2/23/2016

Modernization of the
PHILIPPINE GEODETIC REFERENCE SYSTEM

# STRATEGIC PLAN 2016-2020

2016

2017

2018

2019

2020

Geodesy Division – Mapping and Geodesy Branch
NATIONAL MAPPING AND RESOURCE INFORMATION AUTHORITY

# Contents

## Introduction

The National Mapping and Resource Information Authority (NAMRIA), as the key agency mandated to establish and maintain the country's geodetic control network, is currently undertaking the modernization of the Philippine Geodetic Reference System. The program is one of the core initiatives identified by the Agency as part of its strategic objective to help create a geospatially empowered Philippines by 2020.

The modernization initiative is aimed at addressing the pressing problem of using an outdated and static primary reference for surveying and mapping, despite the constantly changing landforms in the country. The current system in use, the Philippine Reference System of 1992 (PRS92), has been established more than twenty (20) years ago and has remained unchanged. Since then, the country has been subjected to significant ground deformations such as the Magnitude 7.2 Bohol Earthquake last October 2013. Crustal movement in the Philippines alone is estimated to be an average of 2-3 cm/year based on the monitoring of the Philippine Institute of Volcanology and Seismology (Phivolcs). As a result, the integrity of the PRS92 geodetic control network is gradually degraded with the coordinates of control points increasingly becoming inconsistent with their real world positions.

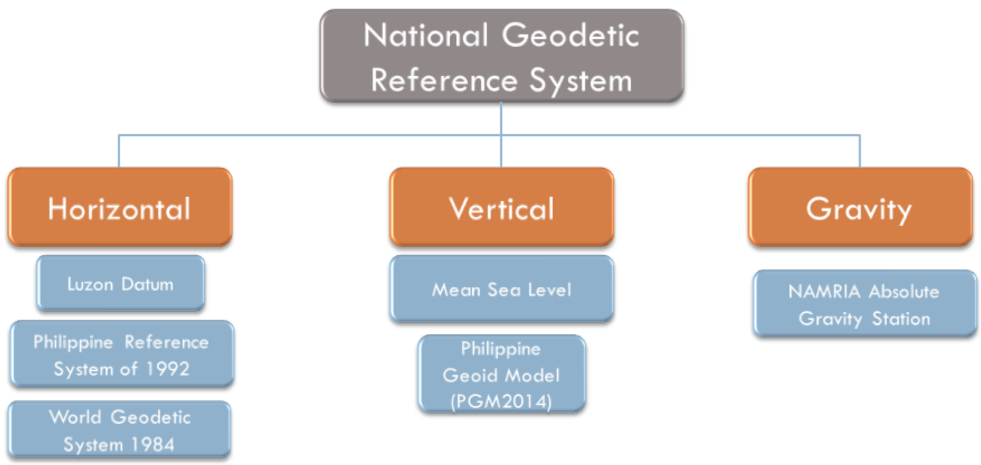
Likewise, elevation of benchmarks (reference monuments with known elevation) in the country is still determined using conventional levelling techniques. This tedious and time consuming process has hindered the densification of benchmarks resulting to insufficient number of reference monuments to be used in construction engineering, mining, and aviation, to name a few.

Meanwhile, the global community have seen a shift on how geospatial information is acquired, managed and exchanged. There has been an increasing demand for a global geodetic reference frame (GGRF) that will underpin all geospatial information. At the same time, the past decades have seen the development of positioning technologies, such as Global Navigation Satellite Systems (GNSS), that make possible the accurate definition of, and easy utilization and connection to a GGRF. It is because of these developments that the 69$^{th}$ session of the United Nation's General Assembly approve Resolution No. A/RES/69/266 calling on all member states to adopt and contribute to the development of this GGRF in support to sustainable development.

These changes have made the modernization of the Philippine Geodetic Reference System the next logical step for NAMRIA to effectively respond to the needs of the changing times.

## Existing Systems

At present, the geodetic reference primarily in use is the PRS92 and local definition of World Geodetic System 1984 (WGS84) for geometric positioning, and the mean sea level (MSL) and Philippine Geoid Model 2014 (PGM2014) for elevation measurements.




## Horizontal Control Network

PRS92 is a local geodetic datum established using the Global Positioning System (GPS) under the Geodetic Survey Component of the Natural Resources Management and Development Project (NRMDP), an undertaking in partnership with the government of Australia. It was designed to be the reference framework for all surveying and mapping that will replace the primary triangulation network of the country established by the US Coast and Geodetic Survey from 1901-1927, whose accuracy was found by NRMDP to be less than third order based on the current standards.

The PRS92 comprised of 471 1$^{st}$ to 3$^{rd}$ order stations, 84 of which were common to the triangulation network. It retained most of the parameters of the old Luzon Datum of 1911 to minimize the changes in the coordinates, and introduced a geoid-spheroid separation at the origin in Balanacan, Marinduque.

