# DEVELOPMENT and IMPLEMENTATION OF A GEODETIC FRAMEWORK for EL SALVADOR, GUATEMALA, HONDURAS, and NICARAGUA

(AS PROVIDED UNDER THE HURRICANE MITCH RECONSTRUCTION PROGRAM FOR CENTRAL AMERICA)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

NATIONAL GEODETIC SURVEY
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## HURRICANE MITCH RELIEF ACTIVITIES

As part of the Department of Commerce (DOC) "Implementation Plan for Reconstruction Work in Central America," dated July 1999, the National Geodetic Survey (NGS) is tasked to develop a modern geodetic reference system for El Salvador, Guatemala, Honduras, and Nicaragua. This system will provide the spatial framework for precision marine, air and land navigation, mapping and charting, resource management, disaster relief operations, engineering and cadastral surveys, and Geographic Information Systems (GIS). The design of this framework will include, to the extent possible, several elements of the U. S. National Spatial Reference System (NSRS), including Continuously Operating Reference Stations (CORS), a High Accuracy Reference Network (HARN), absolute gravity observations, and technology transfer to ensure a sustainable infrastructure. These data will become the framework for an Inter-American Geospatial Data Network (IGDN). (NOTE: At this time, funding for activities in El Salvador and Guatemala is undetermined. All references to activities in those countries are contingent on appropriate funding levels.)

To ensure the successful completion of this plan, NGS must develop a close relationship with the national government agencies and academic institutions in these countries responsible for surveying and mapping activities. The contacts listed below have not been completely verified at this time:

Honduras: Instituto Geográfico Nacional (IGN)
Director - Dr. Noe Pineda Portillo
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Nicaragua: Instituto Nicaragüense de Estudios Territoriales (INETER)
Director - Ing. Claudio Gutierrez
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El Salvador - Ing. Roberto Meyer
Guatemala - Ing Fernando Boiton

In addition, a working relationship with other U.S. Federal agencies involved in "Mitch" , as well as World Bank (WB) related activities in this region is essential. These include the Federal Aviation Administration (FAA), National Imagery and Mapping Agency (NIMA), U.S. Geological Survey (USGS), and the U.S. Department of Transportation Volpe Transportation Center (Volpe).

## CONTINUOUSLY OPERATING REFERENCE STATIONS (CORS)

The core of any modern geodetic network must take advantage of the powerful capabilities of CORS. While this activity has been very successful in the United States, there are currently only 2 Central American CORS, located in Aguasalientes, Mexico (INEGI) and Moin, Costa Rica (MOIN), in coordination with the International GPS Service (IGS). The Mexican government, under the direction of the Instituto Nacional de Estadistica Geografia e Informatica (INEGI), maintains an extensive network of CORS stations, including the site listed above, that are proprietary to their activities. While these data are available, INEGI charges for downloading data. NGS will make every effort to ensure the integrity of new CORS with the existing INEGI network.

To establish a strong framework, a network of at least 3-4 CORS each in Honduras and Nicaragua, 2-3 in Guatemala, and 1-2 in El Salvador, is recommended. The establishment of these sites will be done in coordination with Volpe (Figure 1). Under the overall "Mitch" program, Volpe is funded to establish Differential GPS (DGPS) sites in Honduras and Nicaragua. These sites are planned to be standard U.S. Coast Guard DGPS packages using single-frequency GPS "resource/navigation" grade receivers not suitable for CORS. NGS will coordinate with Volpe to ensure the site specifications are upgraded to include dual-frequency GPS units and communications to allow transfer of these data to NGS for processing. CORS should achieve an accuracy of better than 2 cm horizontal and 4 cm ellipsoid height relative to the existing IGS stations at the 95% (2 sigma) confidence level.

