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Feasibility Study on The Sihanoukville Combined Cycle Power Development Project in The Kingdom of Cambodia

FINAL REPORT

(SUPPLEMENT)

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THE KINGDOM OF CAMBODIA
THE SIHANOUKVILLE COMBINED CYCLE POWER DEVELOPMENT PROJECT

FINAL REPORT

SUPPLEMENT

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1. Miscellaneous Data/Information and Study Related to the Site Area

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1.1. Road Condition between Sihanoukville Port and Sokimex Oil Terminal

From Sihanoukville Port to Sokimex Oil Terminal, the road is mainly asphalt-paved two lanes road, and will be no difficulties for use of transportation during construction and operation period, provided if some portion of the road could be improved as below:

- To repair of Bridge B-5, 20 m length and 9.3 m width the concrete beam of which has aged, especially concrete of beam resulting visible steel bars some portion
- To repair of drain pipe at B-3 and B-4, where part of drain pipes are damaged.
- To repair improvement of broken pavement parts scattered frequently between B-2 to B-5.

Fig.1.1-1 shows the location of drain pipes, bridge between Sihanoukville Port and Sokimex Oil Terminal.

Although the road between Sihanoukville Port and the site area can be used for transportation of construction materials, construction equipment and heavy plant equipment during construction, it is still necessary to repair especially bridge at B-5 and drain pipes between B-3 ~ B-4 in addition to repair of pavement with foundation treatment at severely damaged portion around B-4 ~ B-4A as shown in Fig.1.1-2.

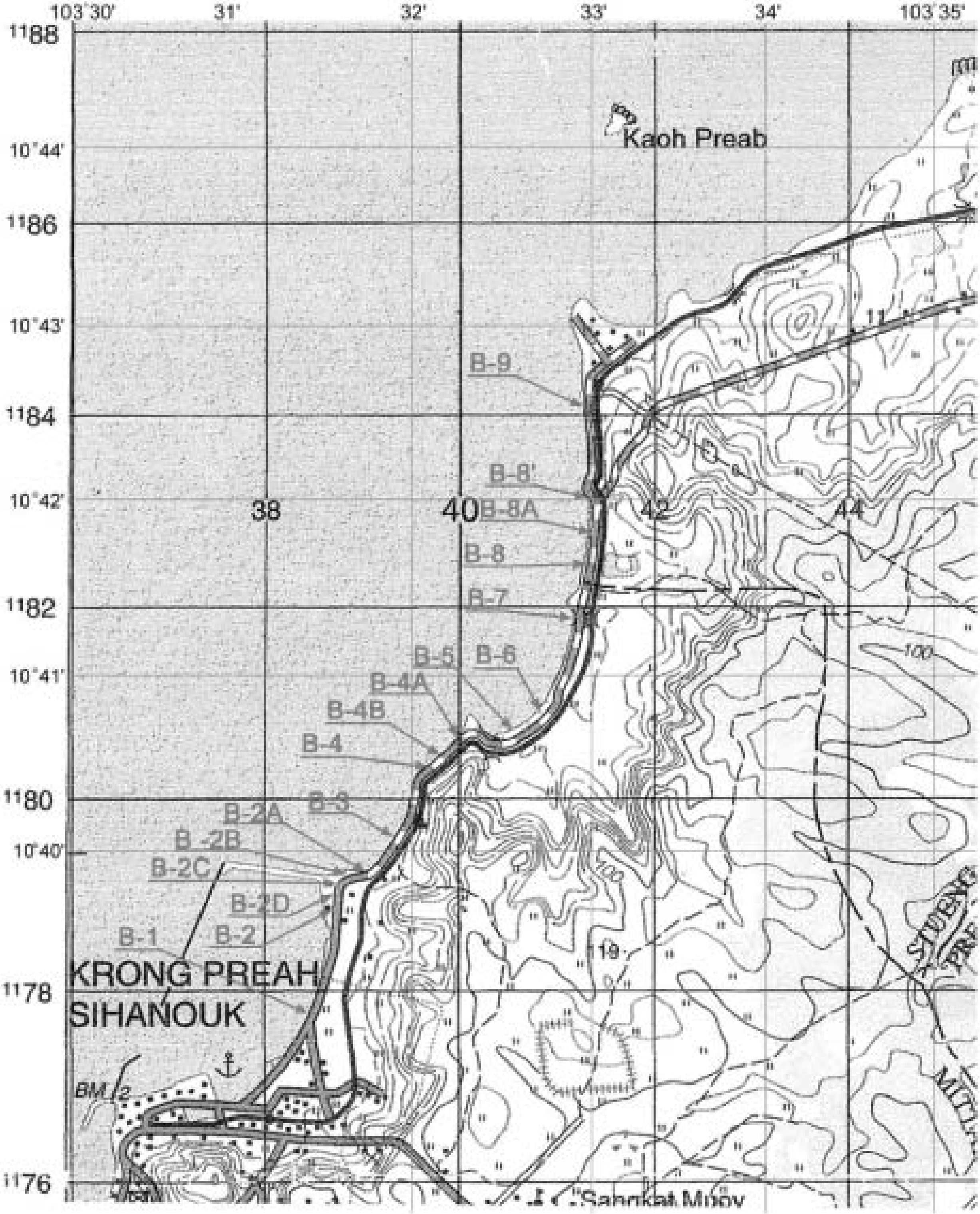

Fig.1.1-1 Location of Drain Pipes and Bridges

Table 1.1-1 Field Survey Results on Drain Pipes and Bridge between Sihanoukville Port and Sokimex Oil Terminal

No.	Structure	Unit	Dia. (m)	Remark
B-1	D.P.	4	0.8	
B-2	D.P.	5	1.4	
B-2D	D.P.	1	0.8	
B-2C	D.P.	1	0.8	
B-2B	D.P.	1	1.0	
B-2A	D.P.	3	1.5	
B-3	D.P.	1	1.0	Eroded at connection part
B-4	D.P.	2	0.6	Pipes disconnected
B-4B	D.P.	1	1.3	
B-4A	D.P.	1	0.6	
B-5	Bridge	-	-	W=9.3 m, L=20 m, Slub concrete severe erosion, re-bar appears
B-6	D.P.	1	1.0	
B-7	D.P.	3	1.4	
B-8	D.P.	5	0.8	
B-8A	D.P.	2	0.8	
B-8'	D.P.	2	0.9	
B-9	D.P.	2	-	

D.P. = Drain Pipe

Fig.1.1-2 Road Condition around B-4 ~ B-4A

2. Results of Topographic, Geological, Hydrological, Bathymetric, Offshore Geological, and Oceanographic Investigation

2. Results of Topographic, Geological, Hydrological, Bathymetric, Offshore Geological, and Oceanographic Investigation

2.1. Topographic Survey

2.1.1. General

Topographic survey report is prepared after the completion of the entire survey work as outlined in the scope of work described below. The survey was carried out to assist the feasibility study of power generation project at Sihanoukville, Cambodia. The location of the project site is as shown in Drawing CB-21.

2.1.2. Scope of Works

(1) GPS Control Survey

(a) A geometrically sound GPS control network was established to transfer the horizontal and vertical control from the existing control in Sihanoukville (Cambodian survey Network System) to the project and to Hun Sen Dam.

(b) GPS Control network was established to transfer the Cambodian Survey Network System to the project area for detailed survey.

(2) Topographic Survey

(a) Field survey and preparation of topographic map

Two scale maps were prepared as below:

- Scale 1:1,000 with contour interval 1 m covering the area of 0.50 km^2.
- Scale 1:500 with contour interval 0.5 m covering the area of 0.25 km^2.

Location of topographic survey area is shown in Fig.2.1-1.

(b) The horizontal and vertical controls were connected to the existing survey monuments with Cambodian Survey Network System.

2.1.3. Methodology

(1) GPS Control Survey

(a) Horizontal and Vertical Control

Cambodian National Survey datum was used in establishing the horizontal and vertical control within the project area. Vertical Datum is Mean Sea Level at Ha Tien (in Vietnam).

There are 14 survey stations in Sihanoukville Port for “The Sihanoukville Port Urgent Rehabilitation Project” during May 2000. These survey monuments were established by GPS method using Cambodian National Survey Network System.

This Survey network system was connected to one of the existing station CB-11 at the road junction in Sihanoukville Port, as shown in Drawing CB-22.

(b) GPS Receivers

GPS observations in static differential mode were utilized to transfer the horizontal and vertical control to the project area. The timing of the observation were chosen during the minimum GDOP (Satellite Geometry).

The permanent survey monuments were established in pair for future use.

Altogether 8 stations (CB-20 to CB-27) were established from this network establishment as shown in Drawing CB-22. Coordinates of each point are summarized in Table 2.1-1.

(c) Processing

The GPS data has been post processed. The final GPS data in WGS 84 spheroid has been transformed into Cambodian National Datum, thus the final coordinates are tabulated in UTM grid system and the elevation referred from Mean Sea Level at Ha Tien in Vietnam.

(2) Topographic Survey

(a) Survey Areas

After the preliminary filed survey of the location of proposed site area, the extent of the topographic survey area was finalized.

(b) Detailed Survey

The total station “Sokkia Set 2C” was set up at existing survey monuments.

The field data were recorded in memory card and downloaded into computer. All the physical features, creek, road, railway etc. were surveyed and a sufficient number of spot elevations were surveyed.

(c) Topographic Map

The filed data were transferred into microcomputer and every point’s co-ordinates were computed in ASCII format.

The ASCII files were processed to create the Digital Terrain Model (DTM), from which counter interpolations were done.
The final map were prepared by AutoCAD Ver.14 in 3D format.

2.1.4. Results

Drawings of the topographic survey results are prepared as presented in Drawings CB-24-1 ~ CB-26-5. List of drawings is shown in Table 2.1-2.

2.1.5. Consideration and Conclusion

Topographic survey was successfully carried out in and around the power plant site area.
The area is generally flat in the southern part with height of EL. 1 ~ 8 m, and a slope of approximately 1/70 in west-east direction. Northern and eastern edges are surrounded by foot of mountains with mild slopes to gradually steep slope. South part of the area is partly extended by pond and two creeks are flowing into the pond.

2.2. <u>Geological Investigation</u>

2.2.1. General

The geological investigation is a part attached in the Feasibility Study on the Sihanoukville Combined Cycle Power Development Project. The proposed project area of investigation is shown in Fig.2.2-1.

The objective of geological investigation was done to obtain necessary geological information to verify the suitability of the site for construction of 180 MW thermal power plant which requires sufficient bearing capacity and long term stability for supporting heavy superstructures.

2.2.2. Scope of Work

The work for geological investigation consists of three (3) items as follows:
- Boring work
- Laboratory test
- Ground resistivity test

(1) Boring Work

- To perform the drilling works of 7 points (5 of first priority holes and 2 of second priority holes), total length of 145.13 m with soil : 96.57 m and rock : 48.56 m.
- To perform the continuous all core sampling of soil and rock including five Undisturbed Samples (UD sample).
- To perform Standard Penetration Test (SPT) of 182 tests during drilling work for every 1 m interval.
- To perform the permeability test in borehole for 6 tests in total.
- To construct the observation wells at the first priority drilled holes in total of 5 wells.

(2) Laboratory Test

- To perform the laboratory test on the collected samples. The tests included with physical property test (soil: 41 pcs., rock : 7 pcs.) and strength test in total of 22 pcs. (soil : 5 samples × 3 pcs. = 15 pcs, rock : 7 pcs.).

(3) Ground Resistivity Test

- To perform Wenner Configuration Method to obtain distribution of ground resistivity in the site area.

2.2.3. Methodology

(1) Boring Work on Land

The boring work on land had been started in September 14, 2000 and was completed in October 10, 2000. The total of 7 holes were drilled which including of 5 priority holes and 2 additional holes. The observation wells were constructed at these drilled holes. Locations of each borehole are shown in Fig.2.2-2.

During the drilling work, the geotechnical work such as sampling and testing were performed as specified in the scope of work. The summary of boring works is shown in Table 2.2-1.

