Progress towards Establishment of a Unique Vertical Datum for Hydrography and Land Surveying in the Emirate of Dubai-Case Study

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Key words: Vertical reference datum, Tide / Meteorological data, Lowest and Highest Astronomical Tides, Tidal stream prediction, Geoid model.

SUMMARY

A unique vertical reference datum became inevitable considering the massive construction of near-shore and offshore artificial islands along the coastal area of Dubai Emirate. The Survey Section of Dubai Municipality established a network of five Tide/Meteorological Stations along the coastal side of Dubai Emirate and started monitoring continuous Tide / Meteorological data collected from all these stations for establishing a precise vertical datum for Dubai Emirate. The tide data collected from the five fully automated tide stations made possible for the determination and maintenance of a well defined marine Vertical Datum for Dubai Emirate. This Datum is now being used by Hydrographers and Marine Engineers for the Management of Coastal / Offshore Constructions, Marine Boundary Determination, Tidal prediction, Storm Surges detection, Sudden Variation in Sea Level and determination of long-term water sea level variations (e.g. trends).

The data collected from the Tide/Meteorological includes an extended series of water level measurements, meteorological data such as Wind Speed, Wind Direction, Humidity, Air Pressure, Air Temperature, Visibility and Water Temperature. These data are processed to generate a number of products, such as monthly and yearly averages for mean tide and sea level, mean high and low water, mean range, Lowest and Highest Astronomical tides (LAT & HAT). The paper explains the fundamental of the vertical datum in Dubai, which is computed from Tidal data. It also outlines the practical advantages of the following subjects:

- Defining a unified vertical datum for land and sea surveying based on the tidal observations
- Determination of inland and offshore Geoid model
- Transferring accurate vertical datum to offshore Islands
- Monitoring the island deformation reference to the tidal and GPS stations
- Creation numerical modeling for Tide and Tidal stream
- Revising the Coastal boundary lines (Base line, Coast line and Shore line) based on tidal data, Topography, Bathymetry and satellite images
- Progress toward a warning system in Dubai coastal area due to abnormal water raise

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1. INTRODUCTION

All Surveyed features are depicted on maps/charts uses some predominant vertical and horizontal datum. For navigational safety as well as for marine constructions depths on a hydrographic chart are shown from a low-water surface called chart datum. Chart datum is selected so that the water level will seldom fall below it and only rarely will there be less depth available than what is portrayed on a chart. Hence it is very important to define a vertical datum known as chart datum for Hydrographic Surveys

Sea level measurements in Dubai, one of the seven emirates of UAE, were performed by local port authorities by establishing different tide gauges and analyzed by different engineering consultants. The data from these tide gauges are used only as an aid to navigation. But continuous records of tide data are not available from these stations for analysis and also the vertical datum reference is not fully traceable from historical records. This is the prime reason for Dubai Municipality to deploy its own permanent tide gauges in the coast of Dubai for the determination of Mean Sea Level and a precise Vertical Datum for topographic and hydrographic surveying.

The Survey Section of Dubai Municipality established a network of five fully automated Tide/Meteorological Stations along the coastal side of Dubai Emirate and started monitoring continuous Tide / Meteorological data collected from all these stations for establishing a precise vertical datum for Dubai Emirate. Tidal Datums are based on water level observations related to a land reference mark (Benchmark) from a water level measurement system (Tide gauge). The tide data from the five fully automated tide stations made possible for the determination and maintenance of a well defined marine Vertical Datum for Dubai Emirate.

When annual values of mean sea level are compared, small differences between them can be found, and annual variation or rise in mean seal level can easily be determined. One amoung the goals of this paper are to present the standard definitions of tidal datum. All water level measurements are now referenced to Dubai Municipality Datum (Staff “0”) and can be referenced to user defined levels. The data collected from the Tide/Meteorological stations are distributed to the end users by either hard copy, floppy disk, CD, or over the web. which includes Mean Sea Level , Lowest Astronomical Tide, Highest Astronomical Tide, Tidal Constituents, Tidal and Tidal Stream Predictions and Meteorological data such as Wind Speed, Wind Direction, Humidity, Visibility, Air temperature and Water Temperature.

