# PREDICTION OF SHORLINE CHANGE BY USING SATELLITE AERIAL IMAGERY

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**KEY WORDS:** Coast, Hazards, Photogrammetry, Aerial Images, Shoreline Change

**ABSTRACT:**

The shoreline change due to erosion and/or sedimentation, which are induced by the effect of wave attack and/or the effect of the coastal structures extended into the sea, could be studied by using the aerial images. Satellite aerial imagery could play an important role in studying the changes of the shoreline. Aerial photography and remote sensed images can provide an overview of much wider areas and a shorter space of time than the possible used methods of field surveying or GPS. The current study was carried out to investigate the shoreline change due to erosion and/or sedimentation by analysing aerial images and comparing its results with that obtained from the ordinary methods of surveying. A sufficient accuracy investigated for the shoreline change of Port Said city, which located on the northern coast of Egypt, could be obtained by using the advanced soft-wares which covered the biases and noises from aerial images. This study showed that the use of aerial images is a useful tool to pull all information together to understand what happening in the shoreline and predict the future events.

## 1. INTRODUCTION

Many of the Egyptian coastlines are subjected to varying degrees of erosion, high profile example is the region of Port Said city, which is located on the northern coast of Egypt. In order to understand what is happening around the Egyptian coastlines, maritime councils and operating authorities require up-to-date and accurate information about the coastal geomorphology. They are using ordinary surveying, which are concerning with collecting, presenting and using spatial and geographic data in digital form. The principles of land surveying, geomatics utilities contemporary science and technology such as GPS, satellite remote sensing and computer-based geographic information system (GIS) are very useful to help us understanding the changes occurred in the shoreline. For wider area, aerial imagery can be used for a large scale of area in which the measurements, and the results achieved digitally.

Coastal engineering studies by remote sensing have not widely established. This is because of the fact that the scientists do not use the full operational capabilities of remote sensing to coastal and environmental studies. Here, the addressed question is that whether aerial imagery can help us to investigate the shoreline change with high accuracy?.

Aerial photography can provide an overview of much wider areas in a shorter space of time than the possible used methods of field surveying and/or GPS, but the results accuracy with using aerial imagery must be studied carefully. This study shows a sufficient accuracy to trace the shoreline change of the studied area using the advanced soft-wares which covered the biases and noises from high resolutions images, so the results from images can be improved.

Imagery with the highest available spatial resolution is required to detect changes within shorelines. Four primary sources of high-resolution satellite imagery had been evaluated: SPOT (SPOT Image, Corp.), IRS (Space Imagining, Inc.), SPIN2 (Aerial Images, Inc), and IKNOS (Space Imagining, Inc). The 10 meters spatial resolution of SPOT, 5meters spatial resolution of IRS, 2 meters spatial resolution of SPIN2 and 1 meter spatial resolution of IKNOS.

Finally, this study will show that aerial imagery is a useful tool to pull all of information getting from aerial images together to understand what happening in the shoreline and predict future events.

## 2. STUDY AREA

The studied area is the shoreline of Port Said city located on the Mediterranean on the north-eastern coast of Egypt between 31º 17′ N to 31º 18′ N and 32º 10′ E to 32º 20′ E. This shoreline extends about 15 kilometres to the west of Suez Canal. It has declined seriously over the past 20 years due to the effect of the tidal inlets of El-Manzala lake located at El-Gamil zone and the existence of the western Suez Canal breakwater. The prevailing wind and wave directions in this area are northwest yearly with net longshore sediment transport moving from west to east.

## 3. IMAGES DATA

The images were taken along the shoreline of Port Said, to the north of Egypt. The shoreline of the studied area extends 20 kilometres long with an elevation ranging from 0.5 meter to 1.5 meter. Four images, during the period 1991, 1995, 1998, and 2001 with 2 m resolution, were available and had been used. Figure 1 shows the different four images. The scale of images was 1:60000.

