Research and Development in Support of the Implementation of the Philippine Reference System of 1992: Results and Recommendations

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Key words: PRS92; Philippines, Surveys and mapping, Cadastre; Capacity building

SUMMARY

The Philippine Reference System of 1992 (PRS92) is a network of geodetic control points established by Global Navigation Satellite System (GNSS) that became the standard reference system for all surveying and mapping activities of the archipelagic nation in 1993. Since then however, the PRS92 has remained largely confined at the realm of local geodesists and mapping specialists. It was only recently that PRS92 gained its much-needed attention due to the increased support from the government and improved access to satellite-based positioning systems technologies among stakeholders. In 2008, a collaborative research and development project was undertaken by the National Mapping and Resource Information Authority (NAMRIA) and the University of the Philippines (UP) intended to support its full implementation. This paper summarizes the key findings and recommendations of the research project. The key issues tackled by the PRS92 research included: i. the state and condition current geodetic network, ii. The validation of global geopotential models for the development of a Philippine geoid model, iii. the determination of relationship between GNSS and astrogeodetic azimuth observations in support of survey practice iv. the transformation of previous and local coordinates applied by cadastral systems to PRS92 grid coordinates. The research finding eventually precipitated a set of recommendations to improve, in an integrated manner, the policies, design, planning and implementation of the various aspects of surveys of mapping with PRS92 as the single reference frame. Part of the recommendations included standards, specifications, guidelines, manuals and information dissemination materials to foster the use of the new reference system and ensure its sustainability in the future. This paper also identified various research topics for further collaboration among concerned parties.

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1. INTRODUCTION

The Philippine Reference System of 1992 (PRS92), a national network of geodetic control points is the current standard reference system for all mapping and surveying activities in the Philippines (NAMRIA, 1992). Since its adoption in 1993, an intertwine of numerous scientific and technical issues have arisen since it affects the regular operations and services of the government and some private sectors involving land and other natural resources (DENR, 1994, DENR, 1998a, DENR, 1998b). Some of the issues that compounded the implementation of PRS92 include: the varied horizontal and vertical datum across islands in the nation; minimal usage of a geoid model; the emerging discrepancies between the use of Global Navigation Satellite System (GNSS) and astronomically-derived azimuths; the inconsistencies in the transformation of Philippine Plane Coordinate System-Philippine Transverse Mercator of 1965 (PPCS-TM65) to and from PPCS/TM-PRS92 and other local coordinate systems; manual and cumbersome method of converting Transverse Mercator (TM) projection grid to geographic coordinates (Bureau of Lands, 1976, Bureau of Lands, 1967); and the feeble effort to digitalize the cadastre.

1.1 Brief background on state of reference systems and its application in the Philippines

The first networked geodetic control in the archipelagic Philippines was established through a series of triangulation surveys starting from different parts of the country that were eventually tied to the Luzon datum of 1911 found in Balanacan, a port area in the island of Marinduque. During the development of PRS92 from 1987 to 1991, a total of 360 (332 1st order, 17 2nd Order, 11 Third Order) GNSS stations were established. Of these stations, 69 were common to the primary triangulation network stations defined with the old Luzon datum. Out of the reoccupied stations, 29 stations were used for refining the datum and extracting the transformation parameters necessary for relating the redefined datum dubbed PRS92 to WGS84, the datum of the GNSS. The coordinates of Luzon Datum in Balacanan was retained with a refinement of 0.34m geoid-spheroid separation. Since then, all government agencies were required to adopt PRS92 by virtue of Executive Order No. 45 in 1993.

While the mapping and surveying sectors in both government agencies and private industry were undergoing the transition from the old datum to PRS92, the geodetic network languished in a regressive state of deterioration, neglect and indifference. Rapid and mature developments in technology, standards and conventions in defining references frames based on GNSS have set the impetus to re-examine the state of the present geodetic network.

