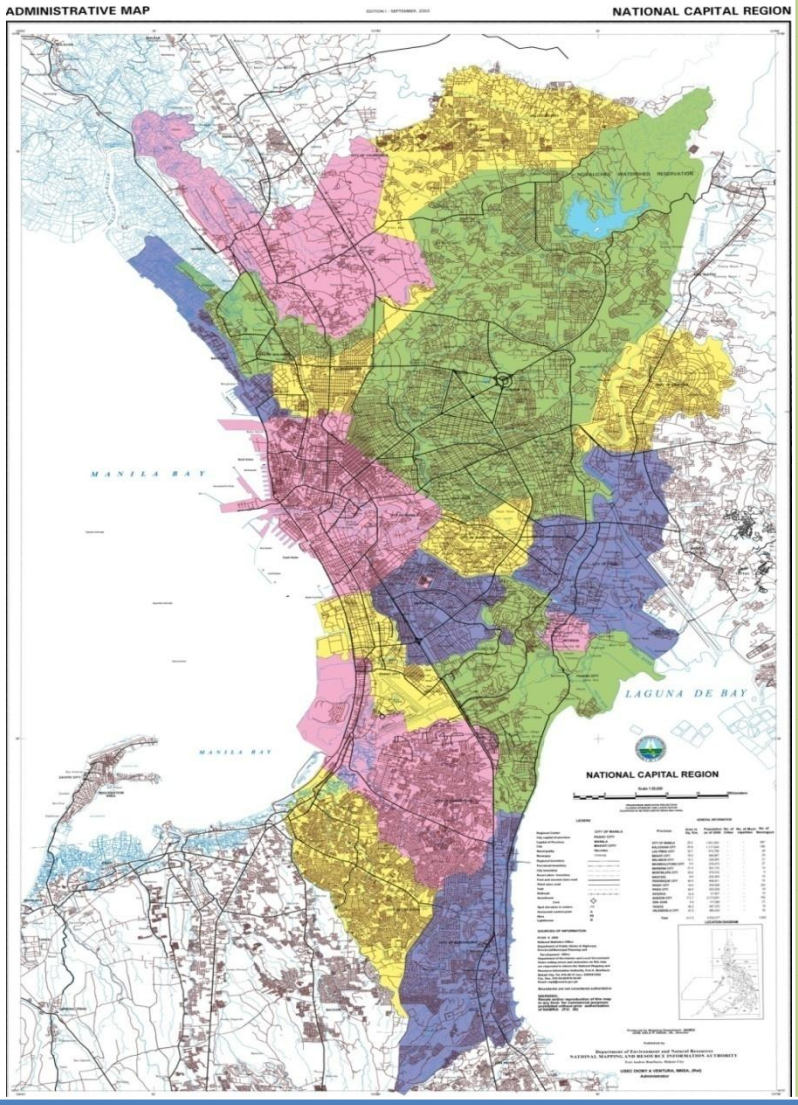

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First Order Geodetic Leveling: Determining Elevation Changes in Metro Manila

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NATIONAL MAPPING AND RESOURCE INFORMATION AUTHORITY

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ABSTRACT

Is Metro Manila or part of it sinking? Are we experiencing sea level rise, ground subsidence or both? These are important questions that need to be answered in order to enlighten the people of the metropolis and the local government units to help them solve one of the biggest problems of Metro Manila, which is flooding.

First Order Geodetic Leveling in Metro Manila Project was conducted to check for elevation changes to previously known benchmarks and to establish new ones as needed along the way. A tidal benchmark in Port Area, Manila (TBM-66) was used as reference in the survey upon examination of the changes in differences in elevation (D.E.) of the old benchmarks and after considering the lithology of the region. Results indicated that there were considerable changes in elevation (subsidence) to previously known benchmarks in Navotas, Caloocan, Tondo, Binondo, Sampaloc(Manila), Malabon and Pateros. These findings was confirmed and validated through GPS height comparison of the previously known PRS92 stations in the area.

Continuous tide observation data since 1947 revealed that there is a 0.526m sea level rise in Manila Bay with reference to the tidal benchmark TBM-66. To verify this apparent sea level rise, the stability of the reference TBM was investigated. The survey results indicated that there is no subsidence in TBM-66, which confirms the sea level rise of 0.526m. Further analysis revealed that there were ground subsidence in some parts of the metropolis. New elevations were computed that accounts for the sea level rise and subsidence in metro manila.

I. INTRODUCTION

In the early days of the Bureau of Coast & Geodetic Survey (BCGS), triangulation and hydrographic surveying were given priority over geodetic leveling due to lack of sufficient funding. Prior to 1942, only two first order level lines were run by the US Coast & Geodetic Survey (USCGS). As part of a long range program for mapping the Philippine Islands, a vertical network system was planned and executed during the Japanese occupation. Unfortunately, the original records were destroyed and several of the established benchmarks were disturbed in the course of the war. Upon liberation of the Philippines in 1945, BCGS personnel were recalled and mandated to recover previous survey works. All salvageable data, including that of the Manila levels, were compiled. Through financial and technical assistance from the USCGS, which ended upon the expiration of the Rehabilitation Act in June of 1950, a network of level lines to cover the Manila area and its environs was carried out. Since then, re-leveling was done to check for changes on previously known benchmarks and to establish new ones as needed along the way. These were made up of short level lines in various areas and are usually in the second order accuracy.

In the advent of PRS92, re-leveling the whole of Metro Manila was carried out in the first order accuracy. It aims to check for elevation changes to previously known benchmarks since 1970's and at the same time establish new ones as needed along the way. The new BM elevations will be utilized in the adjustment of the National Level Network and the changes in elevations will be used in the analysis and determination of the amount of ground subsidence, if there is, brought about by soil consolidation or any other reason. The output of this project would be useful to city planners, lot owners, developers and in flood risk reduction and management.

This report covers the extent of leveling works undertaken for the Metro Manila First Order Geodetic Leveling and elevation change detection of the previously known benchmarks. The project was carried out by the Geodesy and Geophysics Division (GGD) under the Mapping and Geodesy Department (MGD) in collaboration with the Hydrography Department, which provides the manpower in the fieldworks.

II. PROJECT AREA

The project covers the Metropolitan Manila (MM) or the National Capital Region (NCR) which can be found in Luzon, specifically from latitudes 14° 22' to 45' North and longitudes 120° 55' to 121° 07' East. Bounded on the North by Bulacan, on the East by Rizal, on the South by Laguna and on the Southwest by Cavite, MetroManila covers a total area of 638.55 km^2 (246.5 sq mi). Population as of the 2007 Census was 11,553,427 persons. It is composed of 16 cities and 1 municipality namely, Caloocan, Las Piñas, Makati, Malabon, Mandaluyong, Manila, Marikina, Muntinlupa, Navotas, Parañaque, Pasay, Pasig, Quezon City, San Juan, Taguig, Valenzuela and Pateros. Majority of

MetroManila is situated on a wide plain that is frequently inundated even during moderate rains. (See Fig.1)