*Reference Ellipsoid:* Clarke Spheroid of 1866

*Origin:* Station Balanacan

Latitude $13^{0}$33’41.000” N

Longitude $121^{0}$52’03.000” E

Reference Azimuth $9^{0}$12’37.000” (from South, Sta. Balanacan to Sta. Baltasar)

*Geoid-Spheroid Separation* 0.34 m

A local definition of WGS84 in its original state (WGS84 Doppler) was used to facilitate the processing of the GPS baselines and adjustment of the network. The local definition of the WGS84 is estimated to approximate WGS84 to within six meters in latitude, longitude and height (Jones, 1991). To relate the WGS84 to the modified Luzon Datum (PRS92), a set of transformation parameters were likewise developed using twenty-nine common stations.

The adoption of PRS92 as the standard reference system for surveying and mapping activities was mandated through Executive Order No. 45, series of 1991. This law was subsequently amended, the latest being Executive Order No. 321 series of 2004, extending the deadline for the full adoption of the new system until 2010. However, problems with integrating existing land survey datasets into PRS92 have resulted to users still referring to the old Luzon Datum for their surveying and mapping. Regional environment and natural resources offices, which are mandated to undertake the data integration, have experienced difficulties in integrating the old cadastral datasets due to the inconsistencies and errors in the old surveys.

Complicating the matter is the presence of active ground deformations that affect the integrity of the national geodetic control network. The Philippines is located in a tectonically-active region that is subject to an average crustal drift of 2cm/year, not to mention the local distortions brought about by earthquakes. PRS92, being a local and static datum, fails to account for this distortion.

This limitation has constrained the applicability of PRS92 to meet the requirements of all sectors. As a result, different thematic information is still referred to different systems which are, in turn, inconsistent with the whole concept of PRS92: a standard and homogeneous reference system for surveying and mapping activities in the country.

## Vertical Control Network

The vertical control network is referred to the mean sea level and its bench marks (BMs) are propagated using geodetic levelling techniques. Started by the US Coast and Geodetic Surveys in the early 1900s, the level network was subsequently densified in the following decades with intermittent levelling campaigns carried out throughout the islands. Most of the bench marks were originally reckoned from the primary tide gauge bench mark located in Manila Harbor (i.e. BM-66), but other tidal bench marks were established throughout the country to serve as reference for the level network.

During the PRS92 Campaign from 2007 to 2012, 22,851 Benchmarks were established along major roads nationwide. These first order level networks were connected to their respective reference tidal BMs to provide local MSL elevation.

With the advent of GNSS, it has become much easier to estimate MSL elevations using a geoid model. Applying a geoid model in GNSS surveys will eliminate the conduct of levelling. On October 28, 2014 with the assistance of Denmark Technical University (DTU-Space) and National Geospatial Intelligence Agency (NGIA), a preliminary geoid model has been computed for the country (Philippine Geoid Model of 2014, PGM2014) with an accuracy of 0.30meters.

## Gravity Control Network

Gravity observations in the country were few and far between, with gravimetric surveys being conducted by visiting scientists only. Later on, with the establishment of the Bureau of Coast and Geodetic Surveys, gravimetric data were collected intermittently from 1964 up to 1989. During the PRS92 Campaign from 2007 to 2012, 1,711 gravity stations were established in every province and municipality nationwide. These land gravity stations, together with the airborne and satellite gravity data were used to compute the PGM2014.

## The International Terrestrial Reference System (ITRS) and the International Terrestrial Reference Frame (ITRF)

The ITRS is an Earth-centered and Earth-fixed (ECEF) reference system wherein the definition of terrestrial coordinates to the highest possible accuracy is based (Rizos, 2012). The ITRF is its physical realization and is defined and maintained by the International Earth Rotation Service (IERS) through a worldwide network of ground stations using a combination of four space geodetic techniques: VLBI, DORIS, GNSS and

SLR/LLR. It is closely aligned to the World Geodetic System of 1984 (WGS84) to within the centimetre level. Throughout the years, different ITRF realizations have been made, the latest being ITRF2014. The differences in the coordinates between realizations are attributed mainly to crustal deformations and tectonic plate motions.

## Goals and Objectives

The modernization program is anchored on one of the strategic objectives of NAMRIA, i.e. *Building a geospatially empowered Philippines by 2020:* which aims to deliver relevant quality maps, nautical charts, ENR data and geospatial services on time.

The primary goal of the modernization program is:

***"To develop and provide access to an authoritative geodetic reference system aligned with a global geodetic reference frame, that will serve as the common reference for all surveying and mapping activities in the country"***

Specifically, the modern Philippine Geodetic Reference System is envisioned to:

1. Improve geospatial positioning (i.e. 1-cm accuracy in real time, 4D positioning) and management by full utilization of data from space geodetic techniques such as GNSS
2. Meet multi-sectoral positioning requirements of the government and the private sector (including academe and scientific community) that is consistent with international standards
3. Facilitate use of the geodetic system (encourage use of the system)
4. Connect to a global geodetic reference frame (i.e. international terrestrial reference frame) and contribute to its realization
5. Account for geodynamics in geodetic measurements and positioning