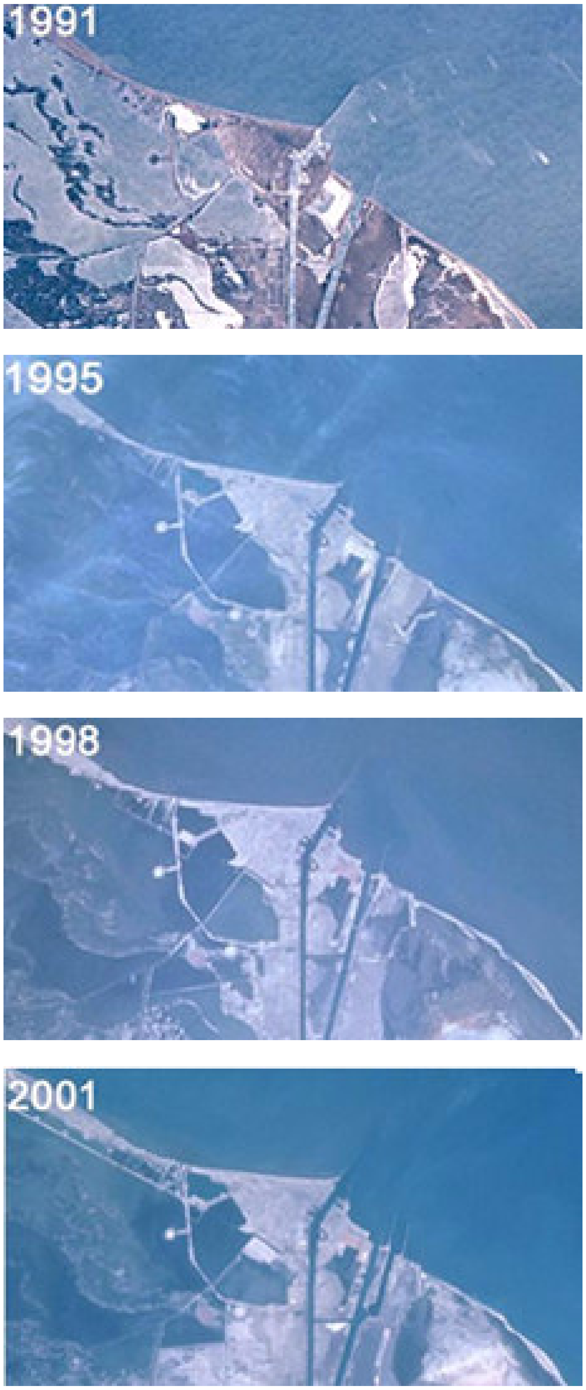


Figure 1 The different four satellite images for the studied area of Port Said during the years 1991,1995, 1998, and 2001

## 4. SHORELINE GENERATION

After removing the noise from the images, a raster-to-vector conversion is applied to the images. All the segmented regions are represented as vector polygons. The major water body can be identified from the other regions using statistical and shape information. In our experiment, the region with the biggest size is recognized as the major water body. Then the initial shoreline is automatically extracted from the boundary between the major water body and other regions. Figure 2 shows the initial shoreline extracted from the image.

The initial shoreline extracted from image is superimposed on the segmented images. By visual checking, one can see that as the boundary of the initial shoreline is generally at the correct position; a method is needed to correct the deviated shoreline portions either automatically or interactively. In our case study, it is easy to extract the shoreline. The extracted shoreline developed in a GIS setting by manually selecting the correct boundaries. Figure 2 shows that the extraction of shoreline had been accepted while; it is difficult to locate the breakwater, so it can be added manually. Also we can use the edge detection as shown in Figure 3.

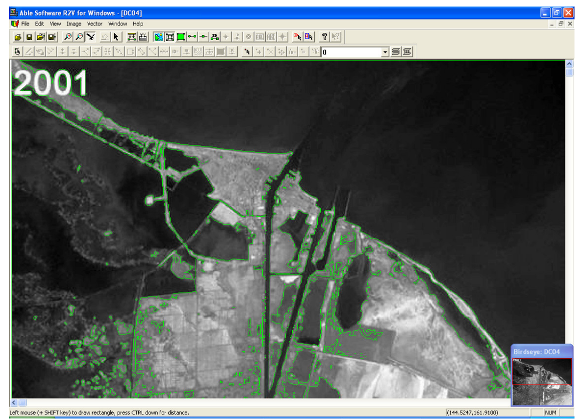


Figure 2 The initial shoreline extraction for image 2001

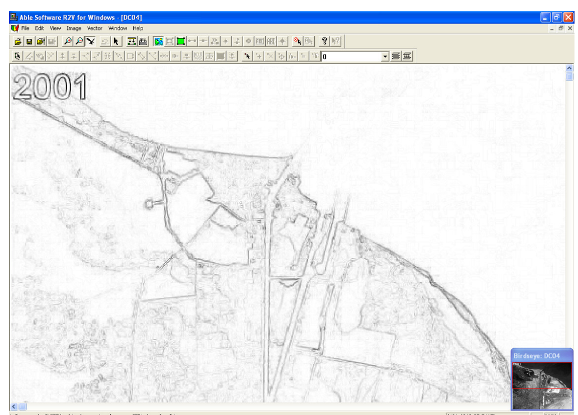


Figure 3 Edge detection for the shoreline.

