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# ESTABLISHMENT OF THE FIRST MODERN SEA LEVEL MONITORING SYSTEM IN EGYPT

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## ABSTRACT

Even though, the current sea level rise is consisted of oscillations of small amplitude, yet it is still essential to be monitored due to the anticipated harmful effects from environmental and development points of view. Results of changes of sea level in Egypt over the last century, based on analysis of collected data of old tide gauges, verify that the Mediterranean sea level is rising by a rate of 1.7 mm/year at Alexandria, and 2.4 mm/year at Port Said.

The Survey Research Institute (SRI) has started a pioneer research project to precisely monitor the rise of the sea level in Egypt. Within this study, a state-of-the-art sea level monitoring system has been established and operated in Alexandria. This advanced system consists of three accurate devices in a unified scheme: a tide gauge, a meteorological unit; and a satellite-based geodetic GPS receiver. This paper describes the present high-technology system in terms of design, accuracy, and suitability. The new multi-purpose observing system has several merits especially in terms of accuracy and compatibility. It is recommended that several monitoring stations of this structure should be established over the Egyptian coasts in order to obtain more precise and reliable frames describing the sea level rise phenomena in Egypt. The precise estimates and results of such systems must be taken into consideration in the development planes of the coastal areas in Egypt.

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## 1- INTRODUCTION

Mean Sea Level (MSL) is defined as the average level of the sea, usually based on hourly values taken over a period of at least a year. The major effective cause for long-periodic sea level oscillations is the glacial melt and the yield of the earth to the melt load. Some estimates of this effect vary between 6 and 10 cm per century. Recent long-period sea level measurements at several stations show that there is a general increase of MSL of about 0.10-0.20 meter per century (IOC, 1985).

Sea level observing systems, or traditional tide gauges, have been employed since the nineteenth century when most devices were simply graduated markings inscribed on rocks, or on masonry or boards at the entrances of harbors, with measurements of sea level made visually. Only in 1830's did the first mechanical gauges appear which were equipped with clocks and charts recorders and with a stilling well.

The Survey Research Institute (SRI) has designed, acquired, and implemented a precise sea level observing system in Alexandria. It can be considered as the first, out of many, observing system to be employed for precisely monitoring changes of sea level in Egypt. Section Two of this paper presents a brief of tide gauge types. Section Three discusses the need and objectives of the current sea-level observing project executing by SRI. Section Four focuses on the design and structure criteria of the up-to-date system admitted in Egypt. Section Five illustrates results of recent data analysis studies for estimating sea-level changes in Egypt. Drawn conclusions and some future recommendations are contributed in Section Six.

## 2- TYPES OF TIDE GAUGES

Mainly, there are four categories of tide gauge equipment available now, which are of significant differences in terms of accuracy and costs. These groups are floating, pressure, acoustic, and radar systems. Each category is summarized in the following sub-sections.

### 2.1 Floating gauges

The traditional type of tide gauge is the analogue floating type. The main reasons to use a float gauge are its low technology and, hence, low price. Recently, other types of tide gauge are available that are more precise and convenient to use. For example, there are floating tide gauges that uses punched tape recorders instead of the paper sheets for data recording. This type of gauges does not give a continuous record of the tidal level but records spot heights at pre-determined time intervals. These instruments contain a coding unit driven from the float mechanism that is designed to transfer a height reading into a recording tape at each recording period. The height is punched out in a binary code form. An automatic reader is usually used to translate the information on the tape into a more usable form. Another improvement that can be added to a working float gauge is attaching an encoder device in order to be able to store recorded data on a local data logger in electronic form. Most types of floating tide gauges suffer from several problems such as the long-term drift, possibly due to ‘tidal hystresis’, and jumps when float and counterweight collide if disturbed [IOC, 2000].

### 2.2 Pressure gauges

The more convenient, cost-effective, and practical recent tide gauges are those instruments depend on measuring the hydrostatic pressure of the water column above a fixed pressure point and converting this pressure to a sea level equivalent. There are two main categories of pressure tide gauges, namely the pneumatic bubbler system and the direct reading, or transducer, system, as discussed below.

