(2) **Stage 4 Monitoring Results (Summer)**

1) **Water Quality Indicators**

The water quality results of field measurement and laboratory analyses during the site work in Stage 4 are shown in Table 4.4.12 and Table 4.4.13, respectively.
It was found that little difference of results of between Stage 3 and Stage 4 were existed and that the only concentrations of nutrient in the stage 4 were smaller than that i n the Stage 3 at several locations.
Following are explanations about each zone.

**[Zone D]**

In the same way as in Stage 3, the pollution was not found as at DD20. Although the concentration of TKN had been 1.5mg/l at Stage 3, in Stage 4 it was only 0.4mg/l.
The clarity has been increased from 2.25m in Stage 3 to 2.7m in Stage 4.

**[Zone J]**

No serious water pollution were found in the area of zone J or Al-Jubail Area.
The concentrations of TOC and TSS have increased from 1-2mg/l to 2-4mg/l and from <1-3mg/l to 2.4mg/l, respectively.

**[Zone R]**

At station R1, a small concentration of Oil&Grease, or 0.2mg/l was detected, where had not been detected in Stage 3. At station R40, The residual chlorine was detected as 0.1mg/l which was the same value as in Stage 3.

**[Zone T]**

The concentrations of chlorophyll in Tarut Bay show 0.6-12ug/l in Stage 4, which is lower than that in Stage 3 but higher than that at other stations.

At the stations of T6 and T7, maximum of chlorophyll concentration was detected as 10ug/l and 12ug/l, respectively. At the stations of T2 and T3, where are located near the mouth of the bay, chlorophyll concentrations relating to eutrophication such as TOC, TKN, and NH4 were detected as relatively high values.

**[Zone K]**

At the stations of K2, K3, K4 and K5, where are related to the outfalls of plant, the parameters relating to eutrophication such as TKN, NH4 and phosphorus indicate higher concentration in comparison with other stations. At the discharge area of desalination plant, no serious pollution was found.

**[Zone H]**

Based on the concentration comparison of phosphorous in Half-Moon Bay, it was suggested that nutrient has been possibly accumulated.

The reason is that, at the station of H3, the concentrations of phosphorous were detected as 0.08mg/l of bottom water and 0.01mg/l of surface water. On the other hand, the flow direction of water is observed from outside to inside of the bay on water surface and from inside to outside near sea bottom. Near the outfall of power plant at Al-Qulayyah, no serious water quality degradation was found.

# Table 4.4.12(1) Results of Field Survey

| | | | | | | | MET-OCEAN CONDITIONS | | | | | | | | | FIELD WATERT PARAMETERS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site Code | Site Name | Location (GPS) | | | Sampling | | Air Temp. | Cloudiness | Wind Direction | Wind Speed | Wave Height | Tide | Depth (m) | Water Current Direction | Water Current Speed | Water Temp. | Salinity | pH | DO | Turbidity | Water Clarity | Water Color | Odor | Sheen | Rubbish | Res.Cl | |
| | | Lat. | Long. | GPS/Chart | Date | Time | (°C) | (%) | (o) | (m/s) | (m) | | | (°) | (cm/s) | (°C) | (g/L) | | (mg/L) (%) | (NTU) | (m) | | | | | as Total (mg/L) | as Free (mg/L) |
| DD20 | Gumah Island | 27° 07.92'N | 49° 29.22'E | G | 24.Jun.00 | 17:30 | 35.0 | 0 | 335 | 1-2 | <0.1 | | 6.0 | 332(S)<br>350(B) | 10(S)<br>5(B) | 29.6(S)<br>29.5(B) | 54.9(S)<br>54.6(B) | 7.95(S)<br>7.92(B) | 2.83(42.9)(S)<br>2.36(42.6)(B) | 0.2(S)<br>2.3(B) | 2.7 | Pale Green | no | no | no | 0.02 | 0.05 |
| J1 | Abul Ali North | 27° 23.29'N | 49° 44.65'E | G | 25.Jun.00 | 11:25 | 32.5 | 0 | 280 | 6 | <1.0 | | 29.0 | - | - | 29.7(S)<br>29.0(5m) | 41.8(S)<br>41.7(5m) | 8.0(S)<br>8.1(5m) | 3.1(53%)(S)<br>3.2(53%)(5m) | 0.0(S)<br>0.0(5m) | 10.6 | Pale Geen | no | no | no | 0.05 | 0.13 |
| J2 | Berri Oil Field | 27° 10.82'N | 49° 42.15'E | G | 25.Jun.00 | 14:20 | 35.0 | 0 | 320 | 6 | <1 | | 29.9 | 320(S)<br>344(B) | 27.8(S)<br>28.5(B) | 30.1(S)<br>29.7(B) | 41.9(S)<br>42.0(B) | 8.03(S)<br>8.03(B) | 3.17(56.7%)(S)<br>3.29(55.5%)(B) | 0.0(S)<br>0.0(B) | 15.7 | blue | no | no | no | 0.05 | 0.06 |
| J4 | North Jubail | 27° 07.16'N | 49° 41.85'E | G | 25.Jun.00 | 15:20 | 35.0 | 0 | 320 | 5 | <0.5 | | 6.8 | 24 | 24 | 30.5(S)<br>30.5(B) | 42.1(S)<br>42.4(B) | 8.02(S)<br>8.05(B) | 3.2(55)(S)<br>-(60)(B) | 5.0(S)<br>0.0(B) | >6.8 | Pale Green | no | no | floating seagrass | 0.03 | 0.06 |
| J5 | Jubail Shared Outfall | 27° 03.36'N | 49° 37.18'E | G | 24.Jun.00 | 11:05 | 36.0 | 0 | 290 | 6 | <0.3 | | 10.5 | - | - | 38.0(S)<br>38.0(B) | 42.8(S)<br>42.8(B) | 8.06(S)<br>8.05(B) | 1.99(38.7%)(S)<br>2.13(41.5%)(B) | 4.0(S)<br>0.0(B) | 4.0 | blue | no | no | scum | 0.1 | 0.23 |
| J6 | Jubail Harbour | 27° 02.53'N | 49° 40.97'E | G | 24.Jun.00 | 10:05 | 36.0 | 0 | 290 | 6-7 | <0.7 | | 6.9 | 109(S)<br>65(B) | 13(S)<br>8(B) | 30.1(S)<br>30.1(B) | 42.5(S)<br>42.5(B) | 8.04(S)<br>8.05(B) | 2.05(35%)(S)<br>2.05(35%)(B) | 1.0(S)<br>2.0(B) | 4.0 | - | - | - | - | 0.11 | 0.1 |
| J7 | South Jubail | 27° 00.97'N | 49° 42.27'E | G | 24.Jun.00 | 9:10 | 35.8 | 0 | 351 | 6-7 | <0.5 | | 11.4 | 337(B) | 10(B) | 30.2(S)<br>30.1(B) | 42.4(S)<br>42.4(B) | 8.04(S)<br>8.02(B) | 1.69(28.9%)(S)<br>1.37(23.5%)(B) | 0.0(S)<br>0.0(B) | 7.1 | Green | no | no | scum | 0.07 | 0.11 |
| J8O | Jubail Boat Harbour | 27° 05.11'N | 49° 40.34'E | G | 25.Jun.00 | 7:50 | 35.0 | 0 | 335 | 3-4 | <0.1 | | 6.9 | - | - | 29.9(S)<br>29.9(B) | 42.3(S)<br>42.3(B) | 8.00(S)<br>7.97(B) | 2.75(46.9)(S)<br>2.56(43.7)(B) | 0.0(S)<br>0.7(B) | 6.0 | Pale Geen | no | no | no | 0.06 | 0.12 |
| J9O | Near Jubail Outfall | 27° 03.53'N | 49° 37.69'E | G | 24.Jun.00 | 12:00 | 37.2 | 0 | 355 | 6 | <0.2 | | 5.5 | 85(S)<br>245(B) | 28(S)<br>13(B) | 37.2(S)<br>30.7(B) | 40.9(S)<br>42.4(B) | 8.06(S)<br>8.07(B) | 2.11(S)<br>2.30(B) | 0.0(S)<br>9.8(B) | 4.2 | Pale Geen | no | no | little algae | 0.04 | 0.02 |
| H1 | Half Moon Bay - North | 26° 12.00'N | 50° 02.24'E | G | 11.Jun.00 | 7:40 | 35.0 | 0 | 309 | 5-6 | <0.2 | | 4.2 | - | - | 28.14(S)<br>27.83(B) | 61.04(S)<br>61.33(B) | 8.07(S)<br>8.12(B) | 3.11(60)(S)<br>3.40(63)(B) | 0.0(S)<br>0.0(B) | >4.2 | Green | no | no | no | 0.06 | 0.05 |
| H2 | Half Moon Bay - mid | 26° 04.05'N | 50° 04.95'E | G | 18.Jun.00 | 9:40 | 37.5 | 0 | - | calm | <0.1 | | 5.7 | 69(S)<br>79(B) | 7.7(S)<br>4.9(B) | 30.7(S)<br>30.2(B) | 59.9(S)<br>60.9(B) | 7.86(S)<br>7.91(B) | 3.08(59.3)(S)<br>3.34(64.5)(B) | 6.0(S)<br>0.0(B) | >5.7 | Dark Green | no | no | no | 0.15 | 0.16 |
| H3O | Half Moon Bay - South | 26° 00.00'N | 50° 09.99'E | G | 18.Jun.00 | 8:35 | 34.0 | 0 | 348 | <2 | <0.2 | | 7.2 | 220(S)<br>105(B) | 32(S)<br>9(B) | 30.4(S)<br>31.0(B) | 54.3(S)<br>56.0(B) | 7.8(S)<br>7.8(B) | 3.2(60.7)(S)<br>3.2(60.3)(B) | 0.0(S)<br>0.9(B) | 5.2 | Green | no | no | no | 0.08 | 0.18 |
| R1 | Sea Island Terminal | 26° 39.06'N | 50° 11.00'E | G | 20.Jun.00 | 9:00 | 34.0 | 0 | 350 | 5-7 | <0.5 | | 27.0 | 110(S)<br>109(B) | 15(S)<br>12(B) | 30.7(S)<br>30.3(B) | 42.0(S)<br>42.4(B) | 7.96(S)<br>8.04(B) | 1.79(30.7)(S)<br>1.89(32.4)(B) | 0.0(S)<br>0.4(B) | 7.5 | Dark Green | no | no | small bubble | 0.08 | 0.13 |
| R2 | Ras Tannura Spit | 26° 37.60'N | 50° 09.83'E | G | 20.Jun.00 | 12:20 | 35.2 | 0 | 350 | 6-7 | <0.5 | | 6.0 | 244(S)<br>256(B) | 21.3(S)<br>27.4(B) | 31.0(S)<br>30.9(B) | 42.4(S)<br>42.45 | 7.98(S)<br>8.06(B) | 1.75(30.2)(S)<br>1.81(31.4)(B) | 0.0(S)<br>0.2(B) | >6 | Pale Green | no | no | no | 0.09 | 0.17 |

## Table 4.4.12 (2) Results of Field Survey

| Site Code | Site Name | Location (GPS) Lat. | Location (GPS) Long. | Location (GPS) GPS/Chart | Sampling Date | Sampling Time | MET-OCEAN CONDITIONS: Air Temp. (°C) | Cloudiness (%) | Wind Direction (°) | Wind Speed (m/s) | Wave Height (m) | Tide | Depth (m) | Water Current Direction (°) | Water Current Speed (cm/s) | FIELD WATERT PARAMETERS: Water Temp. (°C) | Salinity (g/L) | pH | DO (mg/L) (%) | Tur-bidity (NTU) | Water Clarity (m) | Water Color | Odor | Sheen | Rubbish | Res.Cl as Total (mg/L) | Res.Cl as Free (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R4O | Refinery Outfall | 26° 41.84'N | 50° 06.46'E | G | 20.Jun.00 | 11:00 | 34.5 | 0 | 350 | 5-6 | <0.5 | | 1.5 | 86 | 34.6 | 31.6(middle) | 42.6(middle) | 8.07(middle) | 1.89(33.2)middle | 6.4(middle) | >1.5 | Pale Green | no | no | no | 0.11 | 0.1 |
| T1 | Tarut - Zur | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| T2 | Tarut - Zur | 26° 36.14'N | 50° 04.51'E | G | 19.Jun.00 | 8:50 | 36.0 | 0 | 350 | 2 | <0.1 | | 1.4 | 100 | 23 | 29.94 | 46.18 | 8.03 | 2.47(43.9) | 0 | >1.4 | Pale Green | no | no | floating seagrass | 0.1 | 0.09 |
| T3 | Tarut - East | 26° 33.81'N | 50° 06.66'E | G | 19.Jun.00 | 9:50 | 36.0 | 0 | 350 | 4 | <0.2 | | 1.5 | 93 | 4 | 30.8 | 43.2 | 8.0 | 3.6(60.3) | 2.5 | >1.5 | Pale Green | no | no | floating seagrass | 0.38 | 0.11 |
| T4 | Tarut - Darin | 26° 32.43'N | 50° 05.12'E | G | 19.Jun.00 | 10:15 | 39.0 | 0 | 350 | 4-5 | <0.2 | | 0.9 | 252 | 8 | 30.2(S)<br>29.7(B) | 44(S)<br>44(B) | 8.1(S)<br>8.1(B) | 3.7(63.4)(S)<br>3.7(63.1)(B) | 6.0(S)<br>16.0(B) | 0.9 | Pale Green | no | no | floating seagrass | 0.16 | 0.09 |
| T6 | Qatif/Anik urban drain | 26° 30.55'N | 50° 02.11'E | G | 11.Jun.00 | 11:35 | 40.0 | 0 | 10 | 4-6 | <0.1 | | 0.7 | 50(Flow out) | 4 | 29.64(S)<br>29.40(B) | 4.16(S)<br>4.16(B) | 7.43(S)<br>7.49(B) | 2.10(28.3)(S)<br>1.83(24.2)(B) | 21(S)<br>23(B) | 0.3 | Dark Green | weak sewage smell | no | no | 0.16 | 0.09 |
| T7 | Qatif/Anik Drain Mouth | 26° 30.53'N | 50° 02.57'E | G | 11.Jun.00 | 12:50 | 38.5 | 0 | 350 | 3-5 | <0.2 | | 0.9 | - | - | 30.1 | 42.9 | 8.2 | 4.4 | 0 | >0.9 | pale green | no | no | Edge of mangeove | 0.13 | 0.1 |
| T9 | Dammam Fishing Harbour - Entrance | 26° 29.51'N | 50° 18.15'E | G | 17.Jun.00 | 9:50 | 36.0 | 0 | 338 | 1-2 | <0.2 | - | 3.4 | 358 | 8 | 30.5(S)<br>30.4(B) | 43.0(S)<br>43.1(B) | 8.0(S)<br>8.0(B) | 3.86(67.4)(S)<br>3.96(68.0)(B) | 1.0(S)<br>1.7(B) | 1.7 | Green | no | no | no | - | - |
| T11O | Dammam Fishing Harbour | 26° 27.59'N | 50° 08.02'E | G | 17.Jun.00 | 9:10 | 36.0 | 0 | 338 | 5 | <0.2 | | 2.7 | 350 | 12 | 31.0(S)<br>30.0(B) | 42.0(S)<br>43.0(B) | 7.9(S)<br>7.9(B) | 3.5(61)(S)<br>3.4(50)(B) | 6-10(S)<br>45(B) | 0.74 | Green | no | no | no | 0.07 | 0.05 |
| T12O | Swfwa | 26° 38.95'N | 50° 01.15'E | G | 11.Jun.00 | 13:40 | 38.5 | 0 | 351 | 3-5 | <0.3 | | 1.5 | 73 | 2 | 29.1(S)<br>29.1(B) | 48.2(S)<br>48.2(B) | 8.11(S)<br>8.20(B) | 4.5(79.6)(S)<br>4.6(80.0)(B) | 24.0(S)<br>18.0(B) | >1.5 | pale green | no | no | no | 0.14 | 0.12 |
| K1 | Dammam South | 26° 25.15'N | 50° 14.24'E | G | 14.Jun.00 | 9:00 | 34.0 | 0 | 350 | 2-3 | <0.3 | | 2.7 | 329 | 14 | 29.5(S)<br>29.5(2m) | 42.9(S)<br>42.9(2m) | 8.19(S)<br>8.20(2m) | 4.0(69.6)(S)<br>4.2(72)(2m) | 0.0(S)<br>0.0(2m) | >2.7 | Pale Green | no | no | floating seagrass | 0.02 | 0.16 |
| K2 | SAFCO outfall | 26° 24.52'N | 50° 11.42'E | G | 17.Jun.00 | 10:50 | 39.0 | 0 | 338 | 5-7 | <0.1 | | <0.7 | - | - | 40.0 | 30.6 | 7.5 | 2.4(39) | 0 | >0.7 | Pale Green | no | no | no | 0.03 | 0.1 |
| K3 | SAFCO south | 26° 24.71'N | 50° 12.20'E | G | 14.Jun.00 | 8:10 | 35.0 | 0 | 350 | <3 | <0.2 | | 0.9 | 0 | 0 | 27.9 | 43.7 | 8.1 | 3.6(60.3) | 0 | >0.85 | Pale Green | no | no | no | 0.02 | 0.14 |
| K4 | Khobar Central | 26° 14.95'N | 50° 13.48'E | G | 12.Jun.00 | 11:25 | 34.0 | 0 | 351 | 5 | <0.3 | | 5.5 | 0(S)<br>2(B) | 43.9(S)<br>51.5(B) | 28.73(S)<br>28.92(B) | 48.46(S)<br>49.80(B) | 8.12(S)<br>8.17(B) | 3.59(62.8)(S)<br>3.53(61.9)(B) | 1.7(S)<br>2.4(B) | 1.8 | pale green | no | no | no | 0.08 | 0.02 |
| K5 | Khobar STP Outfall | 26° 14.46'N | 50° 13.38'E | G | 12.Jun.00 | 9:35 | 37.0 | 0 | 350 | 6-8 | <0.3 | | 1.1 | 38 | 26 | 29.2(S)<br>28.9(B) | 41(S)<br>49.1(B) | 8.0(S)<br>8.2(B) | 3.8(62.5)(S)<br>3.8(67.4)(B) | 16(S)<br>25(B) | 1.05 | brown green | no | no | small rubbish | 0.19 | 0.14 |