(a) Drilling Work

The drilling work was proceeded by rotary drilling machine model TONE TDC-1. Boreholes were penetrated by water circulation method. This was a procedure by which rapidly drilling drag bits (dia. 3 inch, in approximately) attached to the bottom of the drill rod, cut and grind, then advance into the borehole. Water was forced down, by drilling pump (NA-60), through the drill rods and bit. Then, the returned flow forced the cuttings up to the surface. The drill bit was replaced by the sampler whenever the soil sample was required at the specified level.

In some cases, in order to protect collapsing of hole which might happen while drilling, the temporary steel casings (HQ size or ID 3 1/16 inches pipe) were installed, in sequence with drilling, down to the rock surface.

All coring work, in soil, was proceeded by means of split spoon sampling as same method as Standard Penetration Test.

(b) Undisturbed Sampling

The undisturbed sampling covers a procedure for using of a thin wall tube to recover relatively undisturbed soil samples suitable for laboratory tests of structural properties. This thin wall tube is in the diameter of 75 mm. (ID) and 78 mm. (OD) stainless steel pipe with 1 m. long. The sampler head contains a steel ball check valve to protect water pressure wash away the soil sample while lifting.

After cleaning the borehole to the designed depth, the sampler head was attached to the diameter 44.5 mm. drill rod. Then, the sampler tube was installed to the designed depth at bottom of the hole. The sampler tube was advanced by hydraulic power of drilling machine, without rotation, through the soil formation. The length of advance was determined due to the resistance and condition of soil formation, but the length shall never exceed 5 to 10 diameters of the tube in sands and 10 to 15 diameters of the tube in clays. UD-sampling by thin wall tube is shown as in Fig.2.2-3.

In case of soil formation was very soft or cohesionless soil, the piston sampler was applied. The sampler consists of sampling tube (75 mm. (ID) stainless steel tube) connect to the outer rod), an internal piston and rods connected to the piston and running through the outer rod.

After cleaning the borehole to the designed depth, the sampler head was attached to the diameter 44.5 mm. drill rod. This piston was held inside the UD tube by inner rod which insert upward through the drill rod and hanging with hook for drilling. As the tube was pushed down into the soil formation by hydraulic chuck of drilling machine, the piston was held stationary. Once the tube had been advanced through the sampling interval, it was rotated to break suction that might had developed between the soil and the outside wall of the tube. The sampler was then pulled to the surface, then, the piston was taken out. UD-sampling by piston sampler is shown as in Fig.2.2-4.

After the sampler was pulled to the surface, immediately, both end of UD tube was cleaned and waxed to protect the loss of moisture. The waxed sealant shall be opened in the laboratory.

The UD sampling was performed at every 1.0 m interval.

(c) Standard Penetration Test

This method describes the procedure for driving a split–barrel sampler to obtain a representative soil sample and to determine the resistance of the soil from the numbers of blow count during penetration of the sampler.

The OD 51 mm split-barrel was attached to the dia. 44.5 m drill rod and be installed to the designed level at the bottom of borehole. The top of drill rod, which was above the ground level, was fixed by free drop hammer. The hammer weight is 63.5 kg and the drop height is 76 cm. The split-barrel was penetrated into the soil formation by pressure form hammer dropping. The hammer weight was lifted up along the guide by wire rope of drilling machine. Once the hammer had been lifted up to height of 76 cm., it fell down automatically which was controlled by knob to loose the hanger. The hammer weight hit the knocking plate, then, drive the split-barrel down into the soil formation.

The penetration resistance of the soil N-value, is represented by blowcount. N-value, reported in blow/foot, equals the sum of the number of blows required to drive the sampler over the depth interval of 6 to 18 inches (150 mm. to 450 mm).

Standard Penetration Testing is shown in Fig.2.2-5.

(d) Rock Coring

Once the sample from boring or SPT was identified to be rock surface, the NWM core barrel (core dia. 2 1/8”) was installed for rock coring purpose.
All the core samples were collected and storage in the termite proofed wooden core box.

(e) Permeability Test

Permeability test was performed in the aquifer formation of each drilled hole. The test was carried out by Constant Head Method. The ideal of this method is to maintain the water level at the certain level, at all the time. The quantity of water filling up to maintain water level in each elapsing time shall be calculated for permeability of tested section. Of course, the test section of formation must be bared without cased and be cleaned by water before testing.

Permeability of the tested section shall be calculated as follows:

$$K = \frac{2.30}{2\pi HpL} log\left(L / rw\right)$$

K = Permeability of tested section (cm/sec)

Q = Flow rate of tested section (cm^3/sec)
Calculated from: Quantity of water filled up (cc)/Elapsing time (min)

L = Length of tested section (cm)

rw = Radius of drilled hole (cm)

Hp = Water head or distance from level of ground water table to constant water level (cm)

The schematic drawing of Constant Head Test is shown in Fig.2.2-6.

(f) Observation Well

Upon the completion of boring work, the observation wells were constructed at the drilled holes. The perforated PVC dia. 2" (8.5 bars) pipes were installed by setting the slotted pipes at the aquifer formation in order to measure ground water level. The top 0.50 m of PVC pipe above GL. was protected by dia. 4" steel pipe with cap. The steel pipe was anchored with concrete in the size of 50 × 50 × 50 cm. The hole marks were described on the concrete in Fig.2.2-7. The crossection of Observation holes is shown in Fig.2.2-8.

(2) Laboratory Test

Test items are as follows:

(a) Physical Property Test on Soil
- Moisture Content Determination
- Total Unit Weight
- Specific Gravity
- Grain Size Analysis

(b) Strength Test on Soil
- Consolidated Drained Triaxial Compression Test (CID).

(c) Physical Property Test on Rock
- Moisture Content Determination.
- Total Unit Weight.

(d) Strength Test on Rock
- Unconfined Compression Test

The laboratory tests were carried out according to procedures recommended by ASTM standard and the soils were classified in accordance with the Unified Soil Classification System (USCS).

(3) Ground Resistivity Test

The field work for ground resistivity test was started in September 21, 2000 and completed in October 17, 2000. The test was carried out in the total of 40 points as shown in Table 2.2-2. Location of test points are shown in Fig.2.2-2.

(a) Wenner Array

In the Wenner Array four (4) electrodes are equally spaced along a straight line. The distance between adjacent electrodes is called the array spacing "a". For this configuration the equation of (apparent) resistivity shall be calculated by:

$$\rho = 2\pi a \frac{\Delta V}{I}$$

Where, ρ : apparent ground resistivity (ohm·m)

a : spacing

ΔV : measured voltage (V)

I : measured electric current intensity (A)

For the field test, the configuration was arranged as shown in Fig.2.2-9. The cable lines and electrodes were stretched out to get 120 m of "a" in each time. Then, the readings of Resistance (ohm) were taken at "a" = 1, 2, 3, 5, 10, 15, 20, 25, 30, 40, 50, 70, 80, 90, 100, 110 and 120 m. The value of Resistance (ohm) was calculated to find out the value of Resistivity (ohm·m) from the above formula. After that, the graph between Resistivity (ohm·m) vs. "a" (m) was plotted in Semi-log scale paper. Analysis of data to define the apparent resistivity of soil and rock is performed as per each layer.

2.2.4. Results

(1) Boring Work

Boring logs for each borehole are as shown in Figs.2.2-10 (1) ~ (10).

(2) Laboratory Test

(a) Physical Property Test
Physical property test results are summarized in Tables 2.2-3 (1) ~ (3).

(b) CD-Triaxial Test
Isotropically consolidated drained tri-axial test results are summarized in Table 2.2-4.

(c) Unconfined Compression Test
Unconfined compression test results are summarized in Table 2.2-5.

(d) Permeability Test
Permeability test results are summarized in Table 2.2-1.

A geological map in the scale of 1:4,000 and columnar sections were produced by correlating the result of boring work.

(3) Ground Resistivity Test

Ground resistivity at typical points in the site area is summarized in Table 2.2-6. Location of each point is as shown in Fig.2.2-2.

2.2.5. Technical Evaluation and Consideration

(1) General Geology around the Site Area

General topography of the site area is characterized by relatively low relief to moderately high peaks of 100 - 211 m. Sandstone of Upper Jurassic-Cretaceous in age (upper sandstone) is the major rock underlying the Sihanoukville area with minor glass sand and alluvium occurred in narrow strips along the shore lines. Steep slope coast and sandstone cliffs are often noticed in southern parts of the area.

The elevation of outcrops measured range from 19 - 99 m above the Mean Sea Level. From top to bottom, the sandstone varies in grain sizes from mostly fine to medium sand. General outcrops in many places are sandstone, conglomeratic sandstone, siltstone and interbedding shale; white to light gray, greenish gray to dark gray, light brown to dark brown where weathered.

The general attitude of bedding planes of rocks strike N50 - 70E, with gentle dipping of 5 - 10 degree NW toward the sea, which more or less conform the trending (NE - SW) of mountain ranges.

Table 2.2-7, which summarized the description of cores, shows that the overburden is composed mostly of layers of sand, and silty clay; having thickness from 4.35 - 25.75 m. Rather thick (19 - 26 m) overburden has been found in the area between two canals and swamps on southern boundary of the site. The overburden sand is thinning northwards. There is evident that the sand belongs to old beach forming by wave action against sandstone cliffs. The beach sand considered pure glass sand is characterized by very fine to medium grained; subangular to rounded, loosely to moderately compacted; white to light gray, light brown to dark brown. The deposits composed mostly of quartz, which derived from the Upper Jurassic - Cretaceous sandstone along the shorelines as well as the sea floor. In the sea, thickness of deposits is between 4.00 up to tens of meters.

Boreholes penetrated the sandstone basement at relatively high elevation of 3.60 m (BH-2) and the lowest elevation of -21.75 m (BH-4) below the mean seal level. Not only sandstone but also siltstone and claystone are encountered. These sub-surface horizons are of the same sequences that exposed in the adjacent relief which have similar characteristics.

Hole BH-10 drilled in the sea is located 200 meters from shoreline. The hole encountered sandstone that yields about 1.00 m^3/hr of fresh groundwater at depth of 13 - 25 m below the mean sea level. It is flowing well with relatively high peizometric head above the seawater. Water quality is good but slightly high iron and manganese contents of 6.6 and 0.81 milligrams per lit (ppm) respectively; slightly acid (pH = 5.95), with 111 ppm of carbon dioxide gas (CO_2). These data also inform the possibility of groundwater potential for the power plant supply. Profiles of SECTION 1 - 6 indicate variation of overburden loose sand and clay and the underlying sandstone bedrock which is probable fresh water aquifer at depth below 30 m.

(2) Boring Work

From the boring logs at each borehole, including offshore boreholes co-relations of boring log are established to estimate the geological cross sections. Fig.2.2-11 shows the approximate arrangement of cross sections. Estimated geological cross sections are as show in Figs.2.2-12 (1) ~ (6).

For the boreholes drilled on land, the upper soil layers are silty sand with presence of sandy clay at some locations. The stiffness of the upper layers based on the SPT N values, vary from location to location due to the topography. Sandstone and siltstone were also encountered at depth of 4.5 to 25.5 m.

Especially, at the center and southern part of the site area, the elevation of basic rock, sandstone/siltstone is deep, approximately -15 m ~ -22 m MSL at BH-3, BH-4 and BH-5 as shown in Figs.2.2-12 (1), (2) and (4). In northern and north-eastern part of the site area, the elevation of basic rock is approximately +2.0 m ~ -2.0 m MSL, at BH-1, BH-7, BH-2 and BH-9 as shown in Figs.2.2-12 (3), (5) and (6).

For three of four offshore boreholes (Borehole Nos.BH-10, BH-12 and BH-13), the upper soil layers consist of very loose sandy soil beneath the sea. At Borehole No.BH-11, the upper layer consists of loose to medium dense sand. Sandstone was encountered below the sandy deposit at depths of 4.5 to 9.5 m.

Approximately 200 - 250 m offshore from beach, the elevation of basic rock is -14 m ~ -11 m MSL at BH-13, BH-12 and BH-10, as shown in Figs. 2.2-12 (2) and (4). At BH-11, the basic rock elevation is shallow approximately -1 m MSL.