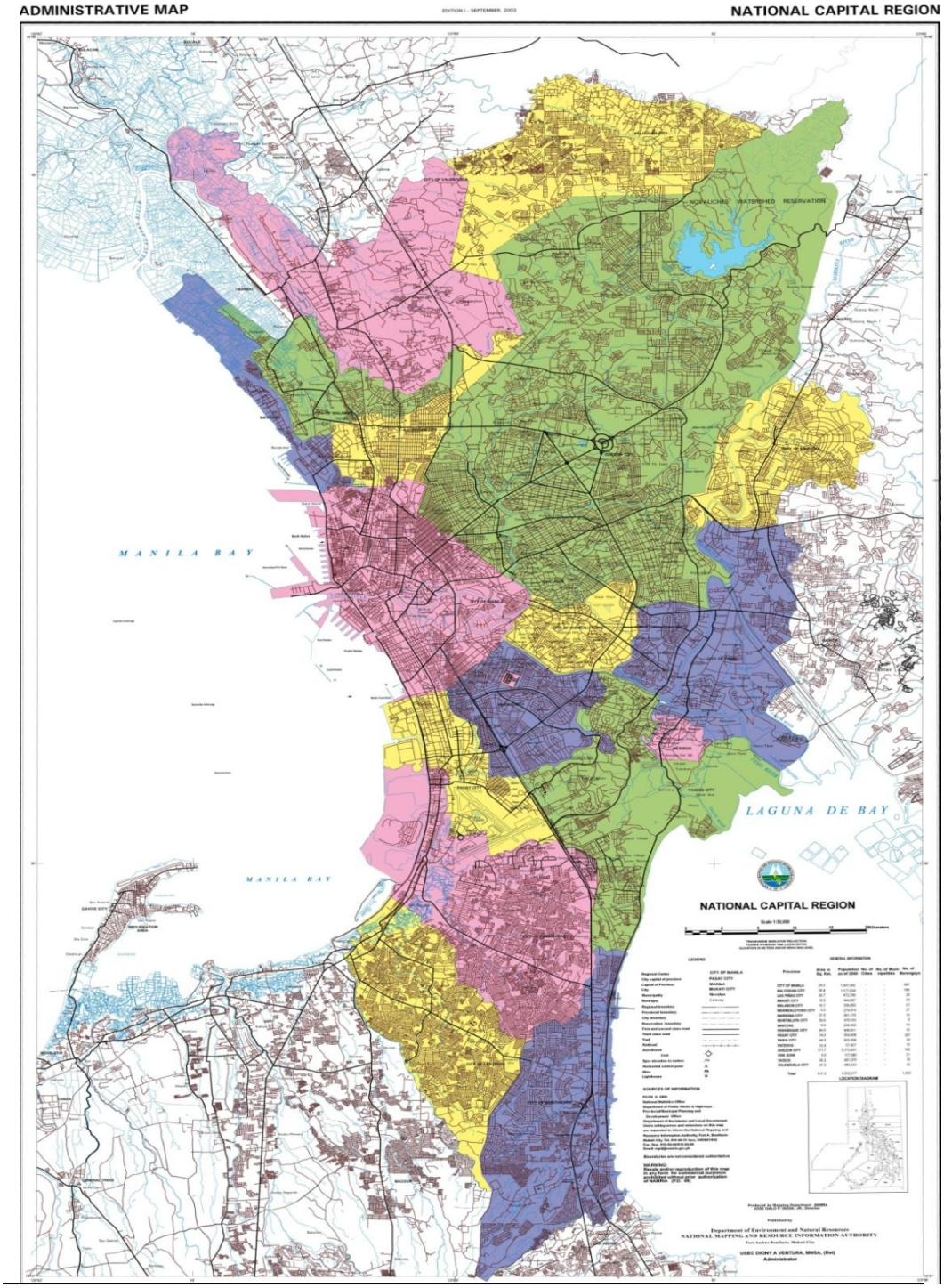

Figure 1. Metro Manila Map showing the scope of the project bounded by Bulacan, Rizal, Cavite and Laguna

III. METHODOLOGY

Two Hundred Sixty Eight (268) kilometers of level lines, new routes included, were re-leveled in Metro Manila. First Order Geodetic Leveling, which requires a 4.0mm of error per kilometer between two runs of level line, was employed. The manner by which the leveling and setting of benchmark was conducted is in accordance with the standard methods specified by the USCGS Special Publication No. 239, Manual of Geodetic Leveling as well as the standard practices of NAMRIA. For the project workflow, see Figure 6.

Benchmarks were established at approximately 1 kilometer interval along the new level routes. Locations were selected according to stability, accessibility and security. Likelihood of immediate and future infrastructure developments in the area were also considered to avoid disturbance of the benchmarks. Newly established benchmarks were marked using 4” copper nails imbedded in 15cm x 15cm cement putty and inscribed with the Designation, Year established and the Agency name. Designation starts with MM-36 for Metro-Manila and BL-201 for Bulacan (Fig. 2).

Figure 2. Benchmark markings in Metro Manila

Leveling was done in the forward and backward runs for each section. Each section was leveled on the same day to make certain that weather, temperature, and other atmospheric conditions were identical. As much as possible, backsight and foresight distances were made equal to minimize the effect of the earth’s curvature, refraction and the collimation error of the instrument. The differences in elevation (DEs) of the forward and backward runs were computed after each section. Divergence between the two DEs should not exceed the allowable value; otherwise the sections were re-leveled immediately. All sections along the route were surveyed until all sections of the designed loop have been leveled. Every survey day, the collimation factor “C” was determined by Two Peg Test method (Determination of “C”, see Manual on Geodetic Leveling). This would check if the collimation axis or the horizontal line of sight is indeed horizontal. A value ranging from 0.005 to 0.010 for the C-factor is deemed allowable. Figure 3 shows the planned level network for Metro Manila.

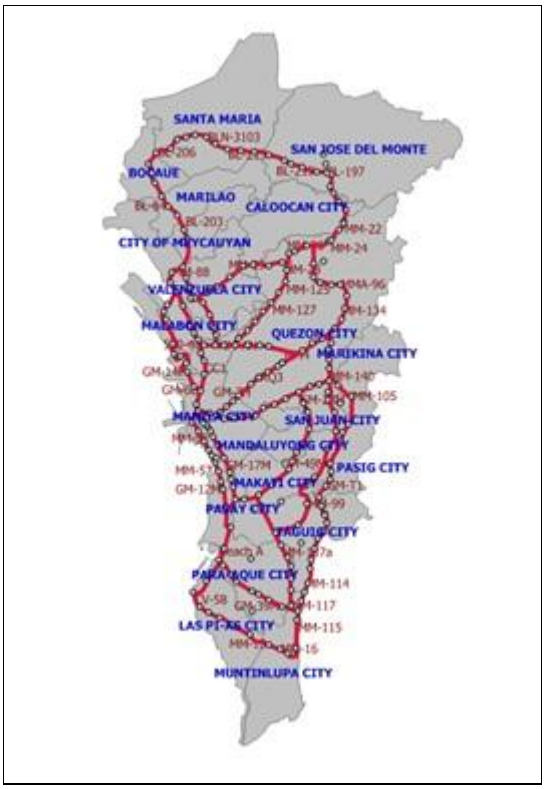

Figure 3. Map showing the Planned Level Network

The network was divided into fourteen (14) loops (Fig.4), executed one loop at a time and made sure that each completed loop meets the required accuracy before proceeding to the next. Processing of level data was carefully performed strictly conforming to the allowable divergence and loop closures. The network was adjusted using the program provided and designed by the Japan International Cooperation Agency (JICA). New elevations of BMs were computed using TBM 66 as reference datum in the MSL 1970 and 2008. Changes in elevations of the previously known BMs were also computed using the MSL 1970 datum. The elevation changes were validated using GPS - a new method of determining changes in heights using satellite technology. Previously established PRS92 stations in Metro-Manila were observed, their old and new Ellipsoidal Heights were compared to detect changes in heights of points near the benchmarks or the locality. Figure 5 shows the location of GCPs used in the validation survey.