# Table 4.4.12 (3) Results of Field Survey

| Site Code | Site Name | Location (GPS) Lat. | Location (GPS) Long. | GPS/Chart | Sampling Date | Sampling Time | MET-OCEAN CONDITIONS: Air Temp. (°C) | Cloudiness (%) | Wind Direction (°) | Wind Speed (m/s) | Wave Height (m) | Tide | Depth (m) | Water Current Direction (°) | Water Current Speed (cm/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K6 | Khobar South | 26° 14.35'N | 50° 13.55'E | G | 12.Jun.00 | 8:40 | 36.0 | 0 | 307 | 5-6 | <0.5 | | 13.2 | 0(S)<br>4(B) | 68(S)<br>46(B) |
| K7 | Desalination intake | 26° 10.40'N | 50° 13.02'E | G | 13.Jun.00 | 8:15 | 34.0 | 0 | 350 | 1 | <0.2 | | 7.8 | 45(S)<br>30(4m) | 44(S)<br>42(4m) |
| K8 | Desalination Outfall | 26° 10.48'N | 50° 12.59'E | G | 13.Jun.00 | 8:50 | 37.2 | 0 | 350 | 1 | <0.2 | | 5.9 | 23(S)<br>35(4m) | 25.4(S)<br>24.6(4m) |
| H4O | Power Station Intake | 25° 51.62'N | 50° 07.31'E | G | 10.Jun.00 | 10:25 | 37.0 | 0 | N | 6 | <0.3 | | 4.2 | - | - |
| H5O | Power Station Outfall | 25° 51.23'N | 50° 07.57'E | G | 10.Jun.00 | 11:15 | 38.9 | 0 | 18.4 | 4-6 | - | - | 1.7 | - | - |

| Site Code | FIELD WATERT PARAMETERS: Water Temp. (°C) | Salinity (g/L) | pH | DO (mg/L) (%) | Turbidity (NTU) | Water Clarity (m) | Water Color | Odor | Sheen | Rubbish | Res.Cl as Total (mg/L) | Res.Cl as Free (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K6 | 29.0(S)<br>29.0(5m) | 50.1(S)<br>50.2(5m) | 8.2(S)<br>8.2(5m) | 4.3(70.7)(S)<br>4.1(70.3)(5m) | 2.4(S)<br>3.0(5m) | 2.1 | pale green | no | no | small bubble | 0.02 | 0.01 |
| K7 | 29.2(S)<br>29.0(5m) | 51.8(S)<br>52.0(5m) | 8.10(S)<br>8.10(5m) | 3.5(63.4)(S)<br>3.6(64.7)(5m) | 0.0(S)<br>0.0(5m) | 3.9 | pale green | no | no | no (scum, near the point) | 0.04 | 0.02 |
| K8 | 31.5(S)<br>31.2(B) | 52.5(S)<br>54.6(B) | 8.1(S)<br>8.2(B) | 3.7(68.8)(S)<br>3.8(71.2)(B) | 0.0(S)<br>0.0(B) | 2.8 | dark green | little smell | no | scum | 0.04 | 0.04 |
| H4O | 29.3 | 54.4 | 7.96 | 3.7 | 0-4.5 | 4.2 | Pale Green | little smell | no | no | 0.23 | 0.05 |
| H5O | 36.5 | 53.9 | 7.94 | 4.1 | - | >1.7 | pale green | little smell | no | scum | 0.16 | 0.09 |

## Table 4.4.12 (4) Results of Field Survey

| Site Code | Site Name | Location (GPS) | | | Sampling | | SEDIMENT PARAMETERS | | | | | Observation and Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Lat. | Long. | GPS/Chart | Date | Time | Color | Odor | Texture | Sediment Temp. (°C) | ORP (mv) | |
| DD20 | Gumah Island | 27° 07.92'N | 49° 29.22'E | O | 24.Jun.00 | 17:30 | gray with white cream sand | no | fine sand | 29.6 | -20 | *Water sampling point was 270790(N), 492911(E).* |
| J1 | Abul Ali North | 27° 23.29'N | 49° 44.65'E | O | 25.Jun.00 | 11:25 | gray | no | muddy | 29.5 | -2 | *Ship miving 15 degree, 2.31km/45min*<br>*Current (S) 350 degree, 34cm/s*<br>*On the way to J1 from harbor, two turtles were found at different points.* |
| J2 | Berri Oil Field | 27° 10.82'N | 49° 42.15'E | G | 25.Jun.00 | 14:20 | grey (little yellow) | no | sandy, silty | 28 | 20 | *Sediment color was differnet from 3rd stage. Influned by drilling?* |
| J4 | North Jubail | 27° 07.16'N | 49° 41.85'E | G | 25.Jun.00 | 15:20 | - | - | - | - | - | - |
| J5 | Jubail Shared Outfall | 27° 03.36'N | 49° 37.18'E | O | 24.Jun.00 | 11:05 | dark gray | little (H2S) | mudy | 33 | 19 | *Sediment sampling point was 500m far from water sampling point.* |
| J6 | Jubail Harbour | 27° 02.53'N | 49° 40.97'E | G | 24.Jun.00 | 10:05 | slight gray | no | coarse sand | 29.7 | 56 | |
| J7 | South Jubail | 27° 00.97'N | 49° 42.27'E | O | 24.Jun.00 | 9:10 | clay | no | sandy | 29.6 | 160 | |
| J8O | Jubail Boat Harbour | 27° 05.11'N | 49° 40.34'E | G | 25.Jun.00 | 7:50 | gray | little | sandy | 30.2 | -27 | *Jerry fishes with long sails could be seen in the harbour.* |
| J9O | Near Jubail Outfall | 27° 03.53'N | 49° 37.69'E | G | 24.Jun.00 | 12:00 | - | - | - | - | - | |
| H1 | Half Moon Bay - North | 26° 12.00'N | 50° 02.24'E | G | 11.Jun.00 | 7:40 | Dark brown | no | silty sand | 28.7 | -20 | *Jerry fishes and small fishes were found.* |
| H2 | Half Moon Bay - mid | 26° 04.05'N | 50° 04.95'E | G | 18.Jun.00 | 9:40 | - | - | - | - | - | *Harbour at Al-khaleej Village is located 260476(N), 500061(E).*<br>*Two jerry fishes were foun at one side of the boat.* |
| H3O | Half Moon Bay - South | 26° 00.00'N | 50° 09.99'E | G | 18.Jun.00 | 8:35 | - | - | - | - | - | *Harbour at Al-khaleej Village is located 260476(N), 500061(E).*<br>*Five jerry fishes were foun at one side of the boat.* |
| R1 | Sea Island Terminal | 26° 39.06'N | 50° 11.00'E | G | 20.Jun.00 | 9:00 | gray | smell | mudy | 29.7 | 180 | |
| R2 | Ras Tannura Spit | 26° 37.60'N | 50° 09.83'E | G | 20.Jun.00 | 12:20 | light gray | no | silty sand | 29.8 | 96 | |

# Table 4.4.12 (5) Results of Field Survey

| Site Code | Site Name | Location (GPS) | | | Sampling | | SEDIMENT PARAMETERS | | | | | Observation and Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Lat. | Long. | GPS/Chart | Date | Time | Color | Odor | Texture | Sediment Temp. (°C) | ORP (mv) | |
| R4O | Refinery Outfall | 26° 41.84'N | 50° 06.46'E | G | 20.Jun.00 | 11:00 | gray | no | sandy | 31.6 | 83 | |
| T1 | Tarut - Zur | - | - | - | - | - | - | - | - | - | - | |
| T2 | Tarut - Zur | 26° 36.14'N | 50° 04.51'E | G | 19.Jun.00 | 8:50 | gray | no | sandy | 29.9 | 10 | |
| T3 | Tarut - East | 26° 33.81'N | 50° 06.66'E | G | 19.Jun.00 | 9:50 | - | - | - | - | - | |
| T4 | Tarut - Darin | 26° 32.43'N | 50° 05.12'E | G | 19.Jun.00 | 10:15 | little dark gray | no | mudy | 29.4 | 40 | |
| T6 | Qatif/Anik urban drain | 26° 30.55'N | 50° 02.11'E | G | 11.Jun.00 | 11:35 | - | - | - | - | - | |
| T7 | Qatif/Anik Drain Mouth | 26° 30.53'N | 50° 02.57'E | G | 11.Jun.00 | 12:50 | - | - | - | - | - | |
| T9 | Dammam Fishing Harbour - Entrance | 26° 29.51'N | 50° 18.15'E | G | 17.Jun.00 | 9:50 | gray | no | silty sand | 30.4 | 260 | |
| T11O | Dammam Fishing Harbour | 26° 27.59'N | 50° 08.02'E | G | 17.Jun.00 | 9:10 | gray | no | sandy | 31.2 | 180 | *Extro sample (sediment) at 262680(N), 50800(E).* |
| T12O | Swfwa | 26° 38.95'N | 50° 01.15'E | G | 11.Jun.00 | 13:40 | - | - | - | - | - | |
| K1 | Dammam South | 26° 25.15'N | 50° 14.24'E | G | 14.Jun.00 | 9:00 | gray | no | coarse sand | 29.5 | 73 | *Extra sample (water and sediment) near the landfill (approximately 80m). Sampling position was 262785(N), 501226(E). Water quality : Temp28.9, Sal42.8, pH8.22, DO3.89(65.4), Turb19.3, Sediment: ORP +25mV* |
| K2 | SAFCO outfall | 26° 24.52'N | 50° 11.42'E | G | 17.Jun.00 | 10:50 | dark gray | no | clayee | 30.5 | -15 | |
| K3 | SAFCO south | 26° 24.71'N | 50° 12.20'E | G | 14.Jun.00 | 8:10 | light gray | no | silty sand | 27.9 | -4 | |
| K4 | Khobar Central | 26° 14.95'N | 50° 13.48'E | G | 12.Jun.00 | 11:25 | cream | no | silty sand | 28.7 | -38 | |
| K5 | Khobar STP Outfall | 26° 14.46'N | 50° 13.38'E | G | 12.Jun.00 | 9:35 | gray | little | sand | 29.1 | -14 | *Sampling poin was close to the outfall (approximately 10).* |

## Table 4.4.12 (6) Results of Field Survey

| | | | | | | | SEDIMENT PARAMETERS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site Code | Site Name | Location (GPS) | | | Sampling | | Color | Odor | Texture | Sediment Temp. | ORP | Observation and Comment |
| | | Lat. | Long. | GPS/Chart | Date | Time | | | | (°C) | (mv) | |
| K6 | Khobar South | 26° 14.35'N | 50° 13.55'E | G | 12.Jun.00 | 8:40 | creamy | no | silty coarse sand | 29.2 | -22 | *Sediment was sampled at 261425(N), 501343(E) and water depth is 7.5. One crab was found.* |
| K7 | Desalination intake | 26° 10.40'N | 50° 13.02'E | G | 13.Jun.00 | 8:15 | - | - | - | - | - | *Jerry fishes were found. Sampling point was located about 30m far from the Intake.* |
| K8 | Desalination Outfall | 26° 10.48'N | 50° 12.59'E | G | 13.Jun.00 | 8:50 | dark gray | no | silty fine sand | 31.2 | -64 | *Res.Cl at Center Drain : 0.13 as Total, 0.01 as Free.* |
| H4O | Power Station Intake | 25° 51.62'N | 50° 07.31'E | G | 10.Jun.00 | 10:25 | - | - | - | - | - | |
| H5O | Power Station Outfall | 25° 51.23'N | 50° 07.57'E | G | 10.Jun.00 | 11:15 | dark gray | no | Fine sand with green algae | - | - | |

## Table 4.4.13 Analysis Results of Seawater Samples

| Site ID | WATER TSS mg/l | TKN mg/l | $NH_3$ mg/l | T-P mg/l | Chlor ug/l | TOC mg/l | Metals As mg/l | Cr mg/l | Hg mg/l | Mg g/L | Cd mg/l | Co mg/l | Cu mg/l | Ni mg/l | Pb mg/l | Zn mg/l | CN mg/l | Oil& Grse mg/l | TPH mg/l | BTEX mg/l | Phenol mg/l | Res. Cl mg/l | Coliform pcs/100ml (x100) | *OCL mg/l* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DD20 | | 0.4 | | <0.01 | | | | | | | | | | | | | | | | | | 0.02 | | |
| J1 | 2 | 0.1 | <0.1 | <0.01 | <0.1 | 4 | <0.01 | <0.05 | <0.0001 | 1.6 | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | <0.005 | | | | | 0.05 | | |
| J2 | | | | | | | | | | | | | | | | | | <0.2 | | | | 0.05 | | |
| J4 | 3 | 0.2 | | <0.01 | 0.3 | | | | | | | | | | | | | | | | | 0.03 | | |
| J5 | 2 | 1.4 | 0.1 | <0.01 | | 3 | <0.01 | <0.05 | <0.0001 | 1.6 | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | <0.005 | <0.2 | | | <0.005 | 0.1 | | <0.01 |
| J6 | 3 | 0.3 | | <0.01 | 1.0 | 3 | <0.01 | <0.05 | <0.0001 | | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | <0.005 | | | | | 0.11 | | <0.01 |
| J7 | | 0.2 | | <0.01 | 0.9 | 2 | | | | | | | | | | | | | | | | 0.07 | | <0.01 |
| J8O | 4 | | | | | | | | | | | | | | | | | <0.2 | <0.2 | | | 0.06 | | |
| J9O | | | | | | | | | | | | | | | | | | | | | | 0.04 | | <0.01 |
| R1 | | | | | 0.2 | | | | | | | | | | | | | 0.2 | <0.2 | | | 0.08 | | |
| R2 | | | | | | | | | | | | | | | | | | | | | | 0.09 | | |
| R4O | 3 | | | | | | | | | | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | | | <0.2 | <0.01 | | 0.11 | | |
| T1 | | | | | | | | | | | | | | | | | | | | | | 0.10 | | |
| T2 | 3 | 0.3 | <0.1 | 0.01 | 0.6 | 4 | | | | | | | | | | | | | | | | 0.38 | 6.8 | |
| T3 | 2 | 0.2 | <0.1 | 0.01 | 0.6 | | | | | | | | | | | | | | | | | 0.16 | 11 | |
| T4 | 7 | 0.4 | 0.1 | 0.03 | | 4 | | | | | | | | | | | | | | | | 0.16 | 12 | |
| T6 | 25 | 12 | 9.8 | 1.5 | 10 | 19 | <0.01 | <0.05 | <0.0001 | 0.2 | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | | | | | | 0.13 | 11000 | |
| T7 | 13 | 1.5 | 0.1 | 0.12 | 12 | 6 | | | | | | | | | | | | | | | | | 19 | |
| T9 | | | | | | | | | | | | | | | | | | | | | | | | |
| T11O | 8 | 0.4 | 0.1 | 0.04 | | 5 | <0.01 | <0.05 | <0.0001 | | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | | 0.2 | <0.2 | <0.01 | <0.005 | 0.07 | 2.9 | |
| T12O | 4 | 0.9 | 0.2 | 0.03 | 0.8 | 4 | <0.01 | <0.05 | <0.0001 | 2.0 | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | | | | | | 0.14 | 19 | |
| K1 | 4 | 0.2 | | 0.01 | <0.1 | | | | | | | | | | | | | | | | | 0.02 | | |
| K2 | 6 | 100 | 71 | 0.39 | | 5 | <0.01 | <0.05 | <0.0001 | 0.10 | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | <0.005 | 0.8 | | | | 0.03 | 9200 | |
| K3 | 5 | 2.4 | | 0.02 | 0.3 | 4 | | | | | | | | | | | | | | | | 0.02 | | |
| K4 | 5 | 0.8 | 0.1 | 0.07 | | 4 | | | | | | | | | | | | <0.2 | | | | 0.08 | 130 | |
| K5 | 9 | 3.4 | 2.4 | 0.75 | | 6 | <0.01 | <0.05 | | | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | | 0.2 | | | | 0.19 | 9 | |
| K6 | 3 | 0.5 | | 0.02 | | 3 | | | | 2.2 | | | | | | | | | | | | 0.02 | 52 | |
| K7 | | | | | | | | | | 2.5 | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | | | | | | 0.04 | | |
| K8 | | | | | | | <0.01 | <0.05 | | 2.8 | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | | | | | | 0.04 | | |
| H1 | 3 | 0.5 | | 0.01 | 1.1 | | | | | | | | | | | | | | | | | 0.06 | | |
| H2 | | | | | 1.1 | | | | | | | | | | | | | | | | | 0.15 | | |
| *H3Os* | | 0.4 | | 0.01 | | 3 | | | | | | | | | | | | | | | | 0.08 | | |
| *H3Ob* | | 1.1 | | 0.08 | | 7 | | | | | | | | | | | | | | | | | | |
| H4O | 5 | | | | | | | | | | | | | | | | | | | | | 0.23 | | |
| H5O | 5 | | | | | 4 | | | | | <0.002 | <0.03 | <0.005 | <0.01 | <0.005 | <0.05 | | <0.2 | | | | 0.16 | | |

### 2) Sediment Quality Indicators

Table-4.4.14 indicates the results of sediment quality analysis of Stage 4. Overall , pollution was shown almost the same trend between Stage 3 and Stage 4. The results of analyses at Stage 4 was generally smaller than those of Stage 3. Future monitoring and study will give the answer against the above difference.

**[Zone D]**

At the location of DD20, the higher concentrations of TPH and TOC were detected.

**[Zone J]**

At J80 (Jubail Boat Harbor) and J5 (Outfall of Industrial City), the high concentrations of TPH were detected. At J7 and J80, where cadmium had been detected during Stage 3, this type of metals was not detected during stage 4.

**[Zone R]**

At the location of R1, R2 and R40, the concentrations from 21 to 32mg/kg of TPH were detected. Regarding R1 and R2, oily pollution was considered to be generated during the period between the investigations of Stage 3 and Stage 4. Especially at R1, several metals such as Zinc, Copper, Nickel and Lead were detected. All of these metals are relater to paints for ship and bull.

**[Zone T]**

At T4 (Darin Jetty), the metals such as Zinc, Copper, Nickel and Lead were detected and TPH concentration of 178mg/kg was also detected. All of these are closely related to ship. At T6 (Discharge from Municipality Treatment Plant), high concentration of TPH, Zinc, Copper, Nickel and Lead were detected. Relatively high concentration of Mercury was detected at T110.