2. SITE SELECTION

Five sites along the costal sides of Dubai are selected for establishing the fully automated Tide/Meteorological stations. The sites are so selected by the Dubai Municipality, that they cover evenly the coastal area as well the creek area of Dubai Emirate. The five long term and real time tide and weather monitoring stations along the Dubai coast and creek are established at the following locations

1. Jebel Ali
2. Umm suqim II fishing harbor
3. Hamriya Port
4. Dhow Wharfage inside the Creek area
5. Jadaf (innermost portion of Dubai Creek Area)

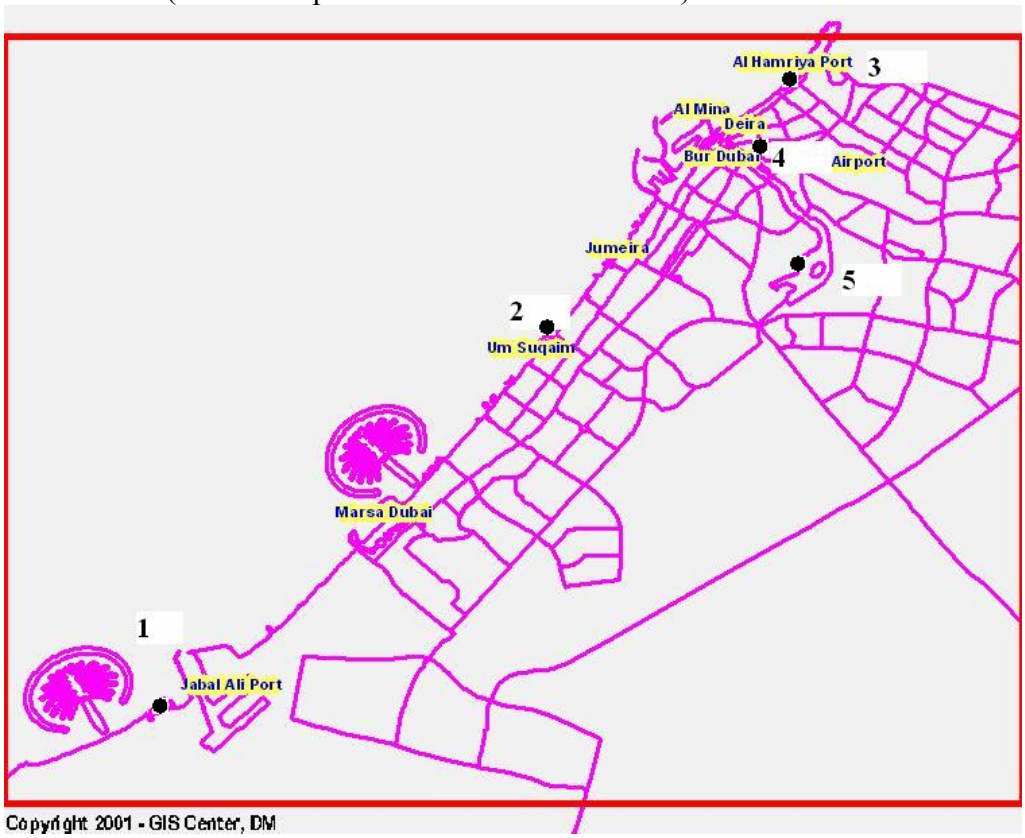

Fig. 1 General Location of Tide/Meteorological Stations

3. SYSTEM DESIGN

While designing the fully automated Tide/Meteorological stations the following points are taken into account

- The fully automatic Tide/Meteorological station have to be installed in remote locations
- The sensors for recording the weather/tide date should be self reading type and should be able to give its output in digital form.