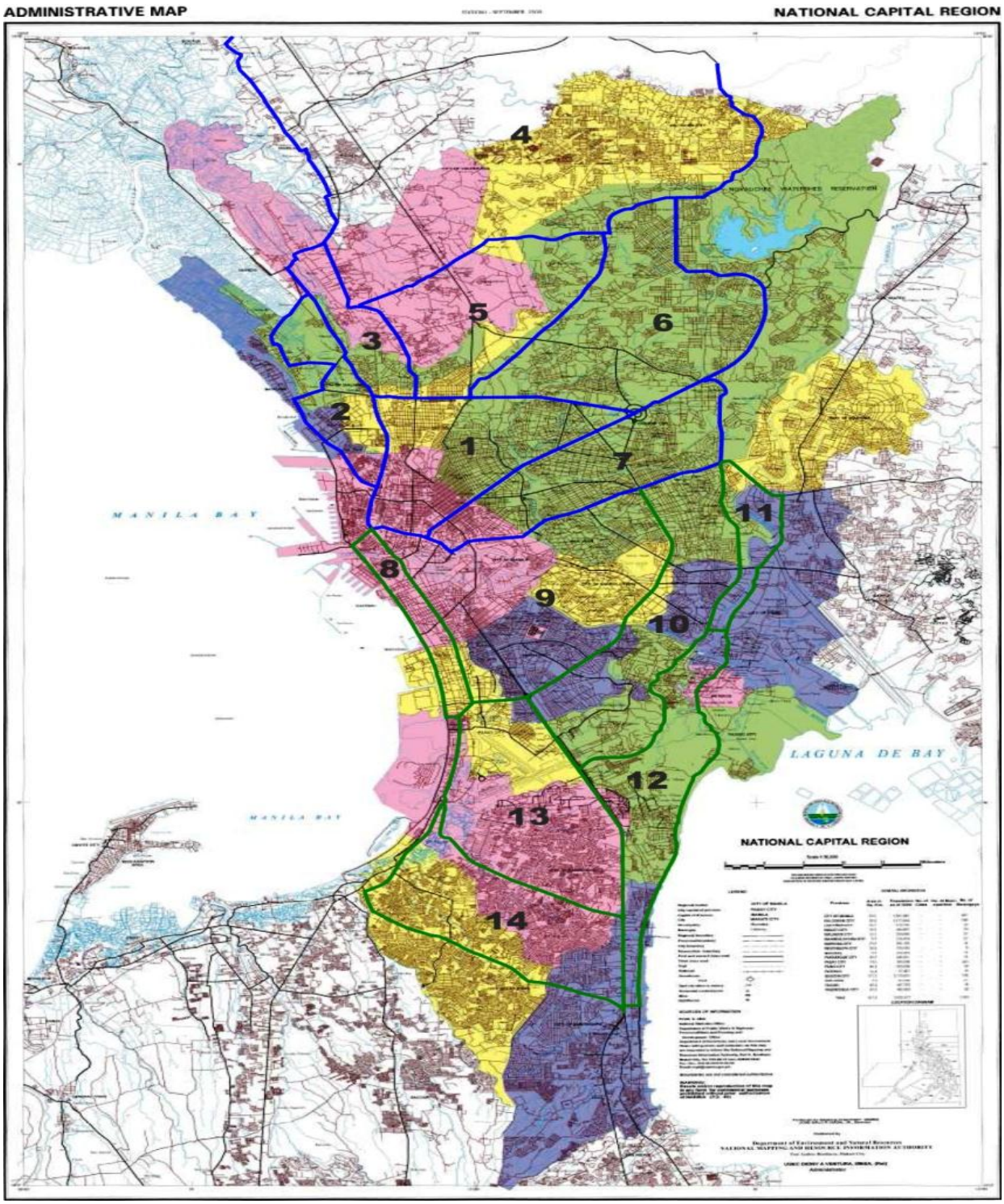

Fig. 4. Map showing the designed Level Loops and corresponding loop numbers

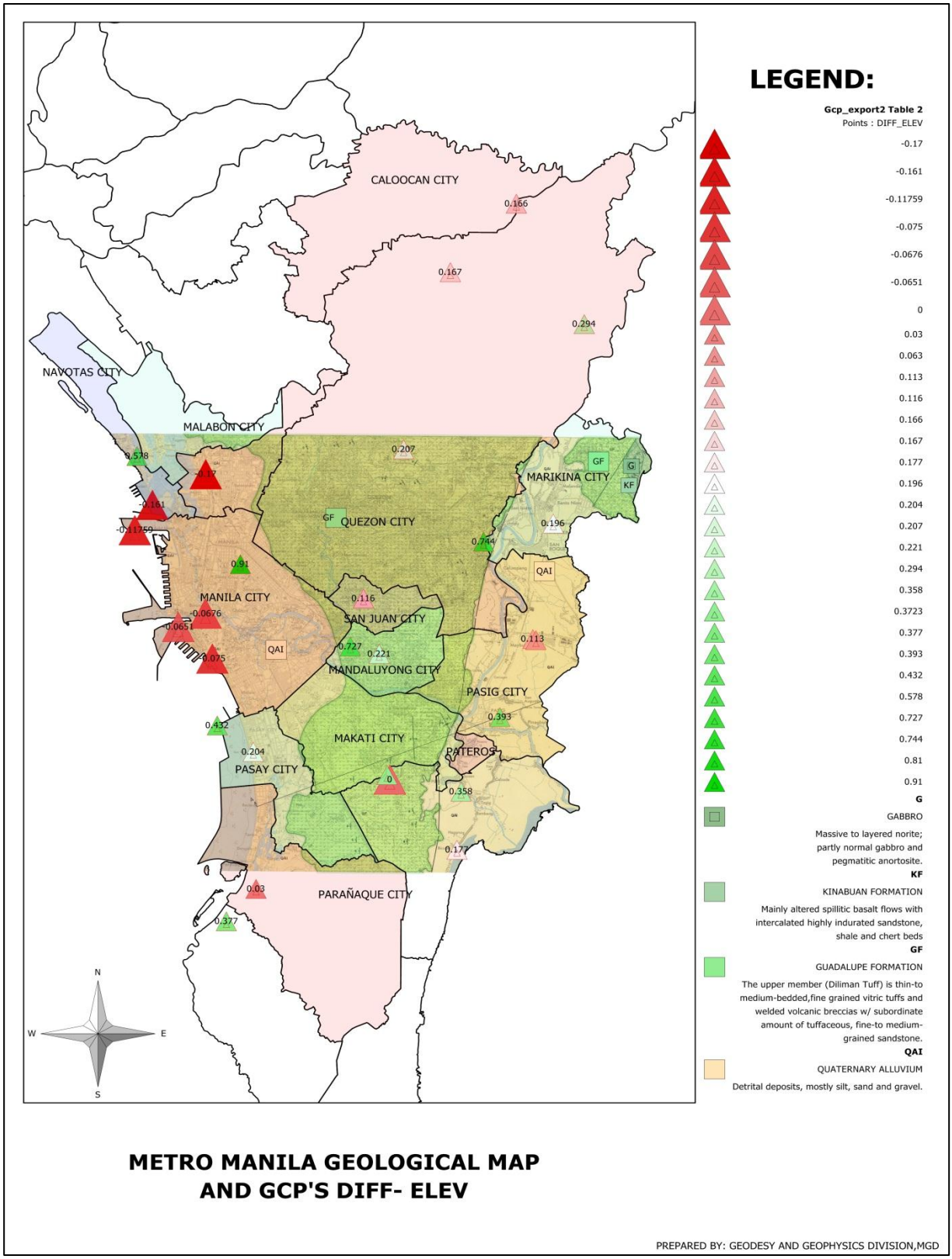

Figure 5. Map showing the GCPs occupied by GPS. Red triangles indicate large ellipsoidal height changes