## Strategies

To achieve these goals and objectives, NAMRIA has come up with the following strategies:

1. Densification of the Philippine Active Geodetic Network
2. Development and Maintenance of the Philippine Geocentric Datum 2016
   - Alignment to a GGRF/ITRF /Migration to a semi-dynamic/dynamic geocentric datum
3. Development, refinement and validation of a deformation model
4. Development and maintenance of the Philippine Geodetic Vertical Datum 2020

5. Strengthening of core competencies on geodesy and deformation modelling.

## Densification of the PageNET

The establishment of the Philippine Active Geodetic Network (PageNET) in 2008 paved the way for the modernization of the Philippine Geodetic Reference System. The network was established with the long term goal of providing a connection to a global geodetic reference frame such as the ITRF, and at the same time, facilitating the surveying and mapping activities in the country.

In line with the modernization of the Philippine Geodetic Reference System, more stations are targeted for establishment in order to improve the quality, availability and reliability of positioning services being provided to PageNET's stakeholders.

## Development and Maintenance of the Philippine Geocentric Datum of 2016- - Alignment to the ITRF/Migration to a Semi-Dynamic/Dynamic Geocentric Datum

The Philippine Geocentric Datum of 2016 (PGD2016) is the upgrade of PRS92 to a geocentric datum. The PGD2016 will be aligned to the ITRF and will also monitor the effect of ground deformations on the geodetic control network.

A geocentric reference system such as the ITRF is deemed better suited to meet the positioning needs of the public and private sector in the country. While it is the consensus that going geocentric is the next step, considerable discussion has taken place on the specific type of datum to be adopted i.e. static, semi-dynamic or dynamic. A static datum is where the coordinates are fixed at a reference epoch and does not take into account the effects of plate tectonics. It is the simplest of the three types of datum, however, the integrity of the datum degrades over time since the coordinates do not change in tandem with the real world conditions.

Like the static datum, a semi-dynamic datum is also fixed to a reference epoch but makes use of a deformation model to incorporate the effects of plate tectonics and ground deformation on the coordinates. The resulting coordinates are propagated back to the fixed reference epoch for seamless integration into the old spatial data. In this datum type precision of spatial data analysis and its control network is maintained. Dynamic datums, meanwhile, have reference coordinates that change continuously. It overcomes the limitations of unmodelled deformation in positioning but still have to make use of a deformation model to integrate spatial data acquired over a long period of time.

Both semi-dynamic and dynamic datums are dependent on the accuracy of the deformation model. It requires all coordinates to be time-tagged and may cause confusion to users, particularly laymen.

Based on the consultation with stakeholders, the choice was pared down to two options:

1. Migrate to geocentric datum and stay static for the next three (3) to five (5) years. In the meantime, develop a deformation model that would best fit the geodynamic behaviour of the country. After this period, decide to go semi-dynamic or fully dynamic.
2. Adopt a fully dynamic geocentric datum and update the coordinates whenever a new ITRF realization is published.

Option 1 addresses the emergent need to align to a geocentric datum while, at the same time, provides ample time to study the country's geodynamic behaviour and develop a deformation model. Option 2 was also a viable alternative given that the ITRF realizations have stabilized during the past decade with longer interval between new realizations. However, a fully dynamic datum was deemed to be difficult to maintain and user acceptance may be limited considering that the country is still in the process of integrating old surveys and maps into PRS92. Having the coordinates change with each new ITRF realization might result to more confusion among the stakeholders. Add to this is the fact that NAMRIA is still in the process of enhancing the technical know-how of its personnel on geodetic reference frame development and maintenance.

After due deliberation, Option 1 was deemed to be the best choice for the migration to geocentric datum.

## Development, refinement and validation of the deformation model

An accurate deformation model is a vital component for an effective semi-dynamic or dynamic datum. With the proposed migration to geocentric datum, careful study has to be undertaken to develop and implement the said deformation model. Partnership with other government agencies and academic institutions engaged in deformation studies/modelling is crucial in order to produce an accurate and up-to-date model.

A sub-TWG comprising of representatives from Phivolcs, the academe and NAMRIA was convened to focus solely on the deformation modelling.

Among the questions tackled are:

1. What is the best approach to model the deformation?
2. How often do we recompute the deformation model?
3. How to validate the model?
4. What happens when there are earthquakes or other sudden, substantial and instantaneous ground movements?
5. What should be the institutional arrangements for the development of the deformation model?

## Development and Maintenance of the Philippine Geodetic Vertical Datum 2020 (PGVD2020)

With the advent of GNSS, ellipsoidal heights can be reduced to MSL elevations using a geoid model. In October 2014, a new preliminary geoid model for the Philippines has been computed from airborne and land gravity data, supplemented with marine satellite altimetry data, and data from the newest GOCE mission. The Philippine Geoid Model 2014 (PGM2014) has a general accuracy of about 30 cm on average across the country. This model can be refined into a 10-cm geoid by establishing additional land gravity stations, re-computation and validation. The recomputed geoid (PGM2020) will be fitted to the levelling benchmarks in order to be consistent with the existing vertical datum. This MSL-based geoid will be called *Philippine Geodetic Vertical Datum 2020 (PGVD2020).*

## Strengthening of core competencies on geodetic reference frame development and maintenance

With the shift in how geodetic control networks are realized and maintained, there is a need to enhance skills set on geodetic reference frame development and maintenance. This holds true not just for NAMRIA's technical personnel, but also the direct implementers of the new reference system, as well as for other stakeholders, such as the academe and the private sector.