#### 2.2.1 Transducer gauges

The second category of pressure tide gauges measure the sea level by fixing a waterproof pressure transducer below the lowest expected tide level with the power/signal cable connected to an on-shore data logging unit or built-in memory. Transducer pressure gauges are basically described by the following mathematical relationship [ibid]:

$$h = ( p - p_a ) / ( \rho g ) \qquad (1)$$

where

- $h$ is the sea level above the pressure point
- $p$ is the total pressure due to both the sea level and the atmospheric measured at the pressure point
- $p_a$ is the atmospheric pressure at the sea surface
- $\rho$ is the average water density in the water column above the sensor
- $g$ is the local gravity acceleration

An important factor in this family of tide gauge is whether the instrument measure absolute or differential pressure. Based on this element, there are two sub-categories of transducer systems. In an absolute pressure transducer, the sensor provides a measurement of the total pressure 'p', and consequently, a separate barometer is required in order to provide a separate measurement of $p_a$. Obviously, both measurements should be recorded using the same clock so they can be readily subtracted to yield the sea level. In a differential pressure transducer, there is a vented power/signal cable in which the reference side of the transducer is vented to atmosphere providing continuous correction for changes in atmospheric pressure.

The majority of these pressure sensors use strain gauge or ceramic technology. Changes in water pressure causes changes in resistance or capacitance in the pressure element. The signal is amplified, displayed, and stored in shore-based data logging equipment. The datum of a transducer mounted underwater is the sensor diaphragm or pressure cell. Pressure transducers are sensitive to temperature variations, and hence, the expected range of temperature to be experienced at the site should not produce an error greater than 0.01% of the full working range. Otherwise, it is recommended that the transducer temperature is monitored for later correction of the recorded data or the transducer is housed in a constant-temperature enclosure. It worth mentioning that pressure transducer tide gauges comprise a major subset of those utilized in the international Global Sea Level Observing System (GLOSS) network [IOC, 1994].

### 2.2.2 Bubbler pressure gauges

In a pneumatic bubbler tide gauge, the air is passed at a metered rate through a small bore to a pressure point fixed below the lowest expected tide level. Provided that the air-flow rate is low and the air supply tube is not too long, the pressure of the air in the system will equal the hydrostatic pressure plus atmospheric pressure. A pressure recording instrument connected to the air supply tube will record changes in water level as changes in pressure. Most pneumatic instruments using the bubbler principle operate in the differential mode, sensors being so constructed that the system pressure is opposed by atmospheric pressure within the instrument. Therefore, the resultant pressure experienced by the sensor becomes the difference in pressure and hence, making height directly proportional to the pressure [IOC, 1985].

### 2.3 Acoustic gauges

Another category of tide gauges is known as acoustic tide gauges. These instruments depend on measuring the travel time of acoustic pulses reflected vertically from the air/sea interface [IOC, 2000]. To ensure continuous and reliable operation, the acoustic pulses are generally contained within a vertical tube or well which can provide some degree of surface stilling. Averaging a number of measurements will also have a stilling effect and give improved accuracy.

### 2.4 Radar gauges

One of the most recent technologies of tide gauges is that system uses the time of flight of a pulse of radar, rather than sound, to measure water level. A radar gauge produces a radar source down onto the water from a sensor in the open air. The sensor transmits the pulse and receives the return pulse, hence determining the time of flight and range. Other radar sensors use pairs of cables or rods, between which the radar pulse is transmitted as a wave guide, and therefore could be deployed in a stilling well [ibid].

## 3- THE NEED AND OBJECTIVES OF A SEA-LEVEL OBSERVING SYSTEM

Although there are several agencies in Egypt operate measuring equipment for determining sea level changes, most of them suffer from several disadvantages in terms of structure, accuracy, and compatibility. For example, the installed out-of-date floating devices are not accurate enough to produce reliable results or estimates for the sea level rise rate. Additionally, there is no distinguishing between the relative and the absolute sea-level rise in these projects. Moreover, most of these activities are designed for a specific goal serving a specific area, with no national interest in mind.

The Survey Research Institute (SRI) has designed, purchased, and implemented a precise sea level observing system in Alexandria. It can be considered as the first, out of many, observing system to be employed for precisely monitoring changes of sea level in Egypt. The research project has several objectives to fulfill both geodetic and environmental goals including:

* Precise monitoring the sea-level rise in Egypt.
* Accurate definition of the vertical geodetic datum in Egypt.
* Study the vertical movement of the Egyptian coasts with respect to the MSL.