PROJECT WORKFLOW

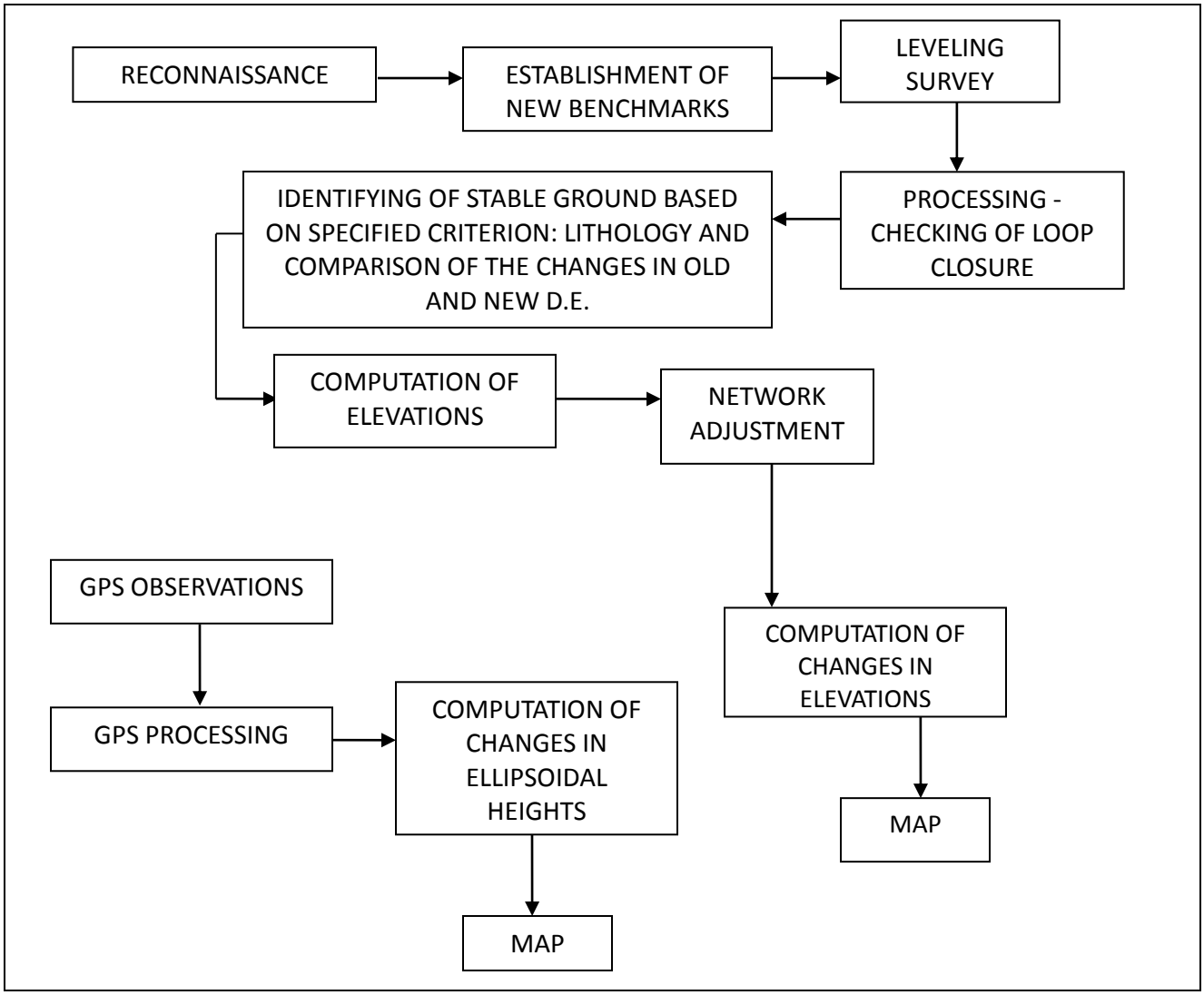

Figure 6. PROJECT WORKFLOW. The team started the survey by doing reconnaissance on the proposed level lines and at the same time recovered old BMs. After reconnaissance, they established benchmarks at approximately one kilometer apart. Leveling survey followed immediately. The level teams submitted the digital data to the GGD office for processing. The GGD processing team identified a stable BM to test whether the old BMs on the network have moved or not. They used the Geologic Map, the table of changes in elevation differences and the JICA MMEIRS Report as references. New elevations were computed using the old MSL datum elevation of the stable BM and then later adjusted. Changes in elevations were computed by comparing the old and new elevations. To validate the changes in elevations, GPS was utilized. Old PRS92 controls were recovered and observed near the BMs or locality. The differences between old and new ellipsoidal heights were computed. Maps were generated using the processed data.

IV. LOGISTICS

Two (2) Leveling survey teams comprising of four (4) officers and twelve (12) Enlisted Personnel from the Hydrography Department were formed for the project. Team A covered Loops 1 to 7 and Team B covered Loops 8 to 14. The two teams work simultaneously to speed up the completion of the project. Each team was composed of seven members namely: OIC/observer, recorder, BM setter/pacer, driver, two rodmen and instrument man.

Leica DNA03 Digital Level with Leica 4-meter INVAR leveling rods, triangular steel turning pads and aluminum tripods were the instruments used by the teams. NAMRIA Spirit Leveling Record Books were used to record level readings.

Leica GX1230 Dual frequency GNSS receivers were used in the validation of ellipsoidal height changes.

A. Leica DNA03

B. GPCL3 leveling rod

C. Leica GX1230

V. RESULTS

1. Statistics

The survey was conducted from 26 March 2009 to 16 March 2010. Delays were experienced due to bad weather conditions and flooded streets (high tide in Malabon and Obando, Bulacan). The total distance of lines leveled for the project was 264.8 km. 130 benchmarks were recovered and 147 BMs were established. Appendices 1 and 2 list the BMs that were recovered and established respectively.

2. Processing

Level data were processed in excel spreadsheet forms. The *leveling record form* contains field readings with summation of foresights and backsights and the corresponding DE of the section. This level record was linked to the *computation of level form* that took the forward and backward DEs and computed the divergence between the two runs. The computation of level form was then linked to the *abstract of leveling form* that grabbed the station name, distance run, DEs and divergence. The abstract form was arranged in a per loop file. Upon entry of elevation of the starting BM, it computed the initial elevations of the succeeding BMs in the file. Appendix 3 shows the respective divergence or discrepancy between the forward and backward DE of each level section. The discrepancy of each section is within the allowable values of 4.0mm $\sqrt{K}$.

In computing the adjusted elevations, the elevation of the check or ending known BM was entered into the abstract form to compute the loop error (difference of computed and old elevation of the ending point). The loop error was divided by the total loop distance to get the Linear Error Correction (LEC). The LEC was then applied to the initial elevation using this formula:

$$\text{Elevation}_{\text{Adjusted}} = \text{Initial Elevation} +/- \text{LEC x distance of succeeding BM from starting BM}$$

After linear adjustment, new elevations were computed for all BMs leveled using the BM-66 as reference station at MSL series 1970 Datum. These new elevations were compared to the old survey to determine any changes in the elevation of BMs. Appendix 4 shows the **current elevations of the old and newly established BMs at MSL 2008 Datum** in Metro Manila while Appendix 5 shows the **new elevation of old BMs at MSL 1970 Datum** (for comparison of DEs).

3. Network Adjustment

The adjustment program from JICA was used in adjusting the metro manila level network. The program uses the elevation of junction points as network check and determines the closures of each loop relative to each other. Respective Adjustment Closures for each Loop of the level network is shown in Table 1, the loop map and the corresponding loop number in Fig.7.

Table 1. Network Loop closures at the junctions

Loop Number	Loop Closure (mm)
1	+0.0040
2	+0.0116
3	+0.0057
4	+0.0019
5	-0.0040
6	+0.0217
7	-0.0036
8	+0.0034
9	-0.0025
10	+0.0037
11	+0.0013
12	+0.0096
13	-0.0090
14	+0.0080