**[Zone K]**

Very severe pollution was found in sediments at K2 (Outfall of a Fertilizer Plant). The metals such as Zinc, Chromium, Copper, Mercury and Arsenic were detected. Accumulation of organic materials into sediment has possibly been progressed since the value of IL was detected as remarkably large.
The location of K3 may be affected by the pollution of K2.

At the area close to the outfall of wastewater treatment plant at Khobar (K5), the high concentrations of TPH and Zinc were detected.

**[Zone H]**

No serious pollutions were found.

**Table 4.4.14 Analysis Results of Sediment Samples**

| | SEDIMENT | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site ID | IL % | TOC % | Metals | | | | | | | | | | TPH mg/kg | BTEX mg/kg | *PCB* mg/kg |
| | | | As mg/kg | Cr mg/kg | Hg mg/kg | V mg/kg | Cd mg/kg | Co mg/kg | Cu mg/kg | Ni mg/kg | Pb mg/kg | Zn mg/kg | | | |
| DD20 | 5.9 | 4.2 | 0.9 | <10 | | <100 | <1 | <5 | <5 | 12 | <20 | 5 | 4400 | | |
| J1 | 10.5 | 2.4 | 1.5 | 19 | <0.05 | <100 | <1 | 7 | 13 | 38 | <20 | 17 | 18 | <0.1 | |
| J2 | 5.3 | | | 10 | | <100 | <1 | 6 | 7 | 23 | <20 | 12 | 14 | | |
| J4 | | | | | | | | | | | | | | | |
| J5 | 9.8 | 1.9 | 1.6 | 18 | <0.05 | <100 | <1 | <5 | 24 | 31 | <20 | 39 | 25 | | <0.1 |
| J6 | 3.0 | 0.7 | 1.3 | <10 | <0.05 | <100 | <1 | <5 | <5 | <10 | <20 | <1 | 12 | | |
| J7 | 3.0 | | | | | | <1 | <5 | <5 | <10 | <20 | 3 | | | |
| J8O | 1.5 | | | <10 | | | <1 | <5 | 10 | <10 | <20 | 21 | 70 | <0.1 | |
| J9O | | | | | | | | | | | | | | | |
| R1 | 5.2 | 1.1 | | | | <100 | <1 | <5 | 31 | 13 | <20 | 73 | 31 | <0.1 | |
| R2 | 2.2 | | | <10 | | <100 | <1 | <5 | <5 | <10 | <20 | 2 | 21 | | |
| R4O | 3.0 | | 1.0 | <10 | <0.05 | <100 | <1 | <5 | <5 | <10 | <20 | 3 | 32 | <0.1 | |
| T1 | | | | | | | | | | | | | | | |
| T2 | 4.1 | 1.3 | | | | | <1 | <5 | <5 | <10 | <20 | 10 | | | |
| T3 | | | | | | | | | | | | | | | |
| T4 | 9.7 | 3.2 | 1.8 | | | | <1 | <5 | 39 | 27 | 35 | 1.4E+02 | 178 | | |
| T6 | 6.1 | 1.8 | | 21 | | | <1 | <5 | 15 | 18 | 26 | 68 | 197 | | <0.1 |
| T7 | | | | | | | | | | | | | | | |
| T9 | | | | | | | | | | | | | | | <0.1 |
| T11O | 3.6 | 0.9 | 1.7 | 11 | 0.52 | <100 | <1 | <5 | 9 | 13 | <20 | 33 | 33 | <0.1 | <0.1 |
| T12O | | | | | | | | | | | | | | | |
| K1 | 5.6 | 2.5 | 2.7 | <10 | | | <1 | <5 | <5 | <10 | <20 | 20 | | | |
| K2 | 18.2 | 10.4 | 14.2 | 7.0E+0 | 0.19 | <100 | <1 | <5 | 71 | 47 | 37 | 4.4E+03 | | | |
| K3 | 3.2 | 0.8 | 1.4 | 23 | | | <1 | <5 | <5 | <10 | <20 | 22 | | | |
| K4 | 4.3 | 0.9 | 2.1 | <10 | | | <1 | <5 | 6 | <10 | <20 | 10 | | | |
| K5 | 3.1 | 1.0 | 1.9 | <10 | | | <1 | <5 | 20 | <10 | <20 | 55 | 110 | | |
| K6 | | 0.8 | | | | | | | | | | | | | |
| K7 | | | | | | | | | | | | | | | |
| K8 | 2.5 | 0.5 | 2.2 | 11 | | | <1 | <5 | 21 | 20 | <20 | 17 | | | |
| H1 | | 0.2 | | | | | | | | | | | | | |
| H2 | | | | | | | | | | | | | | | |
| *H3Os* | | | | | | | | | | | | | | | |
| *H3Ob* | | | | | | | | | | | | | | | |
| H4O | | | | | | | | | | | | | | | |
| H5O | 10.7 | | | | | | <1 | <5 | 13 | 18 | 22 | 71 | | | |

### 3) Plankton Analysis

Table-4.4.15 indicates the results of plankton survey of Stage 4.

According to possible seasonal differences, the quite different results were obtained in the investigation of Stage 4 in comparison with that of Stage 3.

Zooplankton were dominant at the investigations of Stage 4 whereas phytoplankton, especially red tide species, were dominant at that of Stage 3.

Density and spatial difference rate of specied composition of plankton at Stage 4 were lower than those of Stage 3.

Zooplankton found at Stage 4 investigation were mainly composed of Copepoda Class, and larve of bivalves were found relatively high frequency.

## Table 4.4.15 Result of Plankton Survey (1)

| Site Code | Class | Order | Family | Speices | Plankton Density (/L) | Frequency |
|---|---|---|---|---|---|---|
| J1 | Copepoda | Calanoida | Acartiidae | *Acartia sp.* | 18 | + |
| | Sarcodina | Foraminifera | *Globrigorinidae* | *Globrigorinidae sp.* | 5 | + |
| | Gastropoda | Pteropoda | Limacinidae | *Limacina inflata* | 9 | + |
| | Mollusca | Bibalva | - | Bivalve larvae | 5 | + |
| J4 | Copepoda | Cyclopoida | Oithonidae | *Oithona tenuis.* | 16 | + |
| | Copepoda | Calanoida | Calanidae | *Caranus minor?* | 23 | ++ |
| | Copepoda | Calanoida | Acartiidae | *Acartia sp.(nauplius)* | 2 | ++ |
| | Mollusca | Bibalva | - | Bivalve larvae | 107 | +++ |
| | Gastropoda | Pteropoda | Limacinidae | *Limacina inflata?* | 15 | + |
| | Arthropoda | - | - | *Club larvae (zoea)* | 1.65 | + |
| | - | - | - | *Fish egg?* | 20 | + |
| J6 | Copepoda | Cyclopoida | Oithonidae | *Oithona tenuis.* | 20 | ++ |
| | Copepoda | Calanoida | Acartiidae | *Acartia sp.* | 12 | + |
| | Sarcodina | Foraminifera | *Globrigorinidae* | *Globrigorinidae sp.* | 10 | + |
| | Mollusca | Bibalva | - | Bivalve larvae | 135 | +++ |
| | Gastropoda | Pteropoda | Limacinidae | *Limacina inflata?* | 59 | ++ |
| J7 | Copepoda | Calanoida | Acartiidae | *Acartia sp.* | 23 | + |
| | Copepoda | Cyclopoida | Oithonidae | *Oithona tenuis.* | 15 | + |
| | Sarcodina | Foraminifera | *Globrigorinidae* | *Globrigorinidae sp.* | 4 | + |
| | Gastropoda | Pteropoda | Limacinidae | *Limacina inflata?* | 15 | + |
| | Mollusca | Bibalva | - | Bivalve larvae | 73 | + |
| R1 | Copepoda | Calanoida | Acartiidae | *Acartia erythraea* | 13 | + |
| | Crustacea | Balanidae | Balanidae | *Balanus sp.(Nauplius)* | 13 | + |
| | Copepoda | Calanoida | Calanidae | *Calanus sp.* | 67 | ++ |
| | Gastropoda | Pteropoda | Limacinidae | *Limacina inflata?* | 44 | ++ |
| | - | - | - | *Fish egg?* | 31 | ++ |
| T2 | Arthropoda | Eyogaysuacea | Euphausiidae | *Euphausia sp..(nauplius)* | 34 | ++ |
| | Mollusca | Bibalva | - | Bivalve larvae | 68 | ++ |
| | Gastropoda | Pteropoda | Limacinidae | *Limacina inflata?* | 377 | ++++ |
| | Copepoda | Cyclopoida | Oithonidae | *Oithona sp. (nauplius)* | 68 | ++ |
| | Copepoda | Cyclopoida | Oithonidae | *Oithona tenuis* | 86 | +++ |
| | Cyanophceae | Oscillatoriales | Oscillatoriaceae | *Trichodeswmium eryhraem* | 103 | +++ |
| K1 | Copepoda | Calanoida | Acartiidae | *Acartia sp.* | 21 | + |
| | Copepoda | Cyclopoida | Oithonidae | *Oithona tenuis.* | 21 | + |
| | Gastropoda | Pteropoda | Limacinidae | *Limacina inflata?* | 106 | +++ |
| K3 | Copepoda | Calanoida | Acartiidae | *Acartia sp.* | 34 | ++ |
| | Copepoda | Calanoida | Calanidae | *Calanus sp.(nauplius)* | 68 | ++ |
| K6 | Copepoda | Calanoida | Acartiidae | *Acartia erythraea?* | 11 | + |
| | Copepoda | Cyclopoida | Oithonidae | *Oithona tenuis* | 10 | + |
| | Crustacea | Balanidae | Balanidae | *Balanus sp.(nauplius)* | 2 | + |
| | Mollusca | Bibalva | - | Bivalve larvae | 19 | + |
| K7 | Copepoda | Calanoida | Calanidae | *Caranus sp.* | 23 | + |
| | Copepoda | Cyclopoida | Oithonidae | *Oithona tenuis* | 26 | + |
| | Crustacea | Balanidae | Balanidae | *Balanus sp.(nauplius)* | 20 | + |
| | Copepoda | Calanoida | Calanidae | *Caranus sp.(nauplius)* | 7 | + |
| | Mollusca | Bibalva | - | Bivalve larvae | 3 | + |
| | - | - | - | *Fish egg?* | 40 | ++ |
| | Cyanophceae | Oscillatoriales | Oscillatoriaceae | *Trichodeswmium eryhraem* | 23 | + |

## Table 4.4.15 Result of Plankton Survey (2)

| Site Code | Class | Order | Family | *Speices* | Plankton Density (/L) | Frequency |
|---|---|---|---|---|---|---|
| K8 | Copepoda | Cyclopoida | Oithonidae | *Oithona tenuis* | 11 | + |
| | Copepoda | Calanoida | Calanidae | *Caranus sp.(nauplius)* | 26 | + |
| | Copepoda | Cyclopoida | Oithonidae | *Oithona tenuis* | 15 | + |
| | - | - | - | *Fish egg?* | 22 | + |
| H1 | Copepoda | Cyclopoida | Oithonidae | *Oithona sp. (nauplius)* | 11 | + |
| | Copepoda | Calanoida | Acartiidae | *Acartia sp.* | 47 | ++ |
| | Mollusca | Bibalva | - | Bivalve larvae | 11 | + |
| H2 | Copepoda | Calanoida | Acartiidae | *Acartia sp.* | 72 | ++ |
| | Copepoda | Cyclopoida | Oithonidae | *Oithona tenuis.* | 28 | + |
| | Copepoda | Cyclopoida | Oithonidae | *Oithona sp. (Nauplius)* | 28 | + |
| | Gastropoda | Pteropoda | Limacinidae | *Limacina inflata?* | 60 | ++ |
| | Bacillariophyceae | Pennales | Nitzchiaceae | *Nitzchia sigma* | 60 | ++ |
| | Mollusca | Bibalva | - | Bivalve larvae | 52 | ++ |

+ appear very rarely (appearance rate, 10% or less)
++ appear rarely (appearance rate, 20 to 30%)
+++ appear commonly (appearance rate, 40 to 60%)
++++ appear frequently (appearance rate, 70 to 80%)
+++++ appear very frequently (appearance rate, 90% or more)

### (3) Evaluation of Contamination

#### 1) Water Quality Indicators

In order to evaluate the pollution condition of Arabian Gulf, Table4.4.16 indicate the maximum detected value of each parameters obtained both Stage 3 and 4. On the same table, Ambient Seawater and Quality Standard and Effluent Standard of KSA, Regal Commission and Japan are indicated. Also listed in Table4.4.16 are Water Quality 'Alert Values' which were prepared during this study. These 'Alert Values' were derived from international water quality guidelines for the protection of marine ecosystems, as used by countries such as the US, UK, Canada and Australia.
The 'Alert Values' in Table 4.4.16 follow these protocols, with some values adjusted to reflect use of the *'twice local background'* guideline which is generally applied as a trigger for further investigations. It should also be noted that the 'Alert' levels do not represent 'Maximum Permissible' or potentially toxic values. As a rule of thumb the latter are generally between 5 and 15 times normal background, depending on the ecotoxicological properties of particular contaminants and features of the local water column, including temperature, salinity, pH and dissolved oxygen (DO).

It can be seen from Table4.4.16that serious coastal pollution is occurring at sites K2, K5, T6 and T7, where several contaminants have concentrations above effluent standards. At sites T2, T4 and T120, all of which are in Tarut Bay, several indicators of water pollution were above the Ambient Seawater Quality Standard.

On a regional basis the parameters of most concern include TKN, $NH_4$ and Ttl-P, all of which stimulate eutrophication of the coastal water body. Detailed monitoring and management actions need to be implemented as soon as possible.

In addition to the key indicators of eutrophication, TSS, TOC, Oil & Grease and TPH were also found at levels above Ambient Seawater Quality Standards at many sites. TOC values were also higher than the Interim Water Quality 'Alert Value' at several sampling sites.

Continued monitoring of Half Moon Bay will also be necessary, owing to the disparate phosphorous concentrations found at site H30 (one of which is also greater than the ASQS).

Based on the above consideration, pollution condition of each location was evaluated. Classification of evaluation was defined as follows;

[Pollution Level Condition]

- Level 4: more than 4 times of measurement or more than 4 parameters being more than the Ambient Seawater Standard
- Level 3: more than 3 times of measurement or more than 3 parameters being more than the Ambient Seawater Standard
- Level 2: more than 2 times of measurement or more than 2 parameters being more than the Ambient Seawater Standard
- Level 1: less than 2 times of measurement or less than 2 parameters being more than the Ambient Seawater Standard

Figure 4.4.2 shows the results by above classification. According to this figure, followings can be understood.

- Severe pollution can be recognized to exist at Tarut Bay and Khobar.
- In Tarut Bay, pollution trend will have to be carefully monitored since the bay itself is closed and pollution source such as a wastewater discharge and a fishery port are existing.
- The pollution condition of water in Khobar Area is not so serious in comparison with Tarut Bay, since the current is fast. However, existing important source facilities such as Fertilizer Plant and Wastewater Treatment Plant will require careful monitoring of sea water.
- Desalination Plant and Power Plant may not be the source of contamination.

**2) Sediment Quality Indicators**

Table 4.4.17 shows the detected values of sediments. Standard values for marine sediment are not defined in both KSA and Japan. Tentatively, the 'Alert Values' are shown in the same table. The detected values for TOC, TPH and Metals (Cr, Cd, Cu, Hg, Ni, Pb, V and Zn) are more than the alert values.

Figure 4.4.3 shows the level of sediment pollution. The condition of sediment pollution is almost the same as that of water quality. The contamination around J1 and R40 will have to be monitored since there is existing refinery plant around there.

# Table 4.4.16 (1) Evaluation of Water Pollution

Field Measurements (Including Hydrolab DS4 Multiprobe Meter Measurement)

| Indicator | | Temp. | Salinity | pH | DO | Turbidity | Clarity | Odour | Sheen | Flotsam | Residual Chlorine |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Unit | | °C | (g/L) | - | mg/L | NTU | m | +/- | +/- | +/- | Total (ug/L) |
| Detection Limit | | +-0.1 | 0.2 | 0.1 | 0.2 | 2 | 0.3 | na | na | na | 10 |
| Monitoring Results with location | Stage 3 Survay | 34.8 | 59.3 | 7.4 / 8.4 | 2.2 / 9.2 | na | <0.3 / 11.5 | ++ | - | + | 180 |
| | | J5 | H2 | T6 / J1 | T6 / T7 | na | T6 / J2 | T7 | - | J5 | H50 |
| | Stage 4 Survay | 40.0 | 61.04 | 7.43 / 8.2 | 1.69 / 4.5 | 20/0 | 0.3 / 15.7 | + | - | + | 380/20 |
| | | K2 | H1 | T6 / K6 | J7 / T120 | T120/K1 | T6 / J2 | T6 | - | J4,J5,J7,J90,R1, T2,T3,T7,K1,K5, K6,K7,K8,H50 | T3/DD20,K1, K3,K6 |
| Location, of Which value indicates higher than ES in Stage 3 Survay | | - | - | - | - | - | - | - | - | - | - |
| Location, of Which value indicates higher than ES in Stage 4 Survay | | - | - | - | - | - | - | - | - | - | - |
| **Effluent standard (ES)** | H1401-01 | na | na | <6-9> | na | na | na | na | na | na | 500 |
| | RCJY | na | na | <6-9> | na | na | na | na | na | na | 500 |
| Location, of which value indicates higher than ASQS in Stage 3 Survay | | J5,K2,H50 | - | - | - | na | T6 | T7 | - | - | R40,T120,T9, K2,K4,K5,K8, H40,H50 |
| Location, of which value indicates higher than ASQS in Stage 4 Survay | | J5,K2,H50 | - | - | - | T6,T110, T120,K5 | T6 | T6 | - | - | J6,R40,T2,T3, T4,T6,T120,H 2,H40,H50 |
| **Ambient Seawater Quality Standard (ASQS)** | RCJY (10%) | na | na | <6.8-8.5> | <4.0 | na | na | na | na | na | na |
| | RCJY (50%) | na | na | <6.8-8.6> | <5.0 | na | na | na | na | na | na |
| | Japanese Standard (class A) | na | na | <7.8-8.3> | <5.0 | na | na | na | na | na | na |
| | Study 'alert' value | >3 ambient | >70 | <7.2-8.4> | <4.0 | 15 | <0.5 | ++ | + | + | 100 |

*Water Quality 'alert' values are derived for local conditions from normal background range and from marine water quality guidelines recommended by US-EPA, ANZECC, Canada etc. for the protection of marine aquatic ecosystems.