- All the Tide/Meteorological station should work on solar cell module
- There should be ground based housing arrangements for data logging, data storage and keeping the accessories and tools.
- A good mast have to be provided with a housing to hold the meteorological sensors such as air temperature sensor, air pressure sensor, relative humidity sensor, wind direction sensor, wind speed sensor and visibility sensor
- A water pressure sensor which converts the water pressure to direct water level has be provided using a casing pipe and the water sensor has to be fixed well deep into water, for recording the tide / water level variations.
- The housing, mast, sensors, data logger and other parts of the Tide / Meteorological station should be rust free as these stations have to be established very near to the sea.
- The logged data from all the stations have to be communicated to a control room in Dubai Municipality Office in real time using GPRS
- A backup of the logged data should be made in all tide/meteorological stations, which is capable of storing all the monitored data continuously for one month (around 32 days)
- The location of the station should be in open places without any obstruction to sunlight, wind and water level measurements.
- All the data have to be collected at 2 minute interval (sampling rate)
- Data monitoring facility should be provided in all Tide/Meteorological stations
- The real time data received in the control room have to be monitored using suitable software.
- Necessary software for the analysis of the Tide/Meteorological data has to be installed.

4. SYSTEM SPECIFICATION

Consider all the above factors Dubai Municipality selected the famous Norwegian Metrological equipment Aanderaa AWS 2700. There are some reasons behind the selection of this system such as high accuracy, easy to install, low power consumption, potted water proof, light weight; minimum maintenance, factory calibrated, lightening protection, self recording of data, extra data storage unit as backup and easy transmission of data by GSM.

The components of the Hydro-Met equipment consist of the following:

1. Wind speed sensor
2. Wind Direction sensor
3. Air Temperature sensor
4. Relative Humidity sensor
5. Air Pressure sensor
6. MIRA Visibility sensor
7. Rainfall sensor, tipping bucket
8. Specific Water Pressure Sensor and Water Temperature Sensor
9. Data logger
10. External Data storage unit
11. Field Modem

5. DATA PROCESSING AND TIDAL DATUM COMPUTATION

The selected equipment has a sampling rate for the primary Hydro-Met measurements are one sample per second over two minutes. However not all of these data are stored. As per the system design the measurements are averaged over the two minutes period and are stored in the memory at two minutes intervals and in the same time transmitted to the control room in Dubai Municipality.

Data collected from remote stations are transmitted by GPRS to the main office at DM. The content of the database is mainly consisting of meteorological and water level data. The data processing and analysis subsystem is an IT database management system, which receives water level and meteorological data from the stations and performs quality control and analyses of the data, generate resulting products and archive the data.

The daily telemetry status report is generated every 24 hours for all stations that were expected to transmit the data. Another check on the raw data is entitled "processing of 2 minutes data for hourly heights, high and low water, and monthly means" are done by software and verified after review by a senior analyst. Tidal datum and associated tidal products are also computed by software.

6. BENCHMARK

Benchmarks are the fixed elevation marks on the land against which the zero setting of the tide gauge is referred, from which hydrographers may recover chart datum for future surveys, and through which surveyors and engineers may relate their surveys and structures to chart datum. Hydrographic benchmarks landmark the elevation of the benchmarks above chart datum and this procedure is basic to charting and gauging procedures. As part of the installation procedure of any water level gauge, a minimum of two benchmarks are established in the immediate vicinity (½ km) of the gauge, in the same feature or structure. Each station has owned benchmark with standard specification similar to the third order national leveling network.

The height difference between the preliminary gauge zero and each of the benchmarks is then determined by accurate spirit leveling. When the elevation of chart datum is finally chosen with respect to the preliminary gauge zero, the benchmark elevations are converted and recorded in the benchmark descriptions as elevations above chart datum. If the water level gauge is to continue in operation, its permanent zero would be set to chart datum. The benchmarks provide for the recovery of chart datum in future surveys and for consistency in the setting of gauge zero for all water level measurements at the same site. Usually, the benchmark should be located at a stable platform with possible minimum local ground displacement. Monitoring of BM and tide pole with space techniques could solve the ambiguity of the computed MSL rises in many stations. Dubai Municipality has been performing precise GPS measurements for connecting tide gauges to the Dubai geodetic networking Benchmarks. Dubai Municipality constructed Benchmarks within all the Tide stations and connected using precise leveling to the existing Dubai municipality Benchmarks.

