

6. TECHNICAL APPROACH

6.1. Aerial photographs and Satellite Imagery

6.1.1. Existing Photographs

Aerial photos taken by MRC from 1992 to 1995 covering the various parts of Cambodia at the scale of 1:25,000 are currently consigned to the CNMC. From this archive, about 3,000 prints of aerial photos, covering some parts the Eastern Mekong basin area were collected. And another 2,000 prints, which were taken by World Bank project by FINNMAP in 2001 covering the northern parts of the Eastern Mekong basin area, were also collected. Therefore, 5,000 prints of air photographs were collected, which cover approximately 4,100 sq.km in total for the Eastern Mekong basin area. One set of photographs was prepared for interpretation.

6.1.2. Aerial Photographs

Significant changes, especially for the population and the land use, are to be expected in the area of the Western Mekong basin and along the border of Thailand, occupied by the former Pol Pot group. Thus, new aerial photos were taken from November 2001 to January 2003, two year's flight season.

Concerning the aerial photographs around the border of Thai, the flight was not allowed because of permission was rescinded at the end of January 2003.

Also, photographs of the Vietnam border were not available because there was no reply to requests for flight permission. Therefore, there are some missing photographs along the Border of Vietnam and Thai. Missing photographs account for approximately 60 photos on the Thai border and 23 photos on the Vietnam border. An aerial photo-index is as shown in Figure 7.

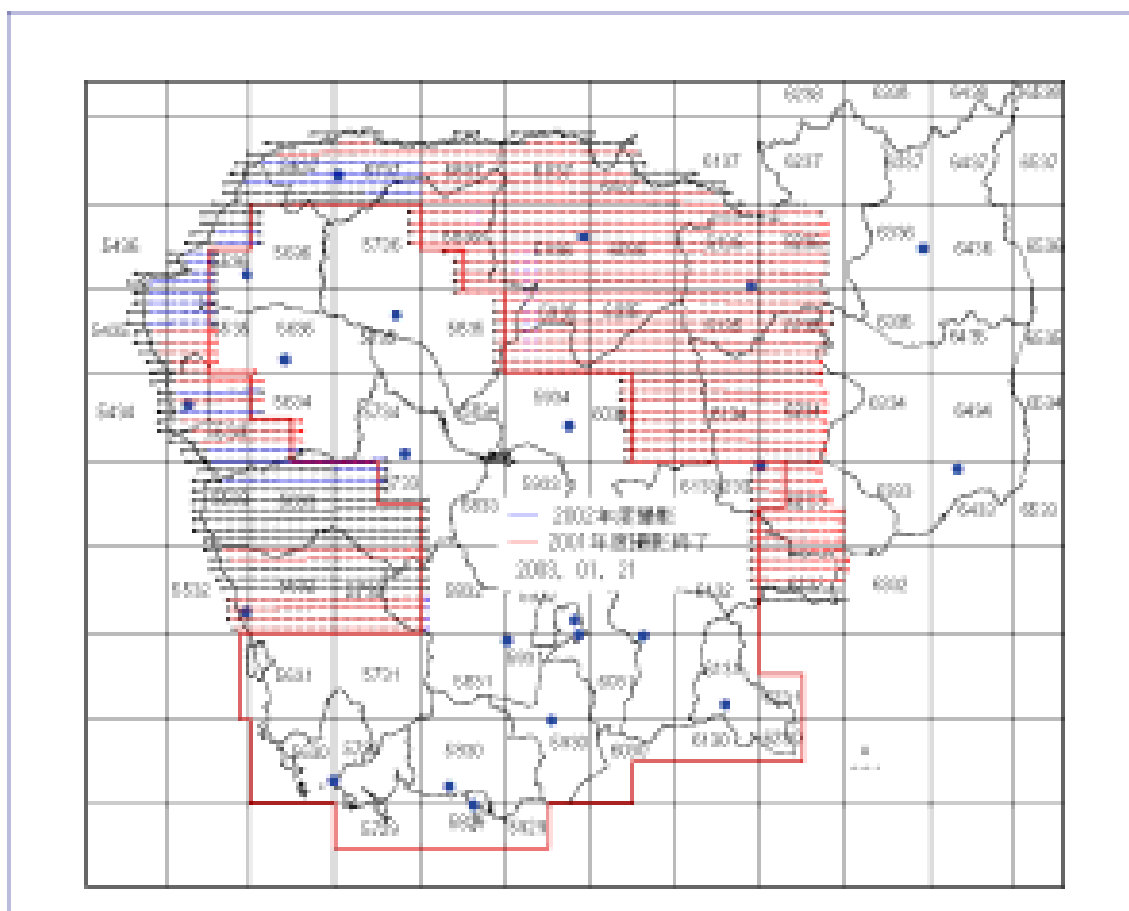


Figure 7: Photo-index

6.1.3. SPOT Ortho-images

(1) Archive Data of SPOT Satellite

SPOT satellite images were used as the data source for extracting some important ground features such as roads, canals and villages. Fig. 8 shows coverage of SPOT images in the study area. The cloud-free SPOT images, which were recently acquired, were prepared. These images were processed using the archived data. The coverage is shown in Fig. 8 and listed in Table 1.

(2) SPOT New Programming

Due to the lack of the archived data, new images were acquired by programming for the eastern part of the study area. The result was that five scenes were acquired with the following specifications.

- Less than 10% cloud cover in each scene
- Overlap (between scenes): 10%
- Overlap (between pairs): 10%
- B/H ratio: 0.7

