watered twice each day	MCGB/Prospective Contractor (PC)
2. Noise pollution	(a)	Operation of heavy construction machinery restricted to daytime hours (6.00 am — 8.00 pm)	MCGB/PC
	(b)	Noise monitoring near blast/drilling site and in nearby sensitive locality (when machinery is under operation)	MCGB
	(c)	Construction of sound barriers if monitoring reveals noise pollution in sensitive locality	MCGB
	(d)	All transport activities causing noise pollution restricted to daytime hours	MCGB/PC
	(e)	Provision of ear muffs for all workers at site during blasting operations	PC
3. Vibrational disturbance	(a)	All blasting/drilling operations to be carried out under supervision	CWPRS/MCGB/PC
	(b)	Monitoring at site and in nearby areas 50-100 mts away during blasting at the ground level	CWPRS/MCGB
4. Air Pollution	(a)	Monitoring at site and on access roads for SPM, NO_x and SO_2 twice each week	MCGB
5. Disposal of excavated material and construction debris	(a)	To be used for land reclaimation at Bandra construction site	MCGB/PC
	(b)	In case of semi solid wastes provision to be made for dewatering/drying prior to its use for reclamation	MCGB/PC
	(c)	Daily inspections at haul road and sites for construction debris, its collection and disposal to landfill site	MCGB

Mitigation Plan for Construction and Operational Impacts of Marine Outfalls *(Contd.)*

Environmental Issues		Action to be Taken	Responsible Entity
6. Traffic and transportation	(a)	Properly planned transportation to be restricted to daytime hours	MCGB/PC
	(b)	All hauling materials to be covered while being transported	PC
	(c)	Routine check of vehicles used for transportation and their proper maintenance to minimise vehicular pollution	PC
7. Water pollution	(a)	Offshore construction activities to be daily inspected for spillage of fuel/oils at the construction head	MCGB
8. Domestic sewage and rubbish	(a)	Provision of waste disposal facilities like septic tanks at construction workers colony	PC
	(b)	Provision at site and in worker's colony for jars/cans for solid waste collection	PC
	(c)	Transportation for dumping the solid wastes from worker's colony to a nearby collection/ dump site within the area	PC
9. Environmental Monitoring			
(i) *Marine Outfalls*	(a)	Monitoring at important beaches and seafronts like Dadar, Juhu and Worli for bacterial and parameters and DO during critical period with respect to tidal cycle and season. Frequency 2 samples/week	MCGB/NEERI
	(b)	Monitoring at reference line during critical slack at selected stations on alternate days for two weeks per year per season. Water samples to be analysed for relevant physicochemical bacterial and biological parameters. Sediment samples to be analysed to be analysed for benthos, nutrients and heavy metals	MCGB/NEERI

Mitigation Plan for Construction and Operational Impacts of Marine Outfalls *(Contd.)*

Environmental Issues		Action to be Taken		Responsible Entity
B.	**Operational Phase**			
1.	Environmental Monitoring			
(i)	*Marine Outfalls*	(a)	Beaches and seafronts Water samples to be collected during low tide slack at stations South of Worli and at low tide and high tide slack for stations North of Worli	MCGB/NEERI
		(b)	Reference Line monitoring similar to that during construction phase	MCGB/NEERI
		(c)	Effluents from grit chambers to be monitored for grit and heavy metals	MCGB/NEERI

Table 8.2

Design details for plantation in areas near the proposed marine outfalls sites

Site	Total Length Approx. (m)	Name of the Plant Species	Plant to Plant Spacing (m)	Total Number of Plants Required
Worli				
Two rows of plants along the inside boundary wall of the Sewage Purification Works at Worli	2300	Cocos nucifera Drooping Asoka	10 10	460 460
Bandra				
Two rows of plants inside the boundary of the proposed Sewage Purification Works at Bandra	2000	Royal Palm Drooping Asoka	10 10	400 400

The hydrodynamic data on the region should be strengthened through further field studies to facilitate use of models of higher sophistication of finalizing the suitable outfall length and land treatment option.

Under exceptionally heavy rains, the outfalls are expected to be surcharged resulting in storm water overflows near the coast. The analysis of impacts of these overflows, however, does not indicate significant water quality impairment because of the low frequency of their occurrence and their discharge through the earlier constructed short pipe outfalls.

8.2.3 ENVIRONMENTAL MONITORING

A comprehensive environmental monitoring programme before and during construction of outfalls and during their operation is essential for effective mitigation of negative impacts of the project. If conducted in a planned way, such monitoring shall provide the basis for efficient post-project auditing and shall yield rich information for planning of similar projects in future.

Since, water quality scenario, both spatially and temporally, shall be very different before and after the implementation of the project, it is appropriate to have different methodologies for water quality monitoring to cover these phases.

Regular environmental monitoring should begin immediately and continue during the construction and post-commissioning phases. The monitoring for each project phase, to begin with, shall cover environmental aspect related to the project and should ave features described in the following sections. As the factual information on the project becomes available through the proposed monitoring, the monitoring programme may be suitably modified in cognizance with water quality surveillance needs.