Center and southern part of the site area will be used for the power plant heavy facilities arrangement. Foundation works such as bored piles/driven piles are necessary to support those facilities. Details could be studied using soil and rock physical characteristics obtained in this stage. As for offshore facilities such as intake and outlet structure, the similar study could be made based on the physical characteristics of soil and rock of offshore area.

(3) Laboratory Test

Those results will be used for design of power plant structures and planning of construction works.

(4) Ground Resistivity

Those results will be used for design of electrical equipment of power plant.

2.3. <u>Hydrological Investigation</u>

2.3.1. General

Hydrological survey was carried out to investigate the possibility of fresh water as a raw water source around the selected site. This survey consists of water level and discharge observation of the Hun Sen Dam as shown in Fig.2.3-1 and of the Prey Treng Pond near the site area and groundwater level in the site area as shown in Fig.2.2-8.

2.3.2. Scope of the Work

(1) River Discharge Observation

a) River cross section survey around the Hun Sen Dam with scales of 1/500 in horizontal and 1/50 in vertical.

b) Water level measurement
Water level of Hun Sen Dam and the Prey Treng Pond, five times a day at 6:00, 9:00, 12:00, 15:00 and 18:00 up to February, 2001.

c) Current measurement
Five (5) times of current measurement at Hun Sen Dam and at Prey Treng Pond were done.

(2) Groundwater Level Observation

Observation of water level once a week for 4 months (at seven (7) boreholes in geological survey boring holes in the site area)

2.3.3. Methodology

(1) The area of Hun Sen Dam is located approximately 11 km away from the project site. To transfer horizontal and vertical control to the Hun Sen Dam site, GPS operating in static mode was used. Epoch interval every 15 seconds and continuous observation for 1 hour were applied. Two pairs (4 stations) were installed in the site.

(2) Installation of Staff Gauges

After two (2) staff gauges, one at Hun Sen Dam site and another at outlet of Prey Treng Pond, were installed, the leveling was done from established survey monument.

The elevations at the bottom of staff are determined and referred from Mean Sea Level (MSL).

(3) Daily Water Level Observation at Hun Sen Dam

Daily water level observation was done at particular of is 6:00, 9:00, 12:00, 15:00 and 18:00. The observation period is 5 months from September 2000 to February 2001.

(4) River cross-section survey around Hun Sen Dam (river width approximate 75 m) is done. There are 4 cross section lines. The cross sections were plotted at the scale of 1/500 in horizontal and 1/50 in vertical.

(5) Current measurements were carried out by current meter (Model OSS B1).

The river water current was measured approximately once a month for four months.

(6) Ground Water Level Observation

The groundwater levels were measured by ST-01 water level gauge. This water level gauge consists of measuring tape made form electric cable and probe. Whenever the probe touches water surface it will create a sound. The location and top elevation of the borehole are related to the reference point in the site area. Water levels at 7 boreholes in the site area were measured once a week up to February of 2001.

2.3.4. Results

(1) River Cross Section

Six (6) river cross sections were surveyed. The location of each section is shown in Drawing CB-30.

Cross sections of each survey line are shown in Drawing CB-31.

The outlet shape of the Prey Treng Pond was surveyed for estimation of discharge coefficient.

(2) Water Level Observation at Hun Sen Dam and at Prey Treng Pond

The water levels at both locations were measured since September 16, 2000 after the completion of staff gauge installation. The zeros of the staff gauge at Hun Sen Dam and at Prey Treng Pond were related to Mean Sea Level with the values of +1.009 and –0.294 m + MSL, respectively.

The water level observation results at Hun Sen Dam and at Prey Treng Pond are as shown in Tables 2.3-1 (1) ~ (6) and 2.3-2 (1) ~ (6).

Variation of water levels at both a Hun Sen Dam and at Prey Treng Pond are as show in Fig.2.3-2 and Fig.2.3-3.

(3) Current Measurement

The current measurement at Hun Sen Dam and at Prey Treng Pond were measured at the weir crest. There are seven measured data being carried out. Tables 2.3-3 (1) and 2.3-3 (2) summarize the results of measurement.

(4) Ground Water Level

Observation results of ground water levels at boreholes BH-1, BH-2, BH-3, BH-4, BH-5, BH-7 and BH-9 are summarized in Tables 2.3-4 (1) and 2.3-4 (2).

2.3.5. Technical Evaluation and Consideration

(1) River Cross Section

Crest elevation of Hun Sen Dam is not uniformly finished along the dam axis. Therefore, detailed crest elevation of Hun Sen Dam was surveyed. The results are as shown in Table 2.3-5. Those results were incorporated into the estimation of overflow discharge coefficient.

(2) Water Level Measurement

Water levels at Hun Sen Dam and at the outlet of Prey Treng Pond are successfully observed.

Water level increases in October, then decreases gradually up to February at both Hun Sen Dam and Prey Treng Pond.

(3) Current Measurement

(a) Crest Type

Hun Sen Dam and Prey Treng Pond weirs are structures which function to enable the flow rate through the channel. They are classified as rectangular broad-crested weir and V-shape (Triangular) broad-crested weir, respectively.

Rectangular broad-crested weir is a rather simple measuring device. It has a truly flat and horizontal crest. The upstream weir faces should be smooth vertical plan. The weir block is placed in a rectangular approach channel perpendicular to the direction of flow.

The V-shape broad-crested weir has several advantages. Firstly, it provides a large breadth at high flows so that the backwater effect is not excessive. Secondly, at low flows the breadth is reduced so that the sensitivity of the weir remains acceptable.

(b) Characteristic of Hun Sen Dam Rectangular Broad-Crested Weir

The basic head-discharge equation used to evaluate the flow rate over the weir can be derived as follows.

$$Q = Cd \bullet \frac{2}{3} \bullet \left(\frac{2g}{3}\right)^{0.5} \bullet bh^{1.5}$$

Where Q = discharge through the weir, cms.

C_d = discharge coefficient

g = 9.81 m/sec^2

b = breadth of weir, 75.32 m.

h = water depth above weir crest, m.

Experimental results have shown that under normal field conditions the discharge coefficient C_d is a function of the ratio h/(h+w) where w is the height of the weir above the bottom of the channel.

While, the discharge equation is also expressed as follows:

$$Q = Cdbh^{1.5}$$

Where, C_d = (1.24 + 1.64 h/w)

W : height of weir (= 0.655 m)

This C_d may be derived from the experimental results, and definitely has value greater than one.

(c) Characteristic of Prey Treng Pond V-Shape Broad-Crested Weir

The basic head-discharge equation used to evaluate the flow over the V-shape weir can be derived as follows:

$$Q = Cd \bullet \frac{16}{25} \bullet \left(\frac{2g}{5}\right)^{0.5} tan\left(\frac{\theta}{2}\right) h^{2.5}$$

Where Q = discharge through the weir, cms.

C_d = discharge coefficient

g = 9.81 m/sec^2

θ = weir notch angle

h = water depth above weir crest, m.

Discharge coefficient C_d of the V-shape weir is also around one.

(d) Calibration of Cd value for Hun Sen Dam Rectangular Broad-Crested Weir

There are ten measured water level and discharge data from the field measurement obtained during the period of 30 September till 18 October 2000. These data are tabulated in Table 2.3-3(1), and will be used for the calibration.

From the field survey data of Hun Sen Dam crest elevation, it reveals that the crest elevation is not perfectly horizontal as shown in Table 2.3-5. It can be, therefore, divided into eight subsections which have difference crest elevation and length as shown in Table 2.3-3(1). The head discharge equation is modified as

$$Q = Cd \bullet 2/3 \bullet \left(\frac{2g}{3}\right)^{0.5} SUMBH$$

Where SUMBH = $(b_1*h_1^{1.5} + b_2*h_2^{1.5} + \ldots + b_8*h_8^{1.5})$

b_1 = weir breadth of subsection number 1, m.

h_1 = water depth above weir crest at subsection 1, m.

…..

b_8 = weir breadth of subsection number 8, m.

h_8 = water depth above weir crest at subsection 8, m.

etc.

One can manipulate this equation into the form of

$$Q = Cd \bullet X$$

Where X = constant*SUMBH

constant = $2/3*(2g/3)^{0.50}$ = 1.705

SUMBH = $(b_1*h_1^{1.5} + b_2*h_2^{1.5} + \ldots + b_8*h_8^{1.5})$

C_d = discharge coefficient

The water depth above the weir crest (h_i) is obtained by subtracting weir crest elevation (m MSL) of each subsection from the observed water level which is also referred to mean sea level (MSL).

By doing least square linear regression after knowing Q and X, and also impose the zero-interception constrain (Fig.2.3-4), the resulted C_d from the above equation is obtained and equals to 0.997 with co-relation coefficient R^2 of 0.991. Applied this C_d to the formula, the calculated discharge error varies from 0.47 to 8.93 % and the average error is equal to 4.51 % as shown in Table 2.3-3(1). The linear regression graph in Fig.2.3-4 shows the points between X (constant*SUMBH) and measured Q with co-relation coefficient R^2 of 0.991. From this figure, data are closely located on the regression line.

The other discharge equation was also used to calculate discharge by using data from Table 2.3-3(1). The results shown in Table 2.3-6 reveals that the calculated discharge error varies from 0.629 to 17.42 % and the average error is equal to 8.38 %. This average error is higher than 4.51% of Table 2.3-3(1). Fig. 2.3-5 also shows good agreement between the measured and calculated discharge (Q) with co-relation coefficient R^2 of 0.979 which is less than the previous one (0.991) shown in Fig.2.3-5. As a result, it is recommended to calculate the discharge through Hun Sen Dam weir by using the former equation.

This equation is used to calculate discharge through Hun Sen Dam weir from the observed water level during this working period.

(e) Calibration of Cd value for Prey Treng Pond V-shape broad-crested weir

There are thirteen measured water level and discharge data from the field measurement obtained during the period of 30 September till 18 October 2000. These measured data are tabulated in Table 2.3-3(2), and are used for the calibration.

The water depth above the weir crest (h) is obtained by subtracting weir crest elevation of +1.025 m + MSL from the observed water level which is also referred to mean sea level (MSL). The weir notch angle is derived from the survey data and equals to 172.3 degree. From the head-discharge equation, one can manipulate this equation into the form of :

$$Q = Cd \bullet X$$

Where X = constant*$h^{2.50}$

constant = $16/25 \bullet \left(\frac{2g}{5}\right)^{0.5} tan\left(\frac{\theta}{2}\right)$=18.8779

By doing least square linear regression after knowing Q and X, and also impose the zero-interception constrain (Fig. 2.3-6), the resulted C_d equals 0.999 with co-relation coefficient R^2 of 0.992. By applied this C_d to the formula, the calculated discharge error varies from 0.18 to 18.01 % and the average error is equal to 5.96 % as shown in Table 2.3-3(2).

Comparison between measured discharge and calculated shown in Fig.2.3-6 gives good agreement.

Therefore, to calculate the discharge through Prey Treng Pond from the observed water level, the above discharge equation is recommended. By substituting all known factors into the above equation, one can obtain the equation as follows:

$$Q = 18.853\ h^{2.50}$$

This equation is used to calculate discharge through Prey Treng Pond from the observed water level during the working period.

(f) Discharge Calculation from Observed Water Level

The discharge at Hun Sen Dam weir of each month are calculated and tabulated in Tables 2.3-7(1) ~ (6).

The calculated discharge at Hun Sen Dam weir are plotted in Fig.2.3-7. The flooding period during rainy season around September and October is almost finished at the end of October and recession just follows. The recession discharge at this location is decreasing till the starting of the next rainy season.

The discharge at Prey Treng Pond of each month are calculated tabulated in Table 2.3-8 (1) ~ (6).

The calculated discharge at Prey Treng Pond are plotted in Fig.2.3-8. The same tendency as that of Hun Sen Dam appears.

(4) Groundwater Level at Boreholes

After the total of 7 observation wells were constructed in BH-1, BH-2, BH-3, BH-4, BH-5, BH-7 and BH-9 (borehole location and section of observation wells are as shown in Fig.2.2-8), the observation of ground water level had been monitored since the middle of October 2000 and completed in February 28, 2001. Variation curves of groundwater observation of each well are shown in Fig.2.3-9.