* Study of the meteorological effects and the observations methods on the sea-level data quality.
* Development of computer strategy and models to re-define the vertical datum.
* Definition of topography of both Mediterranean and Red seas using terrestrial and altimetric satellite data.
* Analysis of levelling networks in Egypt and study the different methods to enhance these networks and detect any errors.
* Analysis and adjustment of precise levelling networks in the Nile valley area and development of specifications and standards.
* The optimum accurate models for meteorological effects on the levelling measurements in Egypt.
* The use of GPS and a precise geoid of Egypt to obtain accurate orthometric height differences compared with the terrestrial levelling techniques in new developed areas.
* Developing data bases for levelling networks in the Nile valley.

## 4- THE DESIGN AND STRUCTURE OF A SEA-LEVEL OBSERVING SYSTEM

Instantaneous measurements of sea level in a series may be considered as the sum of three components: mean sea level, tide, and meteorological residuals. Consequently, in order to obtain mean sea level, both tide and meteorological residuals should be estimated and removed out from the observed sea level data [IOC, 1985].

Although the acoustic and the radar gauges produce sea-level measurements of one-millimeter accuracy, their price and operational costs are considerably high. On the other hand, the floating gauges are relatively cheap, but their accuracy may not be suitable for recent sea level monitoring applications. If accuracy and costs are to be balanced, the pressure tide gauge has proven to be the optimum choice in modern sea level observing systems.

Atmospheric conditions should be monitored and recorded in order to study their effects on the recorded sea level data. For example, changes in atmospheric pressure produce changes in the pressure acting vertically on the sea surface. One-millibar increase of atmospheric pressure decreases sea level by one centimeter. Additionally, the drag of the wind on the sea surface increases as the square of the wind speed, to a first approximation (IOC, 1994). Consequently, a precise sea level observing system should include a device for monitoring meteorological factors.

Recent geodetic and oceanographic MSL studies have shown that neither the sea levels nor the land are permanent with respect to time variations. The data analysis of tide gauges produces "relative" sea level changes. For the purpose of monitoring and understanding long term variations in sea level, the contribution of land motion should be precisely determined. That means that in order to monitor "absolute" changes in sea level, the rates of any vertical land movements at a tide gauge must be determined [e.g. Bingley et al, 2000]. Consequently, a geodetic monitoring technique is required to perform this task at tide gauge sites. The Global Positioning System (GPS) is the most recent and precise geodetic tool used, among a wide range of applications, to monitor crustal movements. The GPS is a global military and civilian navigation system operated by the U.S. Department of Defense for. It consists of 21 satellites (and 3 spares) orbiting the Earth at an altitude of about 20,000 km. Interested readers may obtain detailed information concerning the GPS technology in a variety of publications [e.g. Leick, 1998, and Mohamed and Alnaggar, 1999]. GPS has been utilized in several modern sea level observing projects worldwide [e.g. Zibini et al, 2000, and Bingley et al, 2000]. Another crucial merit of utilizing GPS at tide gauges is the unification of global network of tide gauges in a unique coordinates system, which permits the analysis of sea-level measurements on a global scale. Absolute gravimetry may also be adopted as an alternative procedure to monitor vertical crustal movements at a tide gauge site.

Beside the three mentioned elements of a sea level observing system, the site in which the gauge is installed should fulfill the following criteria (IOC, 2000):

- When completed, the installation must be capable of withstanding the worst storm conditions.
- The ground on which the installation is to be built must be stable.
- The water depth must extend at least two meters beneath the lowest astronomical tide.
- River estuaries should, if possible, be avoided.
- Areas where impounding (becoming cut-off from the sea) can occur at extreme low level should be avoided
- Sharp headlands and sounds should be avoided since theses are places where high currents occur.
- Proximity to outfalls can result in turbulence, currents, dilution and deposits, and should be avoided.
- Electrical power source must be available to operate instruments.
- Accessibility of the site should be easy.

The new installed state-of-the-art system consists of three devices integrated together in a unified scheme: a tide gauge, a meteorological unit; and a satellite-based GPS geodetic receiver (Figure 1). The three components will be presented in details in the following sub-sections.