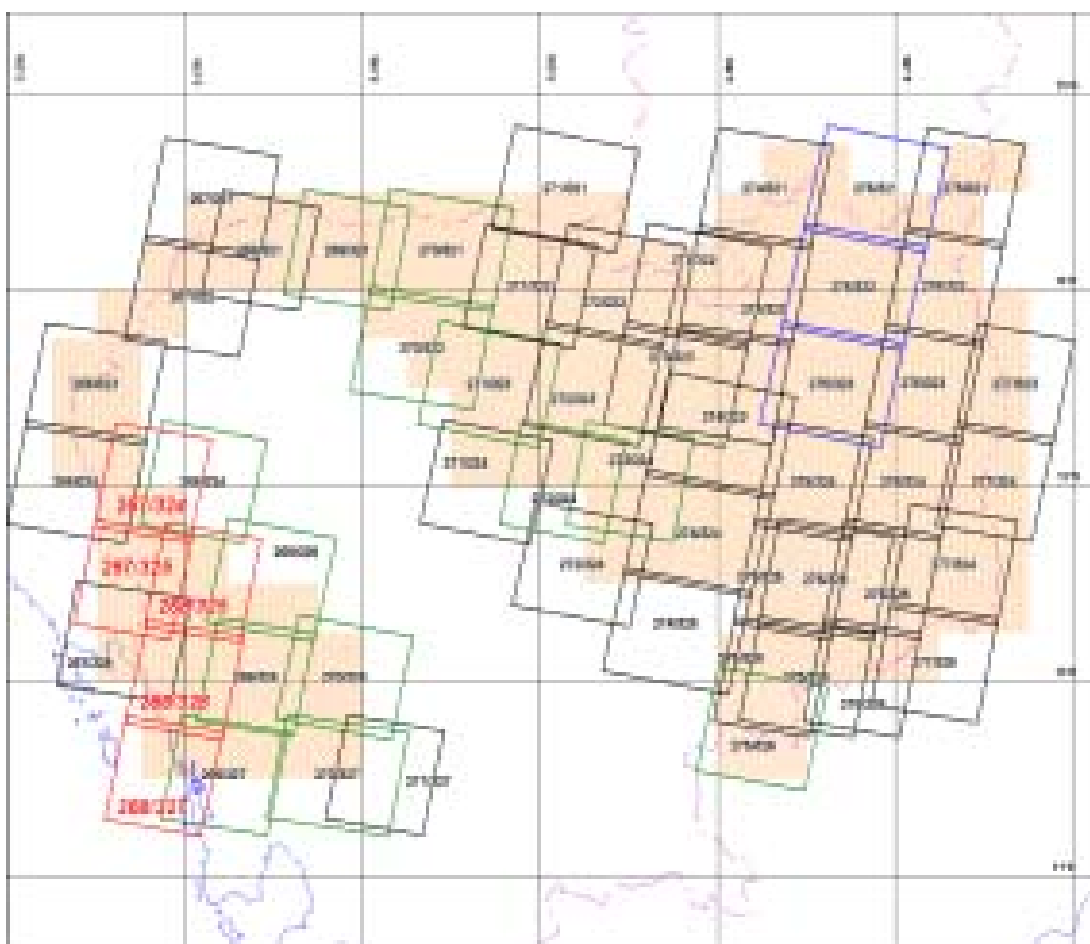


Figure 8: SPOT coverage

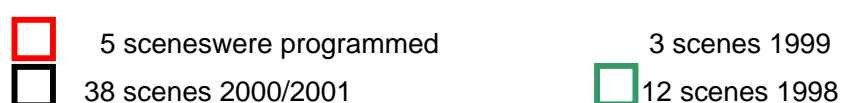


Table 9: 52 panchromatic SPOT scenes 1998/2001

NO.	Satellite	K/J	Date	Time	HRV	Spectral mode	Viewing angle	Cloud cover	Quality	Shift
1	4	266/322	20001105	33453	1	M	-26.9	ABAAAAAA	EEEE	0
2	4	266/323	20001105	33501	1	M	-26.9	AAAAAA	EEEE	0
3	4	266/324	20001105	33510	1	M	-26.9	AAAAAA	EEEE	0
4	4	267/321	20001105	33443	2	M	-23.7	AAAAAA	EEEE	1
5	4	267/322	20001105	33452	2	M	-23.7	AAAAAA	EEEE	1
6	4	267/325	20001105	33517	2	M	-23.7	ABABACAC	EEEE	6
7	1	268/321	20000403	34503	2	P	1.5	AAAAAA	EEEE	6
8	1	268/324	19980321	35131	1	P	16.8	AAAABAAA	EEEE	0
9	2	269/321	19980501	33225	2	P	-18.2	AAAAAA	EEEE	6
10	1	269/325	19980321	35138	2	P	20.6	AAAAAA	EEEE	0
11	2	269/326	19980101	34202	2	P	-2.5	ABAAAABA	EEEE	0
12	1	269/327	19980103	33118	1	P	-18.6	BBABABAB	EEEE	0
13	1	270/321	19980312	32355	1	P	-28.2	AAAAAA	EEEE	6
14	1	270/322	19980312	32403	1	P	-28.2	AAAAAA	EEEE	6
15	2	270/326	19980309	35306	2	P	24.8	ABABABAB	EEEE	0
16	1	270/327	19980312	32446	1	P	-28.2	AAAABACB	EEEE	0
17	1	271/321	20001107	35444	2	P	28.9	AAAAABAB	EEEE	0
18	2	271/322	20010107	35027	1	P	21.6	ABABAAAA	EEEE	0
19	2	271/323	19980309	35240	1	P	27.9	BBCBBABB	EEEE	0
20	2	271/324	20010107	35044	1	P	21.6	AABABBBB	EEEE	0
21	1	271/327	20010225	34020	1	P	-3.6	AAAAAA	EEEE	0
22	1	272/322	20001102	35059	1	P	25.1	AAAAAA	EEEE	0
23	1	272/323	20001102	35108	1	P	25.1	AAAAAA	EEEE	0
24	1	272/324	19980311	34336	1	P	17.5	AAAAAA	EEEE	0
25	1	272/324	20000121	34908	2	P	26.2	AAAAAA	EEEE	8
26	1	273/322	20001102	35058	2	P	28.2	AAAAAA	EEEE	0
27	1	273/323	20001102	35107	2	P	28.2	AAAAAA	EEEE	0
28	2	273/324	19980202	32604	1	P	-18.6	ABAAAAAA	EEEE	0
29	2	274/321	20010219	32323	1	P	-22.7	AAAAAA	EEEE	0
30	2	274/322	20010219	32331	1	P	-22.7	AAAAAA	EEEE	0
31	1	274/323	20001224	35114	2	P	30.3	AAAAAA	EEEE	5
32	2	274/323	20010219	32340	1	P	-22.7	AAAAAA	EEEE	0
33	1	274/324	20001224	35123	2	P	30.3	AAABAAAA	EEEE	5
34	1	274/325	20001224	35132	2	P	30.3	AAAAAA	EEEE	5
35	1	275/321	19991221	34522	1	P	27.9	AAAAAA	EEEE	0
36	1	275/322	19991221	34530	1	P	27.9	AAAAAA	EEEE	0
37	1	275/323	19991221	34539	1	P	27.9	AAAAAA	EEEE	0
38	2	275/324	20010208	33522	2	P	5.6	AAAAAA	EEEE	0
39	1	275/325	20010131	32041	1	P	-24.1	AAAAAA	EEEE	0
40	2	275/325	20010208	33530	2	P	5.6	ACACACAC	EEEE	0
41	1	275/326	20010131	32050	1	P	-24.1	AAAAAA	EEEE	0
42	2	275/326	20010208	33539	2	P	5.6	ACACAAAA	EEEE	0

43	4	275/327	20010310	33111	2	M	-2.5	BAAAAAAA	EEEE	0
44	2	276/321	20010301	33100	2	P	1.5	AAAAAAA	EEEE	0
45	2	276/322	20010301	33109	2	P	1.5	AAAAAAA	EEEE	0
46	2	276/323	20010301	33117	2	P	1.5	AAAAAAA	EEEE	0
47	2	276/324	20010301	33126	2	P	1.5	ABAAAAA	EEEE	0
48	2	276/325	20010301	33134	2	P	1.5	AAAAAAA	EEEE	0
49	2	276/326	20010301	33143	2	P	1.5	AAAAAAA	EEEE	0
50	1	277/323	20000212	32539	2	P	-1.9	AAAAAAA	EEEE	0
51	1	277/324	20000212	32547	2	P	-1.9	AAAAAAA	EEEE	0
52	1	277/324	20010131	32031	2	P	-18.9	AAABAAA	EEEE	8
53	1	277/325	20010131	32039	2	P	-18.9	AAAAAAA	EEEE	8

Information for the New Programmed Scenes (5 scenes)

NO.	Satellite	K/J	Date	Time	HRV	Spectral mode	Viewing angle	Cloud cover	Quality	Shift
1	4	267/324	20011225	35305	2	M	12.2	CBBABABA	EEEE	0
2	4	267/325	20011225	35313	2	M	12.2	AAAAABAB	EEEE	0
3	2	268/325	20020101	34559	1	P	1.6	AAAAAABA	EEEE	0
4	4	268/326	20020110	34536	2	M	2.0	BBBBBBBB	EEEE	0
5	4	268/327	20011130	33433	1	M	-18.8	BBABAAAA	EEEE	0

(3) Methodology of SPOT Ortho Image Processing

Spot ortho-rectified images were generated by Erdas Imagine using the DTM obtained from MRC (50m grids spacing) and SPOT images. The ortho-images were produced to show the features at their true geographical locations and to serve as the images for interpretation/transfer. They were also used for the vector extraction of features for topographic data preparation by Head-up Digitizing. The 60 Spot ortho-images were generated for the study area.

The operation manual was also attached in this report for the technical transfer.

The methodology of the SPOT ortho-image processing is presented in Fig. 9.

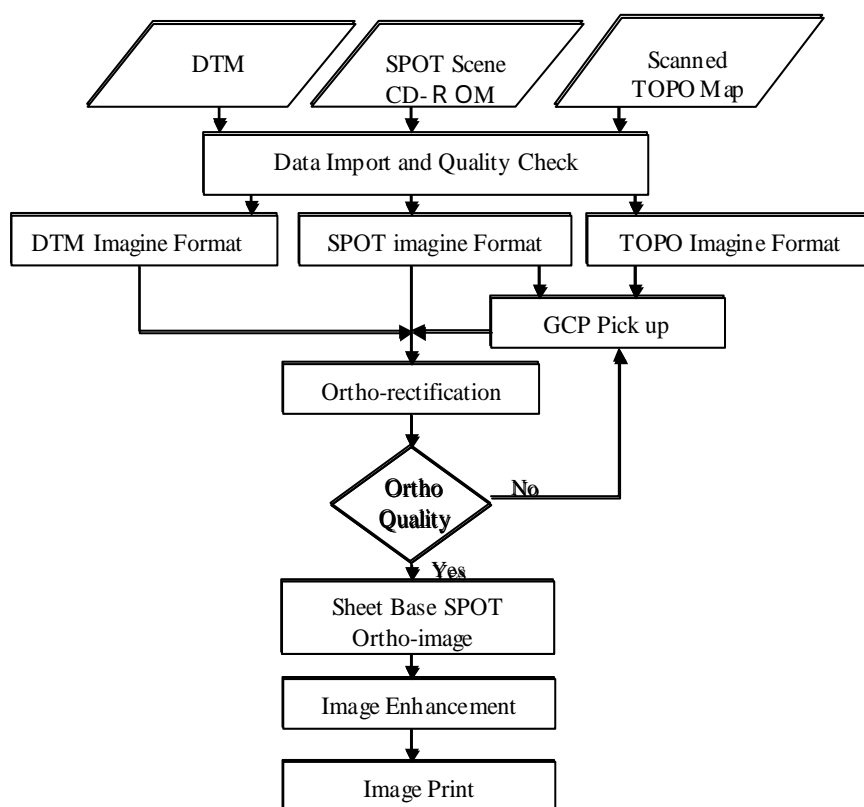


Figure 9: Workflow for SPOT Ortho Image Processing

A brief description of the major steps is mentioned below. Also, the detail operation manual for the creation of SPOT ortho-image by ERDAS Imagine is attached with this report for the technical transfer.

1) Data Import and Quality Check

All the SPOT image scenes mentioned in the above tables were put into the computer using “Import Data Function” of ERDAS Imagine8.4. Similarly, the geo-coded scanned TOPO maps (scale 1:50,000) and the DTM data were also imported into the Imagine8.4 format (*.img). On checking, both DTM and TOPO data were found to be usable for the SPOT ortho-rectification.

The projection parameters of scanned TOPO and DTM were made the same as follows:

Table 10 : Projection

Projection Type	UTM
Zone	48
Spheroid Name	Everest 1830
Datum Name	Indian 1960 (Vietnam Near 16 ° N)
Units	Meters

2) GCP Pick up

Using the “Geometric Correction Function” of ERDAS Imagine 8.4, the GCP (Ground Control Points) that could be identified in both SPOT image and geo-coded scanned TOPO data were picked up for ortho-rectification. The first priority was given to pick up the intersection of roads or location of bridges, etc. In case, where such features were not found, the other necessary GCPs were picked up from the river intersection or even from the meandering point of the river. Attention was also given to ensure that the collected GCPs were distributed throughout the SPOT scene. In general, between 20 and 30 GCPs were picked up for one. The RMS (Root Mean Square) error was kept as low as possible, which in general remained within 1.0 (i.e. inaccuracy within 1 pixel).

3) Ortho-rectification

After achieving the desired RMS error as mentioned in point (2), the re-sampling process was performed using the NN (Nearest Neighbor) interpolation method with 10-meter grid spacing (pixel size).

The ortho-rectified SPOT image outputted from the above process was evaluated by comparing it with the geo-coded scanned TOPO data. During comparison, due consideration was given to the matching of linear features such as roads and rivers. In case any portion of the SPOT ortho-scene showed poor result, the correction was made by adding more GCPs in that area and then, performing the re-sampling again. Thus, at last, SPOT ortho-images of better quality were achieved.

4) Preparation of Sheet Base SPOT Ortho-image

The sheet base (with a scale of 1:100,000) SPOT ortho-image data was prepared from the above scene base SPOT ortho-images by performing clipping and then pasting functions. As shown in Fig. 5, the sections of SPOT ortho-image scenes

falling within a sheet were clipped separately. Then, all these sections were compiled into one.

5) Image Enhancement

In general, due to the lower brightness level of pixels, the original image looks darker. Hence, to make the sheet base SPOT ortho-images more interpretable, further processing to raise the brightness level of pixel appropriately was performed. For this, first, statistical computation was done for each sheet. Then, the grayscale of each pixel value was changed with a standard deviation of 2.0 and was enhanced using 5 X 5 image filter.

6) Image Print

The enhanced sheet base SPOT ortho-images were printed at the scale of 1:100,000. All prints have tics in a latitude/longitude, UTM grid line along with labels (as shown in Fig. 10), acquired date, and other related information. This layout was made with ESRI Arc/Info8.2.