In surveying applications, the vertical position of a point is normally expressed by the orthometric height, which is referred to the geoid, the irregular, equipotential surface closely approximating the mean sea level of the Earth. Orthometric height is derived from traditional leveling measurements which, when utilized on very long distances, proves to be more cumbersome than GNSS-based measurements. Until today, spirit leveling is still the primary recourse for providing vertical control to surveying projects, regardless of the accuracy requirement. An integral part of developing a geoid model is the selection of a best-fitting global geopotential model (GGM) to represent the gravity field of the region of interest. At the time of its development, the Philippine Geoid Model used the then OSU89A relatively new GGM, and was deemed to be the best candidate for the Philippines (Kearsley, 1991). Apparently, the lack of information dissemination on Philippine Geoid Model left the GNSS-based orthometric height determination an untapped utility in vertical distance surveys. More than a decade after, newer GGMs have been produced by different agencies and satellite missions whose data are more recent and whose coverage might be significantly broader and finer.

Most land parcel surveys carried out prior to the introduction of PRS92 are based from azimuth obtained by astronomic observation. The astronomic observation-derived azimuth and GNSS derived-geodetic azimuth are from different systems and references. Therefore, question among surveyors arose as to the equivalence or similarity of the two azimuths. Even with the introduction of GNSS-based techniques through PRS92, technical and financial limitations prevented local surveyors from adopt GNSS technology and still rely on the old surveys not in PRS92, thus contributing to the system's slow and poor implementation. There is a need therefore for a comparative analysis between the azimuth obtained from GNSS and astronomic observations.

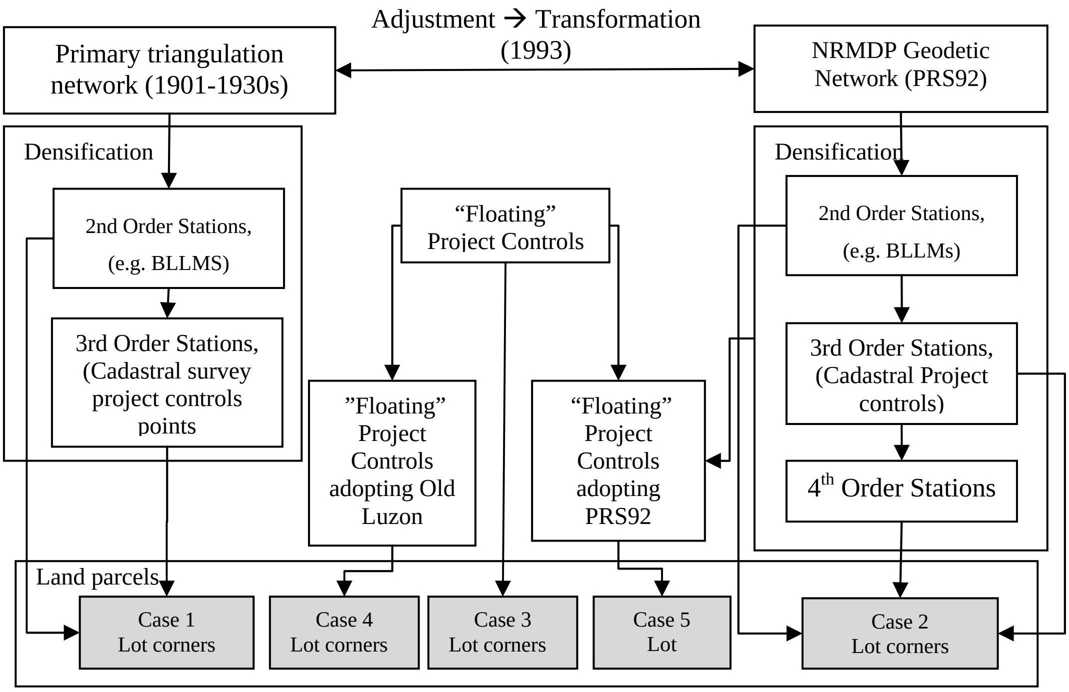

Figure 1. Reference systems used for describing land parcels corners. BLLMs refer to Bureau of Lands Location Monuments.