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CORS sites not established by Volpe will be installed or upgraded by NGS in coordination with the respective national surveying/mapping institutions. These agencies are identified by different names, but for purposes of this plan will be described generically as the Instituto Geografico Nacional (IGN). To the extent possible and practical, all CORS will be designed to conform with the recommendations of NGS Process Action Team 20 "*CORS SITE MONUMENTATION*." Given the nature of the political and physical infrastructure requirements to support CORS, it is very likely that at least 1 CORS will need to be established in the capitol at the IGN headquarters, regardless of the efficiency of that location with respect to other CORS. The NGS team will also attempt to ensure the location of these sites in tectonically stable regions. The realizations of these elements: secured installation site, adequate power, Internet connections, and tectonic stability could be very difficult to achieve!

In order to enhance a regionally strong reference frame, additional efforts will be made to find funding for sites in Belize, Costa Rica, and Panama. "**TENTATIVE**" sites selected for CORS are:

| **El Salvador** | Latitude (N) | Longitude (W) |
|---|---|---|
| San Salvador – New site by NGS | 13° 26' | 89° 03' |
| | | |
| **Guatemala** | | |
| Guatemala City – New site by NGS | 14° 34' | 90° 31' |
| Santa Elena – Upgrade existing site, funded by WB | 16° 55' | 89° 52' |
| | | |
| **Honduras** | | |
| Choluteca - Volpe## | 13° 20' | 87° 10' |
| Puerto Cortez - Volpe** | 15° 50' | 87° 55' |
| or | | |
| Puerto Castilla - Volpe** | 16° 01' | 86° 01' |
| Tegucigalpa – New site by NGS | 14° 04' | 87° 13' |
| | | |
| **Nicaragua** | | |
| Corinto - Volpe## | 12° 48' | 87° 24' |
| Managua – New site by NGS | 12° 09' | 86° 15' |
| Puerto Cabezas - Volpe | 14° 03' | 83° 23' |
| Sabalos – Upgrade existing site established by U. of FL | 11° 03' | 84° 20' |

** Volpe is considering a change of site from Puerto Cortez to Puerto Castilla

## Upon completion of the field reconnaissance, the Volpe CORS may be combined into a single site.

All CORS data will be adjusted into the International Earth Rotation Service (IERS) Terrestrial Reference Frame (ITRF) currently defined as ITRF97. The resulting 3-dimensional coordinates X, Y, and Z will be converted into latitude, longitude, and ellipsoid height using the parameters for the Geodetic Reference System 1980 (GRS80) ellipsoid. These data should be compatible with the Department of Defense World Geodetic System 1984 (WGS 84) solution of GPS week 873, referred to as WGS 84 (G873), +/- less than 10 cm at the 95 % (2 sigma) confidence level.

NGS will train IGN employees to eventually take over the maintenance, analysis, operation and data distribution of CORS. Training of local government technicians and specialists to support CORS is a high priority of this program. This training effort should also include qualified candidates from the universities to provide the technical support base to support the IGNs. CORS support training will be conducted both in the host country and at NGS Headquarters in Silver Spring. The "Mitch" recovery plan provides funding for a 2-year program. At the end of that time, NGS will evaluate the efficiency of each country's capabilities, and determine an appropriate course which could include, but not be limited to: complete transfer of all operations to the host country, continued but limited NGS data analysis and distribution, transfer of the processing to IGS, or establishment of a regional processing center.