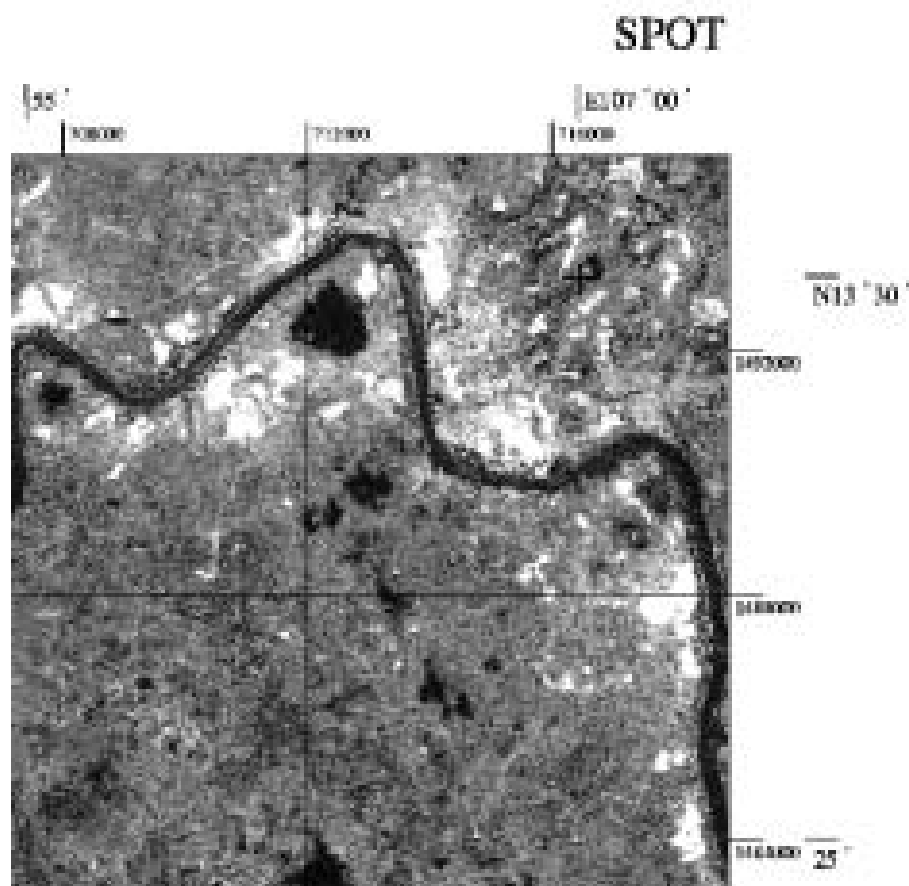


Figure 10 : Sample of SPOT Ortho Image Print (Scale 1:100,000)

6.1.4. Landsat Geo-referenced Images

Besides the aerial photographs, the use of Landsat TM (Thematic Mapper) and ETM (Enhanced Thematic Mapper) images are essential source data for the effective thematic map generation. As listed in Table 2, the selected Landsat images covering the entire study area were acquired between 1998 and 2000. Geometric correction and other necessary image processing carried by ERDAS Imagine 8.4. Two sets of color-composite images at a scale of 1:100,000 were provided to MPWT for the interpretation of land use and geology/geomorphology (land form) mapping.

Table 11: List of Landsat Images

S. No.	Path-Row	Required Quadrant	Remark	Acquired Date
1	124-051	All	T M	08 JAN 2000
2	125-050	All	E T M+	27 MAR 2000
3	125-051	All	E T M+	24 DEC 2000
4	125-051	All	E T M+	27 MAR 2000
5	125-052	All	E T M+	06 NOV 2000
6	125-052	All	T M	28 NOV 1999
7	126-050	All	E T M+	31 DEC 2000
8	126-051	All	E T M+	31 DEC 2000
9	127-050	All	T M	13 JAN 2000
10	127-051	All	T M	13 JAN 2000
11	127-052	All	T M	07 JAN 1998
12	128-050	All	E T M+	13 FEB 2000
13	128-051	All	E T M+	13 FEB 2000

(1) Methodology of Geo-referenced Landsat

1) Data Import

Includes all data mentioned in Table 12, which were imported into the computer using ERDAS Imagine 8.4. An “import data method” was used to convert the Landsat TM raw data into Imagine 8.4 format (*.img). A scanned topographic map was also imported into the Imagine 8.4 format.

2) GCP Pick-up

The GCP(Ground Control Point) picking up was done with ERDAS Imagine 8.4. First, 1/50,000 topographic map image data for the reference data, as in Fig. 11, was prepared. Reference data have geo-coordinates, and can be used like a map on the computer using ERDAS Imagine 8.4, ESRI Arc/Info and ArcView is the most popular GIS software in Cambodia).

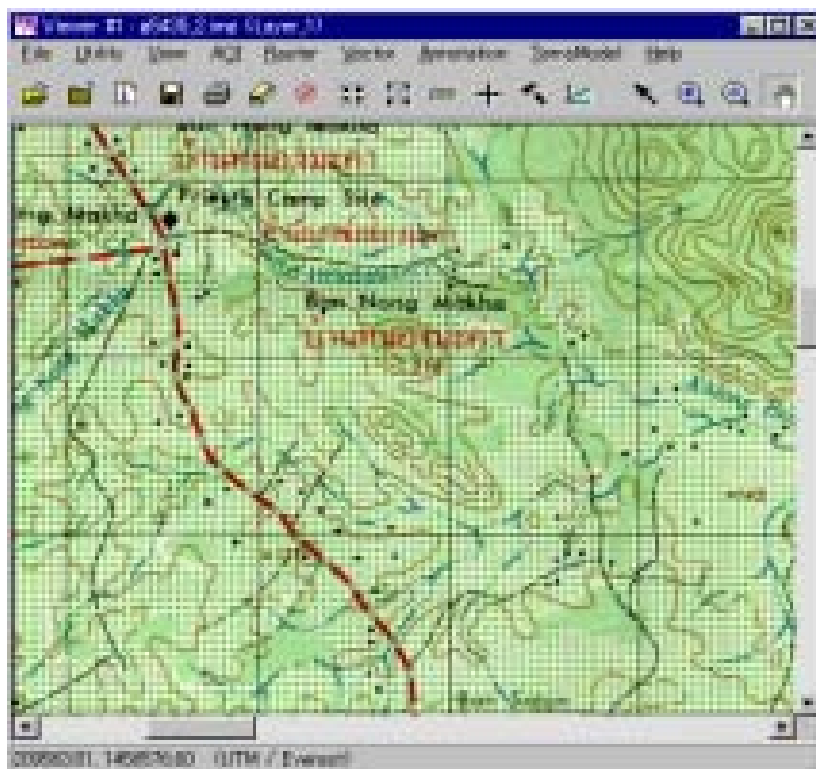


Figure 11 1/50,000 Topographic Map Raster Data

To pick up the GCP from the Landsat TM Image and topographic map image, the reference location (such as the intersection point of roads, bridge locations along the road, etc) should be identified as is the road junction shown in Fig 12. Where no such reference location is found, the meandering point of the river must be used. As shown in Fig. 13, the GCP was picked up from the meandering point of the river, because the road intersection was not visible.

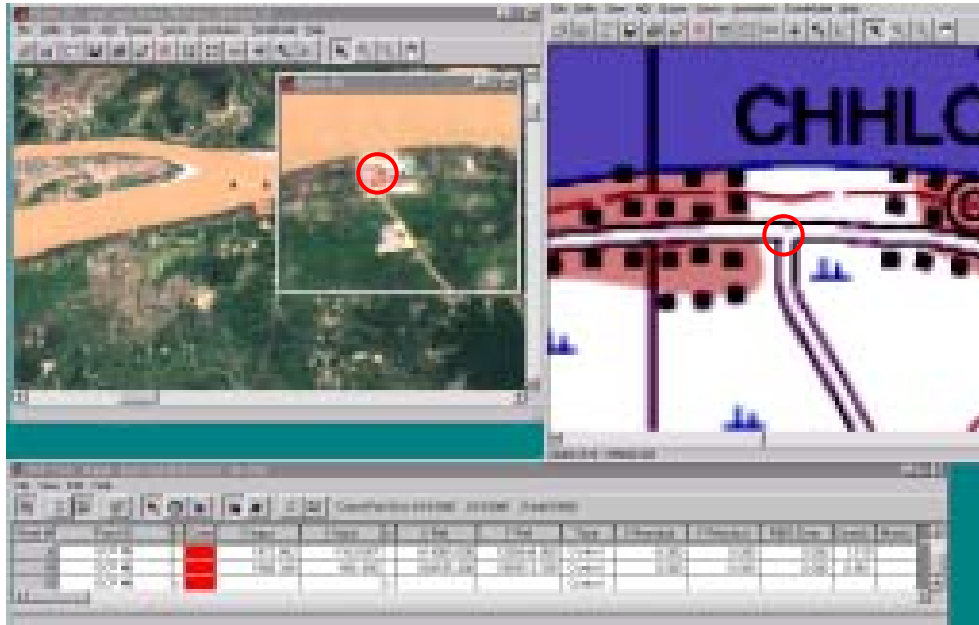


Figure 12: GCP in the Road Junction

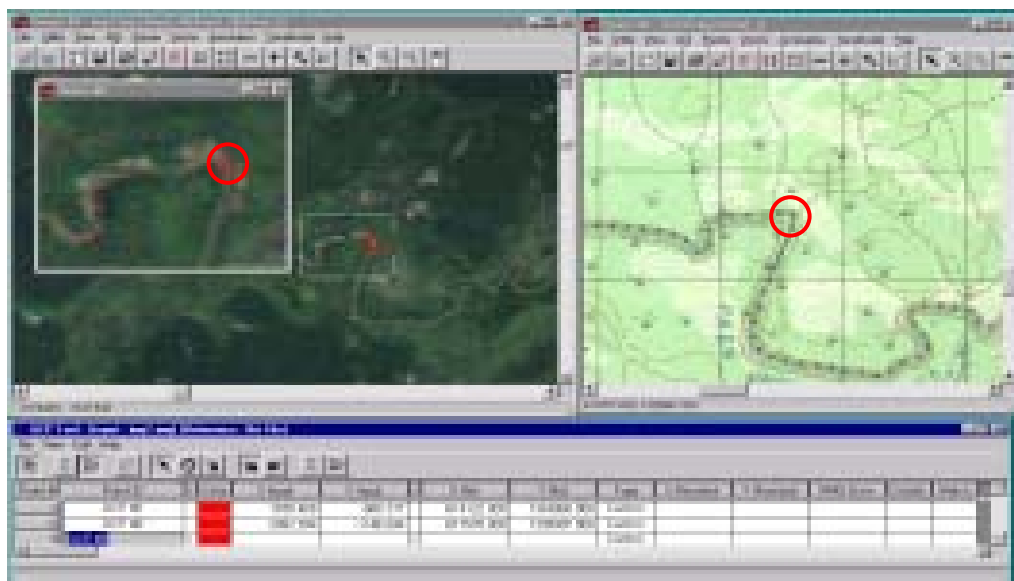


Figure 13: GCP in the Meandering Point of River

Between 20 and 30 points of GCP were picked up so as not to overly emphasize one area. Then, approximately 20 GCP were selected for the lowest value of RMS(Root Mean Square) error calculation from GPC list. There was an RMS error within 1.0 for an accuracy within 1 pixel.

3) Geo-correction

Geo-correction, which is re-sampling, was performed to add geo-coordinates to the image. First, it was used to create numerical expression for removed geometrical warp in Landsat TM Image data using GCP, by scene. Re-sampling processing can be done using one order linear expression. The interpolation method used in this re-sampling process was NN (Nearest Neighbor). And the projection used was the same as the 1/50,000 topographic map image data. This re-sampling process is called geo-correction or rectification. Geo-coordinate was given to Landsat TM Image data by this re-sampling process. The quality of image data with geo-coordinates needs to be evaluated using reference data after geo-correction. Quality was evaluated based on the overlay of 1/50,000 topographic map image data on Landsat TM Image with geo-coordinates. In this evaluation, it had to be confirmed whether or not the road or river feature of the image data matched the topographic map image data. As a result, all scenes showed no difference from topographic map image data.