na = not applicable

# Table 4.4.16 (2) Evaluation of Water Pollution

.aboratory Analyses

| Indicator | | TDS | TSS | TOC | TKN | NH4 | Ttl P | Chl A | As | Cr | Hg | Mg | Cd | Co |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unit | | g/L | mg/L | mg/L | mg/L | mg/L | ug/L | ug/L | ug/L | ug/L | ug/L | g/L | ug/L | ug/L |
| Detection Limit | | 0.2 | 1 | 0.5 | 0.1 | 0.2 | 10 | 0.1 | 10 | 50 | 5 | 0.05 | 10 | 50 |
| **Monitoring Results** Max/min. records with location | Stage 3 Survay | 67.6<br>H1 | 12<br>T7 | 48<br>K2 | 130<br>K2 | 90<br>K2 | 1,030<br>K5 | 54<br>T6 | <10<br>- | 200<br>- | <0.1*<br>- | 1.9<br>K8 | <2*<br>- | <30*<br>- |
| | Stage 4 Survay | na | 25<br>T6 | 19<br>T6 | 100<br>K2 | 71<br>T7 | 1,500<br>T6 | 12<br>T6 | <10<br>- | <50<br>- | <0.1<br>- | 2.8<br>K8 | <2<br>- | <30<br>- |
| Location, of Which value indicates higher than ES in Stage 3 Survay | | - | - | - | K2 | K2,T7 | K5 | - | - | - | - | - | - | - |
| Location, of Which value indicates higher than ES in Stage 4 Survay | | - | - | - | K2 | K2,T7 | T6 | - | - | - | - | - | - | - |
| **Effluent standard (ES)** | H1401-01 | na | 15 | 50 | 5 | na | 1,000 | na | 100 | 100 | 1 | na | 20 | na |
| | RCJY | na | 25 | 50 | 5 | 13 | 1,000 | na | 100 | 100 | 1 | na | 10 | 100 |
| Location, of which value indicates higher than ASQS in Stage 3 Survay | | - | T4,T6,T7, T120,K3, K2,K5 | J1,J5,T2,T4, T6,T7,K2,K 3,K4,K5,K6 ,H50 | T6,T7,K2, K5 | K2,T6,K5 | T6,T7,K2 ,K4,K5 | T2,T6,T7, T120 | - | - | - | - | - | - |
| Location, of which value indicates higher than ASQS in Stage 4 Survay | | - | T4,T6,T7, T110,K2, K5 | All sites in which samples were collected | T6,K2,K3, K5 | K2,T6,K5 | T6,T7,K2 ,K4,K5, H30 | T6,T7 | - | - | - | - | - | - |
| **Ambient Seawater Quality Standard (ASQS)** | RCJY (10%) | na | na | 3.4 | na | 13 | 8 | na | 10 | na | 0.1 | na | na | 100 |
| | RCJY (50%) | na | na | 2.4 | na | 5 | 1 | na | 5 | na | <0.1 | na | na | 50 |
| | Japanese Standard (class A) | na | na | na | na | na | na | na | <10 | <50 | <0.5 | na | <10 | na |
| | Study 'alart' Value" | 75 | 5 | 1 | 2 | 2 | 50 | 2.5 | 20 | 50 | 0.1 | 3 | 2 | 30 |

# Table 4.4.16 (3) Evaluation of Water Pollution

Laboratory Analyses

| Indicator | | Cu | Ni | Pb | Zn | Oil & Grease | TPH | Benzen | Toluene | Ethylene | Xylene | Phenol | Cyanogen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unit | | ug/L | ug/L | ug/L | ug/L | mg/L | mg/L | ug/L | ug/L | ug/L | ug/L | ug/L | ug/L |
| Detection Limit | | 50 | 50 | 100 | 10 | 0.2 | 0.1 | 10 | 10 | 10 | 10 | 5 | 10 |
| **Monitoring Results** with location | Stage 3 Survay | <5*<br>- | <15*<br>- | <9*<br>K7 | 200<br>K2 | 0.6<br>K2 | 0.2<br>T110 | <10<br>- | <10<br>- | <10<br>- | <10<br>- | <5<br>- | <10<br>- |
| | Stage 4 Survay | <5 | <10 | <5 | <10 | 0.8<br>K2 | <0.1 | <10 | <10 | <10 | <10 | <5 | <5 |
| Location, of Which value indicates higher than ES in Stage 3 Survay | | - | - | - | - | - | - | - | - | - | - | - | - |
| Location, of Which value indicates higher than ES in Stage 4 Survay | | - | - | - | - | - | - | - | - | - | - | - | - |
| **Effluent standard (ES)** | H1401-01 | 200 | 200 | 100 | 1,000 | 8 | na | na | na | na | na | 0.17 | 50 |
| | RCJY | 200 | 200 | 100 | 2,000 | 8 | na | na | na | na | na | 0.17 | 50 |
| Location, of which value indicates higher than ASQS in Stage 3 Survay | | - | - | K7 | - | K2 | T110 | - | - | - | - | - | - |
| Location, of which value indicates higher than ASQS in Stage 4 Survay | | - | - | - | - | K2 | - | - | - | - | - | - | - |
| **Ambient Seawater Quality Standard (ASQS)** | RCJY (10%) | na | na | 10 | 100 | na | na | na | na | na | na | 5 | 10 |
| | RCJY (50%) | na | na | na | 20 | na | na | na | na | na | na | 1 | 5 |
| | Japanese Standard (class A) | na | na | <10 | na | na | na | <10 | na | na | na | na | <10 |
| | Study 'alart' Value" | 5 | 15 | 5 | 50 | 0.5 | 0.1 | 10 | 10 | 10 | 10 | 5 | 10 |

*Water Quality 'alert' values are derived for local conditions from normal background range and from marine water quality guidelines recommended by US-EPA, ANZECC, Canada etc. for the protection of marine aquatic ecosystems.

na = not applicable

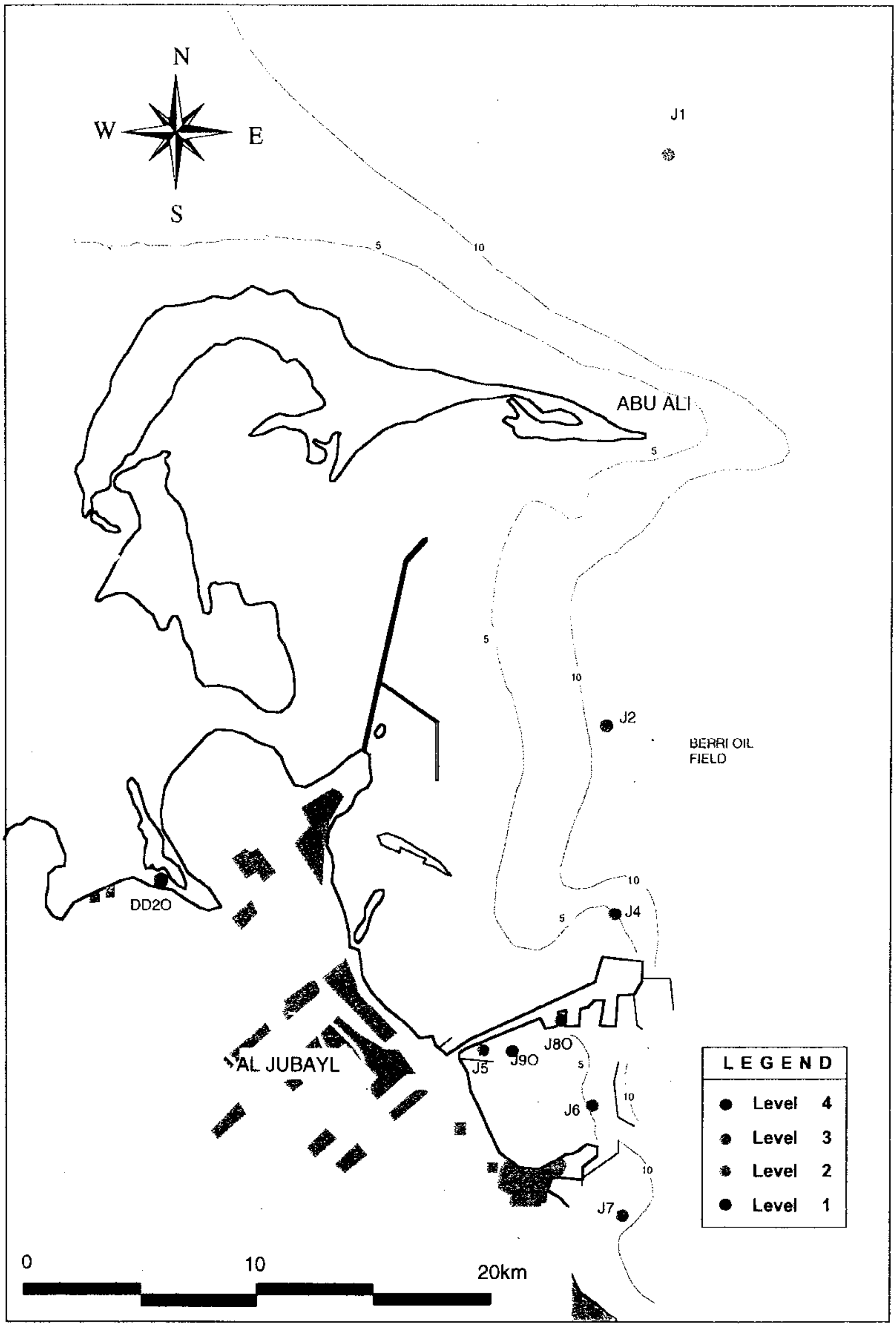


Figure 4.4.2 (1) Estimation of Water Contamination Level

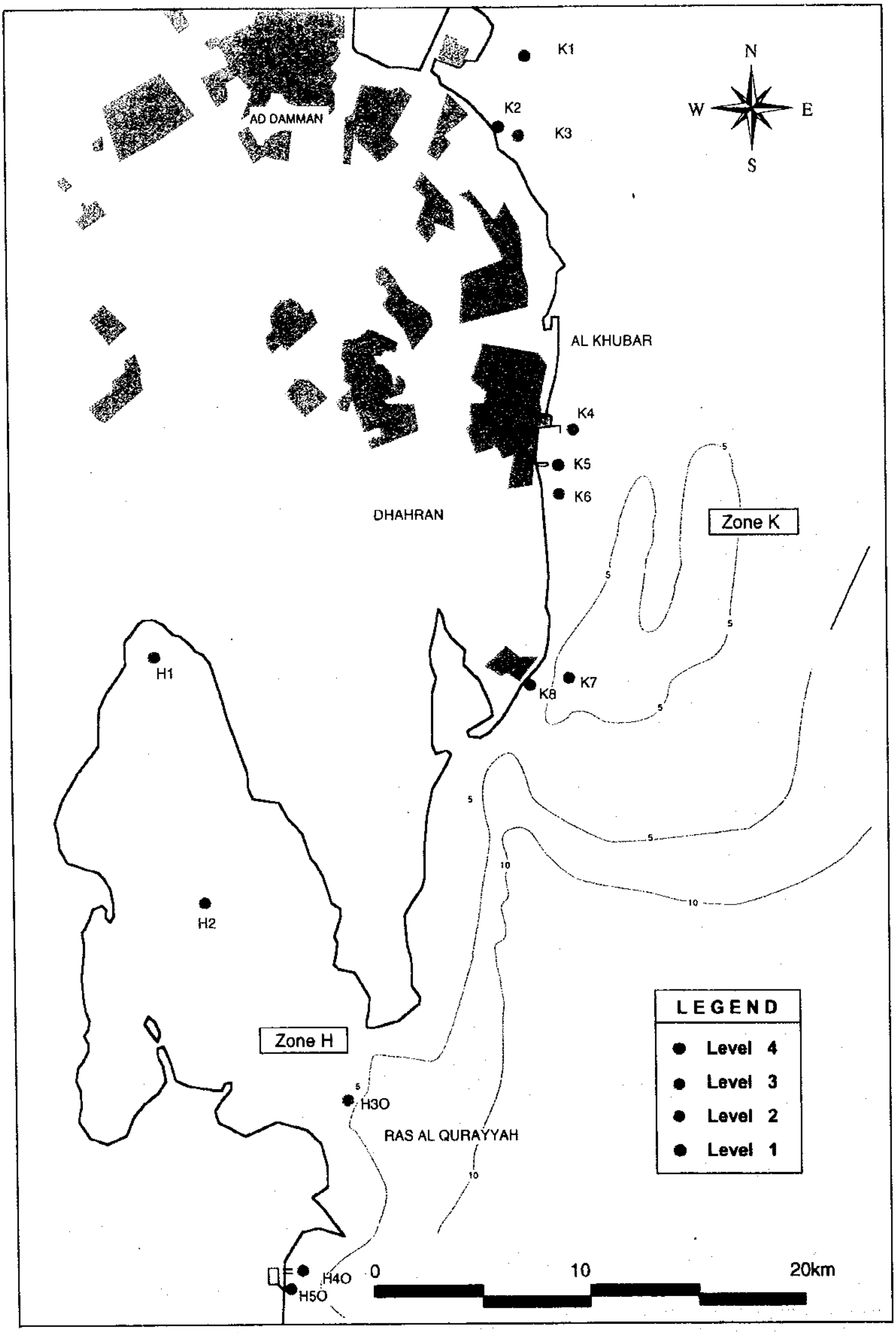


Figure 4.4.2 (2) Estimation of Water Contamination Level

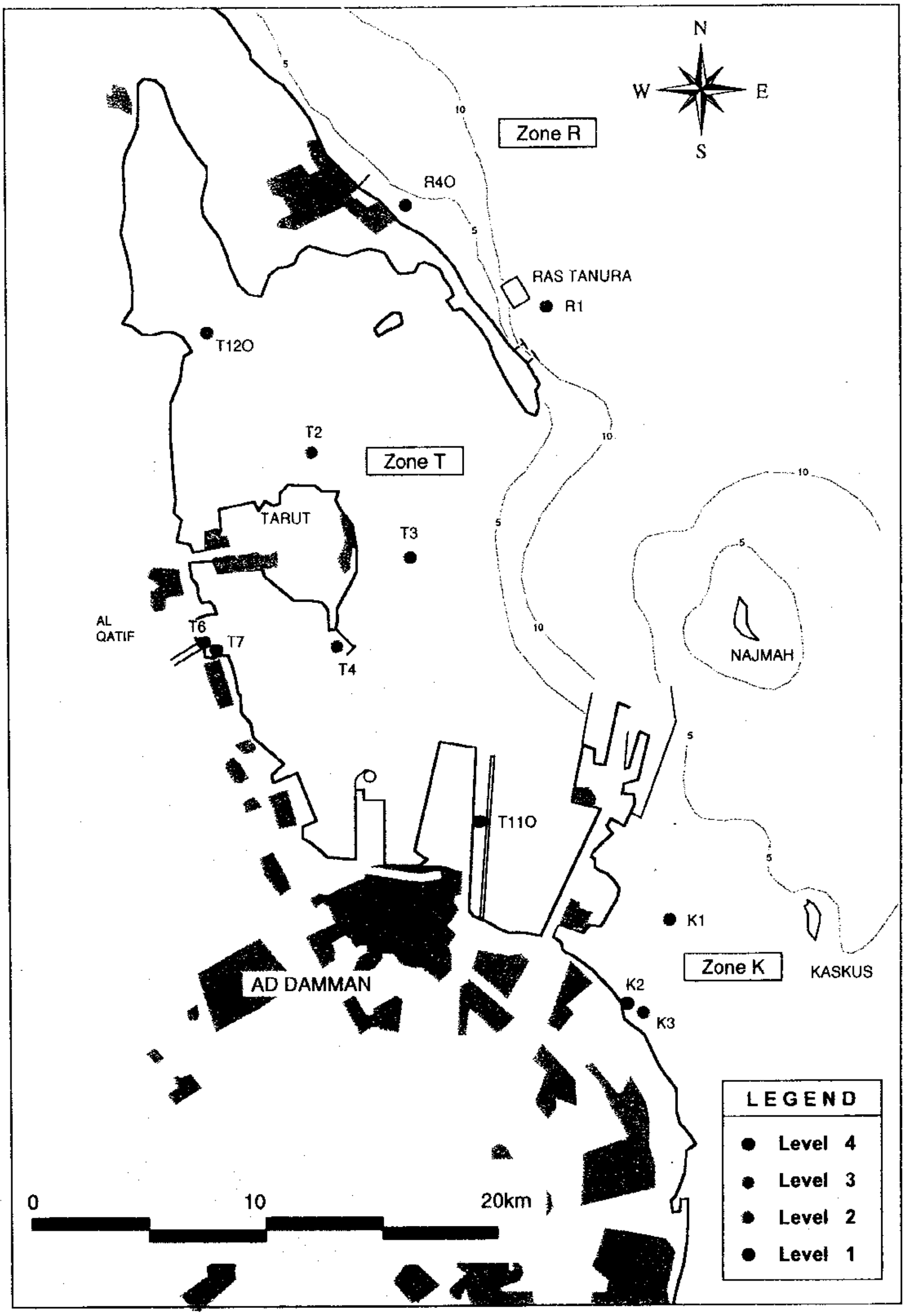


Figure 4.4.2 (3) Estimation of Water Contamination Level

# Table 4.4.17 Evaluation of Sediment Pollution

| Indicator | | Ign. Loss | TOC | As | Cr | Cd | Co | Cu | Hg | Ni | Pb | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unit<br>Detection Limit | | %<br>0.2 | %<br>0.1 | mg/kg<br>0.5 | mg/kg<br>50 | mg/kg<br>1 | mg/kg<br>5 | mg/kg<br>5 | mg/kg<br>0.05 | mg/kg<br>5 | mg/kg<br>20 | mg/kg<br>100 | mg/kg<br>10 |
| Monitoring Results with location | Stage 3 Survay | 26.4<br>K1 | 4.1<br>K2 | 1.6<br>DD20 | 570<br>K2 | 3<br>J7,J80,R1, R40, T2,K1, K3, K4, K5 | 24<br>J1 | 41<br>K2 | 28<br>T110 | 71<br>J1 | 57<br>T4 | 77*<br>K2 | 2,100<br>K2 |
| | Stage 4 Survay | 18.2<br>K2 | 10.4<br>K2 | <10 | <50 | <2 | <30 | 71<br>K2 | 0.52<br>T11,0 | 47<br>K2 | <10 | <70* | 4,400<br>K2 |
| Site above the Study 'alert' value in Stage 3 Survay | | - | DD20,T4, K2 | - | K2 | J7,J80,R1, R40, T2,K1, K3, K4, K5 | - | - | T110,K2 | JI, T4,K2 | K2, T4 | K2 | K2 |
| Site above the Study 'alert' value in Stage 4 Survay | | - | DD20,T4, K2 | - | K2 | - | - | K2 | T110,K2 | K2 | K2, T4 | - | T4, K2 |
| Study 'alert' value | | na | 2.5 | 20 | 70 | 2 | 50 | 50 | 0.15 | 40 | 50 | 70 | 200 |

| Indicator | | TPH | BTEX |
|---|---|---|---|
| Unit<br>Detection Limit | | mg/kg<br>0.2 | mg/kg<br><2 |
| Monitoring Results with location | Stage 3 Survay | 96<br>T6 | <0.2 |
| | Stage 3 Survay | 4,400<br>DD20 | - |
| Site above the Study 'alert' value in Stage 3 Survay | | DD20,J2,R40,T4,T6, | - |
| Site above the Study 'alert' value in Stage 4 Survay | | DD20,J1,J5.J80,R1,R2,R40,T4,T6,T110,K5 | - |
| Study 'alert' value | | 15 | 2.5 |

na = not applicable

*Water Quality 'alert' values are derived for local conditions from normal background range and from marine water quality guidelines recommended by US-EPA, ANZECC, Canada etc. for the protection of marine aquatic ecosystems.