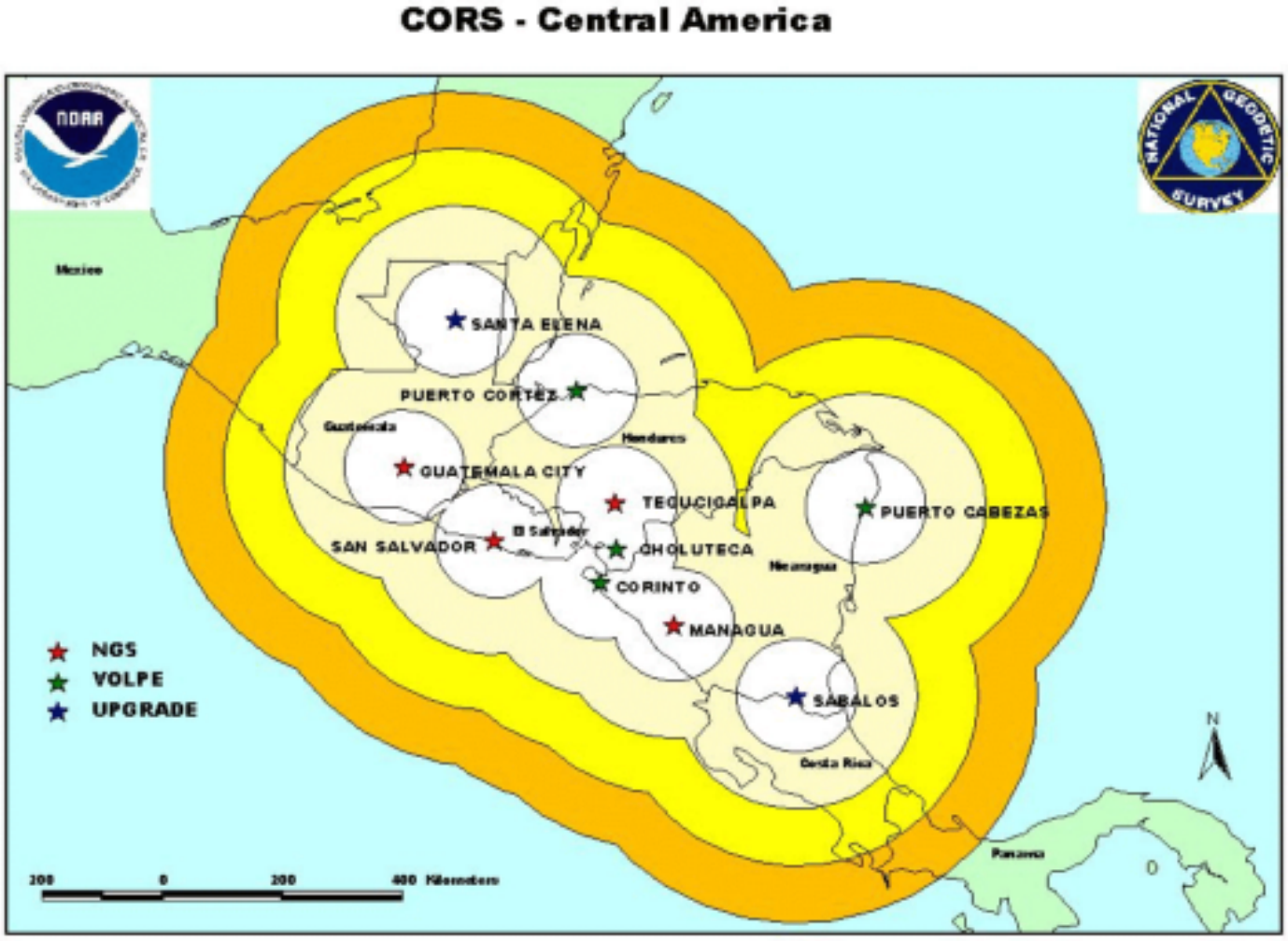


**Figure 1**

## HIGH ACCURACY REFERENCE NETWORK (HARN)

To make the reference frame accessible for the many applications required of these data, a primary network of high accuracy control survey points must be established. Referred to as an High Accuracy Reference Network (HARN), these points will be monumented as conventional survey control points (e.g., a disk in bedrock or a concrete post) and will be spaced approximately 40-50 km apart. This network will support a wide range of surveying and mapping techniques, including conventional surveying measurements (e.g., leveling, traverse, trilateration, and triangulation), static and kinematic GPS, photogrammetry, and remote sensing. The implementation of a HARN in conjunction with CORS in the United States has proven to be an effective, efficient and economical basis for most surveying, mapping, charting, and GIS applications.