4) Band Combination

There are seven bands in the Landsat TM Image data. The characteristic of the reflected wave from the land cover depends on each band. This study used band combinations as in Phase 1. It assigned red to Band 4, green to Band 5, and blue to Band 3. This procedure was for the benefit of the land use and land form interpreter teamland form who had experience in Phase 1 with this band combinationPhase 1. This improved quality assurance, as related to their interpreting work. This band combination also shows characteristics of land cover in tropical and subtropical areas as in Fig. 14.

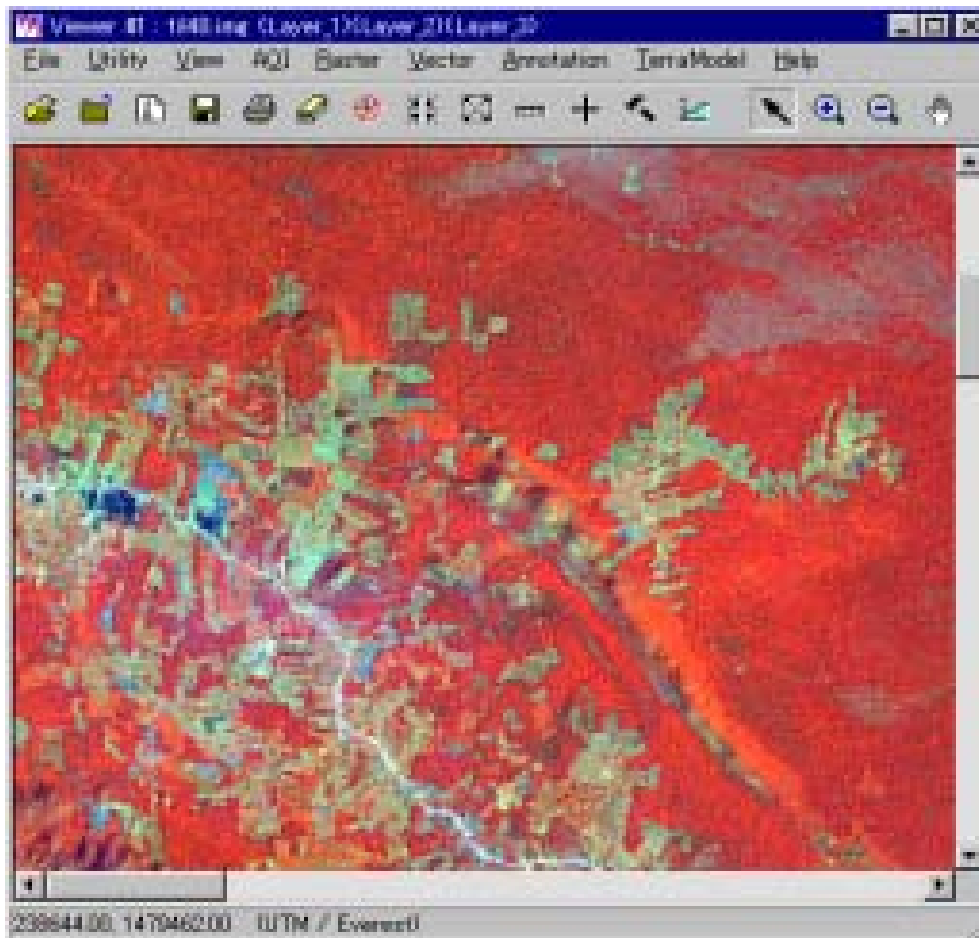


Figure 14: Band Combination R=4:G=5:B=3

5) Image Enhancement

In general, there are dull objects in the Landsat TM image as the brightness level of the original pixel value is low, and this result in dark image which it is difficult to see. To make it easier to interpret, image enhancement processing is necessary after geo-correction processing. Therefore, to raise a brightness level of the pixel value appropriately, statistical computation is done for each scene. Then, grayscale in pixel value was changed within standard deviation of 2.0, and was enhanced using 5 X 5 image filter.

6) Image Print

This study made Landsat TM Image photo map with scale of 1 to 100,000 after image processing. This map has grid line, value of latitude longitude, tics,

acquired date and band combination as in Fig 12, and this was made with ESRI Arc/Info8.2.

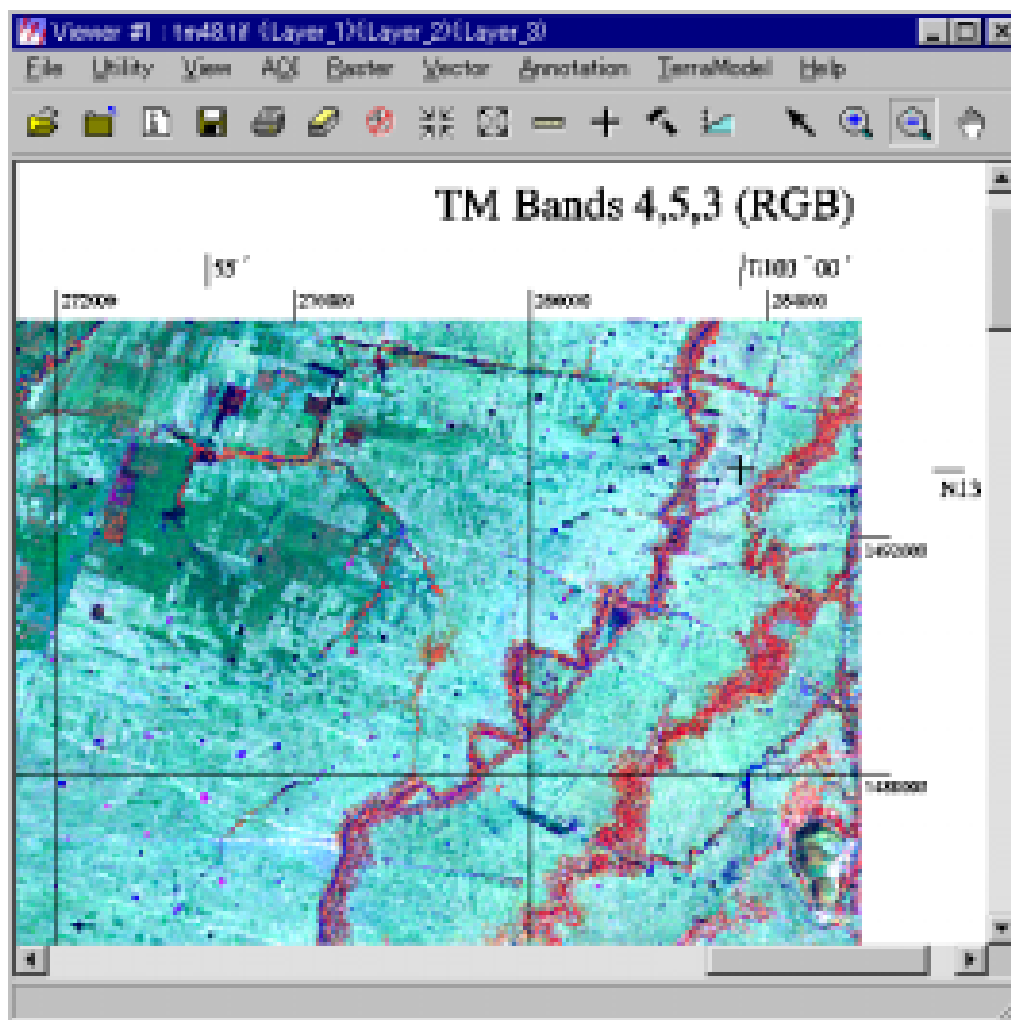


Figure 15 Landsat TM Image Photo Map

6.1.5. IRS Satellite Ortho-Rectified Images

Around the northwest part of Cambodia (specifically the Thai border), aerial photographs could not be acquired in 2002. So, for this area, the ortho-rectified IRS satellite with 5m resolution was used to capture infrastructure data as a first draft to avoid delay of the project schedule. Later on, this draft interpretation result was verified with aerial photographs subsequently acquired in 2003 and on field trips.

The area of the adopted IRS scene is as shown in Figure 16.

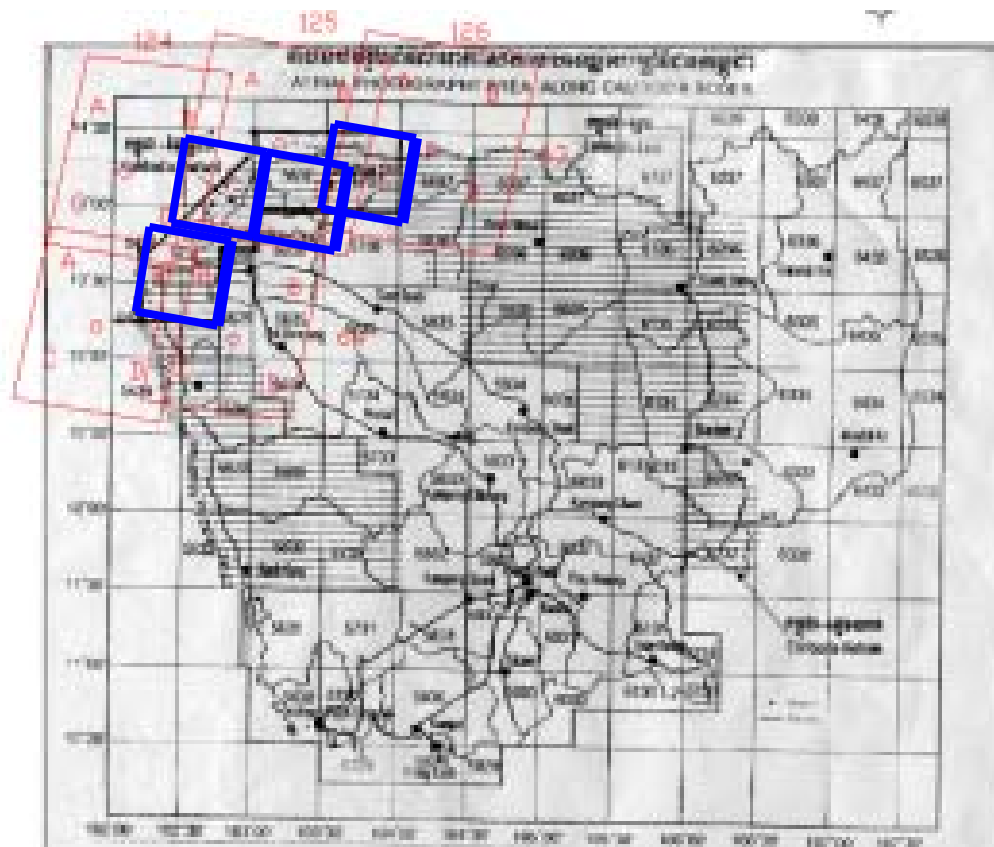


Figure 16: IRS Coverage

6.1.6. Ortho-photography

All data-capturing activity should be based on SPOT as base data, fundamentally. Some sections, however, could not be seen clearly on the SPOT images, due to technical problems (10-m resolution) related to the extraction of ground features. For acquiring information, the aerial photographs were scanned and ortho-rectified. The distortion of the aerial photographs was rectified using DTM after acquiring GCP from the SPOT ortho-imagery. The base images for interpretation and graphic were overlaid on the SPOT images.