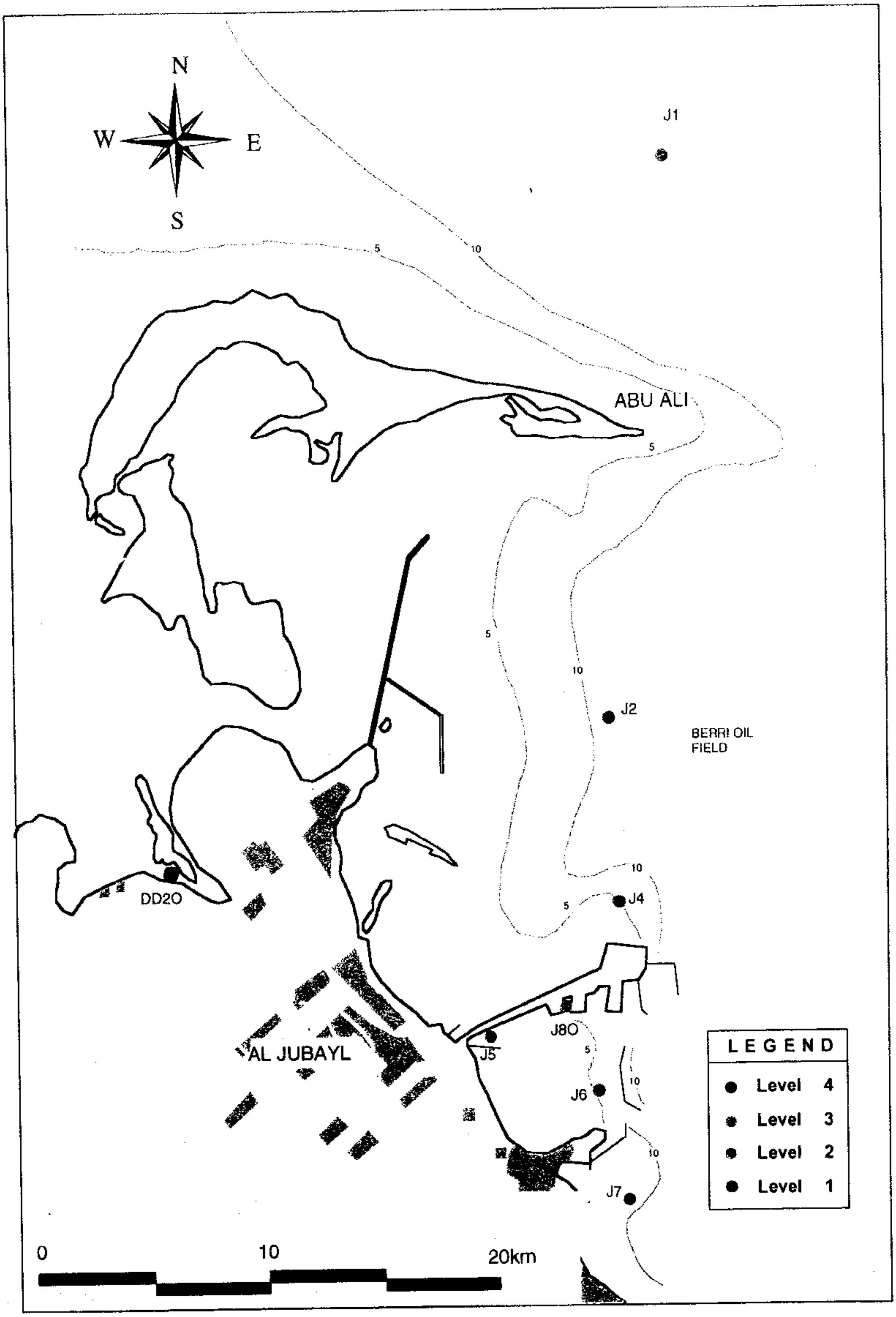


Figure 4.4.3 (1) Estimation of Sediment Contamination Level

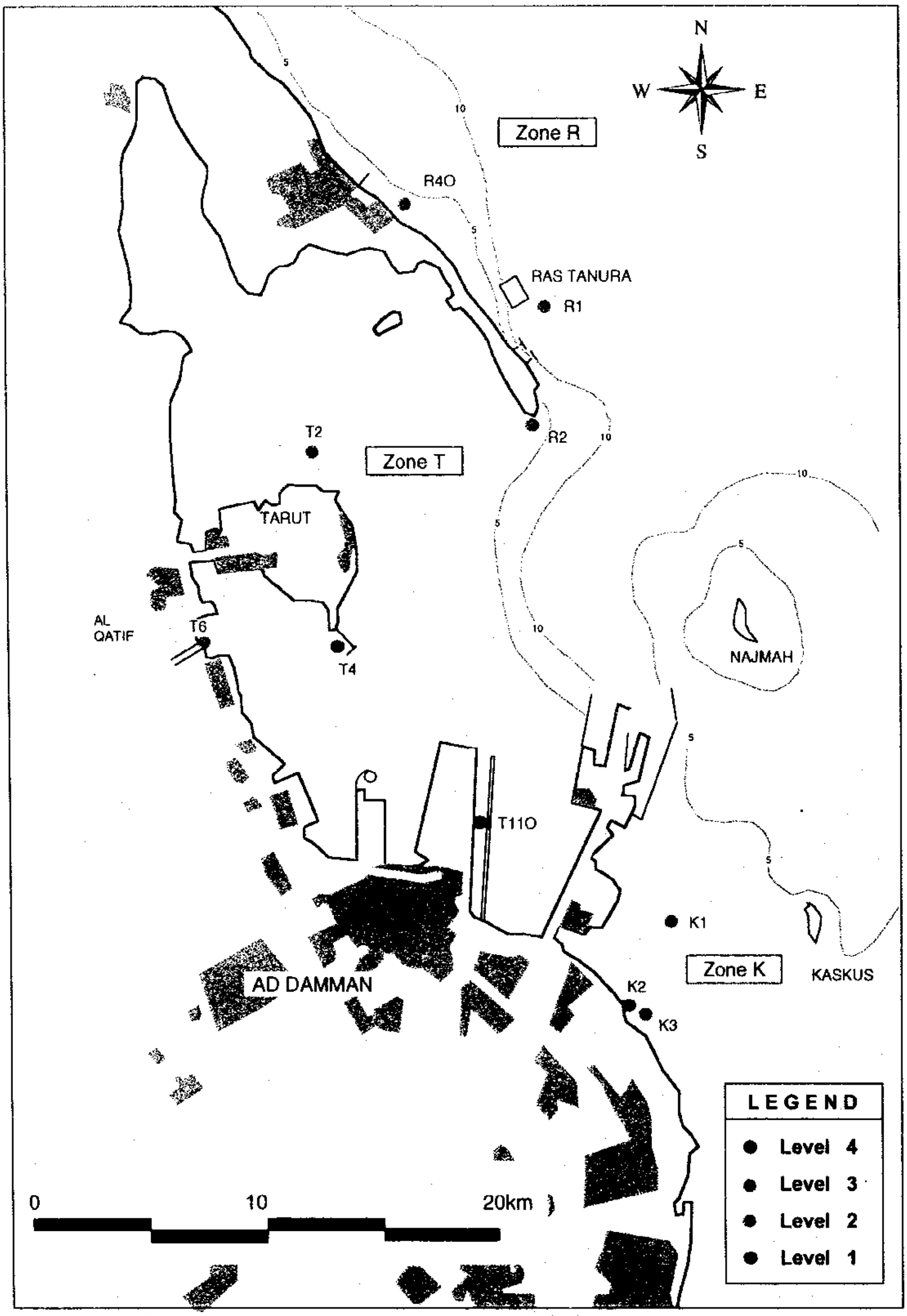


Figure 4.4.3 (2) Estimation of Sediment Contamination Level

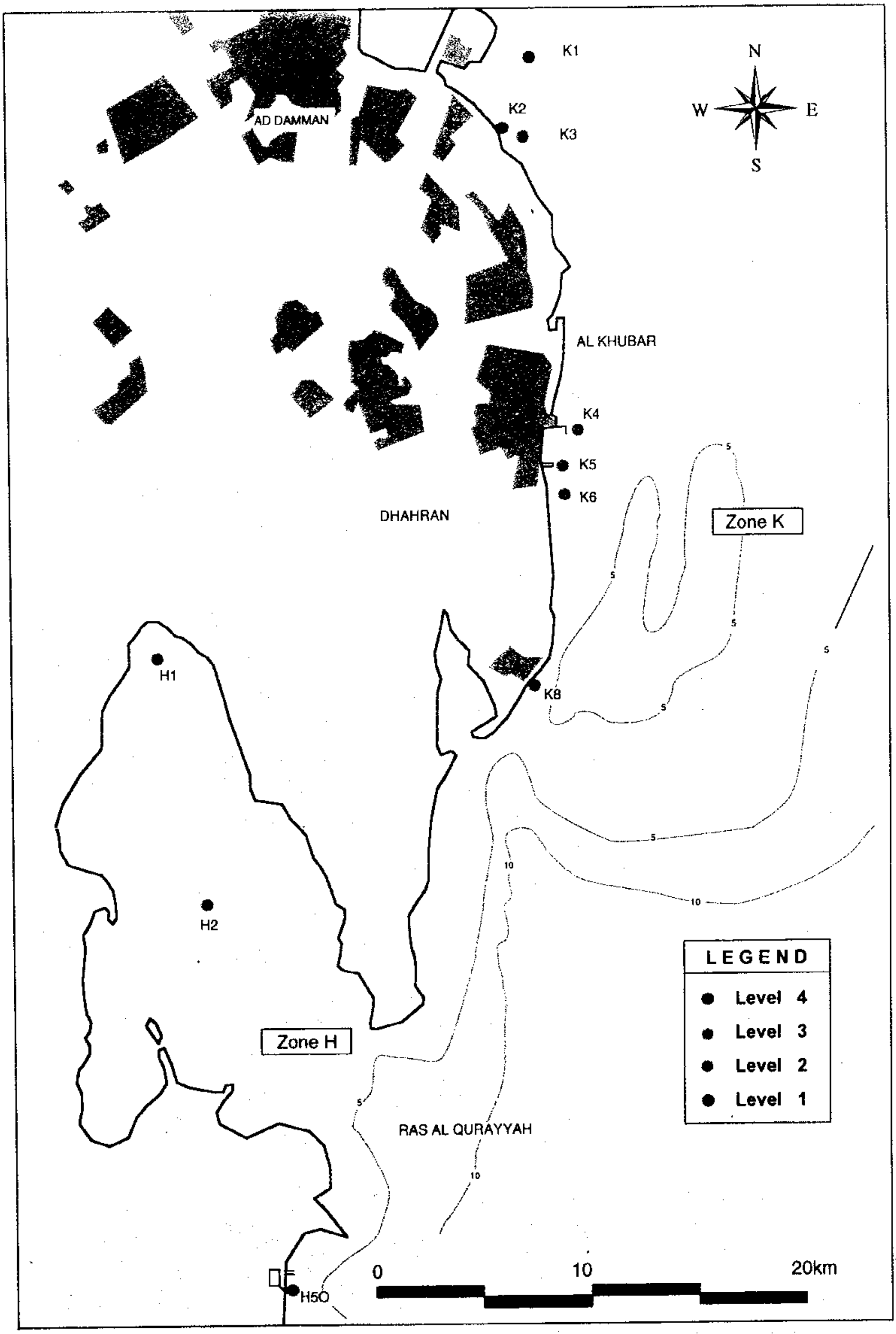


Figure 4.4.3 (3) Estimation of Sediment Contamination Level

### 3) Plankton

Settling volume and diversity index of Stage3 and Stage 4 are compared in Table 4.4.18. The settling volume of plankton in Stage 3 was obviously smaller than that of Stage 4. Also, the species composition was different between Stage 3 and Stage 4.

In the Plankton analysis of Stage 3, *Trichodesmium eryhraem* and *Thalassiothrix frauenfeldii* were mainly observed as phytoplankton. Zooplankton were less in number in comparison with phytoplankton that were mostly composed of species belonging to Class *Oithonidae* and *Calanidae.* In Stage 4 plankton analysis, zooplankton, such as Copepoda and larve of bivalves were dominant. Phytoplankton were less observed than Stage 3.

The result shows that the population of phytoplankton decrease in summer and increase in autumn. The strong sunlight in summer may inadequate for phytoplankton increase.

Phytolankton bloom may occur in autumn to winter in KSA, Whereas, it usually happens from spring in Japan.
To investigate the seasonal change of plankton population in the Gulf, performance of plankton survey in winter and spring season is strongly recommended.

The water quality monitoring result in Al-Jubail area showed that the concentration of Nitrogen and Phosphorus in Stage 3 was higher than that of Stage 4. The difference on the nutrient concentration may influents the plankton multiplication trend.

According to the guideline of USEPA, three alert levels based on algae cell counts have been determined:

* alert level I
  500 - 2000 potentially toxic blue-green algal cells per mL
* alert level II
  2000 - 15000 potentially toxic blue-green algal cells per mL
  ; any cell count over 2000 cells per mL is regarded as a level of concern for drinking-water supplies
* alert level III
  greater than 15000 potentially toxic blue-green algal cells per mL)

In this study, the cell number of *Trichodesmium* (belonging to blue-green algae) was counted below alert level.

Diversity of plankton is usually between 1 and 2.5 in coastal waters, generally being low in estuarine or polluted areas. Values from 3.5 to 4.5 are most frequently measured in the oceanic plankton.

Plankton Diversity Index estimated from the results of this study indicated 1.44-2.9 in Stage 3 and 0.93-2.5 in Stage 4, varying within the normal value, except for the location of site K3 and Al-Jubail area in 3rd sage.

Plankton Diversity Index of K3 was calculated as 0.92 in Stage 3 and showed same value in Stage 4. Plankton Diversity Index of Al-Jubail area was rather low value varying with range of 0.02-0.92 in Stage 3, where was no observation of remarkable pollution.

**Table 4.4.18 Comparison of Settling Volume and Diversity Index between Stage 3 and 4**

| Site Code | Plankton Volume (ml/L) | | Diversity Index | |
|---|---|---|---|---|
| | Stage 3 | Stage4 | Stage 3 | Stage4 |
| J1 | 2 | 0.05 | 1.80 | 0.94 |
| J4 | 1.5 | 0.03 | 1.94 | 0.23 |
| J6 | 1.3 | 0.01 | 1.16 | 0.02 |
| J7 | 2 | 0.01 | 1.78 | 0.06 |
| R1 | 1.5 | 0.01 | 2.05 | 2.52 |
| T2 | 0.3 | 0.01 | 2.10 | 2.84 |
| K1 | 0.1 | 0.01 | 1.15 | 2.90 |
| K3 | 0.2 | 0.01 | 0.92 | 0.92 |
| K6 | 2 | 0.01 | 2.02 | 2.80 |
| K7 | 1 | 0.01 | 2.51 | 1.44 |
| K8 | 1.2 | 0.01 | 1.93 | 2.83 |
| H1 | 0.5 | 0.02 | 1.20 | 1.84 |
| H2 | 0.5 | 0.01 | 2.50 | 2.64 |

### 4.4.6 Conclusion

Results from the Stage 3 and Stage 4 surveys of the Intensive Study Area indicate the following:

- Contaminant concentrations in the offshore waters entering the Intensive Study Area in October 1999 and June 2000 were below national and many international Water Quality and Sediment Quality standards and guidelines, a finding also supported by the results of the Satellite Image Analysis.
- While the offshore waters may be close to a 'near-pristine' condition for much of the time, it appears that the 'background' concentration of certain trace metals in offshore seafloor sediments (e.g. nickel and probably vanadium and barium) may be a little elevated compared to the era before major oil field development. In other words the elevation in certain trace metals can be related to the past 50 years of oil production, tanker traffic and spills within the Gulf.
- Coastal water quality was poorest and impacts on biological resources such as seagrasses and coral reefs were highest in some shallow, near shore and/or partly enclosed areas. These include parts of Tarut Bay (particularly on the north-east side of Tarut Island), and inshore areas south of Dammam Port and also near Al Khobar. Most of the deterioration can be directly related to land-based sources and point discharges that contain high levels of suspended solids, nitrogen, phosphorus and coliform bacteria.
- Fishing harbors that service relatively large fishing fleets (e.g. Darin Jetty at Tarut Island) are also the source of poor water and sediment quality due to the lack of sanitation facilities on these vessels.
- With one exception, the effect on coastal water quality from the four major industrial discharges that were examined in the region (Jubail Shared Outfall; SAFCO (Dammam) factory, Aziziyah Desalination Plant, Al Qu'raiyah Power Plant;) appears to be very low. The exception was the shoreline outfall of the SAFCO fertiliser factory, which is located south of Dammam Port.
- Because the Stage 3 and Stage 4 field monitoring surveys were undertaken in October 1999 and June 2000 respectively, the maximum and minimum values of parameters such as water temperature, salinity and dissolved oxygen were not obtained (the lowest and highest values probably occur in very shallow inshore waters during early August and early February respectively).
- In Tarut Bay (particularly on the north-east side of Tarut Island), Dammam and coastal area of Khobar, water pollution caused by influent water from land area was observed. Especially, water pollution at the area near from the outlets of sewage treatment plant, fertilizer factory and municipal sewage are serious. On the contrary, serious influences of power plant and desalination plant on water quality were not observed. These include parts of Tarut Bay (particularly on the north-east side of Tarut Island), and inshore areas south of Dammam Port and also near Al Khobar.
- Since serious water pollution was observed at fishing harbors in Tarut Bay including Darin Jetty, it can be said that fishing harbor is one of the major pollution sources.