Accordingly, organizational structures have to be revised to accommodate new functions such as deformation modelling and datum maintenance.

## Issues

Modernizing the Philippine Geodetic Reference System (PGRS) entails various issues that need to be properly addressed to ensure the smooth transition into the new datum. A series of consultative meetings with various stakeholders were held to solicit their insights on the proposed migration. Major concerns identified during these meeting are listed below:

| | |
|---|---|
| Technical | - Selection of datum type<br>- Development of deformation model<br>- Processing and adjustment methodology<br>- Data integration of existing datasets<br>- Transformation parameters relating existing systems (PRS92, Luzon datum) to the new system |
| Legal | - Enabling law for the new datum<br>- Revision of land surveying regulations<br>- Effect on titled properties |
| Information, Education, Communication | - Reluctance to adopt another system when PRS92 is still not completely adopted.<br>- Revision of GE curriculum |

## Implementation of Strategies

A technical working group comprising of representatives from the academe, private sector, and other government agencies directly affected by the proposed migration was convened to tackle the technical, legal and IEC issues listed above.

*Technical Working Group on the Modernization of the Philippine Geodetic Reference System*

1. Academe
   University of the Philippines – Department of Geodetic Engineering
   Feati University – Department of Geodetic Engineering
2. Government
   National Mapping and Resource Information Authority
   Lands Management Bureau

Philippine Institute of Volcanology and Seismology

**3.** Private Sector
Geodetic Engineers of the Philippines
Philippine Geodetic Engineering and Geomatics Association

Several of the stakeholders have expressed misgivings regarding the adoption of a new system given that the regional offices of the Department of Environment and Natural Resources (DENR) are still in the process of integrating existing land datasets to PRS92. To address this, it was agreed that prioritization be applied when migrating to a geocentric datum. The primary geodetic reference system which is managed by NAMRIA shall be aligned to the ITRF first. Other sectors may follow suit at a later time once they deem they are ready and capable enough to migrate to the new system.

In light of this, a five-year implementation plan (figure 1) has been prepared for the migration of the primary geodetic reference system with the application of a semi-dynamic/dynamic correction.