6.2. Interpretation

As interpretation work is intended to play the most important role in establishing GIS data-set in the study, the work was done very carefully. Also, maximum guidance was provided by the collection of existing materials, which were used to substitute for the lack of field checking.

According to the S/W agreement, MPWT was to have undertaken the interpretation work. Yet, as skilled technicians within MPWT were unavailable due to retirement or having moved to another agency after the completion of Phase 1 of the project, the study team decided to re-train the interpretation technicians of MPWT for land use by bringing in skilled people recruited from other agencies to be the training core.. These experienced interpreters were recruited from other government agencies such as the Ministry of Environment, Agriculture through the network of MPWT.

6.2.1. Interpretation for Infrastructure Information

Interpretation works for the topographic map information were executed on the aerial photographs with a scale of 1:25,000, as much as possible. Also, existing topographic maps and other materials were used to assist the interpretation work. Interpreted features such as the road classification, canals, villages, and small ground features (schools, temples, etc.) were confirmed by the fieldwork in the third year, 2002.

- (1) Items interpreted and classified using aerial photographs in accordance with the rules of map symbol application are:
 - villages
 - schools,
 - temples,
 - roads classification and bridges
 - hydrology
 - etc.
- (2) The items collected from the existing data-set for the topographic map information are:
 - government buildings,
 - geographical names

- administrative boundaries
- MRC contour line
- river line

(3) Vegetation boundary

A vegetation boundary was delineated using the method of re-classification of land use boundary by ArcInfo coverage.

6.2.2. Interpretation for Land Use

The project area consisted of two sections: A) east of the Mekong River and B) west of the Mekong River. The resources database for interpretation for land use consisted of latest Landsat and SPOT imagery at a scale of 1:100,000, and aerial photos dated ranging from 1994 to 2001. However, aerial photos of some parts of the western section could not be acquired within the timeframe of land use interpretation. Thus, for those areas aerial photographs could not be included as resource database.

The general procedure for land use is described below:

(1) The classification for land use interpretation.

The classification used was the standard classification developed and used by the Mekong River Commission, which originated the mapping of Cambodia. This would ensure that the land use and vegetation data conform to the data of the region. The training and supervisory staff were managed by the experts of the study team. The same land use classification legend as used in Phase 1 was applied in Phase 2. The classification is noted in table below:

Table 12: Land Use Classes with Code

Land Use Code	Classification	Category	Name
1	U	Urban, Built-up Areas	Settlement
2	I	Urban, Built-up Areas	Infrastructure (Airfield, factory, etc.)
3	Ar	Agricultural lands	Paddy field
4	Al	Agricultural lands	Receding and Floating rice fields

5	Au	Agricultural lands	Field crop
6	As	Agricultural lands	Swidden agriculture (Slash and burn)
7	Ao	Agricultural lands	Orchard
8	Ap	Agricultural lands	Plantation (Rubber plantation)
9	Av	Agricultural lands	Village garden crop
10	Ag	Agricultural lands	Garden crop
11	Arv	Agricultural lands	Paddy field with villages
12	G	Grasslands	Grassland (undifferentiated)
13	Ga	Grasslands	Abandoned field covered by grass
14	Gf	Grasslands	Flooded grassland
15	Gs	Grasslands	Grass Savannah
16	Gm	Grasslands	Grass with termite mounds
17	Ms	Grasslands	Marsh and swamp
18	S	Shrublands	Shrubland (undifferentiated)
19	Sa	Shrublands	Abandoned field covered by shrub
20	Sf	Shrublands	Flooded shrub
21	St	Shrublands	Woodland and scattered trees (C < 10%)
22	Fe	Forest covers	Evergreen broad leafed forest
23	Fc	Forest covers	Coniferous forest
24	Fd	Forest covers	Deciduous forest
25	Fdo	Forest covers	Dry Deciduous (Open) forest
26	Fx	Forest covers	Mixed forest from evergreen and deciduous species
27	Fr	Forest covers	Riparian forest
28	Fs	Forest covers	Bamboo and Secondary forests
29	Ff	Forest covers	Flooded forest
30	Fm	Forest covers	Mangrove forest
31	Fmd	Forest covers	Degraded mangrove forest
32	Fp	Forest covers	Forest plantation
33	Wl	Water Features	Lakes (>8 ha)
34	Wp	Water Features	Lakes (<8 ha)
35	Wr	Water Features	Reservoir
36	Ws	Water Features	Shrimp/Fish farming and Salt pan
37	Wo	Water Features	Others (Sea, Bay, etc.)
38	B	Soils and Rocks	Barren land
39	Bs	Soils and Rocks	Sand bank
40	Br	Soils and Rocks	Rock outcrop

(2) Photo and Satellite image interpretation

Land use interpretation was done using the entire resource database mentioned above, i.e. Landsat, SPOT, and aerial photos. The latest aerial photos of the western section remained very useful in identifying and delineating the confusion in types of land use classes. Moreover, field trips were also employed for pattern recognition as well as checking the land use classes, especially in the area where aerial photos were lacking.

At first, the infrastructure and water-related features were delineated from SPOT. This was achieved either by the screen digitizing method of displaying the SPOT data on a computer screen or by delineating on Mylar placed on top of the SPOT imagery. Then, the Mylar with these features was placed onto the Landsat imagery where all other land use classes were interpreted. While interpreting the other land use classes, care was taken not to change the boundary of infrastructure and water body information to make sure that the land use and the infrastructure and water body information fit properly. Interpretation was extended about 1 km beyond the national boundary. The interpretation work was carried out from September 2001 to the end of November 2002 with 14 interpreters. The work was allocated according to map units and the interpreted results were drafted onto a Mylar overlay using different colors to facilitate the inspection of the work.

All mapping results were inspected by the study team. Moreover, during the course of action, all necessary correction as well as problem-solving expertise was provided by the study team.

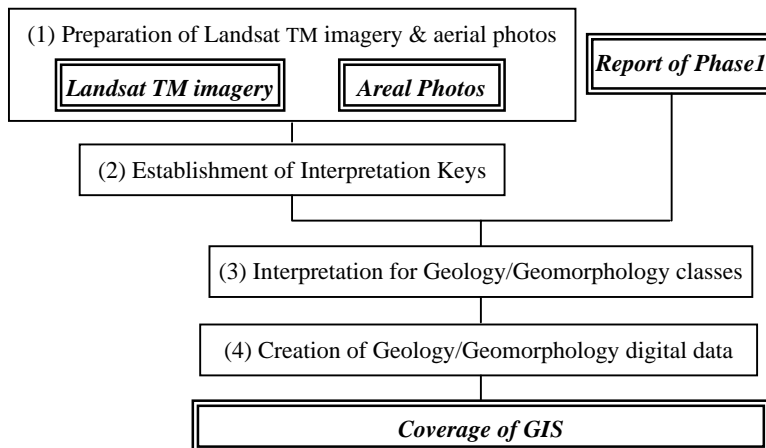
6.2.3. Interpretation for Surface Geology/Geomorphology (Land Form)

The land form analysis followed the procedure and classification used in Phase 1 to ensure that the data from the two phases are integrated to form a comprehensive analysis of the whole country.

Most development activities are related to agriculture development and road construction, and thus soil maps have been urgently needed to plan the use of the land. However, making agricultural soil maps is time-consuming, therefore a substitution of using land forms was made, which provided engineering soil data. Such data is usable for road construction and also can be interpreted for agricultural use through the soil- texture characteristics. But, many people are not familiar with the definition of land forms, and thus, for easier understanding, the term “geology/geomorphology” has been used to clarify the definition of land form.

(1) Procedures.

The analysis process consists of two steps. In the original French/Cambodian maps the unconsolidated material consisted of only alluvial material A1 and A2, and these were classified in detail. This was based on the interpretation of Landsat and SPOT imagery and aerial photography.



- (2) Integration of the input from Interpretation and information from existing geology map

The result of the procedure was that a better contact zone between the unconsolidated deposits and the rock formations was more accurate as it was easier to locate on either the aerial photos or the Landsat imagery.

- (3) Joining Phase 1 and Phase 2 Data.

The phase 1 and the phase 2 data were merged into one database.

Later a 1:500,000 landform or geology/geomorphology map was printed.

- (4) Geology Information:

In the process of this reconnaissance survey, it is concluded that in the future more detailed geologic data can be found using aerial photo and satellite image interpretation, and a recommendation will follow at the end of the chapter.

Permian limestone beds were found in Thailand outcrops in the southwest and around the town of Battambang and also outcrop were found south along the mountains range near Kampot, where it is mined to supply the cement factory there.

However, a belt of sinkholes along the southern and northern shore of the Tonle Sap are visible, where it was not deeply covered by the alluvial fans, or where the laterite cover has been eroded away. Some of the limestone formation underlays the old laterite soils north of Kompong Thom, which could be a

possible source rock for cement. This formation was mapped in detail , because it is a very important economic

It is a very good key bed to use for further geologic mapping. Sinkholes are also visible in the area west of Phnom Penh, buried under varying thickness of alluvium.

Although the limestone outcrops themselves are very limited in appearance, huge belts of sinkholes are visible. The size and density of the occurrence of the sink holes is dependent very much on the depth of the overburden, the soils or rocks above the deposits. However, they are a positive indication of limestone deposits below the surface. Some correlation was made with the occurrence surrounding outcrops as verified by boreholes. Therefore, we can confidently interpret that these areas are underlain by this calcareous material

The location of these Permian beds are also of importance to future detail mapping, because they form a good key bed for referencing the younger Triassic, Jurassic and Cretaceous eras above and eventually developing the structural geologic map of Cambodia.

- 1) Very significant are the large areas east of the Mekong River, which have been extensively eroded with soil thickness of one meter. The rock structures underneath the thin soil and the poorly secondary vegetation are clearly visible on satellite imagery. Similar areas have been eroded north and east of Phnom Kulen due to an uplift. The eroded material of these areas would probably be the source material of the deltaic deposits which filled the northern Battambang plain, while the alluvial fans along the northern shore of the Ton Le Sap Lake caused much of the deposits of the Great lake.

- 2) Several geologically recent volcanoes and lava flows can be clearly observed in the southwest region of Cambodia, indicating recent geologic activities in the Cardamon Mountains.
- 3) Huge structural patterns can be observed on the landsat images and should be mapped to obtain a better view of the geologic activities in the region.

(5) Recommendations:

The geology Department is inheriting Landsat imagery and aerial photographs for their use. They should undertake detailed studies by quadrangles selected for possible interest of the Department according to topic, such as the ones listed above. These are to get a better understanding of the distribution of mineral resources, and potential land usable for agricultural development, or land that should be conserved because of continuing dynamic activities of soil erosion.

6.3. Data transfer and Digitizing for Topographic map data

6.3.1. Ortho-Photography

All data capturing activity should be based on SPOT as base data, fundamentally. Some sections, however, could not be seen clearly on the Spot images it was due to technical problems (10m resolution) related to the extraction of ground features. Oftentimes, because it was very difficult to fix an image on the SPOT image to correlate with the interpreted results on the photographs. Ortho-photo methodology was proposed to solve this technical problem, and the following process was implemented.