The state of cadastral survey referencing has also much to be desired as illustrated in Figure 1 where various reference systems are applied. Early cadastral surveys in the Philippines were carried out and referenced to a floating origin for every city or municipality. To allow integration of land surveys, a national civil grid, the Philippine Plane Coordinate System (PPCS) was introduced in 1965 still referenced to the Luzon Datum and projected in Philippine Transverse Mercator (PTM) of the Gauss-Schreiber variety. This would have ideally unified all existing floating point origins to the Luzon Datum or initiated cadastral survey projects with a PPCS origin. However, succeeding floating-origin surveys after the introduction of the PPCS persisted despite the preparation of a Technical Bulletin (Bureau of Lands, 1965) and supplement (Bureau of Lands, 1967) prescribing its usage. Moreover, despite the supposedly straightforward transformation between PRS92 and WGS84 coordinates either by use of the prescribed 7-parameters (Allman, 1991) or through derivation of local parameters (Parayno, 2007), a remission that was critical to the land sector was the insufficiency of materials to explain the relationship between PRS92 and the old Luzon datum.

In terms of management, while a tremendous increase in volume of records and transactions occurred over the years, the system to retrieve, update and track cadastral data remained largely a manual process albeit the computerization programs of many government offices. Servicing the demand for land-based transactions were hampered by insufficient or lack of funding, vague rules and regulations, shortage in technical manpower, among others. This dire situation was exacerbated by deficient space, poor data management practices, inadequate storage facilities and frequent transfer/reorganization of land-related offices. Fires, thefts, and natural calamities also left valuable land records and documents such as survey plans, lot area computation sheets, technical descriptions, etc. even more susceptible to pilferage, damage or worse permanent loss. The absence of reliable set of cadastral information with the lands management agencies resulted in the proliferation of fake survey plans and spurious land titles.

The National Mapping and Resource Information Authority (NAMRIA), as the central mapping agency, depository, and distribution facility of natural resources data in the form of maps, charts, texts, and statistics, under the Department of Environment and Natural Resources (DENR) was designated as the lead agency tasked to implement the full utilization of PRS92. The agency has drawn an implementation plan which included a component on Research and Development (R&D) to address the issues and problems arising from the standardization of the country's reference system. The University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP), one of the leading local research and academic institution in the field of applied geodesy, entered into a collaborative research agreement with NAMRIA to conduct the "Research and Development in Support of the Implementation of the Philippine Reference System of 1992", otherwise known as the PRS92 R&D Project to address the issues thus identified above.

2. OBJECTIVES OF PRS92 R&D

The main objective of this project was to develop operational methodologies to define, provide access to and maintain PRS92 in strengthening the national geodetic network as means to support the national spatial data infrastructure (NSDI). The specific objectives of the project include:

a. Provide sound scientific basis towards adoption of a common national horizontal and vertical datum;

b. Analyze the applicability of well-known geoid model/s as a basis for horizontal and vertical positioning using GNSS;

c. Analyze the state and recommend methods to reconcile different coordinate systems used in mapping and surveying and prescribe their conversion to a single unified system; and

d. Develop practical and appropriate tools to build and increase local capacity on accurate positioning using PRS92.

3. PRS92 R&D ACTIVITIES

3.1 Organization and activities undertaken under the project

The project was divided into four main (4) components and two (2) supporting components. Each main component was focused on achieving one of the specific objectives enumerated in the last section. The first supporting component addressed the legal aspects of the implementation of PRS92 in relation to the results of all the components. The second supporting component performed the computer programming tasks needed by the four main components. The activities undertaken in the project include:

1. **Data gathering.** Various PRS92-related data were gathered including reports, coordinates or elevation of reference stations and benchmarks, topographic maps and gravity data. Most of these data came from Coast and Geodetic Surveys Department (CGSD) of NAMRIA. Other data such as cadastral records and control descriptions were obtained from the LMS in the regions.
2. **Field surveys.** Numerous field surveys were undertaken to fulfill the data requirements of the Project. Field work activities undertaken include courtesy call to local officials and regional offices of government agencies, gathering of survey data from local offices, recovery of existing horizontal and/or vertical reference monuments, occupation of the reference monuments by surveying instruments such as dual-frequency GNSS receivers, astronomic observations and geodetic leveling.
3. **Data processing and analysis.** Data processing was performed on the computers purchased solely for the project. Some of the software to download and process the GNSS observation files were lent by NAMRIA installed in personal computers acquired for the project. An attempt was also made to introduce referencing to the International Reference System (ITRF) using GAMIT software (Herring et al., 2008; King et al., 2000).
4. **Programming.** A component of the project included programming the techniques, methods and algorithms to be used in the different components of the Project. A software

utility was eventually prepared with the purpose of providing potential end-users with standard computing techniques for geographic data conversion and transformation, azimuth determination and geoid modeling

5. **Report Writing.** Monthly reports with Technical Reports as Annexes were prepared each month. The Technical Reports contained a detailed, technical description of the Project activities for each component as well as the relevant references.
6. **Meetings with NAMRIA PRS92 R&D Technical Working Group.** Numerous technical discussions were held between the Project Team and the counterpart PRS92 R&D Technical Working Group from NAMRIA.

4. SUMMARY OF KEY RESULTS AND FINDINGS

The eight (8) month period of field observations and verification, data gathering, project meetings, consultations with different agencies and research organizations produced the salient findings to respond to the research objectives. A summary of these key results are presented below.

The observed current GNSS-based coordinates of points significantly deviated from published WGS84 (values) derived from Allman (1991); (2) the current geodetic control network has for years, remained static despite the dynamic nature of the Philippines geologic setting (Bautista, et al., 2001; Galgana, 2007) and in dire state of disrepair; (3) the initial implementation of PRS92 was severely hampered by lack of educational and technical resources to enable those concerned to operationalize its application; (4) there is generally a very low confidence on PRS92 among would-be users due to absence of an enabling law and inadequate complementary policies; and (5) there are encouraging indications that PRS92 has been given due attention in recent years mainly due to the efforts of NAMRIA. The analysis of vertical datum data connection (Van Olsen, 1998) showed that inconsistencies between the results of using the published data during the establishment of PRS92 and those data obtained from NAMRIA were mainly due to the differences in the ellipsoidal heights.

As an essential requisite for the development of a national geoid model, there was a need for the Philippines to adopt a new GGM. Among those tested namely EGM96, EIGEN-CG03C, EIGEN-GL05C, GGM02C, OSU89A, PGM2000A, EGM2008), evaluation showed that for Greater Manila Area as test area, the absolute fit of EIGEN-GL05C was the best fit evidenced by its lowest mean difference with that of the control. However, EGM2008 gave the lowest standard deviation for the GGMs, meaning the differences of GGM-derived N and GPS/Level N across the study area is relatively consistent with each other. This is also supported by the accuracy produced by EGM2008 which is the measure of the gradient of the geoid. EGM-2008 model therefore was found to have the best model that can be adopted in the study area.

As for the concerns on astronomic vs. GNSS-based azimuth, it was evident from the actual field observation results that (1) solar observation can produce results within the primary project control requirement; (2) unreferenced solution can be used in the determination of geodetic azimuth and is comparable to the output from the referenced solution; (3) for project controls of primary, secondary and tertiary precision requirements, the use of the geodetic latitude in the determination of the astronomic azimuth is sufficient at least for areas with flat topography; and (4) for project controls, astronomic and geodetic azimuths can be used interchangeably.