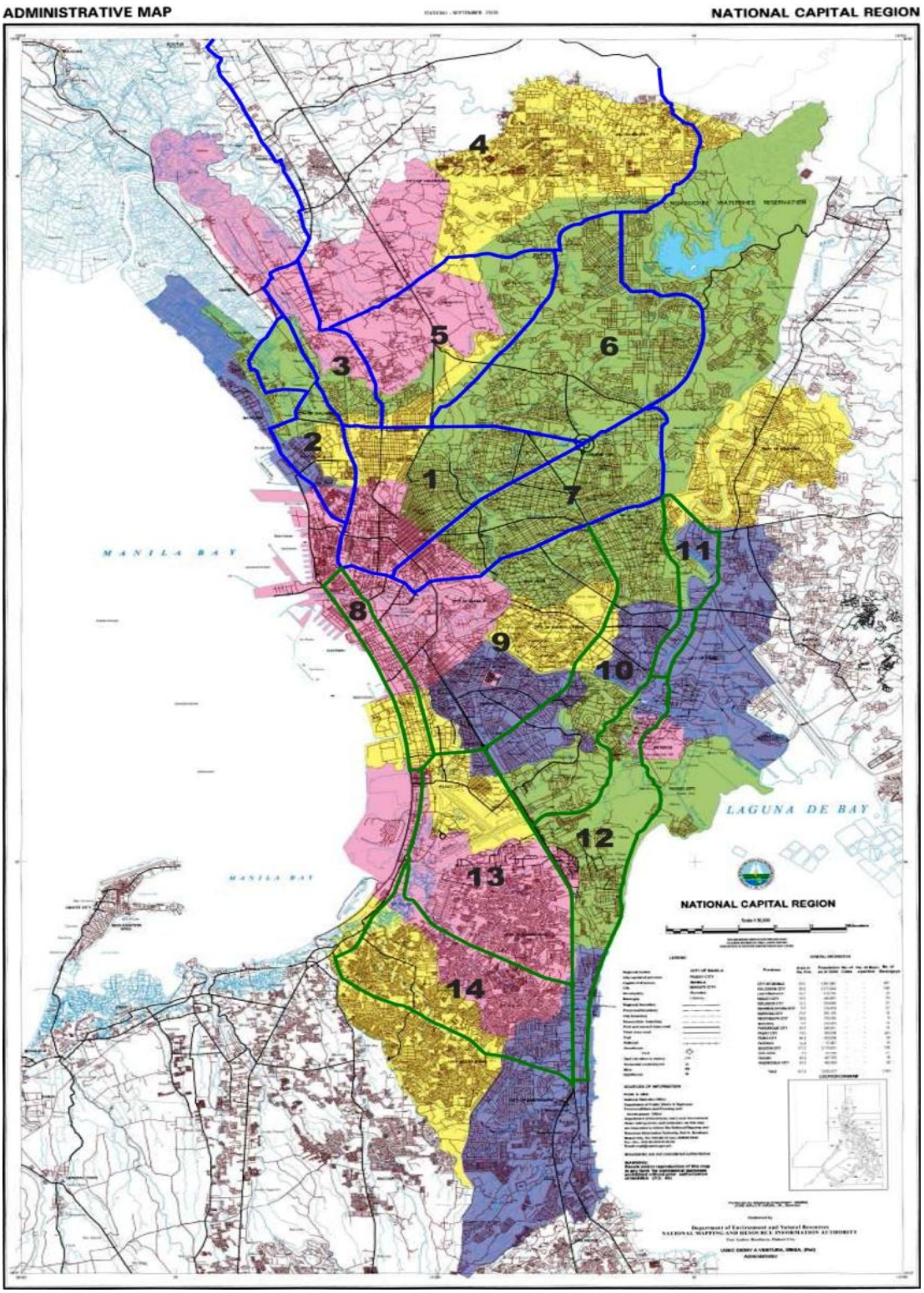

Figure 7. Map showing the designed Network Loops with their loop numbers

4. Changes in Elevation

Table 2. Comparison of the old and new elevation of BMs in Metro Manila referred to BM-66 at MSL 1970.

Station Name	OLD survey (1979)	NEW survey (2009)	Diff. Elev.	Location
1NHA	**4.734**	**3.5335**	**-1.2005**	**Dagat-Dagatan, Navotas**
560-4a	**15.402**	**14.8077**	**-0.5943**	**Sampaloc, Caloocan**
BB-13	**3.9385**	**3.5955**	**-0.343**	**Tinajeros, Malabon**
BB-14	**4.4147**	**4.037**	**-0.3777**	**HulongDuhat, Malabon**
BB-15	**2.2036**	**1.8412**	**-0.3624**	**Concepcion, Malabon**
Beach A	2.616	2.822	**0.206**	San Dionisio, Parañaque
BM-66	**1.832**	**1.832**	**0**	**Port Area, Manila**
CC-1	**9.268**	**8.6284**	**-0.6396**	**A. Mabini& C-3 Road intersection, Caloocan**
CC-3	**6.777**	**6.015**	**-0.762**	**C-3 Road, Caloocan**
CIMA-18a	2.006	1.987	**-0.019**	Sta. Mesa, Manila
F-10	3.52	3.7127	**0.1927**	La Huerta, Parañaque
GM P-2	42.9	42.909	**0.009**	Diliman, Quezon City
GM R-7	36.869	37.0339	**0.1649**	EDSA, Quezon City
GM T-1	**6.616**	**6.2794**	**-0.3366**	**Sto. Rosario Silangan, Pateros**
GM-10M	3.3797	3.2808	**-0.0989**	Malate, Manila
GM-11M	2.4025	2.4367	**0.0342**	Roxas Blvd. & Sen. Gil Puyat Ave. intersection, Pasay
GM-12M	2.2975	2.3289	**0.0314**	Roxas Blvd. & Libertad intersection, Pasay
GM-13M	3.5708	3.5988	**0.028**	Baclaran, Pasay
GM-16	23.3203	23.2945	**-0.0258**	Balintawak, Quezon City
GM-16M	2.1395	2.1363	**-0.0032**	Ermita, Manila
GM-17	2.4464	2.4121	**-0.0343**	Sampaloc, Manila
GM-17M	2.5128	2.5098	**-0.003**	Malate, Manila
GM-19M	3.0295	3.0277	**-0.0018**	Taft & Libertad intersection,Pasay
GM-1A	3.859	3.9376	**0.0786**	Port Area, Manila
GM-21	2.631	2.626	**-0.005**	Liwasang Bonifacio, Manila
GM-22M	5.117	5.1295	**0.0125**	Tambo, Parañaque
GM-23M	41.2829	41.3346	**0.0517**	Cubao, Quezon City
GM-26M	15.8622	15.9153	**0.0531**	McKinley road corner EDSA, Makati

Station Name	OLD survey (1979)	NEW survey (2009)	Diff. Elev.	Location
GM-27M	6.2808	6.2777	**-0.0031**	Dasmariñas, Makati
GM-33M	5.8523	5.8434	**-0.0089**	San Dionisio, Parañaque
GM-35M	6.9927	6.9883	**-0.0044**	Sucat, Parañaque
GM-36M	10.9164	10.9146	**-0.0018**	Sucat, Parañaque
GM-37M	16.5526	16.525	**-0.0276**	Sucat, Parañaque
GM-39M	33.0663	33.0795	**0.0132**	Sucat, Parañaque
GM-3FA	**3.65**	**2.7575**	**-0.8925**	**Bagumbayan, Navotas**
GM-41M	3.7098	3.6823	**-0.0275**	Lower Bicutan, Taguig
GM-42M	3.9152	3.8862	**-0.029**	Lower Bicutan, Taguig
GM-43M	4.6254	4.5754	**-0.05**	Hagonoy, Taguig
GM-44M	6.0823	6.0628	**-0.0195**	Sta. Ana, Taguig
GM-49M	6.9327	6.978	**0.0453**	Capasigan, Pasig
GM-51M	10.784	10.831	**0.047**	Fort Bonifacio, Makati
GM-56M	13.5565	13.5514	**-0.0051**	Cembo, Makati
GM-5E	**2.461**	**1.7848**	**-0.6762**	**Tondo, Manila**
GM-68M	4.8569	4.9049	**0.048**	Caniogan, Pasig
GM-6Ba	**2.694**	**2.2716**	**-0.4224**	**Tondo, Manila**
GM-6E	**2.831**	**2.5022**	**-0.3288**	**Tondo, Manila**
GM-70M	6.205	6.2661	**0.0611**	Maybunga, Pasig
GM-7B	**1.688**	**1.4123**	**-0.2757**	**Binondo, Manila**
GM-7Ba	**2.584**	**2.1869**	**-0.3971**	**Binondo, Manila**
GM-7H	**3.133**	**2.7706**	**-0.3624**	**Sampaloc, Manila**
GM-9ab	3.78	3.5529	**-0.2271**	South Port District, Manila
GM-9M	**3.317**	**3.6273**	**0.3103**	**Malate, Manila**
GM-N4	9.347	9.3375	**-0.0095**	Aurora Blvd., San Juan
JAP	3.475	3.6538	**0.1788**	Daniel Fajardo, Las Piñas
ML-3	57.776	57.9943	**0.2183**	Libis, Quezon City
MM-5	39.777	39.7844	**0.0074**	Quezon City
MM-6	50.919	50.8452	**-0.0738**	Fairview, Quezon City
OS-2	8.162	8.4146	**0.2526**	Quezon City
QUCI-13	61.674	61.596	**-0.078**	Diliman, Quezon City
W2-A	48.313	48.2369	**-0.0761**	Diliman, Quezon City