**5.**

## 6. CONTROL POINTS AND CORRDINATES TRANSFORMATION

Control points and coordinates transformation are required to achieve good accuracy satellite imagery, and reference information.

The ground control points must be clearly discernable on the ground as well as in the image. They were taken to ensure that the correct points are obtained. The available data for the ground control points are obtained from GPS. Control points were taken on the western breakwater at the entrance of the

Suez Canal in addition to three control points using GPS at El-Gamil zone.

By using GIS, once the imagery is prepared, it can be used as a base map for mapping applications or as a first generation (oriented image) data source for extracting second generation data (feature datasets). An accurate reference map which is the admiralty chart No.234 issued at 1994 is currently available for a part of the studied area. Both the detailed location map and an image subset can be supplied to GIS.

## 6. SHORELINE CHANGE ANALYSIS

After the images have been referenced, it is then used for comparison to the raster. The different four images have been obtained to Port Said providing an excellent means for comparing the shoreline on the chart.

The imagery is taken as a base layer in a GIS along with the raster or vector chart as shown in Figure 2. Descriptions of differences between the chart and images are recorded along with the geographic location of each discrepancy. Changes in shorelines were noted including natural shoreline change (due to wave climate, bathymetry effect and amount of longshore sediment transport) as well as changes due to manmade structures ( the detached breakwaters at El-Gamil zone). Using GIS, these can be located by reference to a data type (shoreline change), by location (all geographical locations of shoreline), or by a search through of the contributing parameters.

GIS has the ability to perform data based not only on attributes but also on the location of those attributes it from all other type of database management software. Figure 4 shows the shoreline obtained during the different years from the four images. The shoreline was divided into four zones to make easy comparison and detection for the shoreline change.

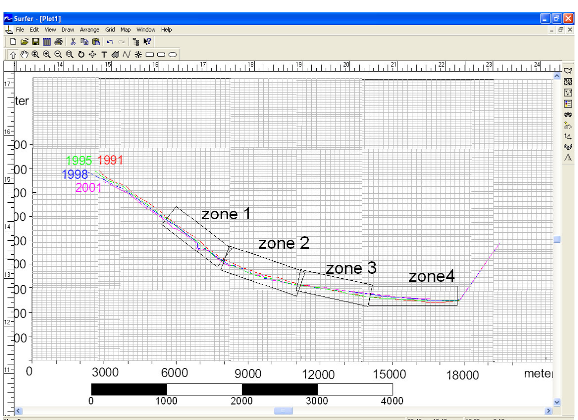


Figure 4 The shoreline obtained during the different years.

### 6.1 Observations of Shoreline Change at Zone 1

This zone of the studied shoreline extends about four kilometres to west of the western breakwater of the Suez Canal at its northern entrance, as shown in Figure 5. This breakwater extends four kilometres offshore into the Mediterranean Sea. The aerial images indicated that the existence of this breakwater precludes the motion of the longshore sediment transport causing sedimentation in this region and the gained area extended with average 100 meters into the sea in the period from 1991 to 2001.

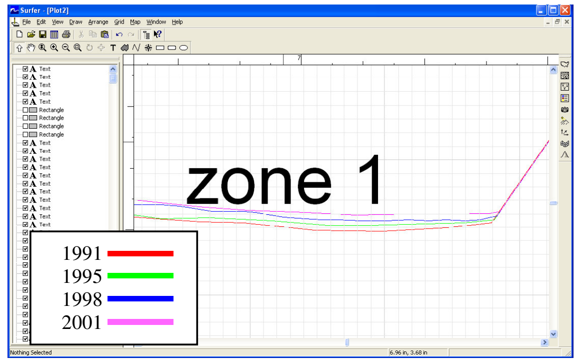


Figure 5 Shoreline change fore Zone 1

### 6.2 Observations of Shoreline Change at Zone 2

This zone extends about three kilometres, as observed from aerial images. Erosion had happened to the shoreline during the period before 1995 and after 1998 and the shoreline became stable as shown from Figure 6.