From the curve, it can be observed that the difference of groundwater level in each well is controlled by elevation height of ground level. Wells at BH-2, BH-7 and BH-9 were constructed at the ground elevation of +9.707, +11.007 and +8.123 MSL, respectively. The differences of water level of these 3 wells are clearly observed during rainy season and dry season. Wells at BH-4 and BH-5 were constructed at the ground elevation of +3.975 and +3.013 MSL, respectively. The differences of groundwater level between rainy season and dry season are not much. These 2 wells are in the plain area which can get recharge and are influenced by both Prey Treng Pond and the sea. Furthermore, it is also observed that since the middle of January 2001, variation of groundwater level in each well has become less and the groundwater levels at BH-4 an BH-5 seem stable.

(5) Fresh Water Supply Source

In the dry season, water discharge observed at Prey Treng Pond is approximately 17 lit/sec in the end of February 2001, that is slightly larger than that of Hun Sen Dam, where the overflow discharge is approximately 10 lit/sec.

As a result, the Prey Treng Pond can be the most preferable fresh water source for the power plant, but further discharge observation for a study of long term stability of fresh water supply will be necessary.

2.4. Bathymetric Survey

2.4.1. General

Bathymetric survey in front of the site area was carried out to get the sea bed formation for the design of cooling water intake and outlet facilities of the power plant.

2.4.2. Scope of Work

Bathymetric survey and preparation of hydrographic chart at the scale 1:1,000 with contour interval of 0.5 m. The elevation was referred from Mean Sea Level.
The area covers approximately 2.3 km^2 as shown in Fig.2.4-1.

2.4.3. Methodology

(1) Bathymetric Survey

(a) Sounding Sea Bed

Echo sounder Raytheon 179 Cm operating at single frequency 208 kHz was used for sounding sea bed. The transducers were mounted on board of survey boat. The standard bar checks were carried out to calibrate the equipment before and after the bathymetric survey.

(b) Position Fixing

The survey boat position fixing was done at the same instant when the echo sounder operator presses the fix mark on echo sounder chart. Two GPS receivers “Leica System 300” were utilized for this work. One GPS receiver was set up as static mode on shore at survey station as the reference point and other GPS in the boat as the “Rover” and operating in Dynamic Mode.
The rate of observation was automatically set at 1 second interval.

(c) Tidal Observation

The tidal observation every 15 minutes interval was observed from installed staff gauge during the hydrographic survey.

(d) Beach Profile

The beach profile surveys was done for the shallow water area where the survey boat could not access. The details from the shoreline approach into the sea was surveyed by total station as far as man could go. This area overlapped the sounding area.

(e) Data Processing

The field data were transferred to micro computer, and combined and processed to point files in ACHII format.

(f) Hydrographic Chart

The point files were transferred to Sofedesk Ver.8 survey software. The Digital Terrain Model (DTM) and automatic contour interpolation was processed.
The final drawing file was prepared by Auto CAD Ver.14 Software in 3D format and plotted by Ink Jet Plotter (HP750C).
The final drawing is plotted at scale 1:1,000 with contour interval 0.5 m, with the elevation referred from Mean Sea Level.

2.4.4. Survey Results

Hydrographic charts, that are results of the bathymetric survey, are presented in Drawing CB-28-1 ~ CB-28-9. The arrangement of each drawing is shown in Fig.2.4-1. Track chart of survey vessel is shown in Drawing CB-27.
Three (3) cross sections from offshore to onland are presented in Drawing CB-29.

2.4.5. Technical Evaluation and Consideration

The site area is facing a beach with length of approximately 1.0 km, north-south direction. Beach slope is approximately 1/50 and gradually becomes mild offshore wards with sea bed slope up to approximately 1/500 at 1.0 km offshore from the beach.
Sea bed formation is relatively simple and no extraordinary undulation.

2.5. <u>Offshore Geology</u>

2.5.1. General

The offshore geological investigation is a part attached in the Feasibility Study on the Sihanoukville Combined Cycle Power Development Project. The work was performed on the project site in Stung Hav District, Sihanoukville City, Cambodia. The proposed project area of investigation is as shown in Fig.2.5-1. The objective of the offshore boring for the project is to obtain necessary geological information to design the cooling water intake/discharge structures.

2.5.2. Scope of Work

The works proceeded for offshore boring are as follows:

(1) Boring	:	4 points total length about 80 m (Soil: 29.7 m, rock: 50.35 m)
(2) Sampling ; undisturbed soil sampling	:	- Continuous core samples for soil and rock - 4 samples (undisturbed soil)
(3) Standard Penetration Test	:	61 tests during drilling work in every one meter
(4) Test / analysis on samples		
a) Physical property test	:	13 pcs. (Rock : 4 pcs, soil : 9 pcs).
b) Strength test	:	16 pcs (Rock : 4 pcs, Soil : 4 samples × 3 pcs. = 12 pcs. for Triaxial test)
c) Consolidation test	:	4 pcs, (soil only)

2.5.3. Methodology

(1) Boring Work Offshore

The offshore boring work had been started in November 5, 2000 and was completed in November 17, 2000. The total of 4 holes were drilled.

During the drilling work, the geotechnical work such as sampling and testing were performed as specified in the scope of work.

The steps of offshore boring work proceeded as shown in the attached flow chart of offshore boring work in Fig.2.5-2.

(a) Drilling Work

After setting up pontoon, before the drilling work had been started, the sea-bed level and sea level were measured by measuring tape. With the end of measuring tape fixed by weight (probe type), once the weight had been lowered down to the sea bed, the curtained length of weight immersed into the mud. The height of seabed to pontoon was calculated accurately by subtracting the length of mud at the weight from the total length.
The drilling work was performed in the same manner as described in Section 2.2.3.

(b) Undisturbed Sampling

The undisturbed sampling was performed in the same manner as described in Section 2.2.3.
UD-sampling by thin wall tube and by piston sampler are shown in Fig.2.5-3 (1) and (2), respectively.

(c) Standard Penetration Test

The method is the same as described in Section 2.2.3.
Arrangement of Standard Penetration Testing Equipment is shown in Fig.2.5-4.

(d) Rock Coring

Rock coring was done in the same manner as described in Section 2.2.3.

(2) Laboratory Test

Laboratory tests were carried out to find out their physical properties and strength on both selected soil samples and rock samples. The tests were conducted for the following items:

(a) Physical Property test on soil
  - Moisture Content Determination
  - Total Unit Weight
  - Specific Gravity
  - Grain Size Analysis

(b) Strength Test on Soil
  - Consolidated Drained Triaxial Compression Test (CID).

(c) Consolidation Test on Soil

(d) Physical Property Test on Rock
  - Moisture Content Determination.
  - Total Unit Weight.

(e) Strength Test on Rock
  - Unconfined Compression Test

The laboratory tests were carried out according to procedures recommended by ASTM standard and the soils were classified in accordance to the Unified Soil Classification System (USCS).

2.5.4. Results

The results of Boring works are summarized in Table 2.5-1.
Boring logs of each borehole are shown in Figs.2.5-5 ~ 2.5-8.
Physical property test results are summarized in Tables 2.5-2 (1) ~ (4).

2.5.5. Technical Evaluation and Consideration

Four (4) offshore borings were conducted in the proposed site area for the combined cycle power plant.
Co-relation of each borehole is established as geological profile as shown in Figs. 2.5-9 (1) ~ (4).

For three of four offshore boreholes (Borehole Nos.BH-10, BH-12 and BH-13), the upper soil layers consist of very loose sandy soil beneath the sea. At Borehole No. BH-11, the upper layer consists of loose to medium dense sand. Sandstone was encountered below the sandy deposit at depths of 4.5 to 9.5 m from the sea bed.

For foundation of offshore structures, it is necessary to embed the pile into the sandstone since the upper soil layer has very little resistance. If bored pile is used, then it will primarily be an end bearing pile.

2.6. <u>Oceanography</u>

2.6.1. General

Tidal level variation in front of the site area was observed for the design of the Sihanoukville Combined Cycle Power Plant.
The measured tidal levels were compared with the observed tide levels at Sihanoukville Port.

2.6.2. Scope of Work

Tidal level measurement was carried out to obtain basic data on tidal characteristics in the sea in front of the project site area. Moreover, the data at Sihanoukville Port, and Khlong Yai and Trat Province in Thailand were analyzed for longer term study.

2.6.3. Methodology

(1) Equipment Installation

Prior to tide gauge installation, a set of steel frame was transported to the site. A 6”-diameter steel pipe was put into the water at the center of the frame. On November 19, 2000, a water level logger (WLL) was installed inside the pipe and a visual tide staff (VTS) was secured outside the pipe.

The location of tide gauge is the same location of borehole No.BH-10 as shown in Fig.2.5-1.

The VTS (Visual Tide Staff) consists of three 1-m-long plastics connected together. On the plastic, 1-cm mark was marked and grouped into 5-cm interval. The VTS was installed in such a way that it can cover the entire sea water level fluctuation during normal astronomical tidal condition. Then, the water level logger was installed inside the pipe and the length of the logger’s cable inside the pipe was adjusted so that the logger gave the same water level as the VTS did.

(2) Observation

The water level logger was left to record sea water level at 10-minutes interval for 35 days from 19 November 2000 to 25 December 2000. During the recording period, VTS reading was performed in order to compare the VTS reading to the data recorded from the water level logger. At the end of the recording period, the water level logger was retrieved and the data were transferred from the Water Level Logger to notebook computer.

(3) Sea Water Level referred to MSL

Land survey was done to tie the water level at the project site area to MSL at Ha Tien. From leveling using GPS techniques, the following information was obtained;

elevation of the top of 6”-diameter pipe 3.912 m above MSL
elevation of the top of VTS 1.437 m+MSL

Thus, zero reading of the VTS was 1.563 m below MSL.

(4) Data Compilation

Three sets of sea-level data are compiled as below:

a) From the site for 35 days, 19 November to 25 December 2000.

b) From Sihanoukville Port for 3 years, the location is
UTM Coordinate : 1176569.130 N, 336434.354 E.
Geo Coordinate : Lat. 10^0 38’ 27.0373” N,
Long. 103^0 30’ 16.1441” E.

c) From the tide data of Khlong Yai in Trat Province, Thailand, from 1993 to present, of which location is Lat. 11^0 46’ 58” N, Long. 102^0, 52’ 03” E as shown in Fig.2.6-1. It is maintained by the Harbour Department of Thailand.

The data from the project site area and Sihanoukville Port were referred to MSL at Ha Tien, Vietnam and the data from Klong Yai was referred to MSL at Ko Lak, Thailand.

(5) Data Analysis

From 3 sets of raw data, after tabulation and performing of quality control of the data, the following parameters were obtained:

a) Harmonic Analysis

Since the duration of observation at the project site area was only 35 days, we can compute some constituents for 29 days period were obtained. For other two stations, the duration of the observation cover the whole year, so more constituents were calculated.

b) By Harmonic Analysis, the tidal type was analyzed by using the Form Number F defined by:

$$F = (K_1 + O_1) / (M_2+S_2)$$

Semidiurnal tide	$0 \leq F \leq 0.25$
Mixed, mainly semidiurnal tide	$0.25 < F \leq 1.50$
Mixed, mainly diurnal tide	$1.50 < F \leq 3.00$
Diurnal tide	$3.00 < F$

c) By Harmonic Analysis, the tidal range empirically expressed as below were obtained:

Mean tidal range	=	$2.2\ M_2$
Spring tidal range	=	$2.0\ (M_2 + S_2)$
Neap tidal range	=	$2.0\ (M_2 - S_2)$
Tropic tidal range	=	$2.0\ (K_1 + O_1)$
Equatorial tidal range	=	$2.0\ (K_1 - O_1)$
Mean diurnal tidal range	=	$1.5\ (K_1 + O_1)$

The values of $(M_2 \pm S_2)$ is a measure of the diurnal inequality.

d) As non-harmonic analysis, the following parameters were calculated:

- Mean Sea-level (MSL) ($\sum$ all data point/n), when n = no. of data point.
- Chart Datum Level (CDL)
- Mean High Water Level

$$(MHWL) = (MHHW+MLHW)/2$$

$MHHW = (\sum HHW)/n$

$MLHW = (\sum LHW)/n$

- Mean Low Water Level

$$(MLWL) = (MLLW+MHLW)/2$$

$$MLLW = (\sum LLW)/n$$

$$MHLW = (\sum LLW)/n$$

- Mean tide level

$$(MTL) = (MHW + MLW)/2$$

- Mean range

$$(Mn) = MHWL - MLWL$$

e) Chart datum. We obtained chart datum for Sihanoukville Port (1.07 m below MSL) and we will try to compute chart datum for the project site from the known chart datum and the available tidal data.