5. Results of GPS Validation Survey

Table 3. Comparison of old and new ellipsoidal heights of PRS92 stations near the BMs

STATION NAME	LATITUDE	LONGITUDE	Old Ellips. Ht	New Ellips. Ht	Diff.
PTAG-NAMRIA	14°32'07.43204"N	121°02'26.78266"E	88.429	88.429	0
CVT3033-Bacoor	N14°26'45.97405"	E120°58'11.30622"	51.722	51.823	0.101
MMA-01-NAMRIA	14°32'13.66270"N	121°02'23.14129"E	70.8027	71.175	0.3723
MMA-111-Parañaque	14°29'35.65322"N	120°59'32.55140"E	49.701	49.731	0.03
MMA-114-Mandaluyong	14°34'59.83925"N	121°02'11.41940"E	59.723	59.944	0.221
MMA-115-Luneta	14°34'51.70490"N	120°58'32.40711"E	49.715	49.64	-0.075
MMA-118-Binondo	14°35'53.35915"N	120°58'22.95229"E	63.8286	63.761	-0.0676
MMA-120-Harbor Center	14°37'47.40344"N	120°56'48.88167"E	50.62759	50.51	-0.11759
MMA-125-Ususan, Taguig	14°31'51.64412"N	121°04'00.27842"E	50.471	50.829	0.358
MMA-126-Navotas	14°39'29.08776"N	120°56'51.01574"E	45.797	46.375	0.578
MMA-3001-Pasig	14°33'34.61491"N	121°04'50.51110"E	49.639	50.032	0.393
MMA-3007-Rosario, Pasig	14°35'22.18029"N	121°05'32.61779"E	53.034	53.147	0.113
MMA-3008-Sta.lucia, Pasig	14°35'20.47571"N	121°05'36.81190"E	54.11	54.173	0.063
MMA-3010-Lower Bicutan	14°30'31.68404"N	121°03'55.66636"E	49.794	49.971	0.177
MMA-3014-Pasay	14°32'43.83180"N	120°59'27.31240"E	48.449	48.653	0.204
MMA-3019-Ilaya, Las Piñas	14°28'50.88896"N	120°58'54.14529"E	51.414	51.791	0.377
MMA-3025-Caloocan	14°39'05.16457"N	120°58'21.27301"E	59.05	58.88	-0.17
MMA-3035-San Roque, Marikina	14°38'01.0896"N	121°05'57.93962"E	56.569	56.765	0.196
MMA-3040-Tunasan, Muntinlupa	14°22'57.64579"N	121°03'12.25984"E	49.918	50.728	0.81
MMA-3051-Corazon de Jesus, San Juan	14°36'16.02816"N	121°01'49.87570"E	73.897	74.013	0.116
MMA-3058-San Lazaro, Manila	14°37'01.75745"N	120°59'08.08539"E	47.638	48.548	0.91
MMA-3068-Escopa 3, QC	14°37'35.20453"N	121°04'26.93100"E	96.143	96.887	0.744
MMA-3073-Mandaluyong	14°35'09.70108"N	121°01'33.36284"E	48.887	49.614	0.727
MMA-44-Navotas	14°38'22.32279"N	120°57'11.66001"E	46.658	46.497	-0.161
MMA-50-Delpan	14°35'34.82554"N	120°57'47.24697"E	46.4501	46.385	-0.0651
MMA-54-CCP	14°33'19.86330"N	120°58'39.59762"E	47.792	48.224	0.432
MMA-56-NBP Compound	14°22'23.24815"N	121°01'00.77626"E	109.344	109.638	0.294
MMA-64-Batasan Hills	14°42'35.53911"N	121°06'36.36690"E	73.076	73.289	0.213
MMA-65-Holy Spirit	14°43'45.27551"N	121°03'40.05658"E	117.43	117.597	0.167
MMA-91-Guadanoville	14°45'20.11984"N	121°05'06.03069"E	146.067	146.233	0.166
MMA-94-Culiat, QC	14°39'41.36334"N	121°02'41.00443"E	84.365	84.572	0.207

VI. DISCUSSION AND ANALYSIS

1. Sea Level Rise

The elevation of benchmark comes from a reference surface called Mean Sea Level (MSL). MSL is the mean of all water level observed in a Tide Station for a period of 19 years. The Manila Tide Station provides MSL reference datum to the Metro Manila area. The Tide Staff where the MSL is referred and measured is tied to at least four (4) Tidal Benchmarks (TBMs) to monitor the stability of the staff.

The Oceanography Division of the Hydrography Department is in charge of the annual monitoring and maintenance of Tide Stations and TBMs in the country. According to their records, the MSL at the Manila Tide Station had risen to about **0.526 m** for the past 38 years. Adopting this rise will change the elevation of the TBMs as well as all BMs in Metro Manila. For example, the elevation of the reference **TBM-66** will change from **1.832m to 1.306m.** This computation assumes that TBM-66 is stable and that there was no land movement in the area.

2. Identification of Stable Benchmark

In the Geological Map of Mines and Geosciences Bureau (MGB) (see Fig.8), the lithology in Quezon City is made up of vitric tuffs and welded volcanic breccias. It is characterized by loose and incoherent ash cemented together by pressure and action of infiltrating water that becomes stronger as time passes by.

In 2003, **BM ML-3** was identified to be the most stable among the benchmarks in Metro Manila. According to the check survey conducted by the JICA Experts in Earthquake Impact Reduction Study for Metropolitan Manila (MMEIRS-2003), ML-3 was found to be **stable and recommended** for use as the height datum for 1:5,000 scale Topographic Mapping for GIS database.

To verify this claim, we have computed and analyzed the changes in DEs of old BMs in the project. Initially, the result of the elevation comparison in Table 2 indicated small differences in elevation of the BMs established in Quezon City with TBM-66 as reference. This excludes ML-3 which has uplifted by 0.2183m. Considering the results of MMIERS' conclusion on the stability of ML-3, there is a need to verify which of the two BMs is stable.

To verify or confirm the stability of BM-66, ML-3 and all other benchmarks in the area, we have computed the differences in elevations of all old benchmarks against each other. The DEs of the old survey (Appendix 6) and new survey (Appendix 7 – ML-3 Fixed and Appendix 8 – BM-66 Fixed) were computed and compared. The stability of the benchmarks was verified by examining the **discrepancies or changes between the old and new DEs** (Appendix 9 – ML-3 Fixed and Appendix 10

– BM-66 Fixed), with the assumption that the old survey has the same accuracy as the new survey. Analysis of the result indicated stability of 16 out of the 60 other BMs paired with BM-66, whereas 1 out of 60 BMs for ML-3 (see Fig.9 for the location of stable BMs).

From this results, we can conclude that BM-66 is the more stable benchmark than ML-3. This may be due to the possible error in previous leveling survey and data processing during the JICA MMEIRS-2003 Project or simply the effect of land movement in some parts of metro manila.