During the pre-commissioning phase, samples collected from important beaches and seafronts should be analyzed for bacterial contamination and dissolved oxygen. The critical period of the tidal cycle corresponding to elevated pollution levels at sampling locations, first, should be identified by sampling at two hourly interval (only day time hours) for a week. Year long sampling during that period should be undertaken with the frequency of 2 samples per week.

Samples at selected locations at the reference line should be collected on alternate days for 15 days, once every year in winter and in summer, to established a database on existing coastal water quality. The samples should be collected at low tide slack and should be analyzed for relevant physio-chemical, biological and bacteriological parameters. Sediments samples should also be collected and analyzed for benthos, nutrients and heavy metals.

During the construction phase additional samples, once every week, should be collected near the construction head and analyzed for physicochemical parameters. Visual inspection, once a day, should beconducted to detect any oil leak from offshore construction machinery. Noise and air pollution levels should also be monitored at the construction sites and if required mitigatory actions should be taken to ensure compliance with the standards. Additionally, daily visual inspection of roads and roadsides in the vicinity of the construction site should be undertaken to identify any nuisance that need attention with respect to dust, spill of construction materials or debris etc.

Post-commissioning monitoring similar to pre-commissioning period should be undertaken. During this phase, water samples at the beaches and seafronts and locations on reference line situated at North of Worli should be collected during low and high tide slack and at South of Worli at low tide slack. The effluents from grit removal facilities should be regularly analyzed for grit and heavy metals.

8.2.4 PUBLIC PARTICIPATION

The survey conducted among the fishing communities and general public residing near the construction sites and beach users reveal lack of awareness about the project. There is therefore a need for public awareness programme specially among the fishing communities on the West coast which fear that discharges from marine outfalls would adversely affect the fish yield.

As the findings of present study show that these apprehensions have no true basis, the first step towards environmental awareness should be to place the assessment report for public discussions among representatives of fishing communities, general public and local NGOs. The report summary should also be translated in vernacular languages and distributed among fishing societies.

A comprehensive awareness programme on the need of the project, major technical and social issues and the environmental benefits should be undertaken through local media. The coverage should include group discussion on TV and radio among panel comprising eminent citizens and officials connected with implementation and environmental assessment of the project. A suggested outline of environmental awareness programme is presented in Annexure I.

8.2.5 INSTITUTIONAL NEEDS

There is a need for substantial infrastructural development within MCGB for effective supervision of construction of the outfalls and their operation. Training programs at various levels within MCGB should be conducted for the associated project staff for effective implementation and efficient operation of the project. Necessary measures for institutional strengthening towards these objectives are being planned through MCGB's in-house Central Research and Training Centre and the management consultants M/s Tata Consuiting Services.

For effective implementation of the recommended environmental monitoring, it will be necessary to develop adequate facilities for sampling and analysis. It will be desirable to operate an environmental monitoring cell, with adequate training and instrumentation support, for coastal water quality monitoring and analysis related to the outfall project. Government and/or private laboratories with adequate infrastructural facilities and expertise may also be identified to assist in these activities.

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ANNEXURE - I

PUBLIC AWARENESS PROGRAMME

A public awareness plan comprising press coverage, talks on All India Radio, TV coverage, meetings with NGO's and project affected communities should be undertaken by MCGB to achieve requisite public awareness and participation. The programme should cover the following aspects for respective components :

Press Coverage

The press coverage should comprise of newspaper articles in Marathi, Gujarati, Hindi and English, published at regular intervals during the course of project conception and execution. The initial article may address the issues such as need and history of the project, description of the proposed schemes, major technical, environmental and social issues and information on collaborating organizations for project implementation etc.

The future articles should inform the people about other relevant issues such as environmental studies, environmental consequences, mitigatory efforts, progress with construction and monitoring plans etc. The basic information for these articles should be provided by concerned agencies and these should be written with the help of professional copy-writers.

All India Radio Talk

AIR talk in Marathi, Hindi, Gujarati and English on the project should involve prominent officials from MCGB such as Municipal Commissioner/Sheriff. The write-ups should be based on the press articles. The talks should cover a vide spectrum of audience through programmes such as Women's programme, Science Talks, Environment programmes, City Round-Up etc.

TV Coverage

TV coverage should be primarily in the form of informative capsule and group discussions. An informative capsule of 10-15 minutes duration should include different sites, proposed works, work in progress, charts based on technical details and coverage of public meetings with concerned communities for project awareness.

Group discussion on TV should be held with the panel comprising of representatives from MCGB, B & P, NEERI, NGO's and Citizen Forums.

NGO's Meetings

For the initiation of the series of meaningful interaction with prominent local NGO's, these organizations should be invited for group discussions and apprised about the project details and environmental concerns. The environmental assessment report should also be made available at public libraries for easy access to citizens. Through follow-up meetings MCGB should seek public reactions to the project and should incorporate them wherever feasible during the project implementation.

Preparation of audio-visual material for continuing awareness programme

It is envisaged that from these meetings information about the perception of the project by the concerned communities, their opinion, apprehensions and aspirations from the project will come forth. This information should be effectively used to prepare the audio visual material for use in further strengthening the awareness and public motivation programmes.