2.6.4. Results

(1) Correction of Recorded Tide Data

The VTS readings are compared with data from the water level logger. The values of water level were given in m above/below MSL at Hatien. The individual reading difference varied from –0.82 m to 0.39 m. This difference is too large to rely on the VTS readings. However, on 11 December 2000, the JICA Study Team and Siam Tone personnel visited the tide gauge site and read the VTS at 13:56 pm. The water level from VTS reading was 1.78 m which was 0.217 m above MSL while that from the logger record was 0.117 m. Therefore, it was judged that increase of the tidal level from the water level logger by 0.10 m was necessary to make the water level from the logger record compatible to the VTS reading.

All data were corrected in this manner.

(2) Data Analysis

The sea water level recorded at 15-minute interval for 35 days from 19 November 2000 to 25 December 2000 were plotted in Fig.2.6-2.

However, the data for 29 days from 20 November to 17 December 2000 are used to compute the 29-days harmonic analysis. The harmonic constants or constituents at this site are listed in Table 2.6-1.

For comparison of the principal constituents from harmonic analysis at 3 stations, they are illustrated in Table 2.6-2.
For non-harmonic analysis for the project site area, the results are also shown in Table 2.6-2.

Comparison of sea-level fluctuation at the site area and Sihanoukville Port during 19 November - 25 December 2000 is shown in Fig.2.6-3.

2.6.5. Technical Evaluation and Consideration

From the tidal constituents obtained from the harmonic analysis based on the tide data at Sihanoukville Port and observed data at the site area, the form number, F is calculated.

The Form number, F at Sihanoukville Port is 2.77, indicating the type of tide as mixed type principally diurnal tide. The form number at the project site area is 2.54, also indicating diurnal tide. The dominant tidal constituents are K_1 and O_1. The semidiurnal constituents, M_2 and S_2 are less important.

At the tide gauge of Sihanoukville Port, the chart datum is –1.07 m below Ha Tien's MSL. Since the hourly tide data at the project site area during November-December 2000 conformed with that at Sihanoukville Port in both amplitude and phase, with the average hourly height difference only 0.02 m which was well below error from GPS leveling survey, it is possible to use the chart datum at Sihanoukville Port as the chart datum for the project site area, i.e. - 1.07 m + MSL.

Mean high water and mean low water are rather small, 0.37 m and –0.17 m, respectively, based on tide data at Sihanoukville Port in 1997 - 1999. During November-December the mean high water is higher than the annual average (Sihanoukville Port), while the mean low water stays almost the same. The mean tide level at the year end is about 0.20 m higher than the annual average at Sihanoukville Port, that is + 0.08 m + MSL. That is considered seasonal variation due to Monsoon. Highest and lowest tide levels in 1997 - 1999 are + 1.17 m on November 1997 and - 1.06 m on April 1997, respectively.

3. Results of Environmental Baseline Survey

3. Results of Environmental Baseline Survey

This chapter presents a summary of results of the year-long environmental baseline survey works that were carried out by TEAM Consulting Engineering and Management Co., under supervision of the JICA Study Team, that included quarterly on-site inspections of the works and monthly reviews of progress and results by fax and e-mail. Full results and documentation are presented in "Environmental Baseline Survey on the Sihanoukville Combined Cycle Power Development Project Final Report" (hereinafter referred as TEAM's Report), which was prepared by TEAM.

Field surveys began in September 2000, continued through February 2001, resumed in June 2001, were completed in August 2001 and provided most of the environmental baseline information for "Environmental Impact Assessment Report for the Sihanoukville Combined Cycle Power Development Project" that are to be prepared separately by the JICA Study Team. The Field surveys are organized into 10 categories of tasks as follows:

a. Land use survey and mapping for all project areas plus the area within a 30-km radius from the plant site.

b. Demographic survey covering all project areas and the 30-km radius.

c. Socio-economic survey covering all project areas and the 30-km radius, and giving special attention to an inventory of structures along the access road and to counts of pedestrian and vehicular traffic at three points along the access road during the wet and dry seasons.

d. Archaeological survey of all project areas.

e. Terrestrial ecological survey of all project areas in the wet and dry seasons, giving special attention to a complete inventory of trees and to protected species that could inhabit project areas.

f. Water quality and aquatic ecology survey of possible sources of plant makeup water for the project (i.e., Hun Sen Dam and stream and Prey Treng Pond) in the wet and dry seasons, covering water quality, plankton (microscopic plants and animals), benthos (species living on the bottom of a pond, stream or the sea), fish, vegetation, birds of both areas and measurement of grain size distribution for the substrate of

Prey Treng Pond only.

g. Marine ecology and fisheries survey covering protected species; wet and dry season surveys of water quality, plankton and benthos; 8 sampling trips for fish, fisheries activity and ichthyoplankton (fish eggs and larvae) abundance; a diving exercise to observe benthos in the vicinity of the intake and discharge structures; and measurement of grain size distribution for the substrate in the vicinity of the intake and discharge structures.

h. Air quality and noise survey for the site and receptor areas in the wet and dry seasons, including an inventory of stationary sources of air pollution within the 30-km radius.

i. Oceanographic monitoring and simulation analysis of thermal diffusion of cooling water.

j. Estimation of ground level concentrations of glue gas emissions.

With the following exceptions, the works were carried out in accordance with locations and methods that were specified or approved by the JICA Study Team. prior to the commencement of the survey.

a. The location and size of the spoil disposal area evolved as follows. Prior to the start of the survey a spoil disposal area had not been identified, so an allowance was made for an off-site area to be as large as 50 ha. In November 2000, following the completion of detailed topographic mapping, a large off-site disposal area was found to be unnecessary. A small adjustment of project site boundaries was determined to be sufficient to incorporate all construction, including all spoil disposal, for three stages of construction into the adjusted site area that covers 0.573 km^2.

b. The land use map for the site was completed ahead of schedule in December 2000 instead of June 2001.

c. Because of the slight delay in gaining night-time access to the site areas, the rainy-season traffic count that had been scheduled for September 2000 could not be carried out before the rainy season had ended, so was rescheduled for June 2001.

In the following discussions of the respective tasks, various areas are defined as follows:

- "Site or project site" refers to the plant site plus the spoil disposal area. It is designated as Area A in various exhibits in this report, in TEAM's Report and in the EIA Report. As explained above, at the start of the survey, the spoil disposal site was expected to be a separate site not connected to the plant site. However, when this was found to be unnecessary, Site A and the spoil disposal site were merged and thereafter designated as Site A.
- "Pipeline corridor" refers to the 100-m-wide study area for the oil pipeline that may extend from the Sokimex Oil Terminal to the plant site. It is designated as Area B in various exhibits in the aforementioned reports. The layout of the pipeline is expected to be entirely within the corridor, but the pipeline itself will require only a small part of the 100-m-wide area.
- "30-km radius" refers to the area within 30-km of the plant site. It is designated as Area C in various exhibits in the aforementioned reports.
- "Laydown area for Stage 3 construction" refers to approximately 11 ha south of Prey Treng Pond that are recommended temporary use during the construction of the third unit, while Stages 1 and 2 are operating. This area is designated as Area D in various exhibits in the aforementioned reports.

Boundaries of these 4 areas as well as locations of environmental studies and sampling are shown in Figures 3-1 through 3-5. Area A is the plant site (including the spoil disposal area). Area B is the oil pipeline corridor. Area C is the 30-km radius from the plant site. Area D is the laydown area for Stage 3. Various sampling points are defined in the legends of these figures.

3.1. <u>Land Use Survey and Mapping</u>

3.1.1. 30-km Radius

The 30-km radius covers 2,827 km^2, of which about 2/3 (1,8 72 km^2) is open sea and 1/3 (956 km^2) is land, fresh water or seacoast. Land use for the 30-km radius is summarized in TEAM's Report (Tables 2.1-1 and 2.1-2 and Fig. 2.1-3 and 2.1-4). In summary, four dominant land uses cover about 97 % of the 956 km^2 of land within the 30-km radius. They are:

- forest (556 km^2 or 58 %),

- agricultural land (135 km^2 or 14 %),
- grassland (128 km^2 or 13 %), and
- shrubland (115 km^2 or 12 %).

Settlements cover only 3 km^2. Bodies of fresh water cover less only 1 km^2.

3.1.2. Plant Site

The plant site and the spoil disposal site were merged into one area of 0.573 km^2 with one perimeter. Its land use is summarized in Table 3.1-1 and Fig. 3.1-1. Two dominant land uses cover about 86 % of this site – namely, grassland (0.383 km^2 or 67 %) and brush / secondary forest (0.110 km^2 or 19 %). The “sand bank” west of the road and railroad is a narrow white-sand beach that is used by small numbers of local residents for weekend and holiday recreation. The northwest corner of this site is a former minefield that was cleared by CMAC (Cambodia Mine Action Center) during the survey, so was inaccessible for on-site inspection. Land use in areas adjacent to the site is comparable to land use on the site.

3.1.3. Oil Pipeline Corridor

Land use of the oil pipeline corridor is summarized in Table 3.1-1 and Fig. 3.1-2. Two dominant land uses cover about 90 % of the corridor – grassland (0.174 km^2 or 60 %) and industrial uses (0.088 km^2 or 30 %).

3.1.4. Laydown Area for Stage 3

Land use within the laydown area for construction of Stage 3 is dominated by grassland (75%) and forest (25%) with a trace of residential area for one household (Table 3.1-1 and Fig. 3.1-3).

3.2. Demography Survey

3.2.1. 30-km Radius

About 84 % of the land within the 30-km radius is within 3 districts in the province that includes the proposed project (i.e., Krong Preah Sihanouk). The remainder consists of scattered fragments of 2 other districts of Kaoh Kong Province (Fig.2.1-4 in TEAM's Report). Sre Ambel District contains the largest fragment, which extends northwest from the northwest border of Stung Hav District to the edge of the radius. Botom Sakor District contains four fragments near the edge of the 35-km radius, across the sea, west of Sihanoukville and northwest of Stung Hav Village. For several reasons, the three districts within Krong Preah Sihanouk are considered to contain the socio-economic data that most faithfully represent the 30-km radius: (i) most of the area of these fragments is remote from the plant site and does not contain settlements; (ii) statistical information is not available for just these fragments; and (iii) most of the population of Sre Ambel and Botom Sakor Districts is outside of the 30-km radius. The data for the three districts of Krong Preah Sihanouk are summarized as follows.

In 1998, the total population of Krong Preah Sihanouk was about 156,000. Females (50.6 %) slightly outnumber males. Age distribution shows small cohorts for three age groups (ages 20-24, 15-19 and 0-4) but is strongly skewed toward persons under 15 years of age (Attachment 1 of TEAM's Report). This results in a high dependency ratio (dependents / working age population) of about 83 percent.

The population is concentrated in Prey Nob and Mittapheap Districts (about 75,000 and 67,000 respectively). The population of Stung Hav is much smaller (about 13,000). Population density is highest in Mittapheap District (more than 350/km^2) and lowest in Prey Nob District (less than 100/km^2). About 52 % of the population of the province has migrated to Krong Preah Sihanouk from another province. About 4 % has immigrated from another country. Two main reasons account for about 2/3 of the immigration - search for employment and relocation of family. Most households are headed by males (77.5 %).