A cadastral data encoding template was developed to provide the necessary tool to compute accurately the other land parcel details included in the Lot Data Computation (LDC) sheets. Tests also indicate that that the entry of coordinates instead of bearing and distances to be the more efficient and accurate encoding method. A number of insignificant errors have been found to exist in the Technical Bulletin No. 26. Although the PTM projection formulation found in the Bulletin Supplement was consistent with Transverse Mercator (TM) formulation based on cited literatures and references, the closed formulation found in Snyder (1997) gave the least amount of discrepancies for both the forward and backward solutions. Lastly, for the coordinate transformation, the least squares 3-parameter and 4-parameter transformations were the only methods suitable for cadastral survey and data transformation. Still, various cases of cadastral data condition might require specific approaches.

5. RECOMMENDATIONS

5.1 Recommendations arising from the research findings and results

5.1.1 Recommendations for transition to a new reference system

Due to the tectonically active nature of the Philippine geological setting, it is recommended that a new datum for the Philippines be dynamic based on, and aligned with, the International Terrestrial Reference System (ITRS) using Global Navigation Satellite System (GNSS) technology. Further, the ellipsoid associated with this datum, be the World Geodetic System of 1984 (WGS84) ellipsoid. It is further recommended that the relationship between the new datum and the ITRS be specified at a nominated reference epoch and that all points coordinated in terms of the new datum have coordinates defined in terms of this epoch. To achieve a dynamic a set of parameters to transform the PRS92 coordinates to the new datum be periodically derived from the GNSS campaigns and permanent GNSS observation stations. From continuously operating reference stations, a the generalized motion of points in the Philippines with respect to the ITRS be modeled to ensure that observations made at a date other than the reference epoch can be used to generate reference epoch coordinates; and allow up-to-date coordinates at a date other than the reference epoch to be generated from reference epoch coordinates. It is recommended that points coordinated in terms of the new datum to have unfixed coordinates but that the coordinates be updated as required to account for new observations, earthquakes or predictable regional mark movement.

If a new datum definition is to be recommended, this new satellite-based, geocentric reference frame should have the following properties: The new datum should be flexible so that resurveys or future surveys can contribute to the datum and not be distorted by it. The new datum should be directly connected with the International Terrestrial Reference Frame (ITRF). The distribution of accurate control stations in the new datum should be of sufficient density to meet the needs of most user communities. The new datum should sustain uniform frame accuracy by appropriate and timely update. The relationship of old surveys and data to the new datum should be established to some level of precision. These recommendations are based on an assessment of various options against the stakeholders of geodetic network. The detailed design of the datum and related systems should take account of these issues and attempt to minimize any adverse effects. A proposed roadmap to an Earth-fixed, Earth centered geocentric reference system is illustrated in Figure 2.

A set of guidelines were also prepared for observation of geodetic control points using GNSS techniques. The sources of literature for guidelines include those of the Federal Geodetic Control Committee (FGCC) and related journal articles that have been published recently (2000 to present)