### 4.1 Utilized Tide Gauge Instrument

The utilized tide gauge is a high-accuracy temperature-compensated self-contained instrument for measuring and recording tide and wave data. The employed technology in this state-of-the-art device is based on the Silicon-On-Sapphire semi-conductor strain gauge pressure type.

The instrument, which is called Wave and Tide Gauge WTG904 Series 3, measures instantaneously the water column pressure, and converts it to height of water with respect to a specific user-defined location (Figure 2). The pressure sensor output is digitized at a 2 Hz sampling rate via a 14-bit A/D converter controlled by a 32-bit CMOS microprocessor. The tide is calculated continuously and recorded automatically every 10 minutes. The measuring depth range of the gauge is from 0 to 35 meters, with a precision of ± 0.15 % of the measuring range, and a resolution of 0.006 % of the measuring range. Knowing that the depth of the water in the steeling well in Alexandria is approximately 1.5 meters, it can be expected that the accuracy of the measurements is 0.2 cm. The apparatus has a built-in battery-backed 64KB RAM memory that can record measurements up to 90 days. A communication interface (RS485 or RS232C) is used to download the recorded data to an attached computer. There are two ASCII output files, for both tide and wave recorded data, which could be used for further analysis and plotting procedures. The device works in operating temperature from -5 $^{o}$C to 35 $^{o}$C. The equipment uses internal alkaline batteries that can provide the required power up to 90 days in normal conditions [InterOcean, 1999].

### 4.2 Utilized meteorological device

The utilized device, WMS-14 from Omega Inc., is a state-of-the-art microprocessor-based weather station (Figure 3). Measurements of wind speed, wind direction, temperature, humidity, and precipitation are collected and processed by the control module of this station. The device consists of five sensors connected to a control unite. Build-in memory can store measured data up to 32 days for later retrieval. The time interval between recordings is user-defined ranging from one to sixty minutes. The device is powered by an external 12V source from a standard 220V outlet. A 12V battery can be plugged into the auxiliary power jack to provide emergency backup power in the event of a loss of main power. A fully charged battery will run the device for five days.

The WMS-14 instrument has five accurate and reliable sensors for collecting different types of meteorological data. A wind speed sensor combines a three-cup anemometer and a wind vane on a single axis. This sensor measures, computes, and stores wind speed and wind direction. Barometric pressure is sensed using a piezoresistive sensing element, which responds to changes in pressure with a corresponding change in resistance. The resistance is converted to a voltage form, which the microprocessor calculates the pressure at the elevation at which the barometer is located. Temperature is sensed using a thermistor element whose resistance changes in response to temperature fluctuations. Relative humidity is sensed by changes in capacitance of a thin polymer film as it absorbs moisture, or sheds it to, the surrounding air. The rain gauge used with the WMS-14 is a traditional tipping bucket design. The accuracy measures of the five sensors are [Omega, 1999]:

| | |
|---|---|
| For barometric pressure: | ± 5 mb |
| For Wind Speed: | ± 3 mph |
| For Wind Direction: | $\pm 2^{o}$ |
| For Rain precipitation: | ± 1 % |
| For Temperature: | $\pm 2^{o}$ F |
| For Relative Humidity: | ± 3% |

### 4.3 Utilized satellite-based GPS receiver

Lieca GPS system 500 comprises GPS receiver, terminal and post-processing software (Figure 4). The SR520 dual-frequency GPS receiver has 12 L1 and 12 L2 continuous data tracking channels that track both codes and carrier phases of the transmitted satellite signals. It tracks up to 12 simultaneously satellites. The collected data is stored on a standard PCMCAI cards that has storage capacity up to 85MB (i.e., up to three months of measurements). An alphanumeric TR500 terminal is connected to the receiver, either via a connection cable or directly to a certain port, in order to configure and control the receiver options. A high-precision AT504 choke-ringe type antenna is utilized in the GPS project configuration.

The normal accuracy of the obtained baseline length, in a static mode, is 5 mm ± 1 ppm (part per million) [Lieca 1999]. In other words, this means that for a baseline of 10 km, the expected mean square error is 15 mm. It worth mentioning that this accuracy limits could be improved using several items, e.g. using precise satellite orbits instead of the normal ones broadcasted in real-time from the GPS satellites.