## TIMELINE

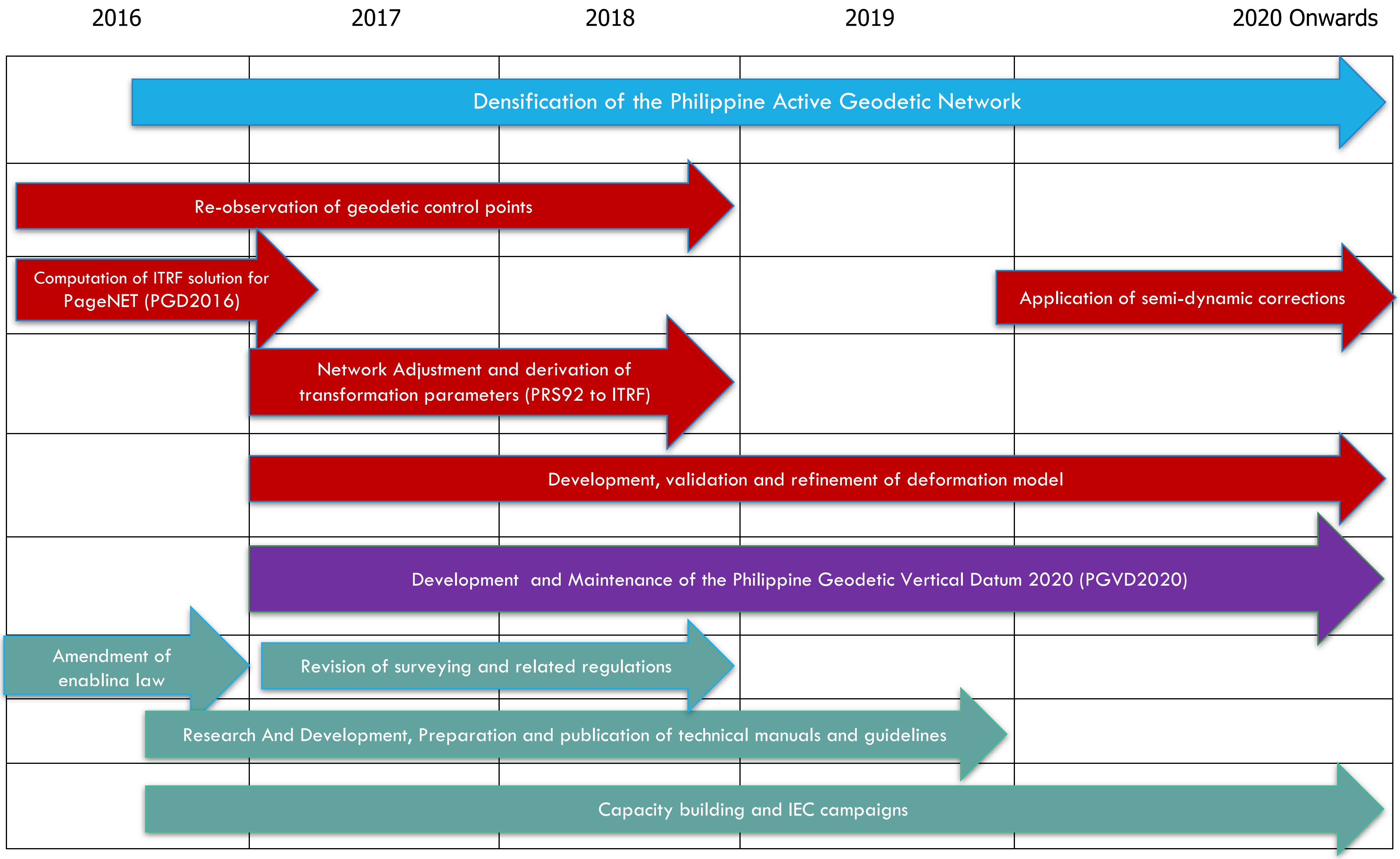



**FIGURE 1. IMPLEMENTATION TIMELINE FROM 2016 TO 2020**

## Strategy for the densification of the PageNET

Densification of the Philippine Active Geodetic Network (PageNET), the country's network of continuously operating GNSS reference stations, will continue. The aim is to establish active geodetic stations at less than 70km spacing throughout the country providing a network accuracy of 5ppm. At present, thirty-four (34) stations have already been set up with plans to ultimately put up 200 active stations by the end of 2020. The design of the PageNET follows the hierarchy of Continuously Operating Reference Stations (CORS) prescribed by Rizos (2008) (figure 2).

| Tier | Purpose | Distance |
|---|---|---|
| 1 | For incorporation to the IGS and fiducial network and to support global geodetic science and research. Provide a tie from the national geodetic reference frame to the ITRF | 500 – 1500 km |
| 2 | National geodetic reference frame realization and development and geodynamic applications | 80 – 500 km |
| 3 | To support real time positioning applications | 20 – 80 km |

**FIGURE 2. NAMRIA CORS SPECIFICATIONS**

The assignment of the stations to different tiers takes into account the zonification (figure 3) of the archipelago based on the crustal velocity field defined by Rangin, et. al. The additional stations to be established after 2016 (figure 4) are intended to improve the development of the deformation model, and at the same time, enhance the quality of the real time positioning service of the PageNET.

Examples of evidence of progress include:

1. By 2020, surveyors can use the 200 Active Geodetic Stations as reference in Network RTK Surveys nationwide
2. PageNET stations can be used in Geodynamic applications starting 2018