The number of economically active persons in the province is about 61,000 of which about 57.5 % are male and 42.5 % are female. Unemployment rates for males and females are about 6.5 % and 10.8 % respectively. About half of the activity is in the primary sector (agriculture, hunting, forestry and fishing). About 11 % is in the secondary sector (mining, quarrying, manufacturing, electricity, gas, water supply and construction). About 38 % is in the tertiary sector (wholesale and retail trade and services). Unemployment rates are about 6.5 % for men and 10.8 % for women.

Literacy rates for persons aged 7 years or older are about 73 % for males and 56 % for females). Education levels of the literate population are:

- 1 % never completed any grade,
- 56 % attended but never completed primary school,
- 27 % completed primary school,
- 11.9 % attended secondary school,
- 3.6 % completed secondary school and
- 0.5 % completed some post-secondary education.

About 62 % of persons aged 15 years or older are married. About 30 % have never been married. The others are widowed, divorced or separated.

Household amenities include the following. Main sources of drinking water include dug wells (66%), purchased of water from vendors (16 %), piped water (8 %) and surface water bodies (5 %). Main sources of lighting include kerosene (57 %), public electricity (37 %) and private generator (2.4 %). Main sources of fuel for cooking include firewood (69 %), charcoal (27 %), liquefied petroleum gas (LPG) (2 %) and kerosene (2 %). Toilet facilities within the premises are available to only about ¼ of the population of the province.

3.2.2. Plant Site and Oil Pipeline Corridor

Census data for the site and as well as for the pipeline corridor indicate that populations in the vicinity of both areas are very small. Only 6 households reside on the site and spoil disposal area. Nine others reside in adjacent areas close to the road or the site. The 100-m wide study area for the pipeline corridor includes 23 households.

The locations of all of these households are shown in Fig. 3.2-1. Families living on the site are young and have no permanent jobs. They sustain themselves by collecting fuelwood and doing part-time jobs. Families living in the corridor area are mostly employees of Sokimex, Shell or Tela oil companies.

3.2.3. Laydown Area for Stage 3

Four families inhabit this area (Fig. 3.2-1) and work as farmers.

3.3. Socio-Economic Survey

3.3.1. Traffic Survey

The traffic survey was carried out at three locations between Sihanoukville Port and Sokimex Oil Terminal, for 24 hours (7 am to 7 am) on a weekend day and a week day in the wet and dry season. One location (TC1) is located at Tamnop Rook Village, an area of high pedestrian traffic near Sihanoukville Port, between the port and the project site. Another (TC2) is located in a sparsely populated area near the project site and the border between Sihanoukville and Stung Hav. TC3 is located near Sokimex Oil Terminal, between the terminal and the project site. Pedestrians were counted by time and direction of travel. Vehicles were counted by type of vehicle and time and direction of travel.

Detailed results are presented in Attachments 2-1 to 2-20 of TEAM's Report and summarized as follows. At TC1 counts of pedestrian and vehicular traffic exceeded 12,000 counts and 10,000 counts per 24 hours respectively on the weekend day and the weekday in the dry season and 8,000 and 7,000 counts respectively in the wet season. Most of the counts were motorcycles and pedestrians, with motorcycles outnumbering pedestrians by nearly 3 to 1. Counts at TC1 were 6 to 8 times higher than at TC2 or TC3.

3.3.2. Structures along Road near Site

Structures within 20 m of the road between Sihanoukville Port and the Sokimex Oil

Terminal were identified, located by GPS, counted and subtotaled in 500-m increments starting from the port. Selected structures were photographed.

Detailed results, including photographs, are presented in Fig. 3.3-1 and TEAM's Report (Table 2.3-1 and Attachment 2-21) and summarized as follows. There are 691 structures within 20 m of the road between Sihanoukville Port and Sokimex Oil Terminal. Of these, 406 (58.7 %) are dwellings, 262 (37.9 %) are shops, 16 are factories and 7 are government offices

3.3.3. Profile of 30-km Radius

The socio-economic profile of the districts within the 30-km radius (Attachments 2-23 and 2-24 of TEAM's Report) was prepared by consulting concerned authorities and available records. Available information covers public schools, hospitals, industrial activity (manufacturing and electricity) and activity in other sectors. Notable findings include the large numbers of pupils in school (especially elementary school); the large numbers of households involved in fishing (most of the households in Stung Hav District and about a third of the households in Mittakpheap District); the small numbers, small scale and resource base of manufacturing facilities; and the small numbers of hospital patients and skilled staff in relation to the size of the population (only 13 doctors in the entire province). Some of the largest industries, including Sokimex and Sihanoukville Port would not reveal information about their operations for national security reasons. Further information on the locations of factories within the 3 districts is presented below in Section 3.8.

3.3.4. Profile of Plant Site, Oil Pipeline Corridor and Laydown Area for Stage 3

The socioeconomic profile of families inhabiting the plant site, the pipeline corridor, and the laydown area for Stage 3 was developed by interviewing 39 heads of households located within these areas or near the plant site. Notable findings include:

- average household size (about 5 persons),
- gender (nearly equal numbers of males and females),
- average age (23 years),
- ethnic group (38 Khmer, 1 Vietnamese),

- employment (20 have a single occupation and the others have multiple occupations, with main occupations as follows: 15 are employed in the private sector, 7 are government employees, 6 are farmers, 4 are shop owners, 3 are housekeepers, 2 are fishermen, 1 is a taxi driver and 1 sells charcoal;
- annual household income (about $1,500),
- household debt (less than $100),
- residential land ownership (100 % own their residential land),
- building ownership (92 % own their house),
- livestock ownership (about 41 % own livestock),
- drinking water supply (87 % boil their drinking water, 46 % have house connections, 36 % use surface water,8 % have shallow wells, 8 % use swamp water)
- water problems (odor, poor quality and lack of disinfection are cited as problems by most of the families)
- mobility (69 percent have moved their residences within 10 years)
- knowledge of the project (about 46 % were aware of the project)
- expectations concerning resettlement (33 % preferred to move to Sihanoukville Town, 95 % expected cash compensation for resettlement and 59 % expected new land for resettlement and community functions)

3.4. Archaeological Survey

The archaeological survey investigated the risk that project areas could contain archaeological materials whose discovery and salvage could affect project schedules or costs. The survey was carried out by an archaeologist and support staff and included (i) literature search, (ii) on-site inspections of the plant site, oil pipeline corridor and laydown area for Stage 3, (iii) interviews with local residents, and (iv) soil sampling and test digs in selected locations that did not include the laydown area for Stage 3. Detailed findings of the survey (including photographs of test pits) are reported in Attachments 3-1 and 3-2 of TEAM's Report and summarized as follows:

- For the plant site and corridor - "As a result of my field study through surface collection at the site and analyzing documents and excavations, I strongly maintain that along the railway line and in the project site there is no evidence of archaeological sites – either on the surface or within the land."

- For the laydown area for Stage 3 – "As a result of my field study through surface collection at the site and analyzing documents, I concluded that along the...the project sites there is no evidence of archaeological sites [on the] surface [of] the land even though a scraper was found nearby those sites. But I strongly suggest that the excavation should be done in those zones to make sure that there is no evidence of archaeological sites within the land [i.e., underground].

3.5. Terrestrial Ecological Survey

3.5.1. Protected Species

The search for protected species of wildlife on project areas began with a literature search of international sources such as IUCN's Red Data Book and Cambodian sources such as the Ministry of Agriculture, Forestry and Fisheries' "Declaration on the Species Listed of Wild Game Forbidden to be Hunted". From these sources, a comprehensive list of protected species that could possibly occur in Cambodia was prepared.

On the basis of this comprehensive list, interviews were conducted with local residents to determine whether any of the species has ever been observed in the vicinity of the project area and site inspections were carried out by competent biologists to determine if any of the species could be found on the site or oil pipeline corridor. Except for several birds observed in the vicinity of Hun Sen Dam and Prey Treng Pond (and described below), none of the species on these lists (i) were observed on or near the site by the study team, or (ii) were described by local residents as having been observed in the region in recent years. The lists are presented in Section 2.5.2 and Attachments 4-1 through 4-3 of TEAM's Report. Internationally recognized protected species that were reported by local residents as having been seen some time ago in the region (but not in recent years) included the fishing cat (classified as insufficiently known), the tiger and Asian elephant (both classified as endangered), and the Indian python (classified as vulnerable).

3.5.2. Inventory of Trees

The inventory of trees on the plant site revealed that 302 trees of 46 species in 23 families have trunk diameters larger than 10 cm DBH (diameter at breast height). The dominant species (*Casuarina equisetifolia*) accounted for 16 % of the trees on the plant site. The fuel pipeline corridor included 147 trees and the dominant species (*Casuarina equisetiafolia*) accounted for 19 %. Complete tree counts for each area are presented in TEAM's Report (Table 2.5-1 and 2.5-2 and Attachment 4-4). Trees were not counted on the laydown area for Stage 3 due to security considerations, but species composition was judged to be similar to the plant site.

3.5.3. Survey of Site, Spoil Disposal Area and Oil Pipeline Corridor

The species and abundance of dominant vegetation other than trees was determined by visual observation of the grassland areas in the dry season. The observation revealed that there are 2 main types of grassland in the study area: (i) pasture grass on poor soil where only grass can survive and (ii) grassland in the early stages of succession following deforestation. The dominant species of grass on both sites is *Imperata cylindrical*, a coarse, hardy pioneer species that is common on degraded land throughout southern Asia. Shrubs and saplings were also found in the grassland areas, especially along the waterways.

3.6. Water Quality and Aquatic Ecology Survey

The water quality and aquatic ecology survey was conduced at three locations: (i) in the reservoir behind Hun Sen Dam (location WAQF1) which was considered as a source of dry-season makeup water for the project; (ii) in the stream downstream of Hun Sen Dam (location WAQF2); (iii) and in Prey Treng Pond (location WAQF3), adjacent to the plant site, which was selected as the source of makeup water for the project.

3.6.1. Survey of Biota

The survey of biota was conducted once in the dry season and once in the wet season and included plankton, benthos, fish, birds and rooted and floating vegetation. Results are presented in the following paragraphs.

3.6.2. Plankton (microscopic plants and animals)

In both wet-season and dry-season grab samples, numbers and diversity of plankton species were high with green algae being the dominant phytoplankton (microscopic plants) at both Hun Sen Dam and Prey Treng Pond, indicating good water quality in both ponds. Cell densities for phytoplankton ranged from 12 to 55 million/m^3 in the dry season and around 12 million/m3 in the wet season. Cell densities for zooplankton (microscopic animals) were in the range of 165,000-323,000/m^3 in the dry season and 92,000-111,000/m^3 in the wet season. Details are presented in Attachments 5-2 and 5-3 of TEAM's Report.

3.6.3. Benthos (animals living on the bottom)

Benthos was sampled by Ekman Dredge and sorted from the substrate with sieves of descending screen size. For each location, multiple samples were collected and combined (composited) before sorting.

Density of benthos was consistently higher in Hun Sen Dam than in Prey Treng Pond (264 vs. 44 organisms/m^2 in the dry season and 1,650 vs. 66 organisms/m^2 in the wet season). Details are presented in Attachment 5.4 of TEAM's Report.

3.6.4. Fish

Freshwater fish sampling was conducted with gill nets of various mesh sizes in the reservoir of Hun Sen Dam and in Prey Treng Pond in the wet season and dry season. Results are presented in Tables 3.6-1 and 3.6-2 and Fig. 3.6-1 and did not include any protected species. Rare or protected species that occur in Thailand and the region and that were searched for in the ponds are profiled and pictured in Attachment 5-8 of TEAM's Report.

3.6.5. Aquatic Vegetation

Results of the visual survey of submerged and emergent vegetation are presented in Table 3.6-3.