Ortho-photos were created using GCPs that were collected by Spot-ortho and DTM collected by Topo-maps. It was confirmed that SPOT ortho-image and Ortho-photos are able to be overlain with acceptable error. This fusion of images is very useful to capture small objects that have been interpreted by photographs. Also, this process succeeded in increasing the image resolution for uncertain areas on Spot image.

6.3.2. Infrastructure Information

From the Spot-ortho plus Ortho-photo images produced, small ground features and linear features were extracted for the respective layers in accordance with the map symbol application rules by using ArcView 3.2.

Procedure was as follows;

(1) Transferring of the photo-interpretation result

The photo-interpreted results were transferred and arranged onto SPOT ortho images.

(2) Head-up digitizing based on Spot-ortho image

By referring the arranged items on the Spot-ortho image, screen digitizing was carried out to capture the infrastructural data using ArcView.

(3) Photographs used for the Spot-ortho plus Ortho-photo images

Only necessary photographs were ortho-rectified and overlaid onto Spot-ortho imagery to increase the resolution part by part.

(4) Visual Interpretation

(5) On-screen digitizing using ortho-rectified photos and visual interpretation was also done in reference to the interpretation results using ArcView.

(6) Attributes

(7) Attributes of digitized data were assigned by ArcView and/or ArcInfo.

(8) Products

Infrastructure data such as road network, village boundary, build-up areas, buildings, etc. are intergraded in shape file (ArcView format)

Sample data image are as shown in Figure 17.

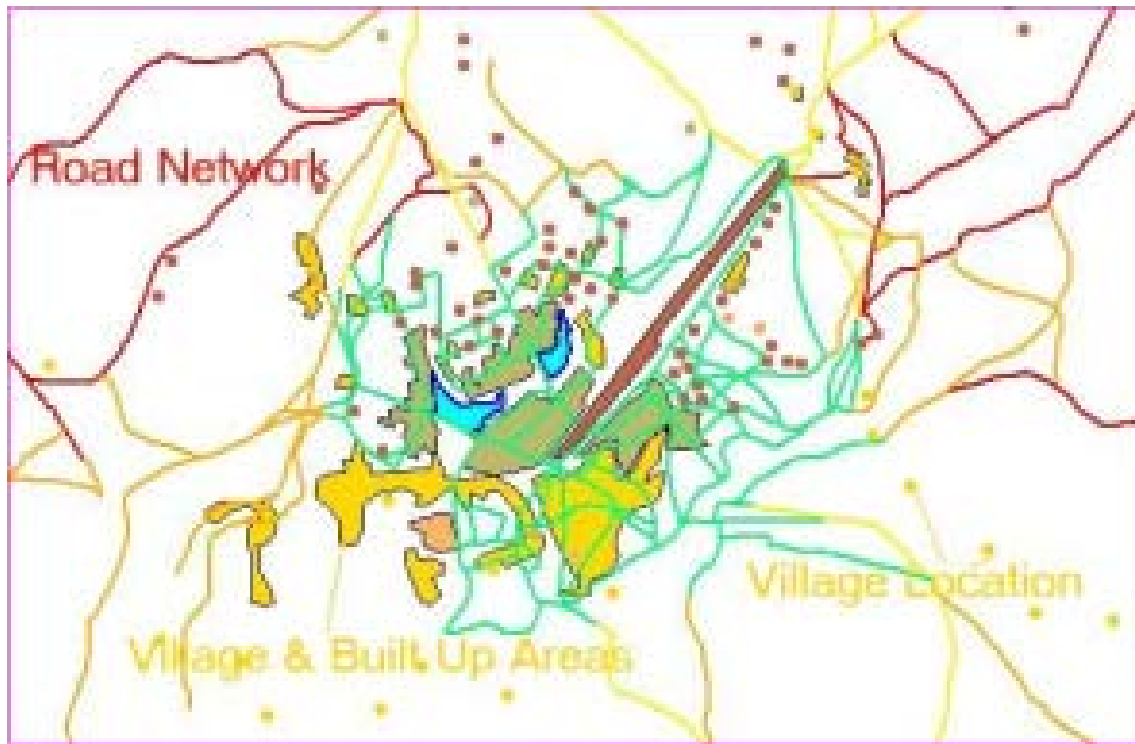


Figure 17: Infrastructure Data by ArcView

(9) Software Used

- Erdas Imagine
- PCI
- ArcView 3.2.

(10) Hardware Used

(11) A3 color Scanner.

6.3.3. Vegetation

For keeping matching of the vegetation boundaries and land use, the polygon data for land use was re-classified and placed as a vegetation boundary polygon of landform maps. Topographical data update

6.3.4. Contour Data Update

The original MRC contour lines were converted to the ArcView shape format, then using ArcView 3.2 for editing errors such as Moving Vertex to match the original contour in its topo-sheets, removing vertex to remove spikes of contour lines,

correcting sliver polygon, deleting duplicates lines, correction joined lines, adding new contour lines, adding additional line 1 Km around international, and correcting line attribute according to its value in the topo-sheet.

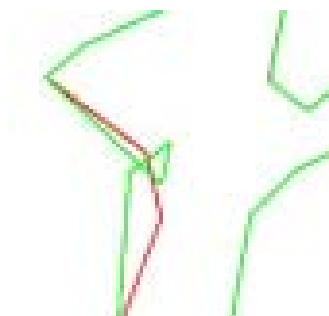
- (1) Moving Vertex to match the original contour in its topo-sheets



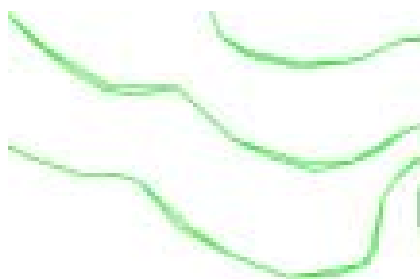
- (2) Removing Vertex to Remove Spikes of Contour Lines



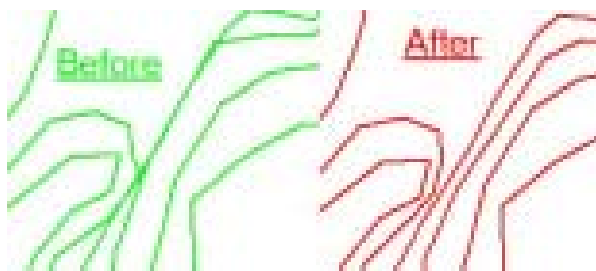
- (3) Correcting Sliver Polygon



- (4) Deleting Duplicates Lines



(5) Correction Joined Lines



(6) Adding New Contour Lines



6.3.5. Spot Height Editing

The available MRC data-set were not spot height and also contained old benchmark information. The information was therefore updated and re-digitized based on the Forest raster map. The attribute data (height value) are also attached. The data were checked by the following procedures.

- (1) Checking and correct position based on the topo-sheet map.
- (2) Checking code:
 - 102: Horizontal Control Point
 - 104: Spot Elevation in Meter
 - 106: Bench Mark, established after 1990

•

(3) Final Checking

The following checking was carried out finally using ArcInfo 8.02.

- ♦ Editing Dangles
- ♦ Edge-matching
- ♦ Joining Map Sheets Together

6.4. Data transfer and Digitizing for Land use

6.4.1. Data Transfer from Landsat to SPOT

After the Landsat interpretation, the interpreted results were transferred to the rectified SPOT Mylar plastic overlays as base image and visually adjusted to make sure that the land use and the infrastructure and water body information fit properly. The adjustment required the data transfer person to fit the Landsat and SPOT for each small area that was being transferred, and it was adjusted every time the transfer moved to another area on the map, which had infrastructure data and water bodies and streams already plotted for proper matching orientation to ensure proper data fit.

6.4.2. Scanning

- (1) The map sheet based interpreted Mylar were scanned at 400 dpi using either A0 color or a black-and-white scanner. An example of black-and-white scanned data is shown below:

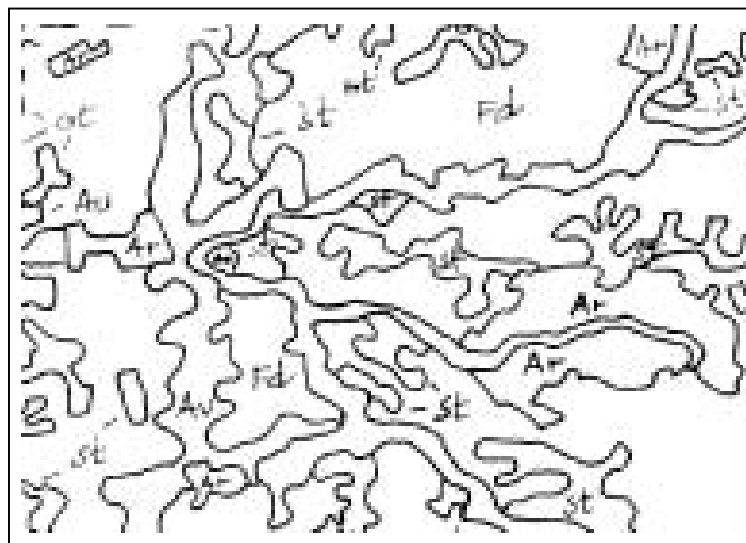


Figure 18: Scanned
land use Mylar

6.4.3. Vectorization

- (1) Vector line was converted from raster one using Raster to Vector (R2V) conversion software. Black and white scanned data were directly opened in R2V software while for color-scanned data, before opening in R2V, Adobe Photoshop software was used to extract the boundaries, only, of land use classes from the scanned map sheets by coloration. An example of converted vector lines is shown below:

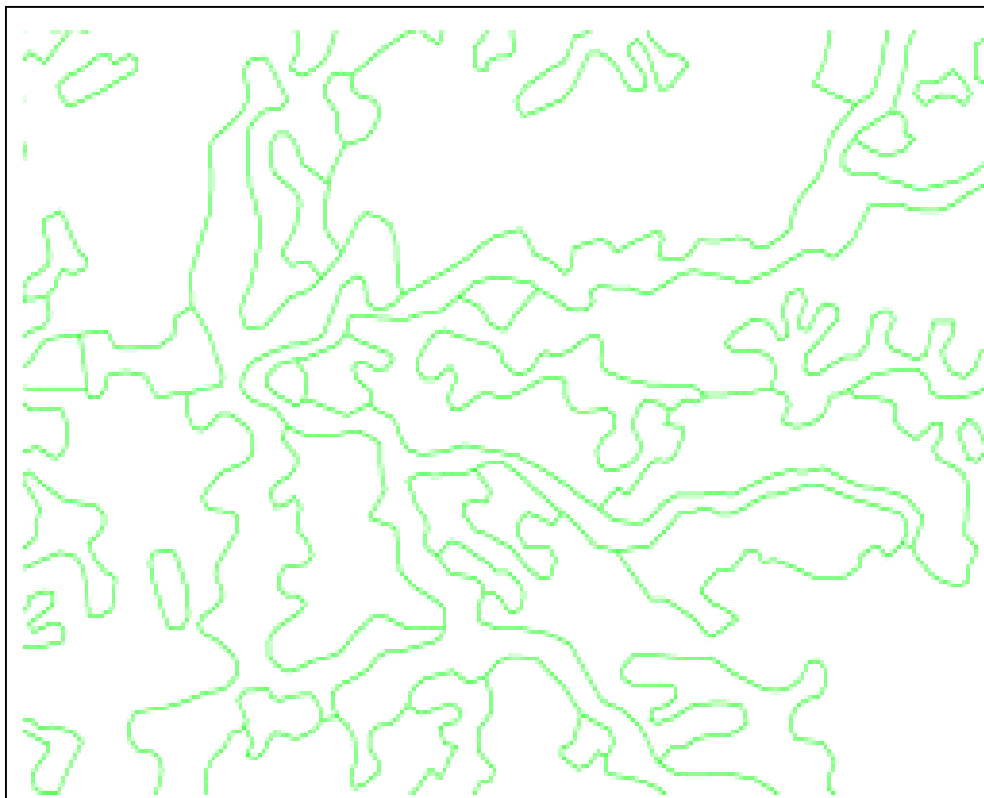


Figure 19: Converted Vector data

6.4.4. Editing converted vector lines

Then, the vector lines were imported into ArcView/ArcInfo. There, all editing

processes were made. The cleaning and building of the topology for the land use coverage was done in ArcInfo.