All of the Central American countries have historical "classical" geodetic triangulation networks established in cooperation with the former InterAmerican Geodetic Survey (IAGS), and adjusted to the North American Datum of 1927 (NAD 27). IAGS was an international outreach effort of the Defense Mapping Agency (DMA), formerly the Army Map Service (AMS), currently NIMA. Some of these data were submitted to NGS by DMA for inclusion in the original adjustment of the North American Datum of 1983 (NAD 83). Unfortunately, NGS was never provided with descriptions of these control points and this data appears to be of minimal value today. Where possible and practical, the HARNs will attempt to incorporate these control points to determine a higher quality datum transformation from NAD 27 to WGS84 than is currently published by NIMA in their technical report TR8350.2 "*World Geodetic System of 1984, Its Definition and Relationship with Local Geodetic Systems*." The GPS programs implemented by NIMA for Honduras (1994) and Nicaragua (1996) indicated that very little of the IAGS networks still exist.

In an effort to reduce duplication of effort, this plan recommends that the monumentation established by NIMA in Honduras (30 stations in 1994) and Nicaragua (50 stations in 1996) (see NIMA publication SMWD3-96-001) be used as the basis for the HARN. As these networks were established prior to Mitch, it is uncertain as to the extent of damage or destruction of these control points in Honduras. A 1998 reconnaissance effort by NIMA for Nicaragua indicates that only about 5 stations were destroyed or damaged by the hurricane. Activities by NIMA in El Salvador (2 stations) and Guatemala (6 stations) have been very limited as of this time. If additional funding is provided under "Mitch," NGS will establish approximately 15-20 HARN stations in El Salvador and 25-30 in Guatemala.

NGS proposes to use the GPS field observation specifications currently used for the Federal Base Network Height Modernization activities in the United States. These specifications should produce a network with accuracies of not worse than 1-2 cm horizontal and 2-3 cm ellipsoid height relative to CORS at the 95% (2 sigma) confidence level. These specifications include:

Only dual-frequency, full-wavelength on L2 GPS receivers
Fixed height poles
Three - 5.5 hour sessions with one session offset by 4 hours
CORS as fixed control
Vector processing with NGS "PAGES" software
Network adjustment with NGS "ADJUST" software
IGS produced precise orbit

Nicaragua HARN: NIMA is currently planning a 400 + station GPS "vertical" campaign for the early part of 2000 (January - March) funded by WB. NGS will recommend that a portion of this network, 40-50 stations spaced approximately 30-70 km, be observed as the HARN. NIMA is under considerable pressure from WB to complete this survey and it may not be possible to have CORS operational prior to this campaign. In the event that this occurs, NGS may recommend that the HARN portion be observed as a stand-alone network and that these data be provided in "Blue Book" format. Following the establishment of CORS, NGS will contract for sufficient additional observations to be able to connect the NIMA survey to CORS.

Honduras HARN: The “office” plan is to use the existing 1994 NIMA GPS network as the basis for this survey. The current physical condition of the network is unknown. This survey will require a full field reconnaissance, remonumentation as required, and reobservation to NGS specifications. This activity should be conducted by a U.S. contractor, providing training to IGN.

El Salvador: The status of any national geodetic network appears to be limited at this time. A

review of records by NIMA indicates only 2 existing GPS stations in their files. Development of a HARN would be in consultation with IGN. Monumentation and observation would be as in Honduras.