## 5- RESULTS OF ESTIMATING SEA LEVEL RISE IN EGYPT

Tide observations, from different sources, have been collected for two tide gauges at Alexandria, and one tide gauge at Port Said [Dawod, 2001]. The available measurements span from 1944 to 1999 for Alexandria, and from 1926 to 1987 for Port Said. The MSL defined in 1906 as the national Egyptian vertical datum has been used to unify all measurements. The annual averages of sea level at Alexandria and Port Said have been analyzed using the available data sets. The results are summarized in Table 1. The annual change of sea level at Alexandria varies from –11.7 cm to 11.5 cm, while it ranges from –7 cm to 12 cm at Port Said. Considering the zero-value for MSL defined in 1906 as a datum, it has been found that the MSL at Alexandria varies from 1.6 cm (in 1947) to 23.5 cm (in 1987) above that datum, with a mean value of 11.1 cm. At Port Said, MSL changes between –1.7 cm (in 1929) to 24.0 cm (in 1980), with an average of 9.0 cm. Figures 5 and 6 depict the MSL annual changes for Alexandria and Port Said respectively, while figures 7 and 8 present the MSL values, above the selected datum, for both tide gauges.

Regression analysis has been performed to compute the rising rates of sea level at Alexandria and Port Said over the last decades. The least-squares estimation technique has been utilized to solve the linear over-determined equations since there exist degrees of freedom. The obtained results are:

For Alexandria:

$$H = 6.09 + 0.1718 * YN_1 \tag{2}$$

For Port Said:

$$H = 2.29 + 0.2390 * YN_2 \tag{3}$$

where,

H is the height of the sea level, in cm, above the chosen datum.
$YN_1$ = Year – 1943, i.e., the number of years from the start of the data series at Alexandria.
$YN_2$ = Year – 1925, i.e., the number of years from the start of the data series at Port Said.

**Table 1**
**Long-Term MSL Rise**

| | Alexandria | Port Said |
|---|---|---|
| Data Span | 1944-1999 | 1926-1987 |
| Minimum Annual Change | -11.7 | -7.0 |
| Maximum Annual Change | 11.5 | 12.0 |
| Minimum MSL Value | 1.6 | -1.7 |
| Maximum MSL Value | 23.5 | 24.0 |
| Average MSL Value | 11.1 | 9.0 |

Based on these findings, it can be concluded that the Mediterranean sea level is rising by a rate of 1.7 mm/year at Alexandria, and 2.4 mm/year at Port Said. These estimates are close to results of similar previous studies [e.g. Alam El-Din, 1993, and Frihy, 1992]. However, it worth mentioning that the data utilized in the present study cover longer time span, and hence could be considered more reliable for long-term MSL rise determination.

## 6- CONCLUSIONS

The sea level rise is one of the main factors that cause shoreline retreat, coastal erosion, lowlands overflow, and increase the salinity of lakes and aquifers. Consequently, there exists a critical demand to explore, on geodetic and environmental basis, the consequences of sea level changes in Egypt. It has been found that the annual change of sea level at Alexandria varies from –11.7 cm to 11.5 cm, while it ranges from –7 cm to 12 cm at Port Said. Considering the zero-value for MSL defined in 1906 as a datum, it has been found that the MSL at Alexandria varies from 1.6 cm (in 1947) to 23.5 cm (in 1987) above that datum, with a mean value of 11.1 cm. At Port Said, MSL changes between –1.7 cm (in 1929) to 24.0 cm (in 1980), with an average of 9.0 cm. Moreover, it has been concluded that the Mediterranean sea level is rising by a rate of 1.7 mm/year at Alexandria, and 2.4 mm/year at Port Said.

The installed state-of-the-art multi-purpose sea level observing system satisfies the recent recommendations and standards of the international respective organizations. It is the first outstanding monitoring system in Egypt that fulfils several geodetic and environmental goals. It is recommended that several such systems must be installed on the Egyptian coastlines in order to obtain more precise and reliable frames describing the sea level rise phenomena in Egypt. The precise estimates and results of such systems must be taken into consideration in the development planes of the coastal areas in Egypt.