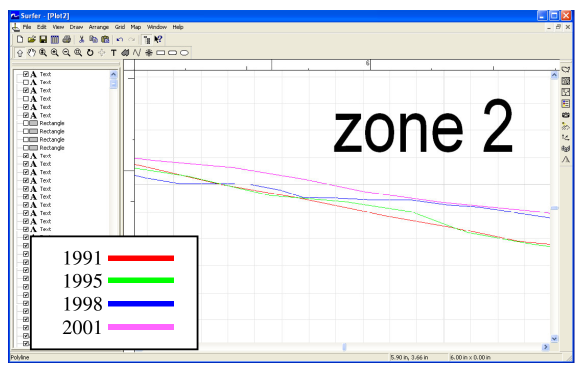


Figure 6 Shoreline change fore Zone 2

### 6.3 Observations of Shoreline Change at Zone 3

Since, 1986 survey works showed that zone 3 which extends about three kilometers had suffered from erosion as shown from Figure 7. From observations it is possible to define the erosion in this zone. This erosion may occur due to different reasons such as interference of current field, bathymetry, sediment grain size and wave climate. Finally, this erosion causes a loss of a great area of the coast.

At 1996, four detached breakwaters were constructed parallel to the beach at El-Gamil zone, each 300 meter long and 200 meter opening between breakwaters, to protect the shoreline from erosion. At 1997, two additional detached breakwaters were constructed, these two breakwaters finished at 1998. The shoreline became more stable than that of the year1995, the sediments were trapped and many (Tombolo and Gulf) were formed and covered all the zone for about two kilometres. This (Tombolo and Gulf) extended about 150 meter into the sea.

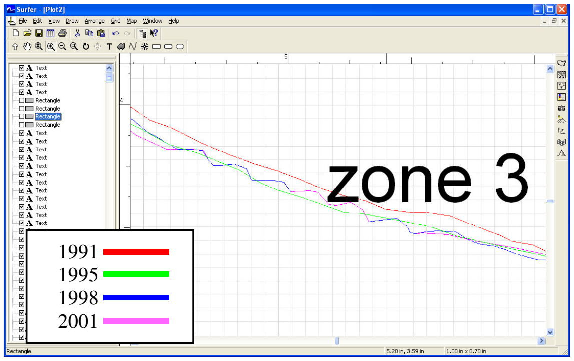


Figure 7 Shoreline change for Zone 3

The changes occurred in the shoreline for this zone due to the existence of the detached breakwaters, had obtained from ordinary surveying which shown in Figure 8. These changes are coinciding with the changes obtained from aerial images shown in Figure 7. The aerial images indicated that, erosion had been occurred in the shoreline in the period between year 1991 and 1995, the changes occurred (Tombolo and Gulf) for the period between 1998 and 2001 are seldom to recognition. The aerial images give high accuracy when comparing the results with ordinary surveying data.

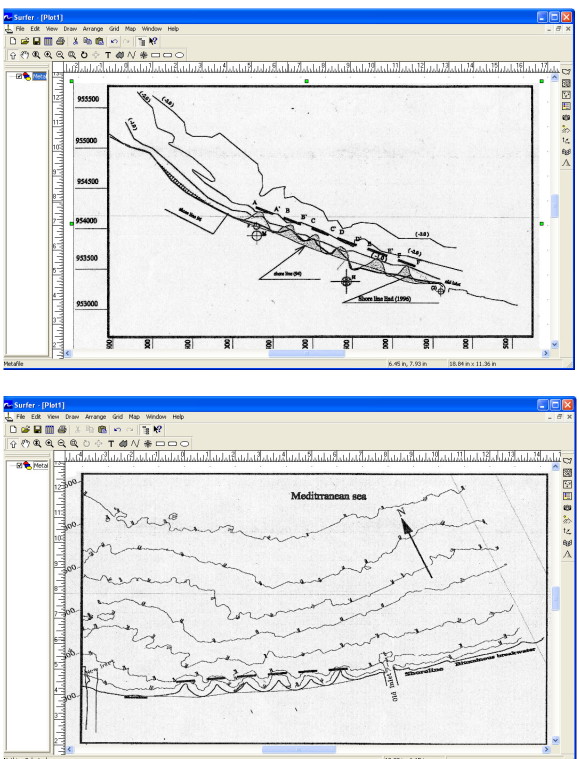


Figure 8 Shoreline change for Zone 3
by using ordinary surveying

### 6.4 Observations of Shoreline Change at Zone 4

This zone extends for three kilometres and has a connection between two tidal inlets of El-Manzala Lake. It is observed from the aerial images that the shoreline west to the first tidal inlet (about two kilometres) suffered from erosion during the period 1991 to 1995, while a seldom change occurred in the period 1995- 1998 , while erosion occurred between 1998-2001. It is observed too, that the area east of that tidal inlet about one kilometre suffered also from erosion between the years (1991-1995) and after that still stable affected by the construction of breakwater at the east of this zone. Figure 9 shows the shoreline change.