3.6.6. Birds and Other Fauna

In the vicinity of Hun Sen Dam 24 species of birds (including 8 protected species) were observed in the dry season and 21 species (including 6 protected species) were observed in the wet season. At Prey Treng Pond, 26 species (including 4 protected species) were observed in the dry season and 25 species (including 8 protected species) were observed in the wet season. Pictures of the protected species are presented in Fig. 3.6-2. Profiles of these protected species are presented in Attachment 5-16 (B) of TEAM's Report. Names of the species pictured in Fig. 3.6-2 are the following:

PBS1 – Black-Capped Kingfisher – *Halcyon pileata*
PBS2 – Lesser Coucal – *Centropus bengalensis*
PBS3 – Oriental Magpie-Robin – *Copsychus saularis*
PBS4 – Cinnamon Bittern – *Ixobrychus cinnamomeus*
PBS5 – White-Throated Kingfisher – *Halcyon smyrnensis*
PBS6 – Pacific Swallow – *Herundo tahitica*
PBS7 – Hill Myna – *Gracula religiosa*
PBS8 – Cotton Pygmy-Goose – *Nettapus coromandelianus*
PBS9 – Cattle Egret – *Bubulcus ibis*
PBS10 – Chinese Pond-Heron – *Ardeola bacchus*
PBS11 – Little Heron – *Butorides striatus*
PBS12 – Lesseer Adjutant – *Leptoptilos javanicus*
PBS13 – Grey Heron – *Adea cinerea*
PBS14 – Lesser Whistling-Duck – *Dendrocygna javanica*
PBS15 – Black-Collared Starling – *Sturnus nigricollis*
PBS16 – Indian Roller – *Coracias benghalensis*
PBS17 – Greater Coucal – *Centropus sinensis*
PBS18 – Red Turtle-Dove – *Streptopelia tranquebarica*

A list of wildlife reported by local residents to occur in the project region, but not observed by the study team, is presented in Attachment 5-15(B) of TEAM's Report. One species on the list (the Red Muntija, *Muntiacus muntijak*) is classified by IUCN as Vulnerable. Seven others are classified by the Cambodian Government as protected: (i) Wild Pig (*Sus scrofa*), (ii) East Asian Porcupine (*Hystrix brachyura*), (iii) Indian Giant Flying Squirrel (*Petaurista phileppensis*), (iv) Siamese Hare (*Lepus peguensis*), (v) Guar (*Bos gaurus*), (vi) Lesser Mousedeer (*Tragulus javanicus*) and (vii) Sunda Pangolin (*Manis javanica*).

3.6.7. Survey of Water Quality

Water quality was measured *in-situ* at each sampling location and in samples collected in the field and analyzed in the laboratory. Parameters and methods of measurement and testing are summarized in Table 3.6-4. Results are presented in Table 3.6-5.
Findings indicate good water quality in the pond and reservoir (locations WAQF1 and WAQF2), and tidal influence (by higher salinity) and pollution from human settlements (by higher bacteria counts) at WAQF3.

Current dry season and wet season uses of water from Hun Sen Dam are mainly for kitchen, garden, fishing, cloths washing, bathing and drinking. People living near the stream below this dam use the water for stocking of crab, mantis shrimp and shrimp, boat parking and fishery activities (catching crabs and fish by gear and by hand). People living near Prey Treng Pond use this water in the wet and dry season for household consumption as well as cloths washing, bathing, agriculture (corn and potatoes) and drinking. Water from Prey Treng Pond is also pumped to the Sokimex Oil Terminal for plant uses.

3.6.8. Sieve Analysis

Detailed results of the analysis of the substrate are presented in Attachments 5-12 and 5-13 of TEAM's Report and summarized as follows. The fraction > 0.074 - 0.42 mm diameters comprised 87.9 % at Prey Treng Pond and 64.9 % at Hun Sen Dam. The fraction of 0.0013 - 0.074 mm diameters comprised 12.1 % at Prey Treng Pond and 35.1 % at Hun Sen Dam.

3.6.9. Laboratory Performance Testing

Laboratory performance testing was not necessary. Analyses were carried out by a laboratory that was duly certified to Thai standards.

3.7. Marine Ecology and Fisheries Survey

3.7.1. Port Surveys of Marine Fisheries

Port surveys of Sihanoukville and Stung Hav Ports were conducted 8 times between late September 2000 and early August 2001. They confirmed that extensive fisheries efforts and captures are occurring in coastal areas in the region of the project site. Detailed tables of the results of each survey including fishing boats and activities, fishing grounds, totals and breakdowns of fish landed, values and destinations of the catches, and some related information such as spawning are presented in Attachment 6-1 of TEAM's Report. Results are summarized briefly as follows.

One hundred and sixty-four fishing boat operators and 19 port owners were interviewed. Most fishermen go fishing for the whole year. Differences in wet season and dry season fisheries products were not significant although less fishing is done in the wet season due to strong winds. Fishing gear used were trawl, gill net, crab trap and squid trap. Favorite fishing grounds are Koah Rong, Koah Rong Samloem, Koah Thas, Koah Sdach, Thmor Sar and Koah Russy. The Sokimex Oil Terminal area is closed to fishing, but is said to be rich in fish stocks. Fisheries products end up in Phnom Penh, Sihanoukville and Thailand.

3.7.2. Profiles of Marine Fish and Protected Species.

One hundred forty-six species of marine fish were collected from fishermen and port owners during this study. A photograph and profile of each species is presented in Attachment 6-2 of TEAM's Report. This collection represents about 80 % of the 183 marine fish species recorded by the Cambodia's Department of Fisheries and indicates the importance of fisheries in the project region.

Pictures (Fig. 3.7-1) and profiles (Attachment 6-3(B) of TEAM's Report) of protected marine species that occur in the project region (approximately within the 30 km radius) were prepared from technical literature, interviews with 61 fishermen and a few direct observations. The species included:

- Mangrove forest dominated by *Rhizophora* sp. – MPS 14
- Seagrass (which is a flowering plant growing in the marine habitat) – MPS 16
- Coral reefs including Mushroom Coral (Fungia spp.), Table Coral (Acropora sp.) and Sea Fans – MPS 15
- Whale Shark, *Rhiniodon typus* – MPS 13
- Sea turtles including:

  Green Turtle (Chelonia mydus)

  Hawksbill Turtle (Eretmochelys imbricata) – MPS 10

  Loggerhead Turtle (Caretta caretta)

  Olive Ridley Turtle (Lepidochelys olivacea)
- Marine mammals including Dugong (MPS 12) and

  10 species of Whales and Dolphins reported to be in Cambodian waters by Easly and Leng (2001). Those which are considered likely to occur within the 30-km radius of the project include:

  Killer Whale (Orcinus orca) – MPS1

  False Killer Whale (Pseudorca crassiden) – MPS2

  Spotted Dolphin (Stenella attenuata) – MPS3

  Common Dolphin (Delphinus delphis) – MPS4

  Common Dolphin (Delphinus capensis) – MPS5

  Bottlenose Dolphin (Tursiops truncatus) – MPS6

  Indo-Pacific Humpback Dolphin (Sousa chinensis) – MPS7

  Irrasaddy Dolphin (Orcaella brevirostris) – MPS8

  Finless Porpoise (Neophocaena phocaenoides) – MPS9

3.7.3. Marine Ichthyoplankton

Forty-eight samples of ichthyoplankton were collected during 8 sampling periods from six sampling locations in the vicinity of the proposed locations of the intake and discharge structures. Results of the analyses are summarized in Table 3.7-1 and Figs. 3.7-2 through 3.7-9. The results indicate that the area is rich in ichthyoplankton (42 families were identified, of which 20 comprised families of commercial species), but that concentrations of ichthyoplankton are lower in the immediate vicinity of the intake and discharge structures than in deeper parts of the adjacent seas. The abundance of fish larvae was somewhat seasonal, with dry-season abundance about 3 times wet season abundance.

3.7.4. Marine Phytoplankton and Zooplankton

Marine plankton were collected by grab samples once in the wet season and once in the dry season at 2 locations (PK1 and PK2). Results are indicative of good water quality, i.e., large numbers of species (70 in the dry season and 85 in the rainy season) and good species diversity (with the diversity index in the range of 3.0). Details are presented in Attachments 6-6 to 6-8 in TEAM's Report.

3.7.5. Marine Benthos (bottom dwelling organisms)

Nine samples of benthos (animals living in the sea bottom) were collected from locations near the intake and discharge structures (BT1 through BT9) during the wet and dry seasons and identified and counted in the laboratory. Results of the collections and analyses are summarized in Table 3.7-2. In summary, 11 families of benthos were observed in the dry season and 13 in the wet season, and the density of benthos at the intake and discharge structures ranged between 300-1,216 individuals/m^2 and 88-1,386 individuals/m^2 respectively.

During a wet season diving exercise to observe the seabed and benthos in the vicinity of the intake and discharge structures, 2 species of sea grass were observed between stations BT2 and BT3 (discharge structure) – *Cymodocea serrulata* and *Halodule* sp. In response to this finding, 5 transects of 30 m each were sampled in the vicinity of the seagrass bed and it was determined that sea grass covered approximately 35 % of the area covered by these transects.

3.7.6. Chemical and Sieve Analyses of Sea Bed Material

Chemical and sieve analyses were carried out on sea bed samples collected during the rainy season in the vicinity of the intake and discharge structures. Results of these analyses are presented in Tables 3.7-3 and 3.7-4.

3.7.7. Sea Water Quality

Sea water quality was surveyed at two locations near the intake and discharge structures (WQo1 and WQo2), in the wet season and dry season, by *in-situ* measurements and sampling from 1 m below the surface and 1 m above the bottom followed by laboratory analysis. Results are presented in Table 3.7-5 and indicate that the water quality is quite good in the vicinity of the plant site.

As part of the ichthyoplankton sampling effort, salinity measurements were made near the sea surface at each sampling location during each survey. The results of this sampling reveal occasional lowering of salinity levels during the rainy season, as follows:

Sampling Date	Salinity (ppt) by Ichthyoplankton Sampling Location					
	IP1	IP2	IP3	IP4	IP5	IP6
30-09-00	24	25	31	30	30	31
28-10-00	25	26	30	26	26	25
02-12-00	34	34	33	32	33	34
06 01-01	33	32	35	32	32	33
01-02-01	34	30	32	31	30	30
16-06-01	32	34	30	31	32	33
06-07-01	15	15	16	16	16	16
04-08-01	24	24	24	24	24	24

3.8. Air Quality and Noise Survey

3.8.1. Inventory of Major Point Sources of Air Pollution

As part of the analysis of existing air quality, point sources of air pollution were surveyed, tabulated and mapped by district within the 30-km radius (excluding the fragments of Sre Ambel and Botum Sakor Districts near the edge of the 30-km radius). Results indicate that with a few exceptions such as Sihanoukville Port and Sokimex Oil Terminal, the number and size of industrial developments is small and not a threat to regional air quality, and the main types of industries are fish meal, fish sauce, frozen fish, timber, rock quarry, brick making, power plants, drinking water, palm oil, tapioca flour, bakery, ice making and shoe and garment manufacturing. Details are presented in Attachments 7-1 through 7-5 in TEAM 's Report.

3.8.2. Air Quality Survey

Concentrations of sulfur dioxide and nitrogen dioxide were measured over 24 hours at two locations (AQ1 and AQ 2) during the rainy season and dry season. AQ1 is the Tamnop Rolok Primary School in Stung Hav Village. AQ2 is the Sihanoukville Meteorological Station in Sihanoukville City. Air sampling and analysis was carried out with the method and procedure adopted by Thailand's Office of Environmental Policy and Planning (OEPP). Air was sampled with an Impinger. Sulfur dioxide was analyzed by the Pararosaniline Method. Nitrogen dioxide was analyzed by the Sodium Arsenate Method.

Results showed concentrations of SO_2 and NO_2 to be very low and far below Cambodian standards and World Bank guidelines. Concentrations of SO_2 varied between 2.45 - 2.94 $\mu g/m^3$ and 5.79 – 9.03 $\mu g/m^3$ for the two locations while NO_2 concentrations ranged between 45.75 – 65.92 $\mu g/m^3$ and 2.27 – 4.95 $\mu g/m^3$ respectively for the meteorological station and the school. Ambient air standards of Cambodia are 24-hour maximum of 500 $\mu g/m^3$ of SOx and 300 $\mu g/m^3$ of NOx. Ambient air quality guidance of World Bank is 24-hour maximum of 125 $\mu g/m^3$ of SOx and 150 $\mu g/m^3$ of NOx.