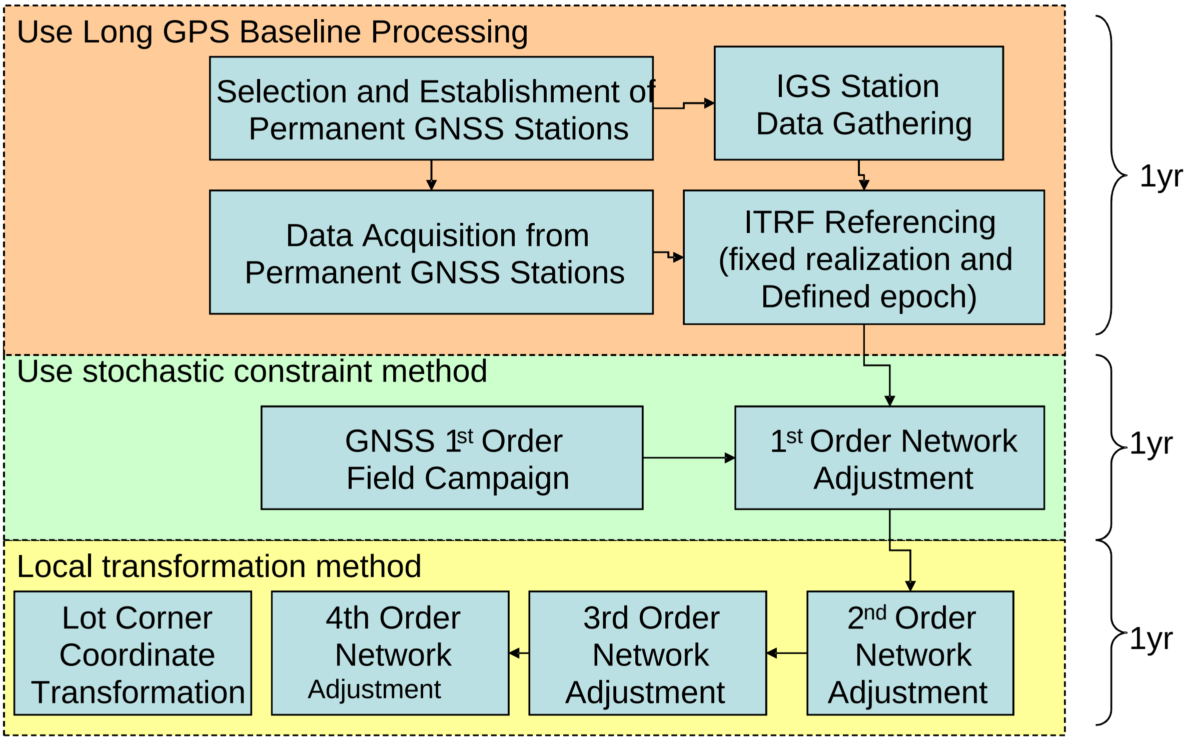

Figure 2. Proposed roadmap to a modern reference frame based on PRS92.

5.1.2 Recommendations for vertical datum connection

The inconsistencies in the published data during the establishment of PRS92 and those data acquired from NAMRIA need be reconciled. This is also important since the same dataset will be used to correct a future geoid model. Since it also affects the accuracy of the computation of the parameters, the Philippine Geoid Model, as the reference surface, may need to be updated using recent gravity data or geopotential models. It is quite obvious that the number of stations needed at each datum zone influences the accuracy of the estimate. The distribution of these stations relative to the fundamental stations also influences the accuracy of the estimation. The consistency of the data also has an effect in the adjustment. Therefore, it is necessary to update the data and additional stations needs to be established around the fundamental stations. A radius of 50 km may be adopted which was computed by Kearsley (1991) as the optimum cap size. The computed height difference at a single landmass can be validated more appropriately if leveling and gravity profile connecting the two datum is available.

5.1.3 Recommendations on geoid modeling and gravity measurements

It is recommended that other quantities such as gravity anomaly and deflection of the vertical computed from the GGMs be compared to those quantities that are obtainable in the field. This will enable stringent selection of the proper GGM that is a much better fit for the gravity field of the country. The test area should be extended on the national level to determine whether findings in Metro Manila and vicinity areas will be consistent in different regions and therefore can be taken into consideration when preparing guidelines and procedures. The need to strengthen benchmark data holdings by recovery and densification is a prerequisite to a better resolution on the assessment of the current geoid model in the Philippines and adoption of a new one. It is also worthwhile to determine the viability of GNSS-derived orthometric heights as alternative to spirit-leveled orthometric heights and initiate the use of GNSS in the conduct of leveling measurements as a means to strengthen and densify vertical networks in the country. It is also recommended that the GNSS network survey procedures and adjustments be examined to achieve not only the highest possible horizontal but vertical accuracy as well. It is also recommended that gravity data holdings be renewed and further explore the use of gravity data to develop a gravimetric geoid model. It was further recommended that the government reopen various channels for consultation with other countries and international agencies in the study and development of the national geoid model, and enable the exchange of available data salient to the advancement of geoid modeling.