Guatemala: Same as El Salvador, with the exception that the NIMA review indicates 6 existing GPS station


**FIGURE 2**

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## LOCAL (CADASTRAL) SURVEY CONTROL

It is not the intention of this program to provide geodetic control monumentation at the local or town level (1 - 2 kilometer station spacing) to directly support local cadastral, engineering and topographic applications. However, the importance of this activity is recognized as being the ultimate goal of many users of geospatial data. NGS will furnish the appropriate GPS equipment, software, and training to enable IGNs to densify this control as need. Part of the NGS implementation team will include geodetic surveyors from the Bureau of Land Management (BLM) and the U.S. Forest Service (USFS) who are trained in the application of GPS and geodetic control for cadastral applications.

## GRAVITY SURVEYS

Any significant improvements to a regional geoid model will require extensive airborne or relative gravity observations. Unfortunately there are insufficient resources in the "Mitch" budget to provide for these activities. NGS can implement a strategically designed network of "absolute" gravity stations in cooperation with NIMA which will provide a framework for future relative surveys. The number of stations per country, and their locations will be determined in discussions between NGS (Dr. Dru Smith) and NIMA (Steve Kenyon), to result in regional network of approximately 6-10 stations. These stations would be co-located at CORS, Water Level Bench Marks, and/or airport HARN station sites.

## AIRPORT SURVEYS

A very important element of any disaster relief plan is the capability of efficiently using both ground, water, and air navigation. A portion of this plan will be dedicated to providing surveys of airports selected in consultation with FAA, NIMA, and the national Civil Aviation Administrations (CAAs). To the extent possible, these surveys will be conducted in accordance with FAA 405 "*Standards for Aeronautical Surveys.*" These standards will ensure compliance

with requirements of the International Civil Aviation Organization (ICAO) as defined in Doc. 9674-AN/946 "*World Geodetic System - 1984 (WGS-84) Manual.*" The surveys will be limited to establishment of Primary and Secondary Airport Stations (PACS/SACS), positioning runway end points, and runway centerline profiles. Obstacle/obstruction surveys will be conducted at approximately 9 airports as listed below. These surveys will be designed as pilot projects to provide to training to contractors/national institutions to develop their own capabilities. Obstruction surveys for the remaining airports will be left to each CAA to contract or perform on its own. The PACS will be included in the development of the national HARN. The airports to be considered include (Figure 2):

**EL SALVADOR**

| AIRPORT | Latitude (N) | Longitude (W) |
|---|---|---|
| EL SALVADOR INTERNATIONAL (O) | 13° 26.5' | 89° 03.5' |
| ILOPANGO (O) | 13° 42.0' | 89° 07.2' |
| LOS COMANDOS | 13° 43.6' | 88° 06.4' |
| TAMARINDO | 13° 09.8' | 87° 54.4' |

**GUATEMALA**

| AIRPORT | Latitude (N) | Longitude (W) |
|---|---|---|
| BANANERA | 15° 28.6' | 88° 50.1' |
| COBAN | 15° 28.1' | 90° 24.4' |
| INTA NORTHESAST | 15° 48.3' | 89° 50.9' |
| LA AURORA (O) | 14° 35.0' | 90° 31.6' |
| POPTUN | 16° 19.6' | 89° 25.0' |
| PUERTO BARRIOS (O) | 15° 43.9' | 88° 35.1' |
| RETALHUELEU | 14° 31.3' | 91° 41.8' |
| SAN JOSE | 13° 54.8' | 90° 50.1' |
| TIKAL INTERNATIONAL (O) | 16° 54.8' | 89° 51.9' |

**HONDURAS**

| AIRPORT | Latitude (N) | Longitude (W) |
|---|---|---|
| AHUAS | 15° 28.2' | 84° 21.2' |
| CORONEL ENRIQUE SOTO CANO (O) | 14° 22.9' | 87° 37.3' |
| CUCUYAGUA | 14° 37.6' | 88° 52.6' |
| GUANAJA | 16° 26.8' | 85° 54.4' |
| ISLAS DEL CISNE | 17° 24.5' | 83° 55.9' |
| LA MESA INTERNATIONAL (O) | 15° 27.1' | 87° 55.5' |
| MOCORON DURZONA | 14° 59.3' | 84° 13.2' |
| PUERTO LEMPIRA | 15° 15.7' | 83° 46.9' |
| TELA | 15° 46.6' | 87° 28.5' |
| TONCONTIN INTERNATIONAL (O) | 14° 03.7' | 87° 13.0' |
| TRUJILLO | 15° 55.6' | 85° 56.3' |