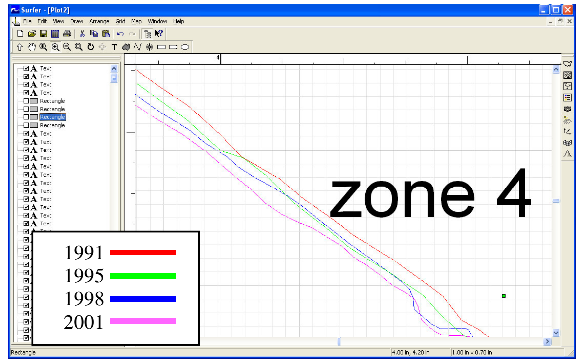


Figure 9 Shoreline change for Zone 4

## 7. CONCLUSIONS

Aerial images are a very useful tool, when applied to shoreline changes. The data obtained from aerial images could be integrated into GIS to study the changes occurs in the shoreline for a wide area during different years which can help us to predict the shoreline changes. Aerial images could be a faster and more efficient monitoring system, with high accuracy when using all available techniques for tracing the shoreline such as least squares matching, coordinates transformation, minimum GPS control points and GIS.

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## APPENDIX A

This appendix shows the coordinates for the different 4 zones during the different years. Coordinates during the different years 1991, 1995, 1998, and 2001 for the different zones , zone 1, and zone 2, zone 3, and zone 4 are indicated in Table 1, Table 2, Table3 and Table 4 respectively.

| X(m) | Y (m) | | | |
|---|---|---|---|---|
| | 1991 | 1995 | 1998 | 2001 |
| 14099.4 | 2657.01 | 2635.20 | 2685.20 | 2740.61 |
| 15007.4 | 2555.24 | 2566.14 | 2586.17 | 2653.38 |
| 15075.5 | 2551.60 | 2562.51 | 2632.50 | 2653.38 |
| 15147.2 | 2547.97 | 2551.60 | 2621.46 | 2649.74 |
| 15215.4 | 2544.33 | 2551.60 | 2631.40 | 2646.11 |
| 15287.2 | 2537.06 | 2551.60 | 2621.00 | 2638.84 |
| 15355.4 | 2529.80 | 2551.60 | 2691.46 | 2627.93 |
| 15420.0 | 2526.16 | 2551.60 | 2691.46 | 2620.66 |
| 15491.9 | 2526.16 | 2555.24 | 2691.46 | 2609.76 |
| 15563.8 | 2522.53 | 2555.24 | 2691.46 | 2598.85 |
| 15628.5 | 2522.53 | 2551.60 | 2691.46 | 2598.85 |
| 15700.5 | 2522.53 | 2544.33 | 2574.38 | 2598.85 |
| 15768.8 | 2522.53 | 2540.70 | 2590.76 | 2602.49 |
| 15840.9 | 2518.89 | 2544.33 | 2574.13 | 2595.22 |
| 15909.3 | 2507.99 | 2537.06 | 2570.26 | 2587.95 |
| 15981.4 | 2500.72 | 2533.43 | 2563.43 | 2580.68 |
| 16049.9 | 2493.45 | 2526.16 | 2546.12 | 2566.14 |
| 16118.4 | 2486.18 | 2522.53 | 2542.43 | 2562.51 |
| 16194.2 | 2482.54 | 2515.26 | 2545.26 | 2555.24 |
| 16255.5 | 2475.27 | 2511.62 | 2541.62 | 2551.60 |
| 16331.3 | 2468.01 | 2504.35 | 2524.45 | 2544.33 |
| 16396.3 | 2468.01 | 2500.72 | 2525.72 | 2544.33 |
| 16465.0 | 2468.01 | 2500.72 | 2525.72 | 2544.33 |
| 16540.9 | 2460.74 | 2500.72 | 2525.72 | 2544.33 |
| 16609.6 | 2464.37 | 2500.72 | 2525.72 | 2540.70 |
| 16682.0 | 2464.37 | 2500.72 | 2523.72 | 2537.06 |
| 16747.1 | 2460.74 | 2504.35 | 2523.72 | 2537.06 |
| 16826.8 | 2460.74 | 2504.35 | 2523.72 | 2533.43 |
| 16892.0 | 2464.37 | 2504.35 | 2523.72 | 2540.70 |
| 16960.8 | 2468.01 | 2504.35 | 2523.72 | 2540.70 |
| 17033.3 | 2464.37 | 2504.35 | 2523.72 | 2544.33 |
| 17105.9 | 2471.64 | 2507.99 | 2536.17 | 2544.33 |
| 17171.2 | 2475.27 | 2511.62 | 2531.22 | 2540.70 |
| 17243.8 | 2478.91 | 2515.26 | 2531.22 | 2540.70 |
| 17312.8 | 2478.91 | 2511.62 | 2531.22 | 2544.33 |
| 17389.0 | 2486.18 | 2515.26 | 2531.22 | 2544.33 |
| 17454.4 | 2497.08 | 2515.26 | 2531.22 | 2537.06 |
| 17527.1 | 2500.72 | 2522.53 | 2531.22 | 2537.06 |
| 17599.9 | 2507.99 | 2529.80 | 2533.24 | 2540.70 |
| 17665.4 | 2515.26 | 2540.70 | 2550.22 | 2558.87 |