6.4.5. Transform land use to real-world coordinate system

The land use was transferred to the real-world coordinate system using the coordinate system as mentioned in 9.7.1

6.4.6. Assigning attribute to coverage

After cleaning and building topology for the coverage, every polygon was assigned with an attribute to make a land use map. An example of land use data with their attributes (classifications) is shown below:

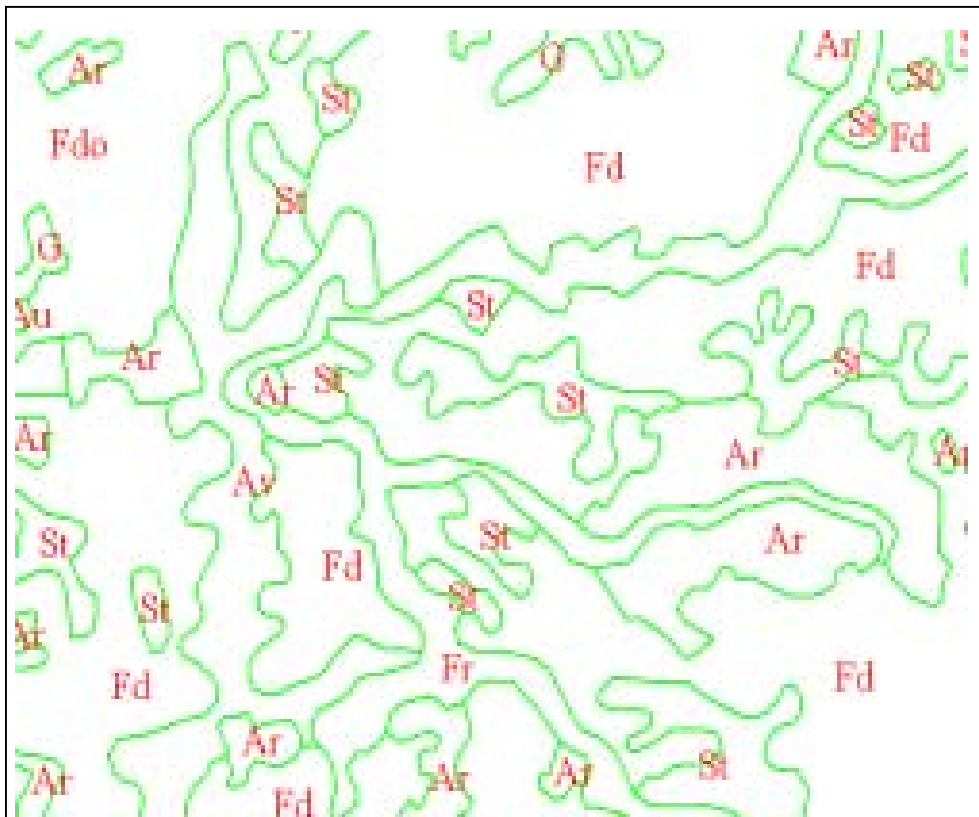


Figure 20: Attributed data

6.4.7. Accuracy check

(1) The check plots were prepared to perform the detail checking of the data. In brief, this included the following points:

- Checking polygons for closure
- Checking polygons for missing labels
- Checking polygons for wrong labels
- Check polygons for corrected class by Inspector (for those maps that by-pass the inspection and were sent directly before final check).

6.4.8. Checking land use boundary with digital satellite data

The land use coverage was finally checked with SPOT digital data in order to be sure that the boundary of infrastructure and water body categories of land use matched. Similarly, the boundary of other land use classes was checked with Landsat digital data. If necessary, some adjustments were made to fit with the digital data.

6.4.9. Edge Matching and Joining Map Sheets

The land use data of all adjacent map sheets were first edge-matched and then joined to be sure they fit together.

6.4.10. Software Used

- ArcInfo Ver.8.02
- ArcView Ver.3.2
- R2V (Raster to Vector Software)
- Photoshop Ver.6.0

6.5. Data transfer and Digitizing for Geology/Geomorphology (Land Form)

The methodology for creating Geology/Geomorphology digital data was almost the same of Land use data creation.

6.5.1. Scanning

The map sheets based on interpreted transparent films were scanned with A0 black and white scanner at 300dpi.

6.5.2. Editing raster data

The scanned map data was edited by using Adobe Photoshop software to reduce the fixing work after vectorization.

6.5.3. Vectorization

Vector lines were converted from scanned raster data with using Raster to Vector (R2V) conversion software.

6.5.4. Editing converted vector lines

The vector lines were imported into ArcView or ArcInfo for editing. After then, cleaning the data and building the topology for the Geology/Geomorphology data was done in ArcInfo.

6.5.5. Assigning attribute to coverage

Every polygon was assigned with attribute to make Geology/Geomorphology map by using ArcView.

6.5.6. Accuracy check

The check plots were prepared to perform the detail checking of the data. In brief, this included regarding the following points:

- Checking polygons for closure
- Checking polygons for missing labels
- Checking polygons for wrong labels
- **Checking polygons for corrected class by Inspector**

6.5.7. Edge Matching and joining Map Sheets

The Geology/Geomorphology data of all adjacent map sheets were edge matched at first and then joined together as one coverage.

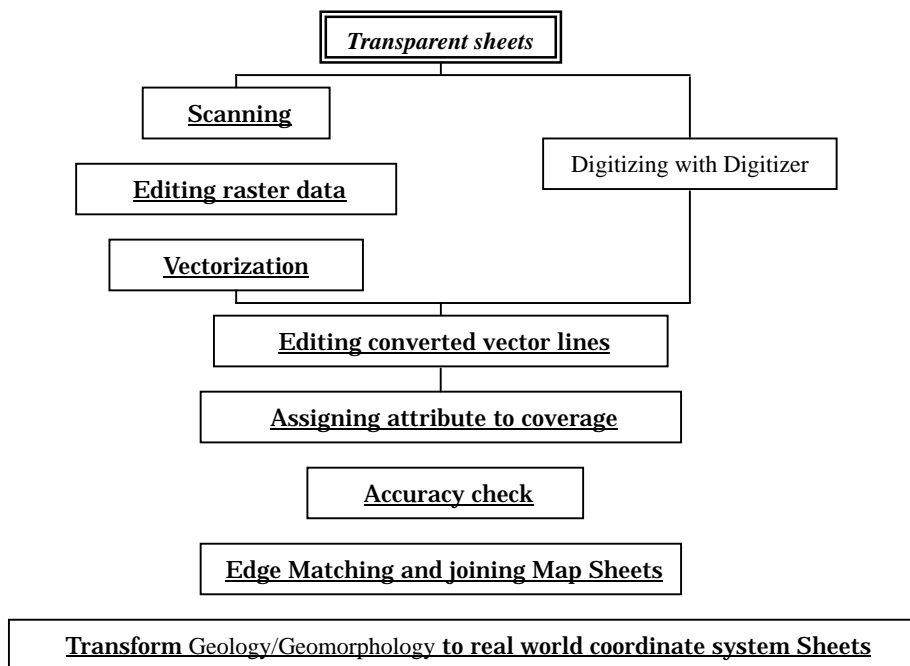


Figure 21: The methodology of creation of Geology/Geomorphology digital data

All rock formations were outlined as rock (RX). The detailed rock information from the French/Cambodian geology map supplied by the Department of Geology replaced the RX polygons of the interpreted landform classes using GIS.

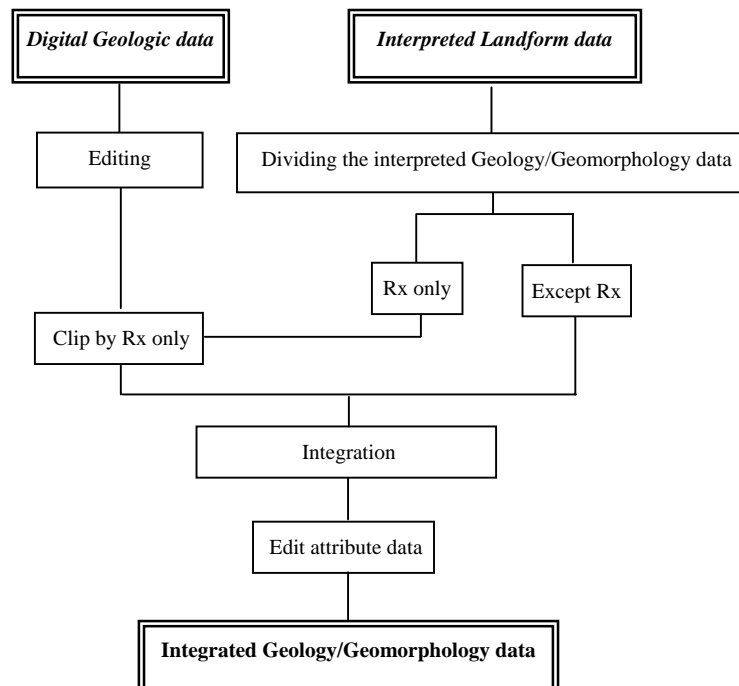


Figure 22 The Methodology of Integration of Geology/Geomorphology data

6.6. Map Symbolization

The topographic map data of Phase 2 were symbolized in accordance with the map symbol application rules of Phase 1, which is shown at ANNEX I.

Adobe Illustrator was used as editing software for the map symbolization.

The various infrastructure data layers are converted from ArcView files to individual Adobe Illustrator files. In addition, the contour line, vegetation boundaries, administration boundaries, village names and annotations were also output into separate Illustrator files.