**NICARAGUA**

| AIRPORT | Latitude (N) | Longitude (W) |
|---|---|---|
| AUGUSTO CESAR SANDINO (O) | 12° 08.5' | 86° 10.1' |

| | | |
|---|---|---|
| BLUEFIELDS | 11° 59.8' | 83° 46.0' |
| EL BLUFF | 11° 59.6' | 83° 41.3' |
| FANOR URROZ | 12° 25.7' | 86° 54.1' |
| LOS BRASILES | 12° 11.4' | 86° 21.2' |
| MONTELIMAR | 11° 48.3' | 86° 30.7' |
| PUERTO CABEZAS | 14° 03.0' | 83° 22.8' |
| PUNTA HUETE | 12° 21.2' | 86° 11.0' |

(O) - Obstruction surveys to be completed.

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## WATER LEVEL NETWORK

Final network design and site selections will be provided by the NOS Center for Operational Oceanographic Products and Services (CO-OPS), and will depend on the results of discussions with the in-country agency participants and a site reconnaissance of existing and historical water level stations. Site reconnaissance will be conducted by agency and CO-OPS representatives. Some of the site selection criteria consist of: 1) length of the Mean Sea Level (MSL) series available, 2) adequate bench mark network, 3) adequate facilities and security for long-term measurements, and 4) if it is an existing site, does the MSL data represent an open coast environment.

The following station list was prepared from information in the CO-OPS historical water level archives. The final network will consist of about 4 or 5 stations which will be selected from the list of historical stations in each country..

**EL SALVADOR**

| Station | Latitude (N) | Longitude (W) | Years |
|---|---|---|---|
| La Union | 13° 20.0' | 87° 49.3' | 19 |
| La Libertad | 13° 28.6' | 89° 19.4' | >1 |

**GUATEMALA**

| Station | Latitude (N) | Longitude (W) | Years |
|---|---|---|---|
| Puerto San Jose | 13° 55.0' | 90° 49.8' | 20 |
| Matias DeGalvez | 15° 41.6' | 88° 37.2' | 6 |

**HONDURAS**

| Station | Latitude (N) | Longitude (W) | Years |
|---|---|---|---|
| Puerto Cortes | 15° 50.1' | 87° 57.2' | 19 |
| Puerto Castilla | 16° 01.0' | 86° 02.0' | 13 |

**NICARAGUA**

| Station | Latitude (N) | Longitude (W) | Years |
|---|---|---|---|
| Puerto Cabezas | 14° 01.2' | 83° 22.9' | 11 |
| Bluefield (El Bluff) | 11° 59.8' | 83° 41.6' | 1 |
| Corinto | 12° 28.7' | 87° 10.1' | 4 |
| Puerto Somoza | 12° 11.0' | 86° 46.0' | >1 |
| San Juan Del Sur | 11° 15.1' | 85° 52.8' | 4.5 |

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## DATA ADJUSTMENTS AND DISTRIBUTION

NGS will conduct a regional network adjustment of all the CORS and HARN stations. This solution will be provided using the ADJUST network software. Every effort will be made to include technical representatives of the IGNs to assist in the adjustment process at NGS Headquarters in Silver Spring, MD. Since it is likely that the HARNs will not be observed concurrently, NGS will ensure the integration of these surveys into a regional network solution. NGS will also pursue cooperative activities with Belize, Coast Rica, Mexico, and Panama to develop an integrated Central American reference frame connected to the South American Sistema de Referência Geocêntrico para a América do Sul (SIRGAS) and United States National Spatial Reference System (NSRS).