- At the coastal area, water pollution by eutrophic substances such as nitrogen and phosphorus is serious. Contamination of metals in water is not so serious.
- Accumulation of metals in sediment was observed in some areas where contamination of metals was not observed in water. High concentration of metals (Chromium, Cadmium, Copper, Mercury, Nickel, Lead, Vanadium, Zinc) and petroleum-hydrocarbon was observed.
- Contaminant concentrations in the offshore waters entering the Intensive Study Area in October 1999 and June 2000 were below national and many international Water Quality and Sediment Quality standards and guidelines, a finding also supported by the results of the Satellite Image Analysis.
- In offshore, deterioration of sediment caused by offshore oil production was observed. High concentration of pollutants including nickel peculiar to oil production was detected.
- A large seasonal variation was observed in plankton study. It is necessary to grasp the fluctuation in the numbers of plankton by conducting all year round monitoring.
- Because the Stage 3 and Stage 4 field monitoring surveys were undertaken in October 1999 and June 2000 respectively, the maximum and minimum values of parameters such as water temperature, salinity and dissolved oxygen were not obtained (the lowest and highest values probably occur in very shallow inshore waters during early August and early February respectively).

From the two baseline surveys conducted so far, it is concluded that eutrophication of inshore coastal waters represents the most significant and worrisome pollution process for the ISA.

Experience around the world shows that excessive amounts of nutrients entering the coastal environment (especially phosphorus, ammonia, nitrate/nitrites, and organic material in general) have a much stronger potential to cause chronic degradation to coastal Water Quality than the occasional small or moderate size oil spill accident.

Eutrophication leads to long term, intractable problems that are difficult and expensive to cure. By contrast, most oil spills exert short- to mid-term impacts, since the toxic components of oil are broken down by several processes of natural weathering, particularly under the high water temperature and UV conditions experienced in the Gulf during much of the year.

Unlike the sudden and mostly short term acute impacts caused by most oil spills, the process of coastal eutrophication tends to proceed in a sinister, unnoticed fashion. Unless monitoring is undertaken to map the early warning signs and sources, the eutrophication problem is often not recognised or addressed until significant impacts are occurring (e.g. seagrass losses, increased incidence/severity of fish kills, appearance of smelly coastal sediments, and/or increased incidence and longevity of red tides).

Loss of seagrass meadows due to algal smothering is already evident on the north side of Tarut Island, and this continues it could reduce sediment stability, fishery production and food sources for green turtles. The most serious direct social impacts of eutrophication may be an increase in plankton blooms, smelly shoreline sediments and/or appearance of toxic red tides.

Unless steps are taken to further monitor and improve management of the land-based sources of nutrients, serious eutrophication impacts can be predicted to arise first in shallow restricted embayments, particularly parts of Tarut Bay and near Dammam. In the longer term, water quality in Half Moon Bay and the Gulf of Salwha could also deteriorate, since these highly evaporative basins receive much of the replenishing water from the main tidal channels that pass close to the Dammam-Al Khobar coastal strip.

The results to date indicate an urgent need to monitor and manage land-based sources of nutrients from industrial sources, and to reduce the amount of raw and poorly treated sewage entering coastal waters. Areas deserving attention are the busy fishing boat harbours and urban drains from historic towns such as Qatif.

Finally, it must be mentioned that plastic, metal and glass debris and litter are very common along most shorelines of the region and represent a significant form of coastal pollution. From the various types of rubbish observed it appears that the majority of items are originating from land sources and coastal fishing vessels rather than international shipping. Apart from reducing the beauty of the coastal landscape and social amenity value, many rubbish items represent a public health risk (especially broken glass and leaking batteries). Many of the plastic items can ensnare seabirds and other protected wildlife, including turtles, causing painful injuries and a slow death by starvation or tissue necrosis.

Based on the various conclusions outlined above, the proposed future monitoring plan for the KSA Gulf coastal waters is presented and discussed in Section 5.

# Chapter 5

# Future Direction of MEPA Water Quality Monitoring

# Chapter 5 Future Direction of MEPA Water Quality Monitoring

## 5.1 Coastal Zone Management Framework and Policy

### 5.1.1 Characteristics and Present Situation of Gulf Coastal Zone

The shallow, gently shelving and sedimentary coastal zone of the KSA Gulf region contains salt marshes (sabkahs), linear sand beaches and seagrass beds, with coral present on both inshore and offshore reefal areas. Significant marine coastal wildlife with high national and international conservation values includes terns, cormorants and other sea birds, sea turtles and dugongs. In the case of turtles, the small islands near Al Jubayl provide their most significant nesting beaches within the Gulf. In the case of dugongs, the population in the Gulf of Salwhat is now one of only three surviving significant populations in the entire Indo-Pacific region (the other two located in Australia).

The Gulf Coastal Zone also provides KSA with significant recreational, fishery, drinking and industrial water resources. The need for clean sea water to maintain energy-efficient and cost-efficient desalination cannot be overlooked, as the coastal waters provide the main feed stock of the Kingdom's water supply for domestic, industrial and agricultural consumption. However the Gulf coastal waters and marine resource they support are both very vulnerable to the effects of contaminant and nutrient inputs for the reasons explained earlier.

Most Gulf coastal zone management and monitoring in recent years has been focussed on the effects of acute (short term) oil spill events. However, it is becoming increasingly clear that, unless prompt regional and national management systems and countermeasures are introduced to reduce the number and size of chronic (long term) land-based sources of pollutants and bio-stimulants (especially nitrogen and phosphorous), water quality will continue to degrade. Degradation will eventually lead to wider-scale public health issues, further loss of fish nursery habitats, fishery stock damage, wildlife mortalities and economic losses to industry. Therefore the importance of ensuring there is an adequate and well-coordinated approach to the environmental management of the Gulf Coastal Zones cannot be over-emphasized.

### 5.1.2 Need for MEPA Coordinated Coastal Zone Management Plan and Monitoring

MEPA is responsible under Government law for protecting the KSA population and natural environmental resources from sickness and damage caused by pollution. This responsibility includes protecting the Water Quality and natural marine resources in the Kingdom's Gulf Coastal Zone.

Maintaining Water Quality in the Gulf Coastal Zone requires far more attention and resources than the Red Sea coast because of three main features:

- there is much more industrial and urban coastal development, activity and inputs along KSA's Gulf coastal zone than on the Red Sea. Examples of significant industrial activity along the KSA Gulf coast include oil refineries, petrochemical plants, fertilizer factories, power stations, desalination plants, cement plants, commercial ports and fishing harbors.
- the Gulf's waters are receiving far more contaminant inputs by air, industrial activities, petroleum production operations and shipping (both to and from and within the Gulf).
- the Gulf is an enclosed and very shallow sea (average depth ~36 m) which has a high evaporation rate and very limited flushing due to the narrow and shallow Straits of Hormuz. Therefore contaminants and nutrients entering the Gulf have reduced opportunity to dilute and disperse, and the overall assimilative capacity of the Gulf system is much less than that offered by the ecosystems of more open, oceanic waters.

To achieve its responsibility for protecting Gulf Coastal Water Quality, MEPA must ensure there is adequate management and monitoring of activities and inputs that otherwise will cause unacceptable degradation of coastal water quality leading to:

- public health risks and loss of amenity / recreational values;
- loss of important marine habitats, fisheries and wildlife; and
- impacts to the clean sea water needs of coastal industries and shipping.

As a focal point for Gulf Coast Protection, MEPA is responsible for promoting and implementing a Coordinated Coastal Zone Management Plan (including monitoring) via close liaison with other agencies.

For efficient and effective monitoring and management of Gulf coastal waters, MEPA needs sufficient staff and technical resources, within a suitable internal organizational structure that operates under a policy framework fully supported and adequately funded by Government. The overall response to prevent further degradation of Coastal Water Quality is shown graphically in Figure 5.1.1.

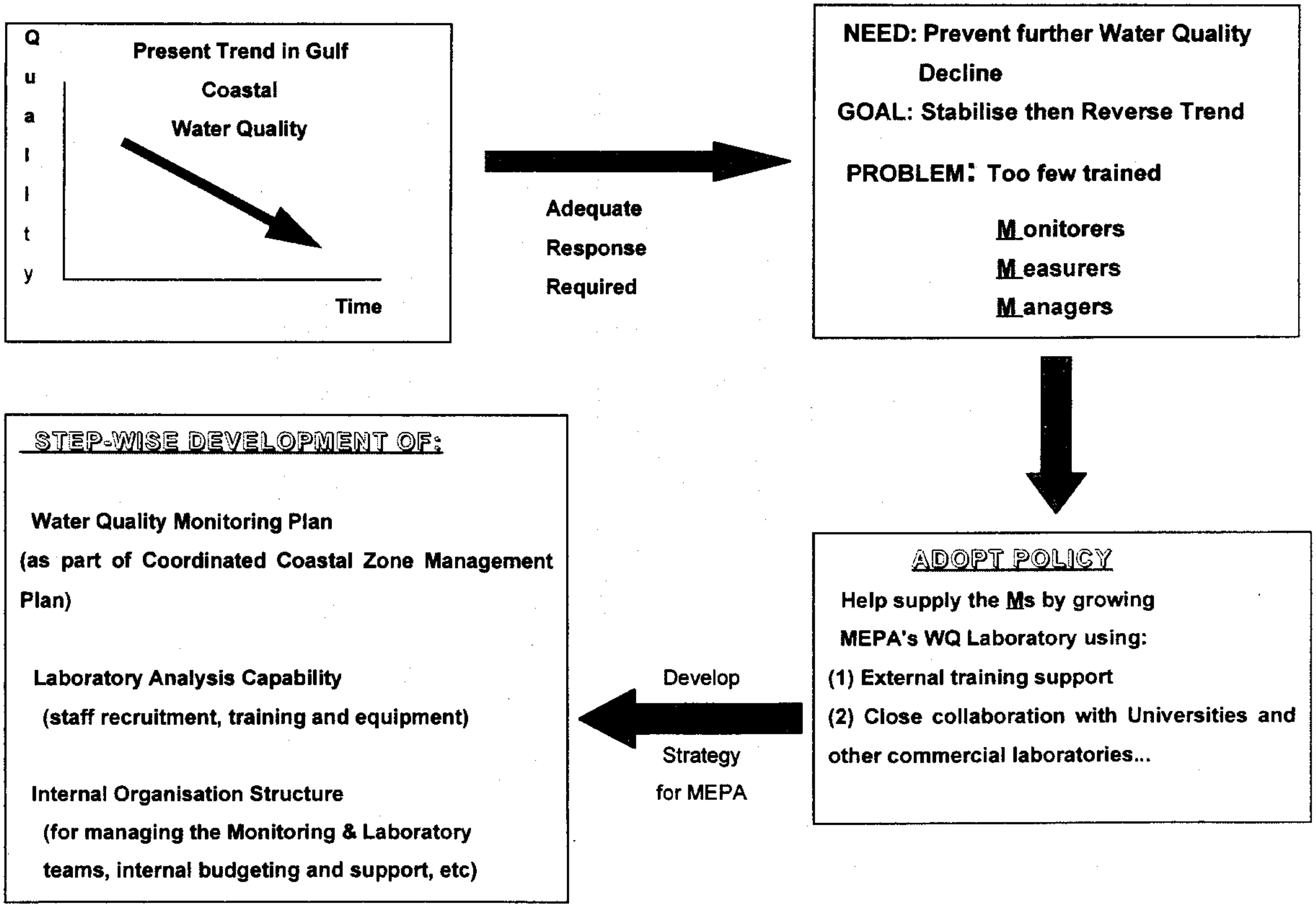


**Figure 5.1.1 Overall response to Prevent Degradation of Coastal Water Quality**

### 5.1.3 Components of Coordinated Coastal Zone Management Plan

The following items and tasks are important components of any coastal zone management plan, including one suitable for co-ordination by MEPA Eastern Province. As shown more graphically in Figure 5.1.2, the items with a '*' involve production and/or use of reliable monitoring data from field sampling and laboratory analyses.

- Routine Baseline Surveillance Monitoring (= Trend Monitoring)*
- Characterization of Problem Areas / 'Hot-Spots' (= Specific Monitoring Tasks)*
- Emergency Response Unit to combat oil spills and other chemical releases*.
- Identification and Prioritization of knowledge 'Gap-Filling' research by external specialists*;
- Review suitability of Coastal Water Quality Standards and Guidelines*;
- Provide advice to Government on improving existing Policies and Regulations on:
  - Content and application of Water Quality Standards;
  - Reducing marine litter and coastal rubbish;
  - Outfall licensing, license conditions and operator monitoring/reporting;
  - Control of nutrient point-sources (and ground-water inputs) to avoid coastal eutrophication;
  - Integrated Coastal Development Planning Strategy for protecting sensitive areas and key habitats.
- Inspections and Compliance Checking*.
- Educational Materials and Promotions to increase General Public and Industry awareness about Coastal Zone values and protection needs*.
- 'State of Coastal Environment' reports to Government, stakeholders and public*.
- Development of Marine Sediment Quality Guidelines and Standards.

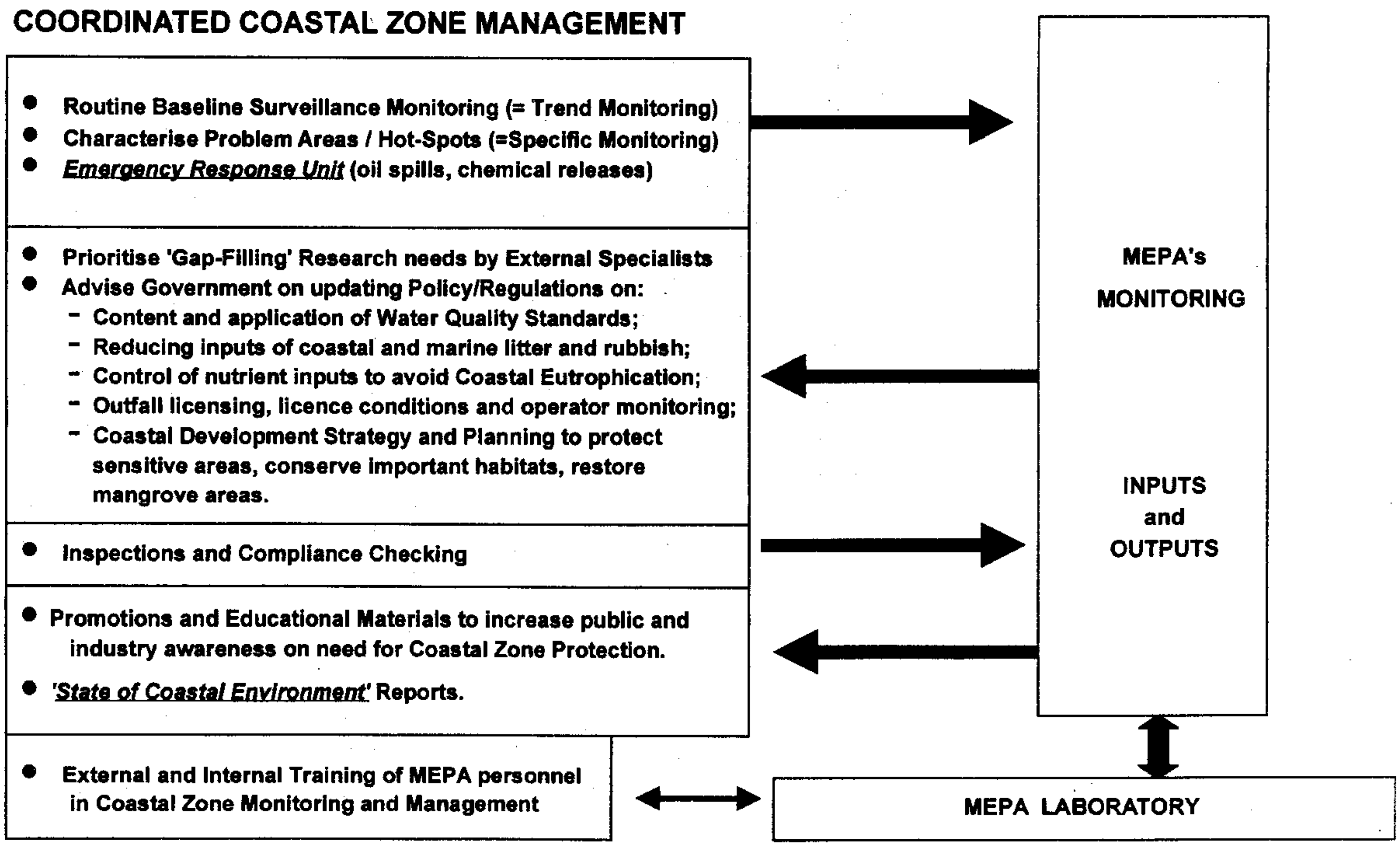


**Figure5.1.2 Components of Coordinated Coastal Zone Management Plan**

### 5.1.4 MEPA's Goal and Objectives in Water Quality Monitoring

MEPA should create the comprehensive monitoring system by expanding the monitoring works made in this study. The data to be obtained in the monitoring should be accumulated and analyzed by MEPA, and the results of the analyses shall be reflected to coastal management activities. Further, in the future, MEPA should develop the information and technology exchange system with organizations related to management and utilization of coastal area, and should act as a leading organization in the environmental management of Arabian Gulf. For the above objectives, MEPA should develop monitoring system, reliable water analysis laboratory and the most suitable organization in the following manner.

- Establish a basic water quality monitoring program for the Gulf Coastal Zone that will supply pertinent, useful information for (a) coastal planning and management, and (b) identifying where specific monitoring investigations are required to help determine the sources, extent and potential solutions to pollution 'hot-spots' and other trouble areas.
- Enhance the technical capabilities of the MEPA Water Quality Laboratory for (a) undertaking routine chemical analyses and (b) ultimately providing a training center for developing staff experience and expertise in aquatic resource management and monitoring.
- Enhance the organizational structure of MEPA to ensure there is an appropriate management framework and budget for achieving (a) its monitoring objectives, and (b) adequate interpretation and use of the monitoring data for environmental management.