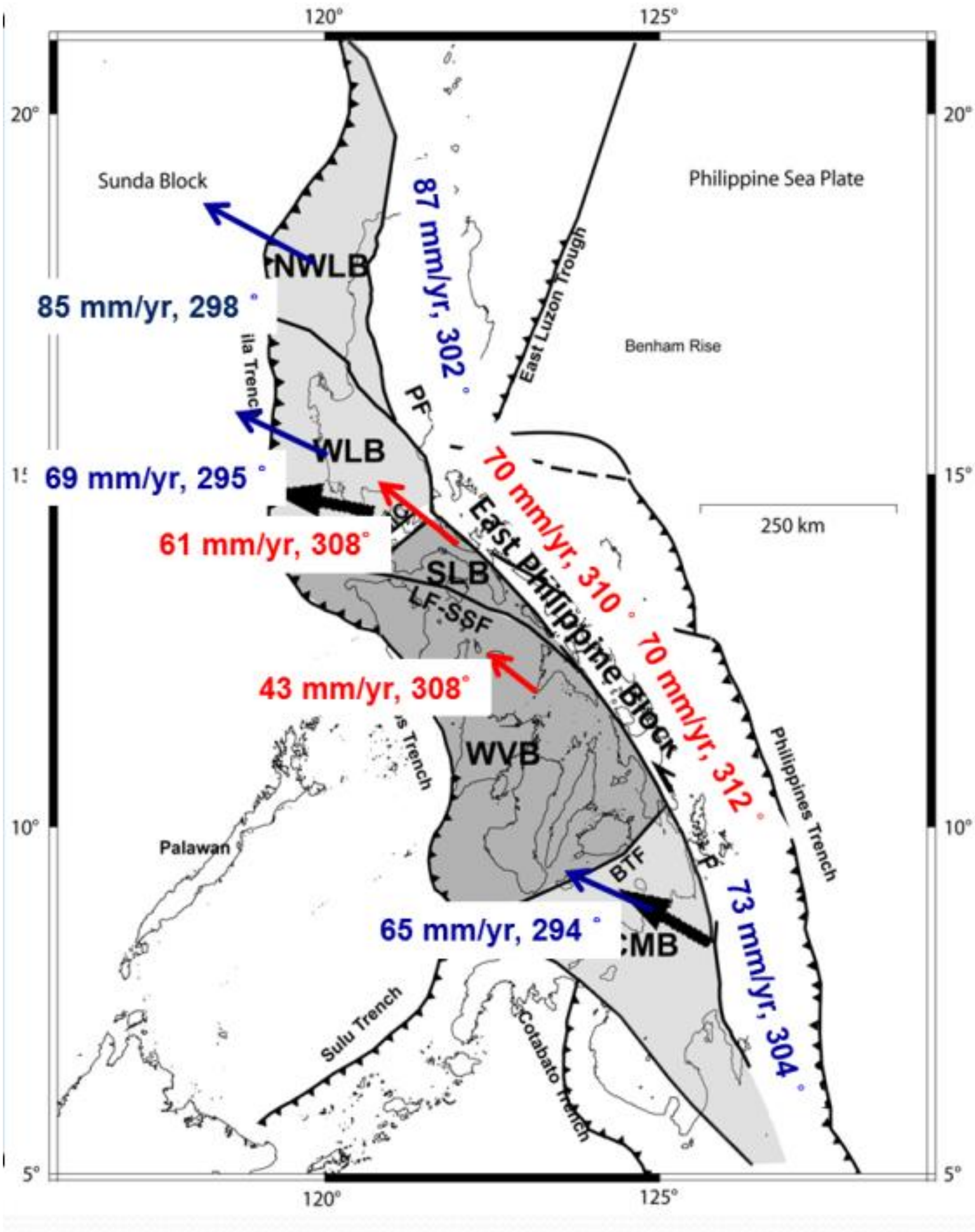



**FIGURE 3. ZONIFICATION OF CRUSTAL BLOCKS**

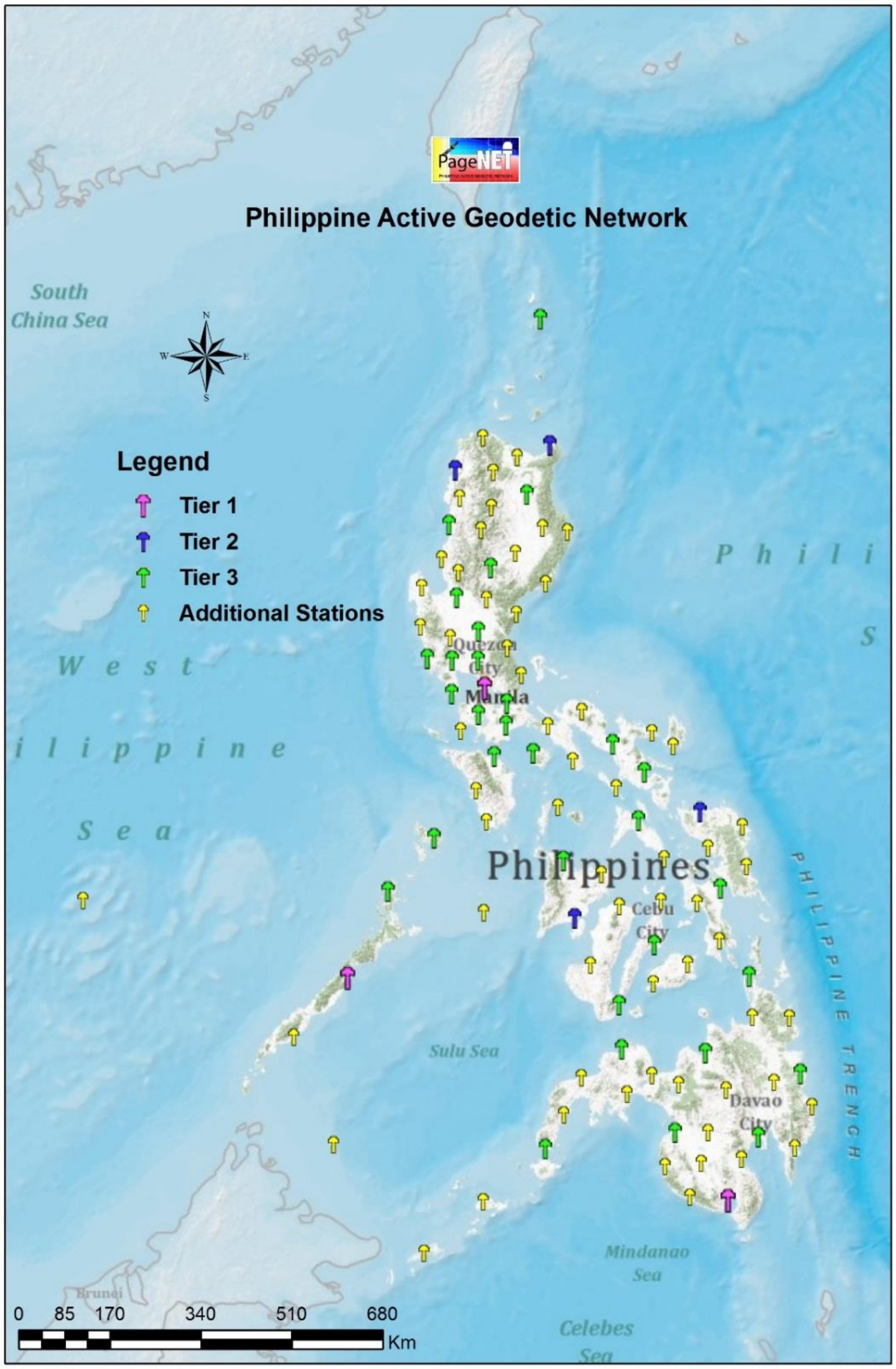



**FIGURE 4. TOTAL NUMBER OF AGS BY 2020**

## Strategy for the Alignment to a GGRF/Migration to Geocentric Datum

Alignment of the country's geodetic reference system to the ITRF at epoch 2016 will start with the processing of one-month GNSS data gathered from the PageNET. The solution will be constrained using at least six IGS sites surrounding the archipelago, see figure 5 for the process workflow.

The sixty four (64) zero-order control points has been re-observed in 2015. This will update the original observations conducted in 2008-2009 and align the network to ITRF by using the PageNET stations as reference.

First and second order GCPs will be unified and re-observed to relate the horizontal control network to ITRF. Lower-order ($3^{rd}$-$4^{th}$ order) and all GCPs used as reference in Cadastral surveys will be re-observed by DENR regional survey and mapping divisions and later adjusted using the first and second order GCPs as reference.