Table 1 shows the coordinates of zone 1
(between 14000m and 18000 m)

| X(m) | Y (m) | | | |
|---|---|---|---|---|
| | 1991 | 1995 | 1998 | 2001 |
| 11085.4 | 3096.25 | 3096.81 | 3116.81 | 3122.25 |
| 11151.9 | 3089.54 | 3100.54 | 3109.54 | 3114.98 |
| 11225.6 | 3107.71 | 3078.64 | 3078.64 | 3067.73 |
| 11288.6 | 3071.37 | 3071.37 | 3089.24 | 3096.81 |
| 11355.2 | 3067.73 | 3069.73 | 3081.73 | 3085.90 |
| 11432.5 | 3042.54 | 3067.73 | 3071.24 | 3075.00 |
| 11492.1 | 3035.73 | 3049.56 | 3059.59 | 3067.73 |
| 11565.9 | 3020.48 | 3042.29 | 3054. 19 | 3060.45 |
| 11629.0 | 3009.58 | 3029.41 | 3035.02 | 3042.51 |
| 11699.3 | 2998.67 | 3021.24 | 3024.11 | 3027.24 |
| 11766.1 | 2987.13 | 3011.57 | 3013.21 | 3016.85 |
| 11836.5 | 2988.67 | 2988.67 | 2994.24 | 2998.13 |
| 11903.3 | 2984.13 | 2984.13 | 2989.33 | 2991.4.0 |
| 11966.6 | 2973.23 | 2969.59 | 2972.22 | 2987.77 |
| 12040.6 | 2955.06 | 2958.69 | 2972.80 | 2976.86 |
| 12107.5 | 2947.79 | 2944.15 | 2960.65 | 2965.96 |
| 12178.0 | 2936.88 | 2936.88 | 2939.28 | 2940.52 |
| 12248.6 | 2922.34 | 2929.61 | 2933.61 | 2936.88 |
| 12319.2 | 2907.80 | 2922.34 | 2929.30 | 2933.25 |
| 12382.6 | 2893.27 | 2915.07 | 2925.27 | 2929.61 |
| 12453.2 | 2878.73 | 2907.8 | 2919.70 | 2925.98 |
| 12516.7 | 2867.82 | 2900.53 | 2918.50 | 2922.34 |
| 12587.4 | 2856.92 | 2886.00 | 2923.10 | 2929.61 |
| 12658.1 | 2842.38 | 2867.82 | 2917.12 | 2922.34 |
| 12725.3 | 2831.48 | 2842.38 | 2906.48 | 2911.44 |
| 12796.0 | 2816.94 | 2816.94 | 2898.94 | 2904.17 |
| 12863.3 | 2806.03 | 2798.76 | 2897.25 | 2900.53 |
| 12930.5 | 2787.86 | 2787.86 | 2787.86 | 2886.00 |
| 12994.2 | 2776.96 | 2776.96 | 2875.09 | 2875.09 |
| 13061.5 | 2769.69 | 2766.05 | 2871.46 | 2871.46 |
| 13128.8 | 2769.69 | 2755.15 | 2856.92 | 2856.92 |
| 13203.3 | 2766.05 | 2747.88 | 2849.65 | 2849.65 |
| 13274.3 | 2755.15 | 2736.97 | 2835.11 | 2835.11 |
| 13345.3 | 2744.24 | 2726.07 | 2835.11 | 2835.11 |
| 13412.7 | 2726.07 | 2718.80 | 2831.48 | 2831.48 |
| 13480.2 | 2711.53 | 2715.17 | 2816.94 | 2816.94 |
| 13551.3 | 2696.99 | 2707.90 | 2806.03 | 2806.03 |
| 13618.8 | 2686.09 | 2683.36 | 2793.36 | 2798.76 |
| 13686.3 | 2686.09 | 2667.91 | 2767.91 | 2787.86 |
| 13761.1 | 2682.45 | 2657.01 | 2757.01 | 2769.69 |
| 13828.7 | 2682.45 | 2653.38 | 2753.18 | 2762.42 |
| 13896.3 | 2678.82 | 2649.74 | 2749.44 | 2755.15 |
| 13964.0 | 2667.91 | 2642.47 | 2742.47 | 2755.15 |
| 14031.7 | 2660.64 | 2638.84 | 2745.64 | 2762.42 |