7. NATIONAL TIDAL DATUM EPOCH

Tidal datum must be computed relative to a specific 19 years tidal cycle adopted by National Ocean Services (NOS) called the national tidal datum epoch. For determination the Mean Sea Level, one year observation also is accepted but the accuracy is less than +/- 3 cm.

8. HYDRO-MET STATION OUTPUT DATA

The following table shows the data, which receive via GPRS system in the server.

No.	Date	TIME	Ref.	W.S	W.G	W.D	Vis.	A.T	Hum.	A.P	W.L	W.T	R.F
1	17-Apr-04	5:30:00	617	4.27	10.57	159.275	3000	32.1	19	1007.0	2.75	26.2	0.00
2	17-Apr-04	5:32:00	617	4.27	10.57	164.197	3000	32.1	18	1007.0	2.75	26.2	0.00
3	17-Apr-04	5:34:00	617	3.73	5.28	167.010	3000	32.2	18	1007.0	2.75	26.3	0.00
4	17-Apr-04	5:36:00	617	4.27	5.59	172.987	3000	32.3	17	1007.0	2.77	26.3	0.00
5	17-Apr-04	5:38:00	617	4.35	5.59	176.503	3000	32.4	19	1007.0	2.78	26.3	0.00
6	17-Apr-04	5:40:00	617	1.86	0.62	185.645	3000	32.5	20	1006.9	2.80	26.3	0.00
7	17-Apr-04	5:42:00	617	4.97	6.53	174.394	3000	32.5	17	1006.9	2.79	26.3	0.00
8	17-Apr-04	5:44:00	617	4.35	6.22	171.581	3000	32.7	17	1006.9	2.77	26.3	0.00
9	17-Apr-04	5:46:00	617	3.57	4.97	171.932	3000	32.9	18	1006.9	2.79	26.3	0.00
10	17-Apr-04	5:48:00	617	3.73	5.59	176.152	3000	32.9	19	1006.7	2.82	26.3	0.00
11	17-Apr-04	5:50:00	617	4.04	5.28	168.416	3000	33.1	17	1006.7	2.82	26.2	0.00
12	17-Apr-04	5:52:00	617	5.05	6.84	173.339	3000	33.1	16	1006.7	2.79	26.3	0.00
13	17-Apr-04	5:54:00	617	4.66	6.22	182.480	3000	33.1	18	1006.7	2.79	26.3	0.00
14	17-Apr-04	5:56:00	617	4.27	6.53	171.932	3000	33.2	16	1006.9	2.83	26.3	0.00
15	17-Apr-04	5:58:00	617	3.81	6.53	161.736	3000	33.5	15	1006.5	2.83	26.3	0.00
16	17-Apr-04	6:00:00	617	4.35	6.22	168.065	3000	33.5	16	1006.7	2.82	26.3	0.00
17	17-Apr-04	6:02:00	617	4.74	7.15	176.503	3000	33.4	16	1006.7	2.83	26.3	0.00
18	17-Apr-04	6:04:00	617	4.04	5.59	169.823	3000	33.6	17	1006.5	2.85	26.3	0.00
19	17-Apr-04	6:06:00	617	3.89	5.59	178.261	3000	33.7	16	1006.5	2.85	26.3	0.00
No.	Date	Time	Reference No.	Wind Speed	Wind Gust	Wind Direction	Visibility	Air Temperature	Humidity	Air Pressure	Water Level	Water Temperature	Rain Fall

9. DATA PROCESSING AND TIDAL DATUM COMPUTATION

Data from remote stations transmitted by GPRS to the main office at DM.. The content of the database is mainly consisting of meteorological and water level data. The data processing and analysis subsystem is the IT database management system, which receives water level and meteorological data from the stations and performs quality control and analyses of the data, generate resulting products and archive the data. The daily telemetry status report is generated every 24 hours for all stations that were expected to transmit the data. Another check on the raw data is entitled “processing of 2 minutes data for hourly heights, high and

low water, and monthly means" are done by software and verified after review by a senior analyst. Tidal datum and associated tidal products are also computed by software. Tidal datum at tidal control stations is computed by arithmetic method for specific length of record, generally a tide epoch is 18.6 years.