Transformation parameters relating PRS92 to the ITRF will likewise be published to facilitate the computation to and from the new system. Pilot studies on pre-selected areas will be conducted to assess the fit of the ITRF network solution.

Accordingly, new accuracy standards will be employed following the Federal Geographic Data Committee (FGDC) Standards for Geodetic Networks.

Examples of evidence of progress include:

1. New updated 4D coordinates of Zero, First and Second Order GCPs in ITRF has been computed by 2018
2. Transformation parameters relating PRS92 and the ITRF has been computed and published by 2018
3. New accuracy standards on geodetic networks will be employed in the GCP certifications starting 2018

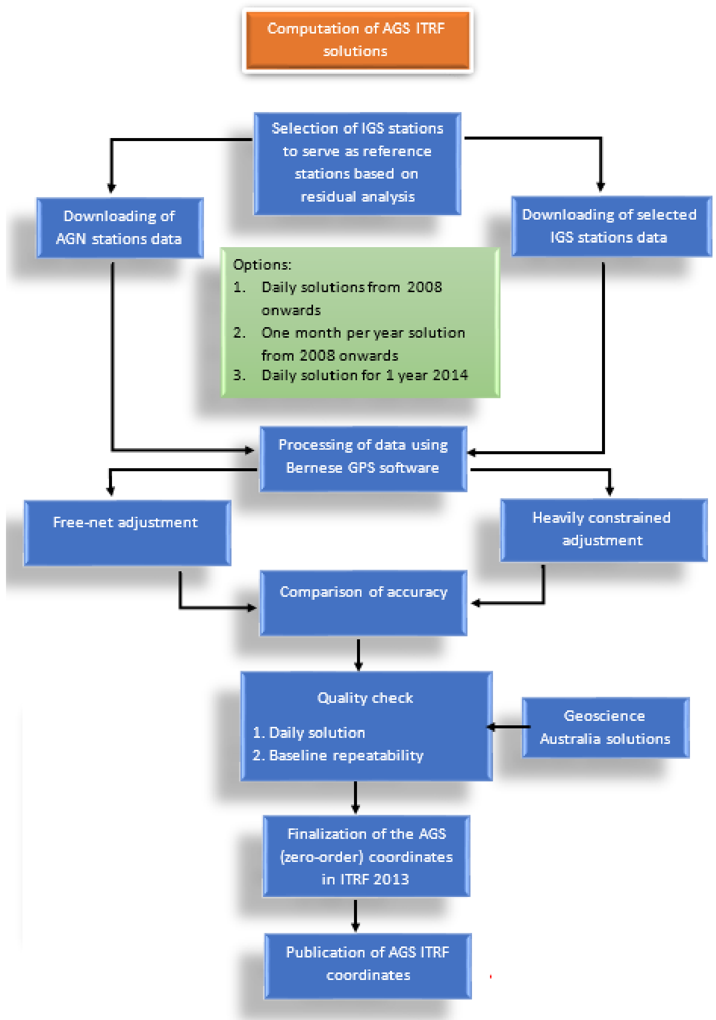



**FIGURE 5. WORKFLOW ON ITRF SOLUTION COMPUTATION**

## Strategy for the development, refinement and validation of the Deformation Model

The development of the country's deformation model will be based on Phivolcs' crustal deformation studies using GPS spanning for almost 20 years. The velocity vectors, assumed to be linear over time, are computed from continuous campaign sites located all over the country.