Table 2 shows the coordinates of zone 3
(between 11000m and 14000 m)

| X(m) | Y (m) | | | |
|---|---|---|---|---|
| | 1991 | 1995 | 1998 | 2001 |
| 8321.59 | 3921.89 | 3841.92 | 3841.92 | 3841.92 |
| 8390.51 | 3896.44 | 3809.21 | 3841.92 | 3841.92 |
| 8455.92 | 3871.00 | 3780.13 | 3823.75 | 3823.75 |
| 8521.36 | 3849.19 | 3743.79 | 3721.98 | 3721.98 |
| 8586.83 | 3827.38 | 3700.17 | 3725.61 | 3725.61 |
| 8659.39 | 3801.94 | 3674.73 | 3725.61 | 3725.61 |
| 8724.92 | 3780.13 | 3645.65 | 3718.34 | 3718.34 |
| 8797.54 | 3754.69 | 3623.84 | 3645.65 | 3645.65 |
| 8859.58 | 3729.25 | 3602.03 | 3645.65 | 3645.65 |
| 8925.19 | 3703.8 | 3583.86 | 3649.28 | 3649.28 |
| 8994.36 | 3674.73 | 3558.42 | 3645.65 | 3645.65 |
| 9056.49 | 3649.28 | 3532.97 | 3565.69 | 3565.69 |
| 9122.17 | 3631.11 | 3511.17 | 3543.88 | 3543.88 |
| 9187.89 | 3609.30 | 3489.36 | 3554.78 | 3554.78 |
| 9260.72 | 3591.13 | 3485.72 | 3551.15 | 3551.15 |
| 9330.04 | 3576.59 | 3482.09 | 3514.80 | 3514.80 |
| 9399.38 | 3547.51 | 3463.91 | 3423.93 | 3423.93 |
| 9465.21 | 3522.07 | 3453.01 | 3427.57 | 3427.57 |
| 9527.52 | 3507.53 | 3442.11 | 3442.11 | 3442.11 |
| 9600.50 | 3496.63 | 3431.20 | 3438.47 | 3438.47 |
| 9659.31 | 3489.36 | 3420.30 | 3387.59 | 3387.59 |
| 9732.35 | 3478.45 | 3398.49 | 3333.06 | 3333.06 |
| 9798.31 | 3478.45 | 3387.59 | 3347.60 | 3347.60 |
| 9864.31 | 3474.82 | 3373.05 | 3351.24 | 3351.24 |
| 9933.88 | 3463.91 | 3347.60 | 3347.60 | 3347.60 |
| 9999.93 | 3453.01 | 3322.16 | 3347.60 | 3347.60 |
| 10069.6 | 3423.93 | 3303.99 | 3311.26 | 3311.26 |
| 10139.2 | 3394.85 | 3289.45 | 3274.91 | 3274.91 |
| 10198.2 | 3369.41 | 3278.54 | 3301.47 | 3253.1 |
| 10271.5 | 3347.6 | 3256.74 | 3266.53 | 3245.83 |
| 10337.7 | 3322.16 | 3242.2 | 3251.98 | 3231.29 |
| 10407.5 | 3285.81 | 3231.29 | 3247.62 | 3213.12 |
| 10477.3 | 3267.64 | 3213.12 | 3139.18 | 3184.04 |
| 10540.0 | 3256.74 | 320.22 | 3134.86 | 3165.87 |
| 10613.4 | 3238.56 | 3187.68 | 3120.29 | 3151.33 |
| 10676.2 | 3209.48 | 3173.14 | 3102.49 | 3140.43 |
| 10749.6 | 3176.77 | 3158.6 | 3074.90 | 3140.43 |
| 10816.0 | 3154.96 | 3147.69 | 3064.02 | 3129.52 |
| 10886.0 | 3122.25 | 3125.89 | 3116.14 | 3136.79 |
| 10952.4 | 3114.98 | 3122.25 | 3115.76 | 3129.52 |
| 11022.5 | 3125.89 | 3111.35 | 3108.11 | 3114.98 |
| 11085.4 | 3122.25 | 3096.81 | 3096.81 | 3096.81 |