10. TIDE TABULATION AND COMPUTATION OF MSL

The continuous 2-minutes interval water level data are used to generate the standard tabulation output products. These products include the times and heights of the high and law waters, hourly heights, maximum and minimum monthly water levels, and monthly mean values for the desired parameters. Hourly heights shall be derived from every 2-minutes value observed on the hour. Monthly mean sea level and monthly mean water level shall be computed from the average of the hourly heights over each calendar month of data through the tidal analysis software. Data shall be tabulated relative to a documented consistent station datum such as tide staff zero, MLLW, LAT, etc. over the duration of the data observations. Monthly means are derived on a month basis in accordance with the definitions for the monthly mean parameters by Doodson's filtering method.

The prediction of the times and heights of high and law water is usually done annually for emirate of Dubai. After analyzing one and a half year full tidal data from each tidal station, the harmonic constituents are calculated and the tides are predicted using suitable tide prediction software. Dubai Municipality uses TASK 2000 software for the preparation of Tide Prediction Tables.

11. DATABASE

From the raw data collected from all the Tide/Meteorological Station, each data corresponding to each meteorological factor is filtered out and prepares a detailed database on benchmarks, tidal data, hydro and weather data for each station. The data and information resides on a server at Dubai Municipality office. The data is stored at DM but maintained by the tidal analyst. From this database, the required tide data for Hydrographic Survey application is filtered and send for hydrographic data processing. Also the data is given to various users according to their request.

12. QUALITY CONTROL ON THE HYDRO-METEOROLOGICAL DATA

Each sensor has to be calibrated annually for the precise measurement of meteorological / tidal data. Hence annual calibration is done by manufacturer and besides in the post processing, all the sensors in each station compare together. The below graphs are presenting a Q/C on the Air pressure and water level observations on all stations.