Monitoring is an essential component of coastal zone management, and MEPA recognizes that it must strive to achieve a level of monitoring and analysis capabilities that can fulfil the following needs:

- provide a regional early-warning system to detect problem areas and trouble spots (to avoid the risk of hard-to-fix and expensive surprises);
- check compliance with (and adequacy of) outfall license conditions and regulations;
- evaluate public health risks (especially those associated with potentially contaminated swimming or fishing areas);

- improving knowledge and understanding of local coastal processes and ecosystems, including the type and size of impacts due to human activities;
- refining impact predictions enabling more precise and cost-efficient management strategies;
- promoting and/or modifying practical Water Quality and Sediment Quality Standards;
- evaluating the success of pollution prevention programs.

### 5.1.5 Scope and Tasks of the MEPA-JICA Study Project

To help achieve MEPA's water quality monitoring objectives, the Project focussed on enhancing the technical marine monitoring and management capabilities of MEPA Eastern Province, with work completed by the Joint MEPA-JICA Study Program on the following tasks:

(a) Establish the basic water quality monitoring system, which is aimed at identifying existing coastal water quality and apparent causes for its degradation along the Gulf coastline;

(b) Strengthen the monitoring and management capacity of the MEPA Eastern Province Office (Dammam) through technology transfer and training, including:

  (i) upgrade of field and laboratory equipment to enable basic water quality monitoring by MEPA Eastern Province Office;

  (ii) training to counterpart personnel, including 'on-job' (hands-on) training, seminars and tutoring at Dammam, as well as training courses in Japan;

  (iii) review of MEPA's existing organizational structure and recommendations for implementing an office management framework for operating the future monitoring program and laboratory.

(c) Review water quality data obtained to date by MEPA and other parties, and develop a plan for implementing a future coastal water quality monitoring system.

## 5.2 Recommended Phased Approach to Future Monitoring

During the 1999-2000 Project, the MEPA-JICA Study Team conducted a pilot survey of the Gulf coast and then established a basic water quality monitoring program in the Central Region of the Gulf Coast (= Intensive Study Area) by undertaking two seasonal surveys (Chapter 4).

Technology transfer (equipment upgrades) and training on field sampling techniques, laboratory analyses and the planning, design and interpretation of monitoring data were also conducted.

However, MEPA Eastern Province still does not have enough sufficient laboratory staff capability to continue developing its water quality monitoring program by itself. Problems to be resolved include:

- successful recruitment of two suitably experienced laboratory technicians (i.e. with good chemistry background) to be trained on the laboratory analytical procedures;
- confirmation of adequate budget allocations to cover future laboratory operations and the logistical costs of field monitoring;
- inexperience in the planning of statistical sampling designs for specific monitoring tasks (i.e. monitoring tasks that need to address particular questions concerning the source/s and fate of particular contaminants, and/or the type and spatial extent of their impacts);
- lack of sensitive laboratory equipment and advanced skills required for determining concentrations of important trace contaminants in the water column at low but environmentally significant levels (i.e. parts per billion; μg/L).

These are not insurmountable problems but they cannot be overcome in a short time.

Therefore a step-wise, phased approach is recommended to enable efficient development of MEPA's water quality monitoring capabilities for the Gulf coastal zone. The recommended approach comprises four phases which correspond to the recently completed project work (Phase I), a consolidation period for the near-term (Phase II), a second period of technical enhancement and strengthening (Phase III), and a maturation and focus period (Phase IV). The objectives and scope of the four phases are outlined as follows:

**1) Phase I** (Preparation and Planning Period)

Phase I is a preparation and planning phase which includes the basic technology transfer and training for basic field sampling, laboratory analyses and future monitoring planning.

Two seasonal surveys of the Central Region of the KSA Gulf coast (the 'Intensive Study Area') in October 1999 and June 2000 with analyses undertaken at the MEPA laboratory.

Technology transfer, equipment upgrades, training on field sampling techniques, laboratory analyses were conducted during this survey. Also, the results of these monitoring surveys can be reflected to develop the 'Future monitoring Plan'.
All these activities will contribute to the preparation and planning of future monitoring works. Therefore, it can be said that the phase I have already completed.

**2) Phase II (Consolidation Phase)**

The objective of Phase II is to provide a solid foundation for MEPA's future monitoring system by consolidating the basic laboratory staffing and organizational capabilities of the MEPA E. P.

Realization of continuous monitoring supported by routine laboratory operations is the goal of this phase, since MEPA must achieve the ability to undertake basic regional monitoring by itself. To achieve this within a reasonable time period, MEPA needs to ensure there is (a) completion of recruitment to achieve a basic level of laboratory staff and (b) adequate annual budgeting to permit field sampling operations and laboratory analyses, as soon as possible. Phase II can then proceed, with key focus on:

- laboratory staff training;
- formation of a suitable management framework for both the field monitoring team and laboratory team;
- further seasonal water quality monitoring in the Central Region of the Gulf coastal zone (= Intensive Study Area of Phase I);
- expansion of the basic Regional Monitoring Program, by initiating seasonal sampling of the northern (Abu Ali to I Khafji) and southern (Gulf of Salwhat) regions of the KSA Gulf coast;
- planning and implementing (but not finishing) three specific monitoring tasks, each of which will require close liaison and co-ordination with at least one other party.
- subcontracting a specialist group to commencement development a hydrodynamic model of inshore water movement in the Khobar-Dammam-Tarut area (results from this study will be needed for completing the three monitoring tasks).

**3) Phase III (Enhancement Phase)**

When the Phase II objectives and tasks have been achieved, MEPA Eastern Province will be ready to enter Phase III. The aim of Phase III is to further enhance and strengthen MEPA's field monitoring and laboratory analysis capabilities. During Phase III, recommended installation of additional laboratory equipment and further laboratory staff recruitment will allow MEPA to enhance its monitoring capabilities. Regional monitoring will be continued and the specific monitoring tasks commenced in Phase II should be completed.

Phase III will probably require two years, and its finish should be marked by a careful review of all laboratory operations and monitoring results obtained so far. The purpose of the review is to confirm if progress in monitoring and laboratory skills has been satisfactory, and to identify an appropriate monitoring and laboratory analysis system that will allow MEPA to move into Phase IV.

**4) Phase IV (Maturation and Focus Phase)**

Phase IV represents the critical maturation phase when MEPA can reach its goal of operating a comprehensive water quality monitoring program under the umbrella of a coordinated Coastal Management Plan for the KSA Gulf coastal zone. Phase IV is therefore the period when:

- MEPA gains sufficient capacity to organize and manage coordinated research level investigations into specific contamination problems and issues.
- Monitoring results provide useful, reliable sources of information that provide the foundation of new or revised environmental protection measures and policies.
- Monitoring tasks are implemented to check the adequacy of such measures following their implementation;

Following brief review of Phase I in the next section (Section 5.3.1), the rationale, objectives and specific monitoring activities recommended for Phases II, III and IV are detailed in Sections 5.3.2, 5.3.3 and 5.3.4 respectively.

### 5.3 Recommended monitoring plan in the future

#### 5.3.1 Phase I

In phase I, namely in this study, basic technology for monitoring was transferred to MEPA, and analytical instruments required for water quality monitoring were installed at its laboratory. As the result of these works and/or technology transfers, it was recognized that the technology foundations for water quality monitoring activities were established in MEPA E. P.

Two monitoring surveys were also completed in both summer and winter seasons in phase I. The results of the monitoring can be summarized as follows.

- In Tarut Bay, Dammam Port and coastal area of Khobar, water pollution caused by influent water from land area was observed. Especially, water pollution at the area near from the outlets of sewage treatment plant, fertilizer factory and municipal sewage are serious. On the contrary, serious influences of power plant and desalination plant on water quality were not observed.
- Since serious water pollution was observed at fishing harbors in Tarut Bay including Darin Jetty, it can be said that fishing harbor is one of the major pollution sources.
- At the coastal area, water pollution by eutrophic substances such as nitrogen and phosphorus is serious. Contamination of metals in water is not so serious.
- Accumulation of metals in sediment was observed in some areas where contamination of metals was not observed in water. High concentration of metals (Chromium, Cadmium, Cupper, Mercury, Nickel, Lead, Vanadium, Zinc) and petroleum-hydrocarbon was observed.
- Contaminant concentrations in the offshore waters entering the Intensive Study Area in October 1999 and June 2000 were below national and many international Water Quality and Sediment Quality standards and guidelines, a finding also supported by the results of the Satellite Image Analysis.
- In offshore, deterioration of sediment caused by offshore oil production was observed. High concentration of pollutants including nickel peculiar to oil production was detected.
- A large seasonal variation was observed in plankton study. It is necessary to grasp the fluctuation in the numbers of plankton by conducting all year round monitoring.

In view of the above results, MEPA should pay attentions to following matters in developing future monitoring plan.

- As for water quality, concentrations of eutrophic substances should be monitored more precisely.
- As for sediment, metals and oil related substances should be monitored more precisely.
- As for coastal areas, effects of onshore pollution sources such as sewage treatment plants, factories and municipal sewage and fishing harbor should be investigated in detail.

### 5.3.2 Phase II

#### (1) Goal and Strategy

The goal of Phase II is to consolidate MEPA's capability to conduct marine monitoring and laboratory analysis operations by:

- Confirming central and regional government policy support for MEPA's responsibilities and roles in Gulf Coastal Zone Management and Monitoring;
- Securing internal budget for the adequate staffing and operation of the MEPA Eastern Province laboratory;
- Securing internal budget to cover the logistics of field monitoring;
- Liaising with key stakeholders (other government agencies, municipalities, industry, research institutions and other laboratories);
- Extending the database of the Baseline Regional Monitoring Program
- Implementing three specific monitoring projects;

#### (2) Phase II Monitoring Tasks

The various monitoring tasks recommended for Phase II are shown in Table 5.2.1, together with the associated laboratory and management activities. Details are given in the following sub-sections.

#### A. Expand Regional Baseline Water Quality Monitoring

#### 1) Rationale and Recommendation

Reliable spatial-temporal data on regional baseline water quality and its trends are an indispensable element of coastal zone environmental management.

Until 1999, however, routine water quality monitoring of coastal waters in the Gulf region has been limited to that undertaken within and near Jubayl Port by the Royal Commission of Jubayl. Previous monitoring activities by MEPA comprised collaborative and essentially 'reactionary' monitoring in response to major oil spills, together with regional and international ship-based efforts that tended to focus on offshore waters in the Gulf (see eg. ROPME, 1999).

Regular collection of seasonal, baseline water quality data for the Gulf Coastal Zone was commenced during Phase I. However this was limited to two seasonal sampling surveys in October 1999 and June 2000 in the Central Region (Al Qurrayah to Abu Ali). Therefore the present database does not cover the maximum and minimum conditions occurring in high summer (late August) and mid-winter (late January). It is therefore recommended that MEPA should:

(i) Continue to collect seasonal water quality monitoring data from the same stations established in the Central Region by Phase I, so that the complete seasonal trends in coastal water quality is obtained.

(ii) Expand the baseline program by planning and conducting two seasonal surveys in the Northern Region (Abu Ali to Al-Khafgi) and Southern Region (Al-Qurrayah to Gulf of Salwhat).

**2) Sampling Design and Survey Planning/Logistics**

The sampling design for each region should follow that developed for the Central Region in Phase I ('Intensive Study Area').

That is, several sites should located in areas away from potential pollution sources to assess 'background' conditions. Other sites should located near examples of the main coastal industry activities and pollution sources in order to determine the affect of these sources.

During the planning and execution of the North and South Regions, logistical support from KSA Coast Guard, plus collaboration/support from Saudi Aramco (for Northern Region) and from National Commission for Wildlife Conservation and Development (NCWCD; for Southern Area) should be sought, respectively.

**3) Survey Timing and Monitoring Parameters**

Baseline monitoring should monitor the parameters listed in Table 5.3.1, as these can be reliably obtained using MEPA's existing field and laboratory equipment and staff experience.

The cost of monitoring parameters such as Temperature, pH, DO, salinity, turbidity, water clarity, TSS, Chlorophyll-a and free chlorine is relatively cheap. These parameters form important indicators of water degradation and they also usually show marked seasonal fluctuations. It is recommended that they should be monitored as frequently as possible (more than once/month), particularly at sites near point-source inputs or in 'problem' areas.

Total Kjealdahl nitrogen (TKN), total phosphorous (TP), ammonia-N ($NH_4$), total organic carbon (TOC) and fecal coliforms are also relatively easy to analyze although their cost is little higher. These parameters are important indicators of sewage effluent influence and eutrophication, and it is recommended they are monitored four times per a year.

The timing of at least one Northern Region survey should be coordinated with the period when external training support is being conducted, so that the same range of parameters determined in Phase I can be obtained for this new area.

Table 5.3.1 Recommended Parameters for Baseline Monitoring

| **Phase II Basic Parameters** | **Season** | **Region -2001** | **Region - 2002** |
|---|---|---|---|
| Weather and wave conditions, | late January (mid- | Central | South and North |
| **Water** | | | |
| Water | mid-April (spring) | Central | |
| Salinity | *late-June (early summer) | South - pilot trial | |
| Dissolved oxygen (DO) | late August (high summer) | Central | South and North |
| pH | *late October (autumn) | North - pilot trial | |
| Total suspended solids (TSS) | | | |
| Water Clarity | * = data were | | |
| Turbidity (NTU) | in Phase I | | |
| Chlorophyll a | | | |
| phytoplankton and zooplankton | | | |
| TOC | | | |
| TKN, NH4 T-P, facal coliform | | | |
| | | | |
| **Sediment** | | | |
| Temperatur | | | |
| ORP | | | |
| Color, Odor | | | |
| Partcle Size Analysis | | | |
| Metals(Cr,Cd,Cu,Hg,Ni,Pb,V,Zn,Ba) | | | |
| TPH | | | |

Reliable measurement of hydrocarbons and metals require advanced equipment and skilled application of analytical techniques, particularly if trace levels need to be detected in the water column. Their analytical costs are also expensive. Except for the period of recommended external training support, use of outside laboratory will be needed should it be necessary during Phase II for MEPA to conduct emergency monitoring of oil spills or other chemicals.

**4) Field and Laboratory Equipment**

MEPA's current field equipment is sufficient for the planned baseline monitoring of Phase II. However, following minor equipment items are recommended for purchase in Phase II to conduct more detailed investigations.

A camera adapter and a low power, wide-field stereomicroscope will improve the efficiency of the plankton analysis and permit archiving of photographic records of the various plankton species.

Present information suggests that levels of barium as well as nickel and vanadium may be elevated in the fine seafloor sediments of the deeper offshore areas (particularly close to any oil production facility, export terminal or tanker navigation lane). It is therefore recommended that:

- a relatively inexpensive light source (Hollow Cathode Lamp; ~U$200) is purchased for MEPA's Varian AAS to enable measurement of barium (and calcium) at appropriate detection limits (e.g. <50 ppm); and
- a concentration method is adopted for lowering the quantifiable detection limit of vanadium in marine sediments from the present 100 ppm to below 50 ppm (preferably <25 ppm); and
- a microwave oven, plus five Teflon containers for acid digestion, is purchased to enable more convenient, reliable and rapid preparations of sediment samples for metal analysis.

**5) Internal Organization and External Collaboration**

The present internal organization structure should be improved to provide effective management, funding and coordination of the field team, laboratory team and managers/administrators.

As established between MEPA and pertinent parties during Phase I, further liaison and co-operation with external parties on monitoring logistics, should be continued. This collaboration should include discussion on the identification of suitable and convenient locations for establishing monitoring sites in the Northern and Southern Regions, and include agencies such as the Coast Guard, Saudi Aramco and the National Commission for Wildlife Conservation and Development (NCWCD).

**B. Specific Monitoring Projects**

**1) Rationale, Recommendation and Objectives for Three Nutrient Focussed Projects**

Phase I data indicate that both water and sediment quality in some embayments of the Central Region are becoming degraded by contaminants and excessive nutrients, organic material and bacteria, originating from various sources including primary treated sewage discharges, urban drains and factory outfalls. Tarut Bay appears particular susceptible to overloading by sewage and nutrient inputs[1]. Apart from the major urban centers at Dammam, Al Qatif, Tarut and Safinyah, Tarut Bay also contains three important fishing boat harbors (Dammam, Qatif and Darin). These harbors represent a significant source of nutrient inputs due to the large number of fishing boats that typically have 3-6 person 'live-aboard' crews.

More focussed, investigative monitoring (i.e. based on specific questions and objectives) is therefore recommended for Tarut Bay, plus two other 'problem' areas in the Central Region. The objectives for these three specific projects are as follows:

- Project 1: Determine the characteristics, dispersal and spatial impacts of the shoreline discharge from a fertilizer factory into a shallow embayment south of Dammam Port;
- Project 2: Investigate characteristics, fate and effects of effluent from a large inshore outfall of the municipal sewage treatment plant at Al Khobar; and

[1] As long as nutrient inputs into any partly enclosed water body exceed the total losses from the system, then water and sediment quality will continue to deteriorate. This, in turn, will lead to increasing incidence of algal blooms and proliferation of smothering benthic and epiphytic algae that will damage and reduce the seagrass meadows. Results from all three projects will help clarify the requirements and need for determining the capacity of the coastal ecosystem in the Al-Khobar - Dammam - Tarut area to receive nutrients without risking eutrophic effects (e.g. smells, nuisance blooms, seagrass losses, oxygen-depletion events, fish kills, etc). Such a study can identify and prioritise (a) where, and how much, coastal housing should be connected to efficient secondary and tertiary sewage treatment plants as soon as possible, and (b) the percentage of nutrient reduction achievable by reducing discharges of nutrient-enriched industrial effluent. Answering such questions requires an integrated mass-balance assessment study that investigates all nutrient entry paths (including coastal ground-water plumes, surface drains and outfalls). It will require field testing and modelling to determine nutrient behaviour in local coastal soils, ground water and sea water interaction and exchange patterns, and biological nutrient recycling in the coastal water column, benthos and sediments. This is beyond the capacity of any single agency, but MEPA could coordinate a multi-agency program involving research institutions and stakeholder industries. Strengthening MEPA's monitoring capabilities and understanding of nutrient behaviour will improve its management effectiveness of any work contracted to academic institutions, specialist consultancies or commercial laboratories.