For the duration of the "Mitch" program, NGS will provide storage of all original GPS observations in the NGS Data Base and distribution of all CORS/HARN data through the Internet. Eventually, these data should be stored and distributed either through the individual IGNs, or through a regional data support center.

## PROVIDING TECHNICAL RESOURCES TO IGNs/UNIVERSITIES

A critical aspect of the "Mitch" relief program is to provide training and technical assistance to the national governments to ensure their ability to sustain these activities. This will include providing GPS receivers, fixed height and collapsible tripods, personal computers, and other associated support hardware and software. The actual amount of equipment to provide each country will require a more extensive review of their current technology, national requirements, and ability to adequately utilize these instruments. At a minimum each country should have:

1): 1-2 CORS "kits" in addition to those established by Volpe. These kits should contain:

A. Dual-frequency, full-wavelength on L2 GPS receivers
B. Choke-ring antennas
C. PCs
D. Communication links
E. Processing software

2). 4-6 dual-frequency, full-wavelength on L2 receivers - These receivers should be obtained from a manufacturer with a proven support network in Central America and should be capable of providing both static and real-time kinematic (RTK) observations.

3). Sufficient number of both collapsible and fixed height poles to support the number of receivers provided.

4). 2 digital bar-code level instruments with geodetic rods.

5). 6-8 PCs for data reduction, adjustments, and storage.

In addition to hardware and software, it will be critical to provide extensive training of personnel. This training will include both in and out of country training on issues such as:

A. Setting survey monumentation
B. GPS and leveling network planning
C. GPS and leveling observations
D. GPS and leveling data reduction
E. Horizontal and vertical network adjustments
F. Datum transformations
G. CORS processing and maintenance
H. Data archiving
I. Data distribution

An important element of this training will include enhancing the capabilities of the national universities to provide education and scientific support to IGNs. Given the expense of supporting many national universities, NGS will recommend to other interested regional partners (e.g., World Bank, Inter-American Development Bank, etc.) that a center of excellence be established at a university that can be supported by the entire region. This center could be selected and organized following an assessment of candidate institutions. At the very least, the NGS plan will support the establishment of connections between the national institutions, the International Federation of Surveyors (FIG), and the International Union of Geodesy and Geophysics (IUGG).

## METEROLOGICAL SENSORS

The use of GPS for the measurement of upper atmospheric water vapor content is a well established process. All CORS established in this program will also be provided with hydrometeorological sensors as part of the data collection network outlined in the Department of Commerce Implementation Plan. These activities will be coordinated with the National Weather Service (NWS).

### NWS COORDINATOR

EL SALVADOR Unavailable at this time
GUATEMALA Unavailable at this time
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NICARAGUA

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## REGIONAL MAPPING ACTIVITIES

USGS has the assigned responsibility to enhance the national mapping, GIS activities and development of national hydrological data bases for the region.. NGS will coordinate activities with USGS to ensure they are able to take full advantage of CORS/HARN data to support the variety of activities defined in their regional implementation plan.

### USGS COORDINATOR

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## PRIVATE SECTOR ACTIVITIES

While NGS will play a leadership role in providing program oversight and technical review, a considerable amount of the field work, particularly the HARNs, can be observed using U.S. private sector surveying firms. All data must meet the specifications and quality control measures assured by the existing data submission process - "Blue Booking." NGS will also investigate the existence of local private sector surveying and mapping activities that will benefit from these programs, and support the formation of partnerships between IGNs and private sector interests.

## WORLD BANK COORDINATION

The World Bank is particularly interested in "Mitch" activities in countries where it has long-term land administration programs, including El Salvador, Guatemala, Honduras, and Nicaragua. Within these long-term programs, WB is financing geodetic activities that could be very complementary to NOS activities. Therefore, every effort will be made to ensure the compatibility, coordination, and enhancement of NOS and WB related programs.

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