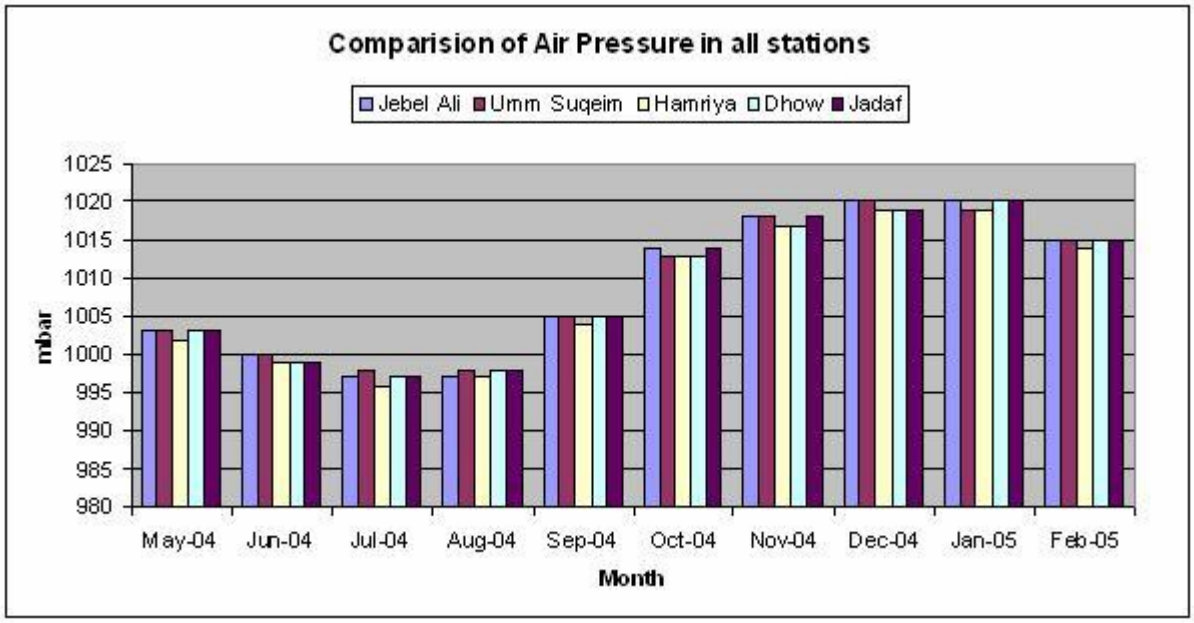

Fig.2 Comparison of Air Pressure in all stations

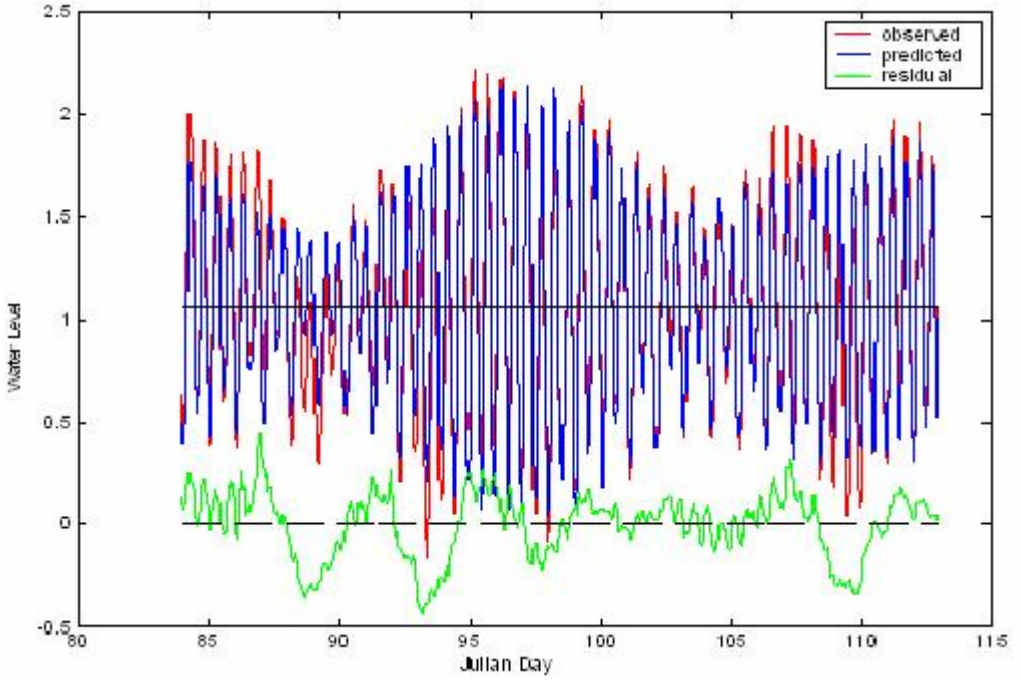

Fig.3 Comparison of observed and predicted tides

13. TIDAL LEVELS - REFERENCE TO DUBAI MUNICIPALITY DATUM

Location	LAT	MLLW	MHLW	MSL	MLHW	MHHW	HAT	Year
Umm Suqeim	-0.20	+0.43	+0.78	+1.05	+1.32	+1.66	+2.20	2004

Note that, the above values are calculated based on two years tidal observation in Dubai.