Table 3 shows the coordinates of the zone 3
(between 8300 m and 11000 m)

| X(m) | Y (m) | | | |
|---|---|---|---|---|
| | 1991 | 1995 | 1998 | 2001 |
| 5544.18 | 5790.12 | 5750.14 | 5717.36 | 5699.26 |
| 5608.40 | 5757.41 | 5684.72 | 5604.86 | 5562.91 |
| 5672.65 | 5702.89 | 5604.75 | 5588.04 | 5522.93 |
| 5740.43 | 5641.10 | 5553.87 | 5530.55 | 5479.31 |
| 5804.74 | 5586.58 | 5506.62 | 5486.68 | 5428.42 |
| 5869.07 | 5542.96 | 5452.10 | 5428.91 | 5477.54 |
| 5933.43 | 5495.71 | 5397.58 | 5381.04 | 5415.75 |
| 6001.32 | 5448.46 | 5143.06 | 5323.28 | 5064.86 |
| 6065.73 | 5393.94 | 5318.53 | 5362.23 | 5317.61 |
| 6137.19 | 5343.06 | 5234.01 | 5314.36 | 5226.73 |
| 6198.15 | 5303.07 | 5223.11 | 5267.64 | 5194.03 |
| 6259.14 | 5263.09 | 5168.59 | 5133.92 | 5130.42 |
| 6334.19 | 5212.21 | 5110.43 | 5103.81 | 5117.70 |
| 6398.75 | 5175.86 | 5074.09 | 5080.72 | 5066.82 |
| 6463.33 | 5132.24 | 5023.20 | 5023.20 | 5023.20 |
| 6531.45 | 5084.99 | 4983.22 | 5003.09 | 4961.41 |
| 6592.58 | 5041.37 | 4935.97 | 5078.80 | 4779.68 |
| 6664.27 | 4990.49 | 4885.08 | 5030.82 | 4728.79 |
| 6728.96 | 4939.60 | 4808.75 | 4730.23 | 4677.90 |
| 6797.19 | 4885.08 | 4736.06 | 4609.65 | 4656.10 |
| 6858.42 | 4797.85 | 4674.27 | 4690.83 | 4656.10 |
| 6926.72 | 4714.25 | 4612.48 | 4566.58 | 4663.37 |
| 6991.52 | 4677.90 | 4561.59 | 4516.05 | 4612.48 |
| 7059.87 | 4637.92 | 4525.25 | 4499.26 | 4554.32 |
| 7124.73 | 4587.04 | 4474.36 | 4451.67 | 4499.80 |
| 7189.61 | 4532.52 | 4416.21 | 4393.50 | 4441.65 |
| 7265.08 | 4470.73 | 4347.15 | 4397.18 | 4337.13 |
| 7330.03 | 4419.84 | 4292.63 | 4369.12 | 4326.24 |
| 7391.48 | 4383.49 | 4256.28 | 4333.15 | 4307.16 |
| 7460.00 | 4343.51 | 4216.30 | 4235.12 | 4256.28 |
| 7521.50 | 4307.16 | 4187.22 | 4213.43 | 4223.57 |
| 7590.07 | 4274.45 | 4150.87 | 4175.85 | 4190.85 |
| 7658.68 | 4234.47 | 4088.34 | 4150.87 | 4118.16 |
| 7723.79 | 4190.85 | 4079.14 | 4099.99 | 4089.08 |
| 7788.92 | 4154.51 | 4046.10 | 4060.01 | 4052.74 |
| 7857.61 | 4132.70 | 4002.84 | 4023.66 | 4012.75 |
| 7926.33 | 4103.62 | 3990.26 | 3996.41 | 3983.68 |
| 7991.55 | 4070.91 | 3972.06 | 3968.23 | 3965.50 |
| 8056.80 | 4034.56 | 3940.79 | 3954.60 | 3947.33 |
| 8122.07 | 4001.85 | 3899.13 | 3947.33 | 3921.89 |
| 8187.37 | 3976.41 | 3895.73 | 3891.90 | 3889.17 |
| 8256.23 | 3947.33 | 3897.03 | 3887.03 | 3867.37 |

Table 4 shows the coordinates of the zone 4
(between 5500 m and 8300 m)