Given the complex geodynamic behaviour of the whole archipelago, Phivolcs suggested that block modelling approach be adopted to yield better results. However, in-depth study has to be undertaken to clearly define the block boundaries. This and other special cases such as localized events (e.g. earthquakes and presence of structures within a defined block) are also subject for research.

The appropriately placed active geodetic stations will define the crustal blocks of the detailed deformation model. Close coordination between NAMRIA and Phivolcs is needed to ensure the optimum design of the network, and guarantee the accuracy and reliability of the computed model, and ultimately the results of future surveys.

Check points shall also be established in strategic locations all over the country. These points shall serve as validation sites to assess the accuracy of the computed model. Deformation of these check points, within and across blocks, have to be ascertained to verify the definition of the block boundaries. The model is deemed acceptable if the surveyed coordinates of the check points is within 5cm of the model.

In terms of implementation, it has been agreed that Phivolcs shall provide NAMRIA with an annual velocity map for the whole Philippines. NAMRIA, for its part, shall process the coordinates of all its AGS, and furnish Phivolcs with the final daily solutions for incorporation into the deformation model. Based on the velocity map provided, NAMRIA shall assess and publish, if needed, the updated coordinates of all its GCPs. The academic partners, on the other hand, shall undertake research studies on topics relevant to crustal deformation and its impact to surveying and mapping, and to the modernization of the PGRS as a whole. A Memorandum of Understanding among the participating organizations shall be drafted to cover this agreement.

Examples of evidence of progress:

1. There are Active Stations established at each crustal block boundaries per province by 2019
2. Check points have been identified for deformation model validation by 2018
3. Research paper topics have been identified by 2017
4. Validated Velocity Map and Corrections have been published by 2020

## Strategy for the development and maintenance of the Philippine Geodetic Vertical Datum 2020 (PGVD2020)

With a preliminary geoid model already available, development of the PGVD2020 is scheduled to begin in 2016. The gravimetric geoid will be annually re-computed until a 10-cm or better accuracy has been met for the MSL-based geoid system.

More land gravity stations are targeted for installation in order to develop PGVD2020. The aim is to cover the 1635 cities and municipalities in the country, with around 25 gravity stations established for each city/municipality from 2015 – 2020. These land gravity stations will be levelled to provide elevation and surveyed by gravimeter and GNSS to position the points. The data from the GNSS/Levelling survey will be used to fit the geoid to the local MSLs of the country. This will keep the existing vertical datum of the country and establish the Philippine Geodetic Vertical Datum 2020 (PGVD2020).

Examples of evidence of progress include:

1. By 2020, 25 gravity stations at each of the 1635 cities and municipalities have been established and surveyed by gravimeter and GNSS nationwide
2. There is an annual recomputed Philippine Geoid from 2016 until 2020
3. The PGVD2020 have been developed which is a refined MSL- based geoid model with 10cm or better accuracy by 2020

## Strategy for the legal and IEC requirements and Strengthening of core competencies on geodetic reference frame development and maintenance

There is a need to amend Executive Order No. 45, which mandates the adoption of PRS92 as the standard for surveying and mapping in the country as early as 2016. This enabling law will be the first step towards standardizing the use of ITRF as the geodetic reference system.

Accordingly, existing land survey regulations (i.e. DENR Department Administrative Order No. 2007-29) need to be updated to reflect the new geodetic reference frame for surveying and mapping by 2020. It was agreed that this revision will only come about after all the methodologies and procedures have already been perfected and tested.

Capacity building is also a vital component of this undertaking. Training needs assessment shows that the technical personnel of NAMRIA has to be schooled until 2020 in the following topics:

1. Geodetic reference frame realization and maintenance
2. Deformation modelling
3. Space geodetic techniques
4. Maintenance of CORS

Starting 2017, training courses for the DENR regional offices and other stakeholders need to be conducted to educate them on the new concept of a geocentric and semi-dynamic/dynamic datum and how it will affect their survey operations. Information campaigns are also necessary to disseminate and discuss issues relevant to the modernization.

To ensure smooth transition to the new geodetic reference system, detailed manuals and guidelines need to be published until 2020 specifying the procedures for integrating existing datasets into ITRF and how the different reference systems in use are related to each other. IEC materials designed for the general public (laymanized) have to be produced starting 2017 to promote the use of the new reference system.

For the long term, it is recommended that the curriculum for Geodetic Engineering and allied disciplines be revised.

Examples of evidence of progress include:

1. There is a signed Executive Order for the adoption of a geocentric datum as the standard geodetic reference of surveys and maps in the country by 2016
2. There is an updated land regulations that is consistent with the new system by 2020
3. Geodesy technical personnel have received trainings on geodetic reference frames, deformation modeling, space geodetic techniques, and maintenance of CORS by 2020
4. There is a revised curriculum for Geodetic Engineering and allied disciplines by 2020