3.8.3. Noise Survey

Noise levels were measured over 24 hours at three locations (NM1, NM2 and MN3), during the rainy season and during the dry season. NM1 is at the plant site. NM2 is south of the site in a community near Prey Treng Pond. NM3 is north of the site near the Sokimex Oil Terminal. Measurement were made with an Integrating Sound Level Meter (NL-04) and averaged at hourly and 24-hour intervals. Sound-producing events such as the passing of trucks and trains were recorded and summed at hourly intervals.

Results are summarized in Table 3.8-1 and indicate low ambient sound levels for the project site. The highest sound levels observed were just over 60 dB(A) and were associated with passing trucks and trains.

3.9. Simulation Analysis of Thermal Diffusion of Cooling Water

3.9.1. Procurement of Equipment

Two 2-Dimensional Acoustic Current Meters were procured from Falmouth Scientific, Inc. in USA for measuring sea water temperature and current speed and direction at 30-minute intervals. Specifications are presented in Attachment 8-2 of TEAM's Report.

3.9.2. Monitoring of Sea Water Temperature, Current & Conductivity

Sampling locations for water temperature and current speed and direction are CT1 (about 2 km southwest of the plant site), CT2 (about 0.5 km west of the plant site, and CT3 (about 3 km northwest of the plant site). The method of installing the current meters at each sampling point is described in Attachments 8-3 and 8-4 of TEAM's Report. Measurements were made at two depths (near the surface and about 1 meter above the bottom) during 15-day sampling periods between October 2000 and August 2001. Results of the measurements are summarized in Tables 3.9-1 and 3.9-2 for the dry and wet season respectively:

3.9.3. Input Data

Bathymetric maps presented in other parts of this Final Report were used to determine water depth for the model. Tidal water level inputs obtained from Sihanoukville Port for October 2000 to February 2001 and for July to August 2001 were used for running the model after the correlation between Sihanoukville Port and the site was demonstrated in another part of this Final Report. Wind data (speed in m/s and direction in 16 directions) from Sihanoukville meteorological station for October 2000 to February 2001 and for July to August 2001 were used for running the model even though measurements were made only 4 times per day.

Plant data inputs included the plant and cooling system layout shown in the project description of this Final Report plus the following details of plant design and operation:

Capacity of power plan	3 × 90 MW
Water discharge rate	3 × 2.5 m^3/s
Temperature rise	7 deg. C
Intake structure	
- No. of intakes	3 units (one / 90 MW)
- Type	Submerged tower
- Water depth location	5 m below MSL
- Diameter	8.4 m
- Height	2.1 m (above sea bed)
- Distance of each tower	30 m
Outlet structure	
- Number of Nozzle	6 (2 for each 90 MW)
- Type	Submerged forced outflow
- Water depth at location	5 m below MSL
- Nozzle diameter	0.85 m
- Setting height	1.0 m above sea bed
- Angle of nozzle	5 deg. upward
- Discharge flow	1.25 m^3/s/nozzle
- Distance of nozzle	10 m

3.9.4. AQUASEA Model

The model used for the simulation is "AQUASEA", a two dimensional software package to solve shallow water flow and transport equations using the Galerkin finite element method. The model consists of two modules – a hydrodynamic flow module and a transport dispersion module.

The flow module can simulate water level variations and flow response to various forcing functions in lakes, estuaries, bays and coastal areas. The water levels and flows are approximated in a numerical finite element grid and calculated on the basis of information on the bathymetry, bed resistance coefficients, wind field and boundary conditions.

The transport dispersion module simulates the spreading of substances in the environment under the influence of the fluid flow and the existing dispersion process. The substances may be a pollutant of any kind including heat.
Model set-up and operation, including actual input data are presented in Attachments 8-1 and 8-5 through 8-11 of TEAM's Report.

A field check of the actual size and depth of a thermal plume for an operating Thai project (Khanom Power Plant in southern Thailand) was made in September 2001 and is presented in Attachments 8-13 and 8-14 of TEAM's Report.

3.9.5. Results of the Simulation

Four cases were run for the completed project (i.e., 270 MW at the time of ultimate site development). Each run was continued until plume size stabilized, which for all cases was about 100 hrs of plant operation. Two cases were run for the wet season and two for the dry season to determine seasonal differences in the location and size of the plume. For each season there was one run with the full water depth (which assumes that the plume is evenly distributed from surface to bottom) and one run for water depth of 2.5 m (which assumes that the plume is confined to and evenly distributed within the top 2.5 m of the water column) to obtain a general indication of how plume buoyancy may affect the location and size of the plume.

The results of the cases are shown graphically in Fig. 3.9-1, 3.9-2, 3.9-3 and 3.9-4. Approximate sizes and maximum distances of various parts (temperature rises) of the plume are summarized for each case in the following tables.

Case 1: Approximate area (km^2) and maximum length (m) of the plume in the dry season with diffusion averaged over full water depth

Temp. Rise ° C	km^2 at Slack Tide	km^2 at Flood Tide	km^2 at Ebb Tide
1.5	0.01	0.01	0.01
1.0	0.16	0.20	0.08
0.5	0.56	0.72	0.51

Temp. Rise ° C	m at Slack Tide	m at Flood Tide	m at Ebb Tide
1.5	100	100	200
1.0	300	300	300
0.5	500	900	1,200

Case 2: Approximate area (km^2) and maximum length (m) of the plume in the dry season with diffusion averaged over 2.5 m surface layer

Temp. Rise ° C	km^2 at Slack Tide	km^2 at Flood Tide	km^2 at Ebb Tide
2.0	0.03	0.04	0.01
1.5	0.20	0.20	0.03
1.0	0.48	0.48	0.48
0.5	1.10	1.20	0.95

Temp. Rise ° C	m at Slack Tide	m at Flood Tide	m at Ebb Tide
2.0	300	300	200
1.5	400	500	300
1.0	600	600	1,000
0.5	1,100	1,200	1,400

Case 3: Approximate area (km^2) and maximum length (m) of the plume in the wet season with diffusion averaged over full water depth

Temp. Rise ° C	km^2 at Slack Tide	km^2 at Flood Tide	km^2 at Ebb Tide
1.5	0.06	0.09	0.10
1.0	0.15	0.20	0.20
0.5	1.0	1.2	0.8

Temp. Rise ° C	m at Slack Tide	m at Flood Tide	m at Ebb Tide
1.5	100	300	400
1.0	300	500	500
0.5	1,500	1,250	1,600

Case 4: Approximate area (km^2) and maximum length (m) of the plume in the dry season with diffusion averaged over 2.5 m surface layer

Temp. Rise ° C	km^2 at Slack Tide	km^2 at Flood Tide	km^2 at Ebb Tide
1.5	0.08	0.12	0.20
1.0	0.56	0.56	0.48
0.5	2.50	2.25	2.20

Temp. Rise ° C	m at Slack Tide	m at Flood Tide	m at Ebb Tide
1.5	250	500	680
1.0	1,300	1,000	1,000
0.5	2,700	1,850	2,500

Field checking of the Khanom thermal plume suggest that Cases 2 and 4 (which assumes plume distribution within the top 2.5 m of the water column) are better indicators of the expected plume for the Sihanoukville Project than Cases 1 and 3.

In all cases, the discharge structures result in rapid lowering of water temperature to within 2°C of ambient temperature. Therefore the mixing zone criteria of World Bank (that 3°C temperature rise not occur beyond 100 m of the discharge structures) appear to be easily satisfied. The possibility that plume rise could be more rapid than expected and could result in a larger, thinner layer of + 3°C water on the surface is not consistent with findings from the Khanom power station (which has more than twice the installed capacity of Sihanoukville, which discharges heated water near the surface without the mitigation of diffusion nozzles and which discharges heated water that has + 8°C temperature rise). At Khanom, + 3°C temperature increase extends to a depth of 2.0 m for a distance of just over 100 m from the outlet. A shallower plume of 2.5 to 2.8°C of temperature rise extends to a depth of about 1.0 m for a distance of about 200 m from the outlet. At Sihanoukville, the smaller installed capacity, the lower temperature of the heated water and the mitigation with diffusers should insure compliance of the proposed project with the aforementioned mixing zone criteria.

Results of the thermal plume modeling and the comparison with Khanom power plant suggest that heated water discharge will involve such small temperature rises over such a small fraction of the coastal area in the vicinity of the project that impacts on marine fisheries or other species will not be significant. Even the largest area predicted for a 0.5°C temperature rise (i.e., 2.5 km^2 for case 4 at slack tide) would cover only about 0.03 % of the 9 million m^2 modeling area (i.e., 6 km × 3 km).

Results of the simulation are somewhat less conclusive on the issue of recirculation of heated water through the intake structure. Runs of the 4 cases reveal that the shape of the plume oscillates to the north and south with tidal currents, that the plume is larger in the wet season than in the dry season, that a layer of slightly heated water (+ 0.5 to 1.0°C and rarely to + 1.5°C) will often extend over the intake structure for at least a few hours per day when tidal currents are moving generally northward. The question that is not clearly answered with the AQUASEA model is whether this plume of slightly heated water (+ 0.5 to 1.0°C) will sometimes extend far enough down in the water column to be drawn into the intake structure. Plume measurements showing 0.6°C temperature rise at the 2-m depth, 400 m from the heated-water discharge structure at Khanom power station, suggest that recirculation of + 0.5°C water is a distinct possibility at Sihanoukville.

3.10. <u>Estimation of Ground Level concentrations of Flue Gas Emissions</u>

3.10.1. Simulation Model

Following two test runs of the air quality simulation using the USEPA Screen 3 Model and the worst case atmospheric stability class, a series of real cases were run with the USEPA Industrial Source Complex 3 model (ISC3). This model is a steady-state Gaussian plume model which can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial source complex. The model can account for the following: concerned parameters and situations, settling and dry deposition of particles, downwash, area, line and volume sources; plume rise as a function of downstream distance and separation of point sources. It operates in both long-term and short-term estimations. Model set-up and operation, including actual input data are presented in Attachments 9-1 through 9-6 of TEAMS's Report.

3.10.2. Cases Simulated

Cases simulated were selected to see effects by stage expansions, fuels used and stack systems. Selected options for simulation calculation are the following:

2 types fuel	Natural gas, Diesel oil

2 stack configurations	3 stacks per 90 MW (called Option I) 1 stack per 90 MW (called Option II)
4 stack heights for natural gas and Option I	30 m, 40 m, 50 m, 65 m
3 stack heights for natural gas and Option II	30 m, 40 m, 50 m
6 stack heights for diesel oil and Option I	30 m, 40 m, 50 m, 75 m, 100 m, 145 m
5 stack heights for diesel oil and Option II	30 m, 40 m, 50 m, 70 m, 120 m
3 stages of project development	90 MW (Stage 1) 180 MW (Stage 2) 270 MW (Stage 3)
Ground level NO_2 for 3 durations	1 hour, 24 hours, annual average
Ground level SO_2 for 3 durations	1 hour, 24 hours, annual average
Ground level CO for 2 durations	1 hour, annual average
Ground level TSP for 2 durations	24 hours, annual average

3.10.3. Stack Characteristics and Emission Rates

Stack characteristics and emission rates that were input to the model for running the various cases are compiled in Table 3.10-1.

3.10.4. Simulation Results

Ground level concentrations are presented as tables of maximum concentrations (Tables 3.10-2 and 3.10-3) and as tables of concentrations at particular receptor sites (Tables 3.10-4 and 3.10-5).

The results indicate that:

- For all pollutants studied, the maximum ground level concentrations consistently occur at the hilltops east and southeast of the plant site.
- Ground level concentrations at Sihanoukville, Sokimex Oil Terminal and Stung Hav (the receptor areas) are significantly lower than the maximum concentrations at the aforementioned hilltops.
- One stack per stage is better for atmospheric dispersion than three stacks per stage.
- The most difficult standard to satisfy is the 1-hour standard for SO_2 at diesel oil firing.

- When diesel oil with sulfur content less than 0.2 %, the 50 m height common stacks (one for each stage, total three stacks) satisfy all Cambodia environmental standards.

Selected ground level concentrations are presented as isopleths on topographic maps (Fig. 3.10-1 through 5) for reference.