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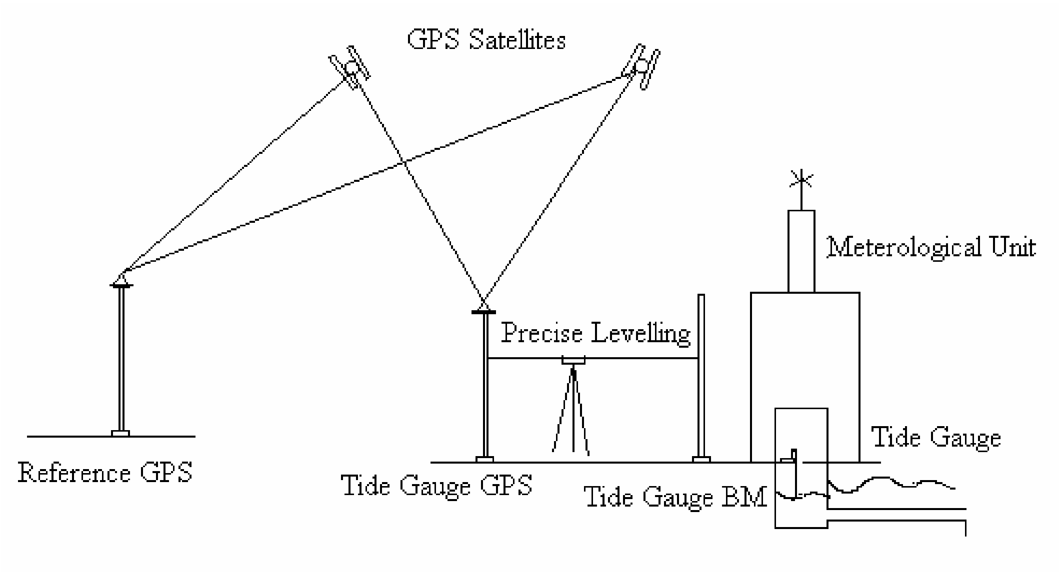


**FIGURE 1**
**MODERN SEA-LEVEL MONITORING SYSTEM**

**FIGURE 2**
**WTG904 TIDE GAUGES**

**FIGURE 3**
**WMS-14 METEOROLOGICAL STATION**

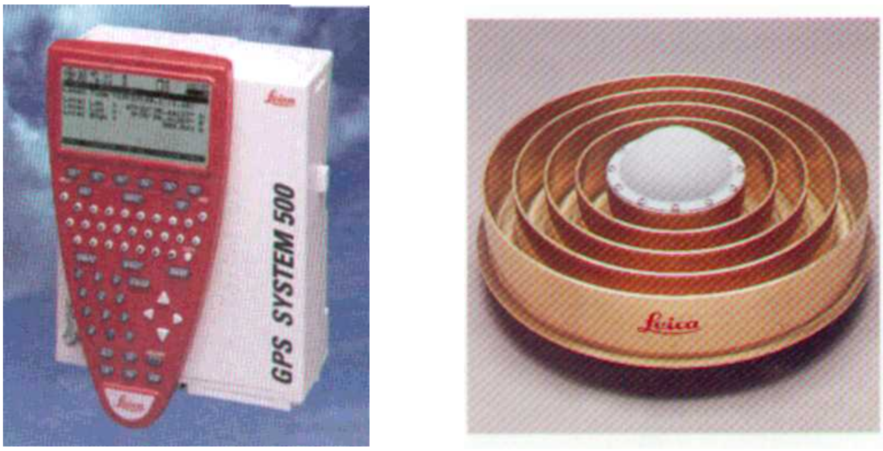


**FIGURE 4**
**LIECA SYSTEM 500 GPS RECEIVER**

**FIGURE 5**
**ANNUAL VARIATIONS OF SEA LEVEL AT ALEXANDRIA**

**FIGURE 6**
**ANNUAL VARIATIONS OF SEA LEVEL AT PORT SAID**

**FIGURE 7**
**LONG-TERM CHANGES OF MSL VALUES AT ALEXANDRIA**
**(RELATIVE TO THE 1906 NATIONAL DATUM)**

**FIGURE 8**
**LONG-TERM CHANGES OF MSL VALUES AT PORT SAID**
**(RELATIVE TO THE 1906 NATIONAL DATUM)**