Other BMs determined to be stable are:

Station Name	Location	Station Name	Location
CIMA-18a	Sta. Mesa, Manila	GM-35M	Sucat, Parañaque
GM-16M	Ermita, Manila	GM-36M	Sucat, Parañaque
GM-17M	Malate, Manila	GM-44M	Sta. Ana, Taguig
GM-19M	Taft-Libertad Intersection, Pasay	GM-56M	Cembo, Makati
GM-21	Liwasang Bonifacio, Manila	GM-N4	Aurora Blvd., San Juan
Gm-27M	Dasmariñas, Makati	GM P-2	Diliman, Quezon City
GM-33M	San Dionisio, Parañaque		

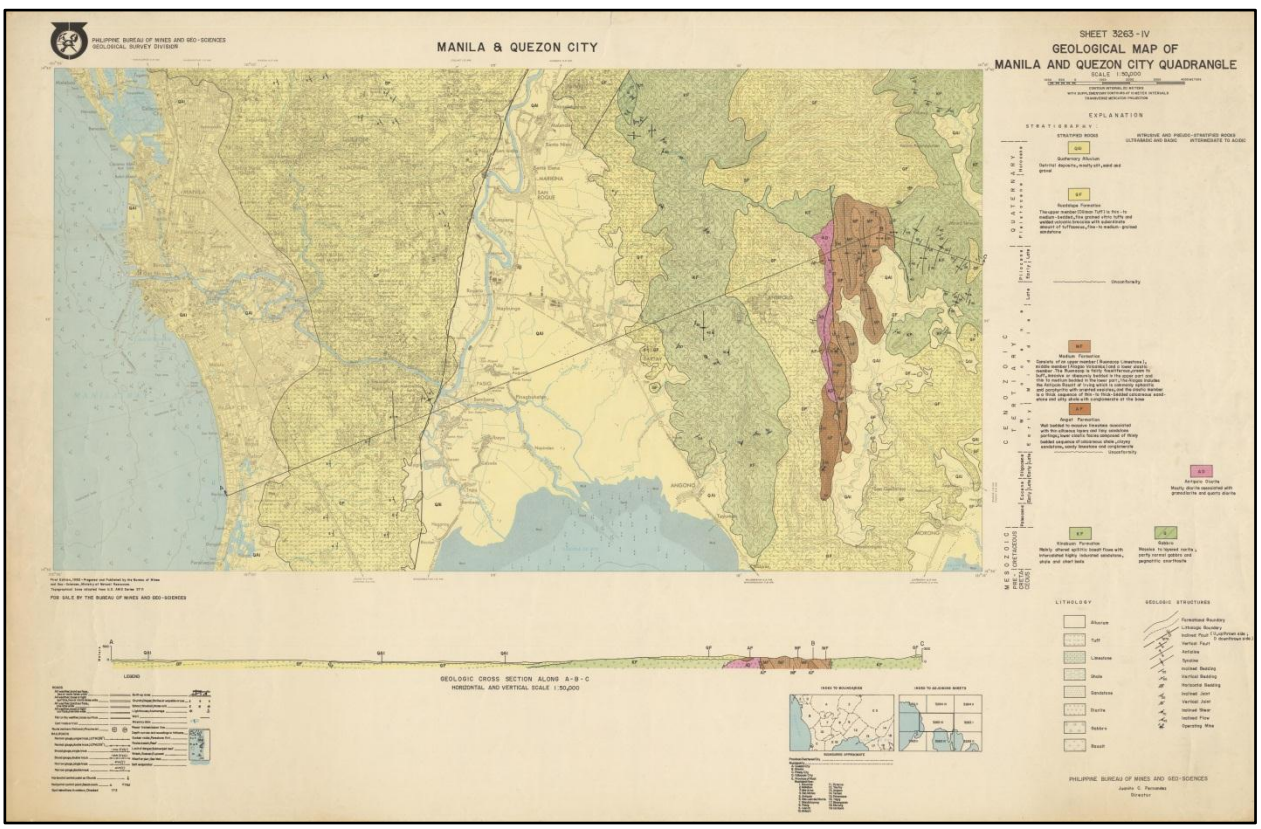

Figure 8. Geological Map of Manila and Quezon City

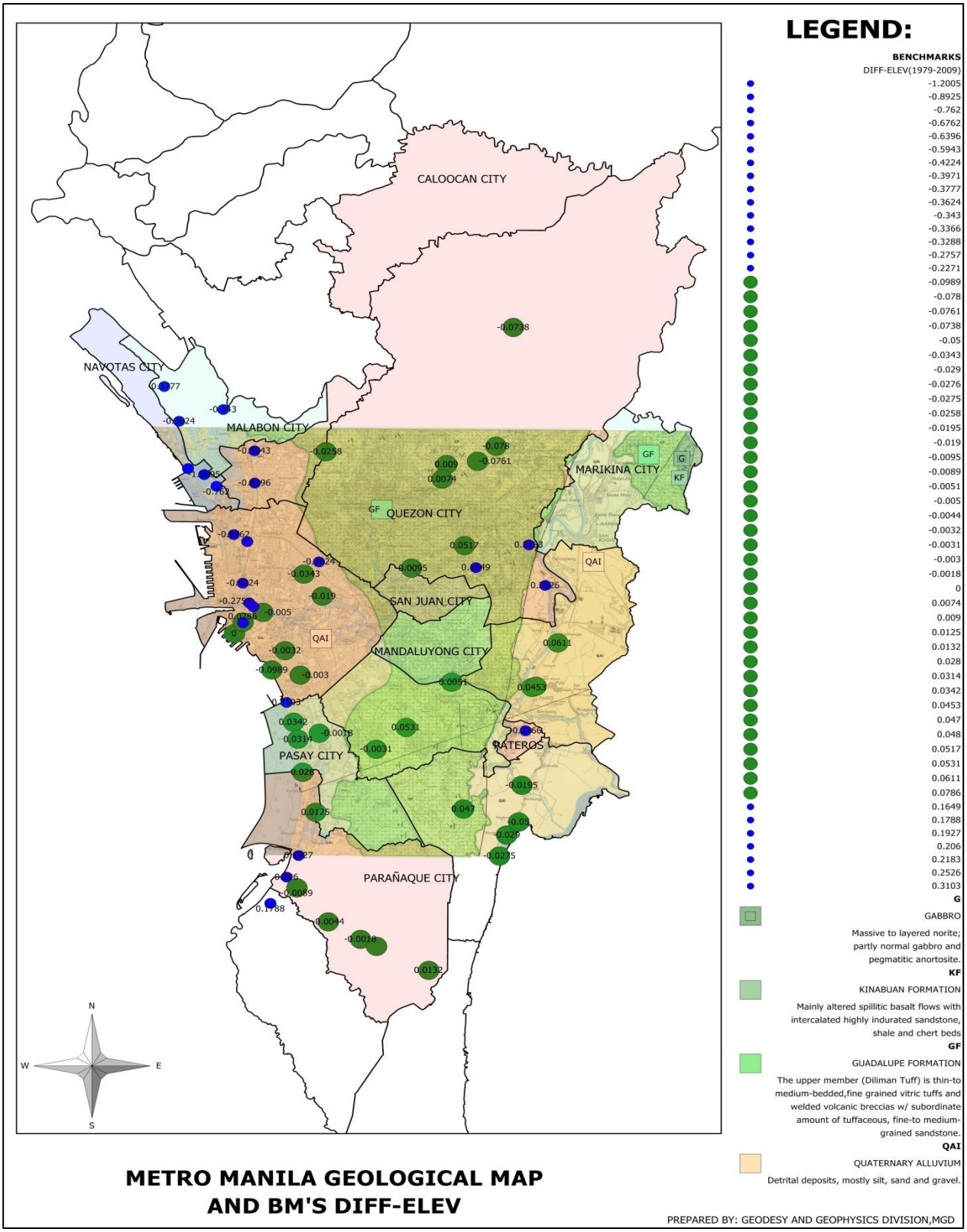

Figure 9. Metro Manila Geological Map showing the BMs with small differences in elevation (green circles)

3. Changes in Elevation

With a confirmed stability of TBM-66 the comparison of the old and new elevations in Table 2 holds true. Figure 10 shows the changes in elevation of all old BMs used in the project. The greatest change in elevation is **-1.2005m** (subsidence), BM-1NHA in Navotas City. Figure 11 shows the graphical representation of the changes in elevations. Figure 11 shows the location of BMs that subsided.