5.1.4 Recommendations on azimuth obtained from GNSS and astronomic observation

The proposed astronomic latitude and astronomic azimuth determination method using at least two redundant set of observation done in the morning and in the afternoon should be validated by direct measurement of latitude. The obtained astronomic longitude obtained by using the Laplace correction should be validated again by having direct measurement of longitude. The Laplace correction to convert from geodetic azimuth to astronomic azimuth was not implemented. This is only possible if astronomic latitude and longitude are obtained from the ground where the values of the deflection of the vertical can be obtained. It is therefore recommended that a standard baseline shall be established for periodic GNSS and astronomic observations. The precision and accuracy of astronomic observation depends on the altitude, latitude and the north polar distance. Altitude and latitude can be obtained from field observation. However, the north polar distance is obtained from the surveyor’s almanac which is annually published by the weather bureau (PAGASA, 2008). An error in publication can therefore lead to an erroneous computation.

Astronomic azimuth although sufficient and still applicable in the determination of the required azimuth, requires proficiency in the use of the optical instrument and faithful observance of procedures. It is therefore recommended that a training on proper astronomic observation be done and a certification of completion be required if astronomic observation will be required on the approval of survey plans. It is recommended that the results of this research be communicated to the concerned stakeholders.

5.2 Recommendations on cadastral data and coordinate conversions and transformations

It was recommended that image files of all LDCs be digitally captured using flatbed scanning to minimize the exposure of such documents to wear and tear. A cadastral data encoding Template was developed for an efficient and rapid entry of LDCs.

As for the conversion from Philippine Transverse Mercator (PTM) Grid-to-Geographic Conversion, a republication of the DENR-LMB Technical Bulletin No.26 and its supplement with the corrections may be necessary. Inclusion of a coordinate conversion method in closed form solution based on a cited literature (Snyder, 1997) in the republished technical bulletin would enable programmers adopt a common method and arrive at the same figures.

It is recommended that implementation of cadastral survey records be verified and validated prior to the transformation and integration into the PPCS-TM/PRS92. There is also a need to make an inventory of cadastral records on per cadastral project basis to analyze the various nuances and idiosyncrasies to make the methods for transformation more robust. There is a further need to improve the quality of the cadastral common point network (CCPN) and this could be accomplished by introduction of more reliable technology (e.g., use of dual instead of single-frequency GNSS receivers). It is also recommended that local government boundaries be integrated to the PPCS-TM/PRS92 only after re-observing the monuments agreed upon by affected municipalities to the transformed cadastral survey. Transformation of local cadastre can only be undertaken if there is sufficient number of control points in an acceptable geometric configuration. Therefore, maintenance of existing reference points (location and boundary monuments) must be institutionalized.

5.3 Recommendations for future research

A broad spectrum of research directions were also identified to better implement and to address the more significant issues pertaining to PRS92. In the conclusion of the project, it was recommended that another phase of research be considered for funding and be conducted by the UP-TCAGP, for the following proposed topics:

a. Migration, updating, monitoring, and maintenance of a New Integrated Reference Frame;
b. Development of gravimetric geoid model from combined GNSS, leveling and gravity measurements;
c. Development of protocols for transformation of maps and other ENR datasets; and
d. Detection and analysis of errors in cadastral survey data and proposed remedies for transformation.

6. CONCLUDING REMARKS

This paper presented the results and findings of the research and development activities undertaken to support the implementation of the PRS92 collaborated by an academic institution and a government agency. So that the rewards of the project might be reaped in full and the vision for PRS92 realized in its entirety, the next major and logical step must be to drive the current momentum all the way to engaging other equally important stakeholders – the industry (survey firms, mapping companies, end-users) and other beneficiaries (local government leaders, civic and non-governmental organizations, ordinary people etc.). With the availability of the technical guidelines, operational manuals and various education and training materials produced from this research project, an intensified, massive education, information and communication campaign can be undertaken. It is also expected that the presentation of these results in the greater international community of experts will provide the opportunity to gather comments and solicit suggestions from a broader perspective and fresh outlook to further enrich the land resource management agenda in the Philippines.

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BIOGRAPHICAL NOTES

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