14. MEAN SEA LEVEL SEASONAL CHANGES ON 2003

Month	MSL	Correction	Description	Corrected Level
Jan	0.97	0	Half Month data	0.97
Feb	0.98	0.1		1.08
Mar	0.98	0.1		1.08
Apr	1.01	0		1.01
May	1.04	0		1.04
Jun	1.2	-0.1		1.10
Jul	1.21	-0.1		1.11
Aug	1.14	-0.1		1.04
Sep	1.09	0		1.09
Oct	1.03	0		1.03
Nov	1.08	0		1.08
Dec	1.01	0		1.01
	Average=1.06m			1.06

15. HARMONIC CONSTITUENTS

Constituents	Dubai Municipality (2004)
Sa	0.095
Ssa	0.050
Mm	0.004
Msf	0.006
O1	0.165
K1	0.239
M2	0.442
S2	0.171
Z0	1.050
Number of derived Constituents	62
Based on one and half years data from Umm Sequim station	

16. HOW ACCURATE ARE THE PREDICTIONS

The Character of tide in Dubai is a mixed, usually semi-diurnal
K1+O1/M2+S2=0.659

The accuracy of the tide depends on the length of observation; Dubai Municipality predicted tide table for 2005 and 2006 based on two years continues observations. Periodically we do a

comparison of the predicted tides versus the observed tides for a calendar year. The information generated is compiled in a Tide Prediction Accuracy Table. We work to ensure that the predictions are as accurate as possible. However, we can only predict the astronomical tides; we cannot predict the effect of wind, rain, freshwater runoff, recent construction and dredging activities and other short-term meteorological events. If we assume the water level raise to 2.9 meter above our local Datum, then some of the coastal area and creek side will affect by water. Therefore, with aid of 3D model of Dubai we are marking the low elevations area near to the open sea and modifying the structures. In the near future, all the mariners must follow Dubai Municipality Vertical Datum for any design on the shore.

17. OFFSHORE GEOID MODEL

Local or regional geoid could only be determined using gravimetric approach which requires good marine gravimetric data for any offshore area. After the determination of the offshore geoid model, the accuracy of that geoid can be checked using the precise vertical datum defined from the continuous tidal observation for a long duration. The vertical datum computed from the mean sea level observation can be combined with the GPS derived heights for checking the accuracy of an offshore geoid. Also the offshore geoid information can be combined with GPS derived heights for the determination of Mean Sea Level height.

18. TRANSFERRING ACCURATE VERTICAL DATUM TO OFFSHORE ISLANDS

Dubai Emirate is now witnessing mass offshore construction (construction of artificial islands) in the history of UAE. Now it became inevitable to establish vertical datum to offshore islands. Hence transferring a well defined vertical datum to offshore manmade islands involves establishing a series of tide gauges along the costal area of these islands and monitoring the tide data simultaneously from the automated tide/meteorological stations and tide gauges established along the coastal sides of islands enables to transfer the precise vertical datum to the manmade islands.

Also the deformation of the islands with reference to the tide and GPS can be made after establishing a precise vertical datum to the offshore islands.

19. HIGH WATER WARNING AND ALARMING SYSTEM

Automated Software is able to compare the predicted tide and actual tide in the same time and make an alarm when the difference is higher than standard. Dubai Municipality is planning to extend the alarming system to the public by setting up the horns in the open beaches and also through SMS in mobiles.


Fig 5: Warning and Alarming systems

20. CONCLUSION

This paper has set out to demonstrate how advantage is being taken of the latest technology advances in marine coastal engineering as applied to land surveying and sea surveying vertical datum and also real-time Hazard systems on Sea level rise. It has been also indicated that, Hydro-Meteorological stations are providing:

- Near Real time Hydro-Meteorological data over the internet for end users
- Highest Astronomical tide for Marine Designers
- Mean Sea level as a land surveying datum and for GEOID modeling
- Lowest Astronomical Tide as a Hydrographic Survey datum
- Harmonic constituents for prediction the tide
- Real-Time Warning System to Public in case of water level rise (Under Construction)
- Predict the Extreme High Water and affection on the Coastal Zone
- Annual Predicted Tide Tables
- Annual Hydro-Meteorological observations
- Expert consultation, including certification of observed and predicted water level data for court evidence and legal documents as requested.
- Marine and Land boundaries determination
- Coastal Monitoring

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