- Project 3: Undertake a search, inventory and characterization of all nutrient sources and inputs into the shallow and environmentally sensitive areas of Tarut Bay.

Based on the Phase I data, the recommended projects all involve significant sources/inshore discharge of biostimulants and coliform bacteria. Such sources have the potential to cause serious eutrophic impacts (e.g. loss of seagrass beds, increased red tides), loss of amenity values and public nuisance (e.g. from smells at low tide), and possibly direct public health risks. The overall aim of the three projects is to provide reliable information and data, as will be required for government policy decisions concerning the regulation and funding needs for reducing nutrient and contaminant inputs, thereby lowering the chances of eutrophication and risks to public health.

**2) Collaborative Planning and Implementation**

All three projects are recommended to commence in Phase II and to finish by the end of Phase III (Section 5.4). Each project will require liaison and collaboration with relevant external parties during the planning and implementation stages. The basic steps for the two projects focussing on the single, point source outfalls will be the same:

(a) Consultation with the managing engineers of the municipal STP / fertilizer factory outfall.
(b) Obtain information on maximum and average flow rates and temporal characteristics of discharge;
(c) Obtain data on physical discharge characteristics (temp, salinity, pH, etc) and contents from operator monitoring and/or other sources of information;
(d) Prepare a sampling design for the Phase II pilot sampling;
(e) Organize a hydrodynamic modelling study to identify water movements and flushing rates in the inshore waters along the Al Khobar - south Dammam coastal strip (covering spring and neap tides and main wind conditions; more details provided in following sub-section);
(f) Synthesize data from pilot sampling and numerical model;
(g) Identify gap-filling questions to be answered during Phase III, and propose the parameters to be measured and the statistical design to answer these questions (see Section 5.4).
(h) Consider use of dyes and/or simple sub-surface drogues to confirm model predictions.

The third project examines environmentally sensitive areas and nutrient inputs inside Tarut Bay, and this is more a complex problem and management issue, because the bay receives a wide variety of inputs at many different places. Therefore the project will require a multi-collaborative effort with several agencies, municipalities and institutions. The results will facilitate understanding about the sources, behavior, effects of organically-enriched effluent containing unwanted biostimulants, including the various species of nitrogen and phosphorus. Basic steps for planning and implementing this project during Phase II (for completion by more advanced sampling work during Phase III) should include:

(a) Consult with all pertinent agencies, municipalities, institutions and commercial parties and undertake field inspections to identify and characterize as many as possible of the various point-source and broad-source discharges of nutrients in Tarut Bay (including Dammam Port and from Dammam Industrial City).

(b) Supplement the knowledge from (1) by mapping residential densities in the coastal zone and determining the average amount of nitrogen and phosphorous entering the ground water per year for coastal households not connected to sewage plants (e.g. use published data from other urban studies and make a census of sewage truck numbers and their service pattern in the Tarut Bay area).

(c) Prepare sampling design for any pilot sampling deemed necessary to achieve Phase II objectives.

Either:

(i) Organize a hydrodynamic modeling study to identify water movements and flushing rates for Tarut Bay; or (preferably)

(ii) Extend the spatial area of the Modeling study organized for Projects 1 and 2 (covering spring and neap tides and main wind conditions);

(d) Synthesize data from the consultations, pilot sampling and the hydrodynamic model;

(e) Identify gap-filling questions to be answered during Phase III, including the parameters to be measured and the statistical design to answer these questions (see Section 5.3.3).

**3) Monitoring Sites and Numerical Hydrodynamic Modeling**

It is recommended that pilot sampling should be undertaken in Phase II, including sampling the effluent of key outfalls if possible, plus a simple array of sites extending from the discharge in three places.

The figures below show examples of sampling site configurations for three different outfall locations.

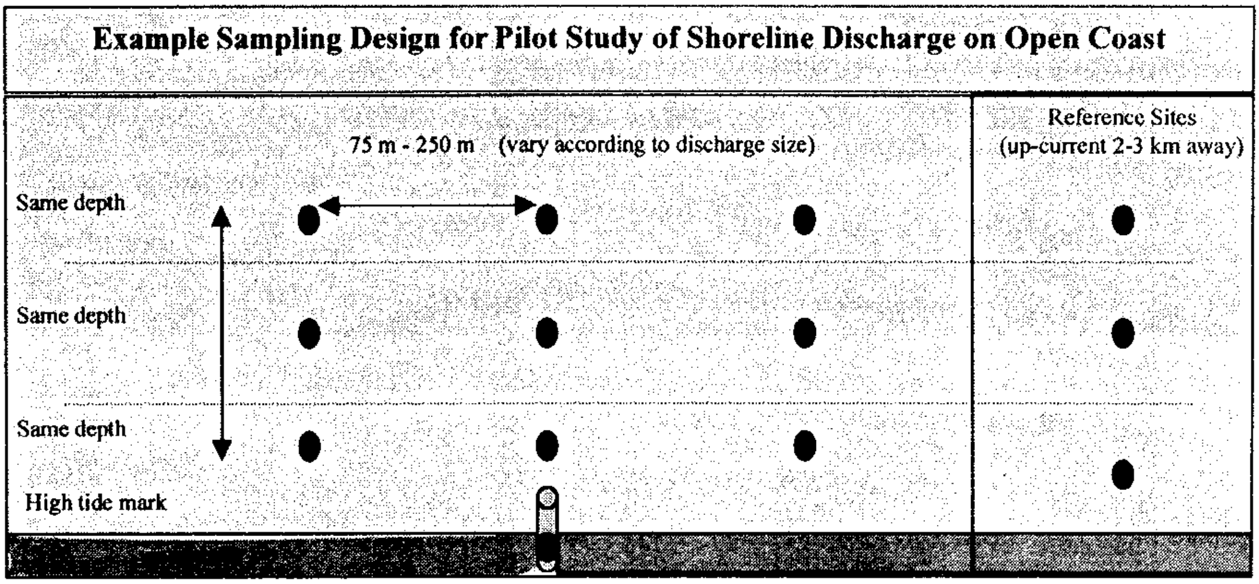


Figure 5.3.1 (1) Example Sampling Design for Pilot Study

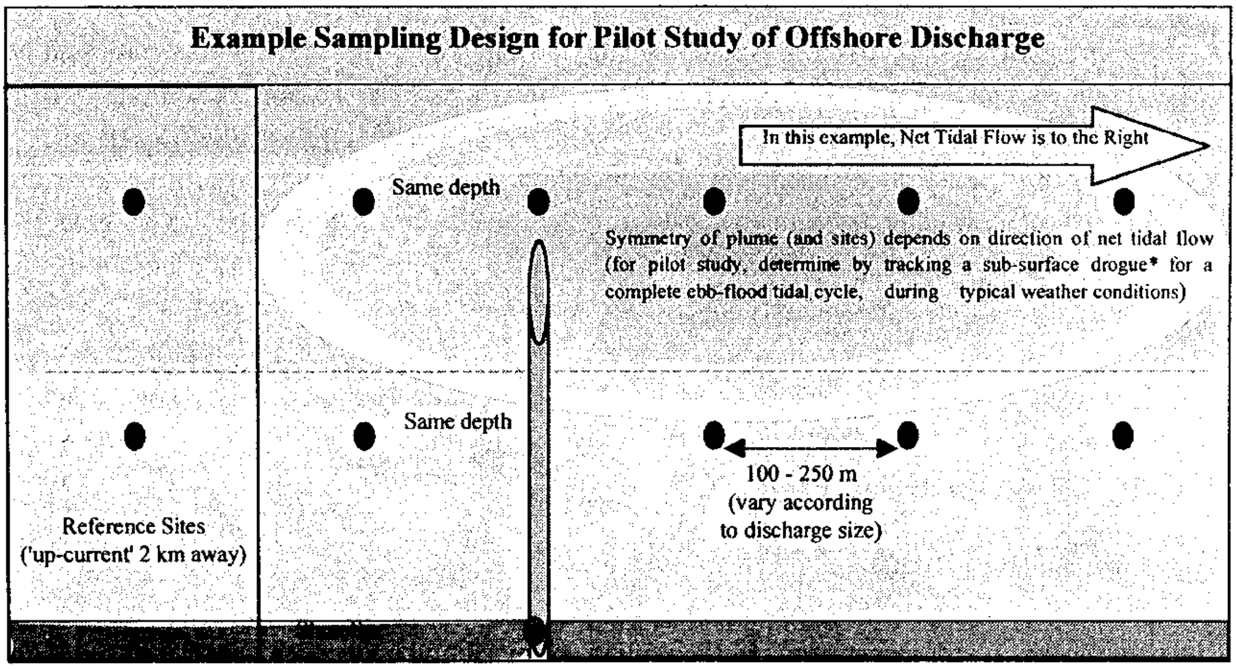


Figure 5.3.1 (2) Example Sampling Design for Pilot Study

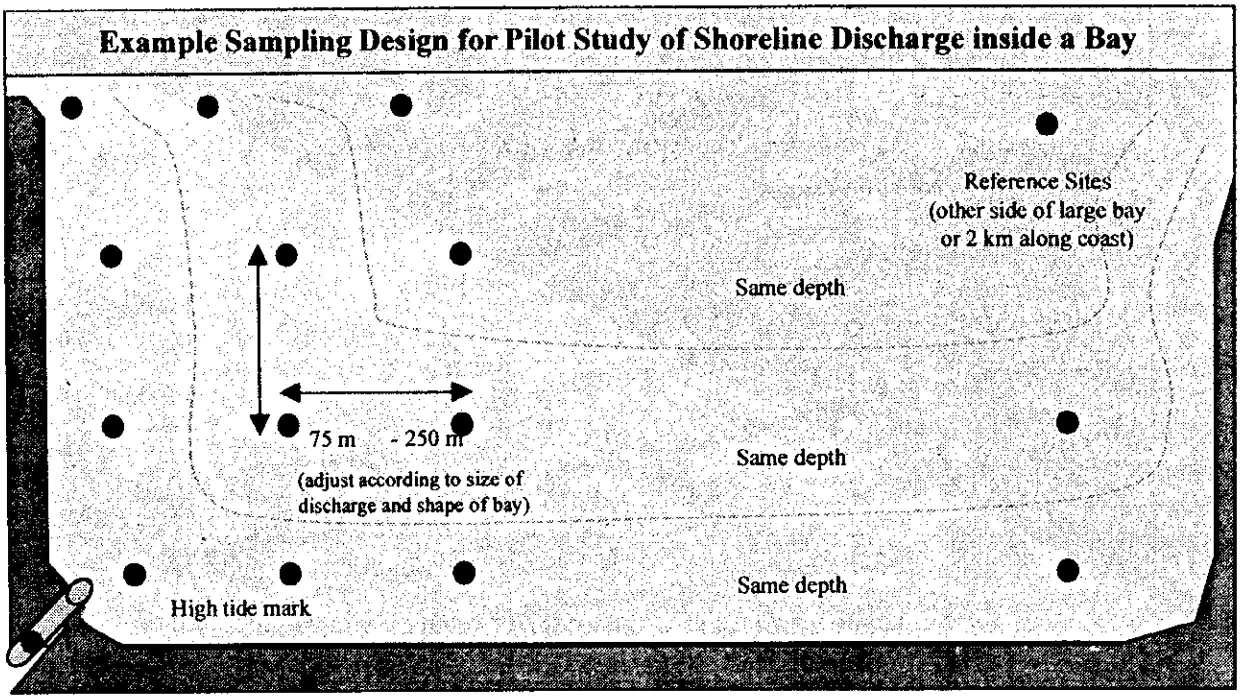


Figure 5.3.1 (3) Example Sampling Design for Pilot Study

At least one group of sites containing 'up-current / up-wind' but similarly located sampling sites should also be sampled to show local background conditions. To determine the size of small-scale variations in sediment contaminant levels (<10 m), two or three replicate sediment samples should be taken from at least 50% of the sites. For the pilot sampling in Tarut Bay, 4-6 samples of water and sediment should be taken, as and where deemed necessary, from any priority 'problem' area identified during the consultative discussions and/or joint site inspections.

Wherever possible, all pilot sampling should be undertaken during 'worst-case' conditions. That is, the discharge (if present) is flowing, mixing due to wind-waves is weak, the tide is low, and the tidal current is also low (e.g. low neap tide). This is particularly important when sampling coastal water at shallow inshore sites inside embayments or fishing harbors in Tarut Bay.

Interpretation of the information obtained from outfall operators and from pilot sampling will benefit considerably from numerical 2D/quasi-3D hydrodynamic modeling of water movement during the major seasons (summer/winter). Output from such models permits calculation of flushing (exchange) rates, and also help identify the best locations and number of stations for more detailed, statistical-based replicate sampling recommended for Phase III. A model covering the coastal sector between Al

Khobar and Tarut Bay-Dammam at a grid resolution of ~500 m would be best, so that local patterns of dispersal can be identified for the outfalls investigated by the three project tasks. This modeling needs to be subcontracted to specialist group or firm, and warrants calibration by field measurements covering spring and neap tides under typical wind conditions.

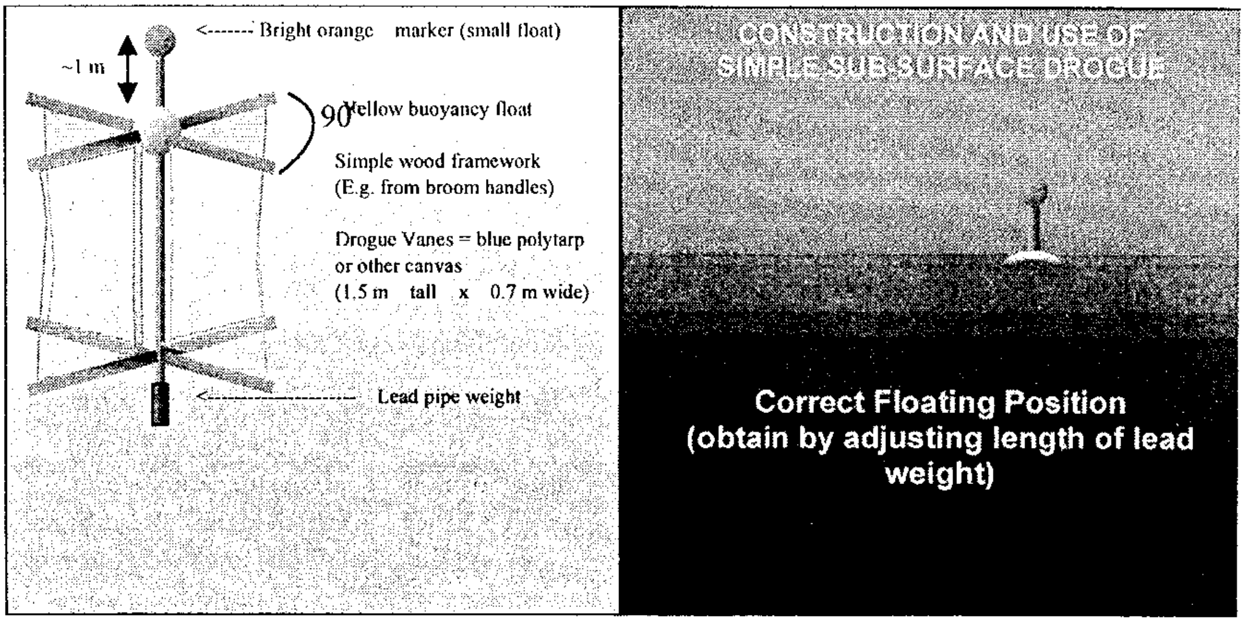


Figure 5.3.2 Example of Field Measurement Method for Tidal Current

**4) Monitoring Parameters and Frequency**

Parameters such as temperature, pH, DO, salinity, turbidity, water clarity, TSS, Chlorophyll-a and free chlorine are cheap to monitor, and they provide useful indicators of effluent discharges. It is recommended that they should be monitored at least once in Phase II (i.e. during the pilot sampling for the three tasks). Similarly, TKN, TP, $NH_4$, TOC, total coliforms and fecal coliforms are also relatively easy to analyze although their cost is little higher. These parameters are important indicators of sewage effluent influence and eutrophication, and it is recommended that they are also monitored in the Phase II pilot sampling.

Thus each task deserves laboratory analyses of total nitrogen, total phosphorous, ammonia, total coliform bacteria and, preferably, fecal coliform bacteria during the pilot sampling of Phase II. Laboratory analyses should focus on parameters concerning nutrients so as to clarify trends indicated by the Phase I for local eutrophication effects by effluent. Heavy metal levels in sediments should also be monitored once during the pilot sampling program - particularly for the task focussing on the factory outfall south of Dammam Port.

### 5) Field and Laboratory Equipment

MEPA's current field equipment is sufficient for the recommended pilot monitoring in Phase II. Additional field monitoring equipment for Phase III is recommended in Section 5.3.3 and summarized in Table 5.3.2.

With the exception of nitrate-nitrite and fecal coliforms, all recommended parameters for Phase II can be analyzed to appropriate detection limits using existing MEPA laboratory equipment. Reliable nitrate-nitrite detection at appropriate limits cannot be undertaken until installation of an Auto-Analyzer at the MEPA Laboratory, as recommended for Phase III (Table 5.3.2; Section 5.3.3). However counts of total coliforms and fecal coliforms can be readily determined during Phase II by the purchase of inexpensive and pre-prepared specific culture media. These media should be readily obtainable from laboratory suppliers and/or hospital pathology departments in KSA.

## C. Other Phase II Tasks

The following tasks are recommended to be undertaken on an opportunistic basis during field inspections and sampling work for the regional baseline monitoring program and the specific projects.

- Photographically document all types and shoreline distribution of marine litter and rubbish. Archive the material for use in public awareness/education campaigns;

- Encourage schools in both urban and remote Gulf coastal towns to conduct local surveys, so as to increase awareness and help build a national coastal database [supply of simple guideline sheets for documenting main litter types and densities (e.g. number per 50 linear metres of beachline) below the extreme high tide mark will permit comparison of data].

- Archive all field notes and coastal habitats photographs, including date and their GPS coordinates, to permit adequate ground-truthing of the satellite-based mapping of sabkah, mangroves, seagrass bed, coral reef, artificially modified shorelines and dredged areas. Reliable, ground-truthed satellite-image data are needed to achieve long term coastal habitat monitoring in the KSA Gulf coastal zone.