Khmer annotation character files were created in accordance with MPWT and NGD. All of these layer files are then combined within Adobe Illustrator to create a single file for each specific map sheet. Symbol coloring, line types and patterning were all created, configured, and applied.

The procedure of symbolization was as follows:

(1) Preparation of grid lines and map frame

- 1) Divided tick lines and the coverage for grid lines were prepared by Arc Info based on the latitude and the longitude shown at the corner of each print.
- 2) Geographic co-ordinates for GIS base data to be included, map frame, and tick grid were converted from the latitude and the longitude into UTM.
- 3) Based on the processed GIS base data as above, either EPS (Encapsulated PostScript) with the regulated scale or the data formatted for Illustrator software were prepared. Each included class in the GIS base data were discriminated in color by layers.

(2) Preparation of marginal design

- 1) A regulated legend and the data for the marginal information layers were prepared by Adobe Illustrator.

(3) Preparation of map symbols and patterns

- 1) Map symbols were prepared with brush function of Adobe Illustrator.
- 2) The vegetation patterns were prepared by Adobe Illustrator.

(4) Topographic data conversion

- 1) Topographic data captured or edited by ArcView was converted into a DXF file. Annotation data and political boundaries were also converted.

(5) Map Symbolization with Adobe illustrator

- 1) The data imported from DXF files were given an actual scale.
- 2) Each line features were assigned colors and styles according to specification.
- 3) Each point features were assigned symbols according to specification.
- 4) Each polygon features were assigned colors or patterns according to specification.
- 5) Annotations, marks of the maps, and other decorations were prepared.
- 6) The marginal design and legend were completed.
- 7) After completing all the above processes, the draft maps were plotted out for visual checking.

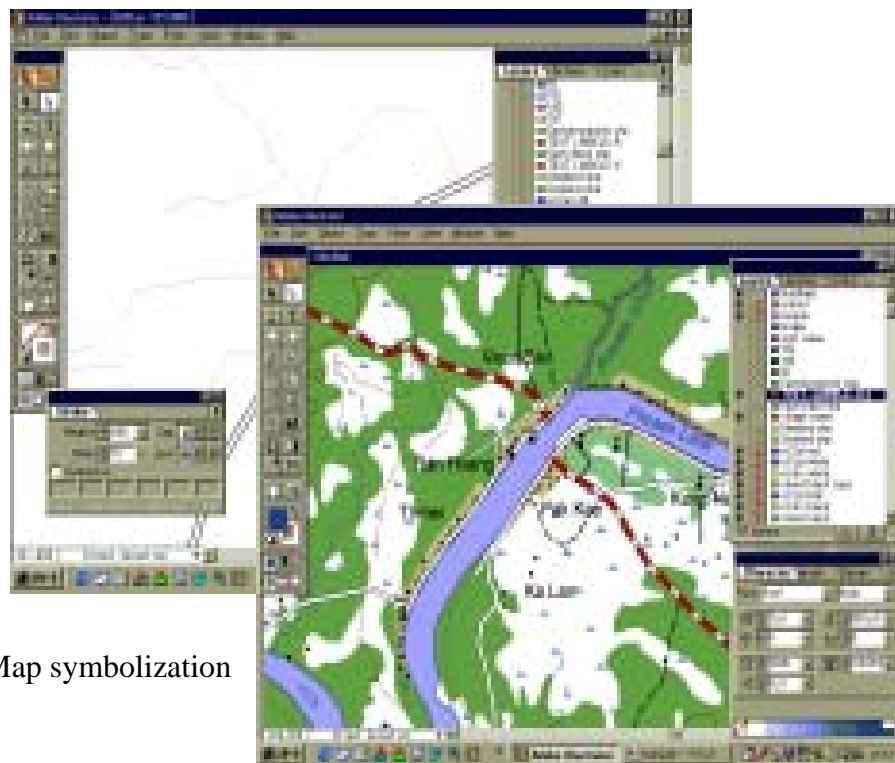


Figure 23: Map symbolization

6.7. Printing of Topographic Maps

Final topographic maps were printed by offset printing. The procedure was as follows:

(1) Preparation of film for plate making

Five positive films for plate making were prepared for each map sheet.

(2) Printing Plates

Printing plates for the respective colors were made from the positive film using aluminum PS plates.

(3) Proof prints

Proof prints from the printing plates were made by a flatbed offset machine.

(4) Proofing

The proof prints were checked for quality of coloring and matching. Defective sheets in matching were corrected and reprinted. The proof prints were approved by MPWT when the draft final report was discussed.

(5) Printing

Printing paper was chosen in terms of representation and endurance. High quality printing ink was used that had good color tones and permanency.

(6) Inspection

Each printed map sheet was checked for the presence of any smears from printing, and for blurs, missing lines, matching, color tones, etc.

6.8. Plotting of Land Use Maps

Land use maps at the scale of 1/25,000 were output, 25 copies each based on the S/W agreement. The format of the output file is Illustrator in consideration of future printings.

6.9. Plotting of Surface Geology/Geomorphology(Land Form)

Geology/Geomorphology (Land form) at the scale of 1/25,000 were output at 25 copies. The format of the output file is Illustrator in consideration of future printings.

7. Database Integration for the Whole Country

7.1. Processing for Data Integration

The GIS database establishment study was completed in two Phases. About 80,000 Km² areas were covered in Phase 1 and the remaining areas, about 101,000 Km², were covered in Phase 2. The data-set of the Phase 1 and Phase 2 were integrated as seamless data.

During both phases, the source data used were satellite data Landsat, SPOT, and aerial photographs, along with employing limited field verification whenever and wherever possible. Topographic and thematic data covering a 181,000 km² area were constructed and built up as the GIS database for the whole country.

The following processes were implemented for the database integration.

(1) Extracting the Data in Each Layer

Only the records belonged to the one layer with its code were extracted from the topographic data

(2) Preparing the Coverage

Each layer of data was converted into coverage. Points, lines, and polygons were created depending on the type of feature. Data attribute characters in each layer will be input to the coverage simultaneously.

(3) Examining and Correcting the Topology

Connection of the lines and closeness of the polygon were examined, and corrected by ArcEdit, if necessary.

(4) Examining and Correcting the Attributes

Attributes characterized in each layer, such as name of the items and scheme, are examined and, if necessary, added correctly.

(5) Edge Matching between Phase 1 and Phase 2 data-set

After completing the data-set of Phase 2, some discrepancies were found at the boundary of Phase 1 and Phase 2 areas. Those were checked for their edge matching and corrected to create a seamless data-set for the whole country.

7.2. Topographic Data

7.2.1. Integration of Contour Line

The contour lines also matched between the Phase 1 and Phase 2 data-set.

In Phase 1, the contour lines were created using the stereo images of the spot. In Phase 2, the contour data based on the existing 1:50,000 topography maps presented by the Mekong River Committee. Since each Phase used a different technical approach, the two did not quite match when put together. Errors observed lied between 10m and 20m and were considered within the allowable margin of 40m main curve agreed at the S/W discussion.

With regard to inconsistent parts, corrections at the joint have been made by adjusting the contour at every 20m, in consideration to the topographical conditions. Since the Mekong River Committee's contour data used in Phase 2 includes 10m of contour, errors have not been deleted on GIS database. On the printed maps, however, 10m contours have not been drawn, for the purpose of matching with the Phase 1 printed maps.

7.2.2. Integrated Dataset for Infrastructure

The infrastructure data has also been matched between Phase 1 and 2. Below is an example Integrated seamless infrastructure dataset..

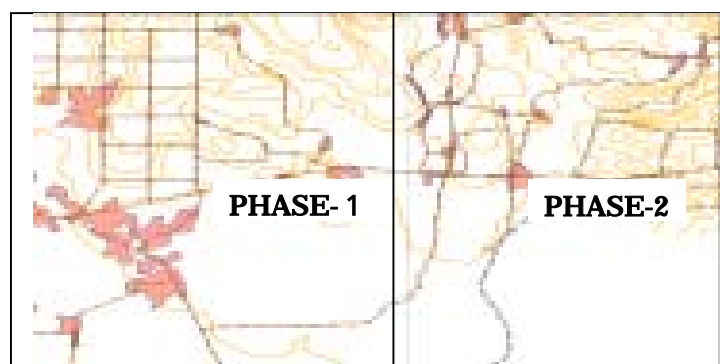


Figure 24: Integrated seamless infrastructure dataset

7.2.3. Integrated Dataset for topographic dataset

Integrated seamless topographic dataset is as shown in Figure 25.

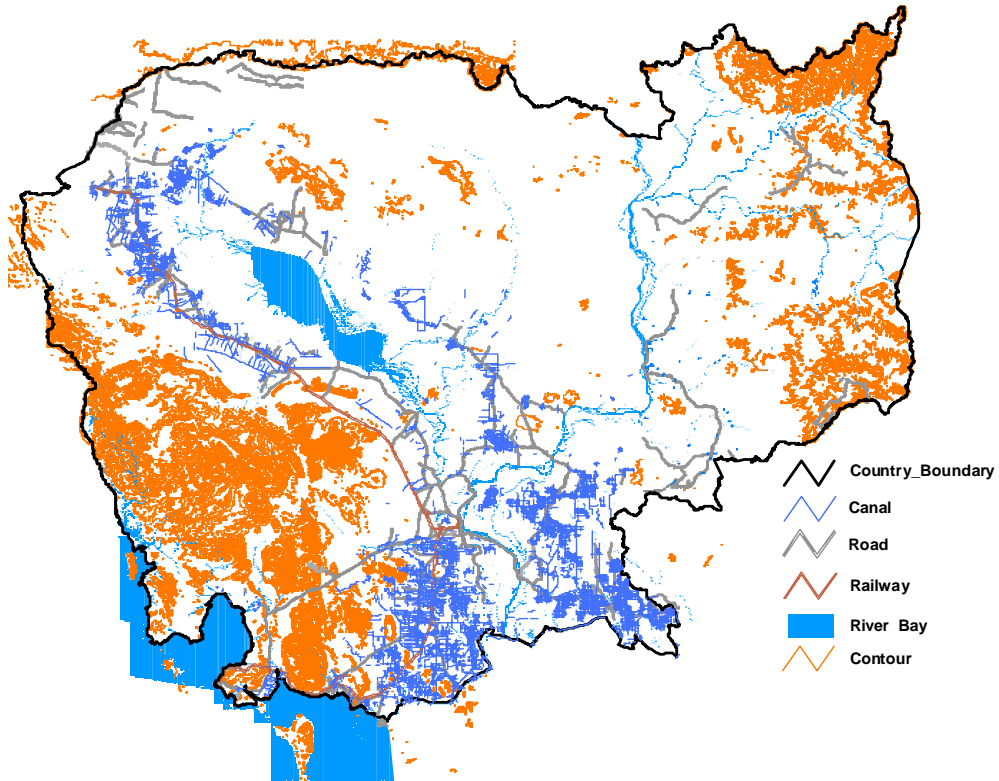


Figure 25: Integrated seamless topographic dataset (Contour data and River)