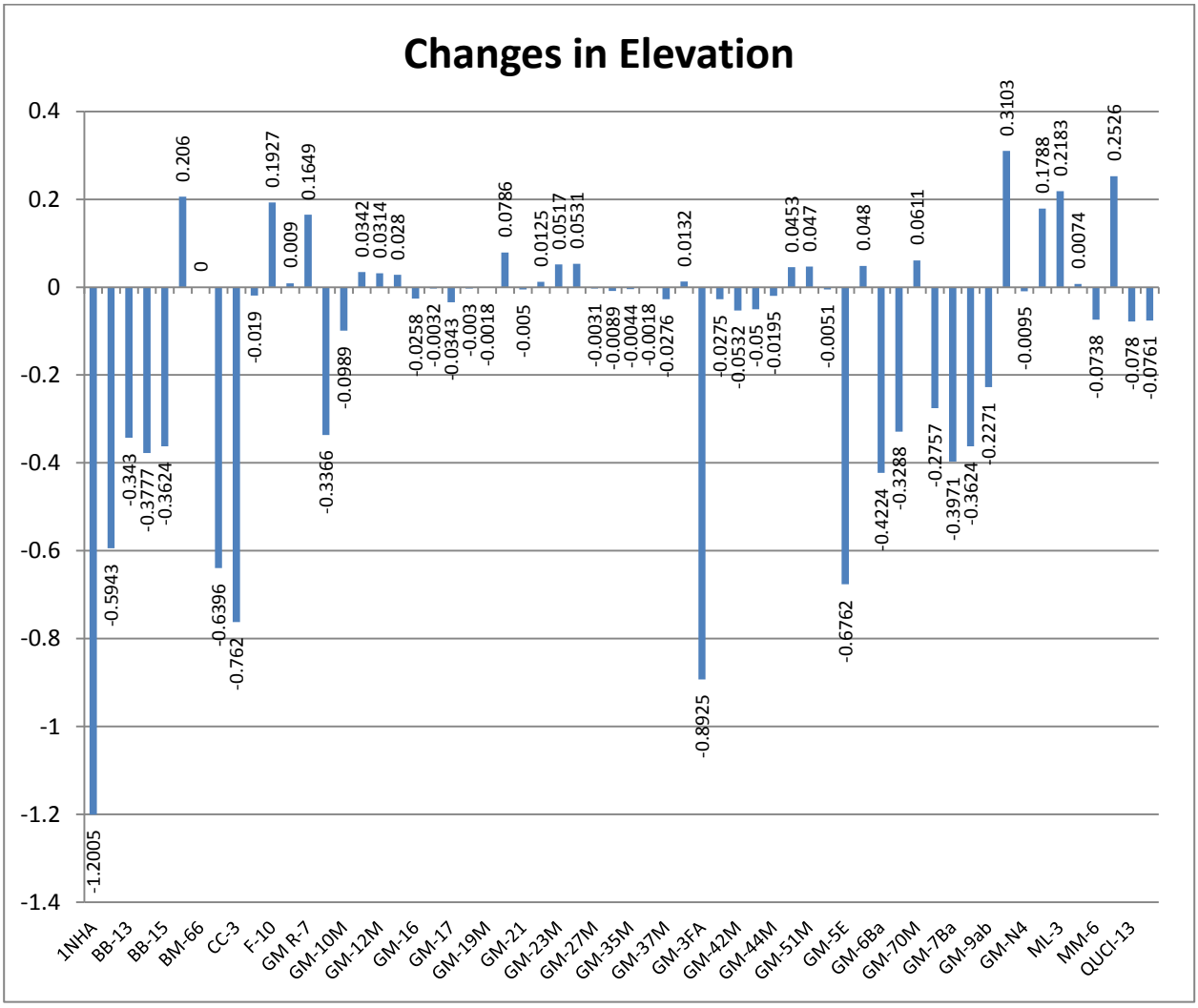

Figure 10. Graphical representation of the changes in elevation of all old BMs used in the project

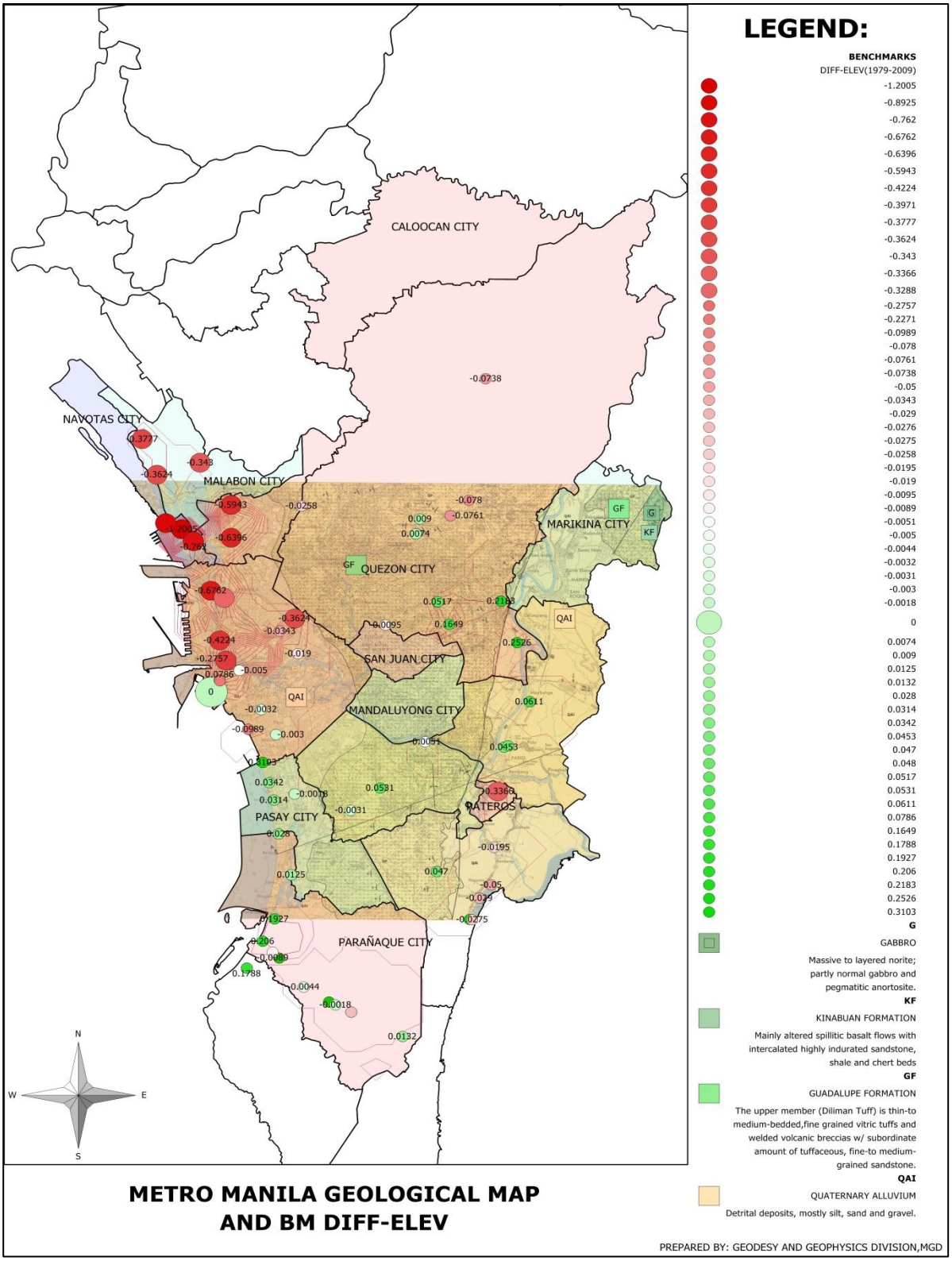

Figure 11. Map showing the location of the BMs that subsided. Red circles are areas where high subsidence occurred.

4. Validation Survey Through GPS

GPS survey was conducted to validate the results of the leveling survey. PRS92 stations near the benchmarks that were established since 1992 were recovered and observed. Processing results indicated that the stations conform to 2nd order accuracy, both in horizontal and vertical. The ellipsoidal heights of the old and new survey were compared. An examination of Table 3 and Figure 12 shows that most of the GCPs located near the BMs in Navotas, Caloocan and Harbor Center have also subsided over the years. Figure 13 shows the location and changes in ellipsoidal heights of the GCPs. The highest change in ellipsoidal height is -0.16m in Navotas City, which confirms the result of leveling. The uplift in ellipsoidal heights of most PRS92 stations may be due to the errors of the previous survey and/or there may really be an uplift of land mass in some parts of metro manila.

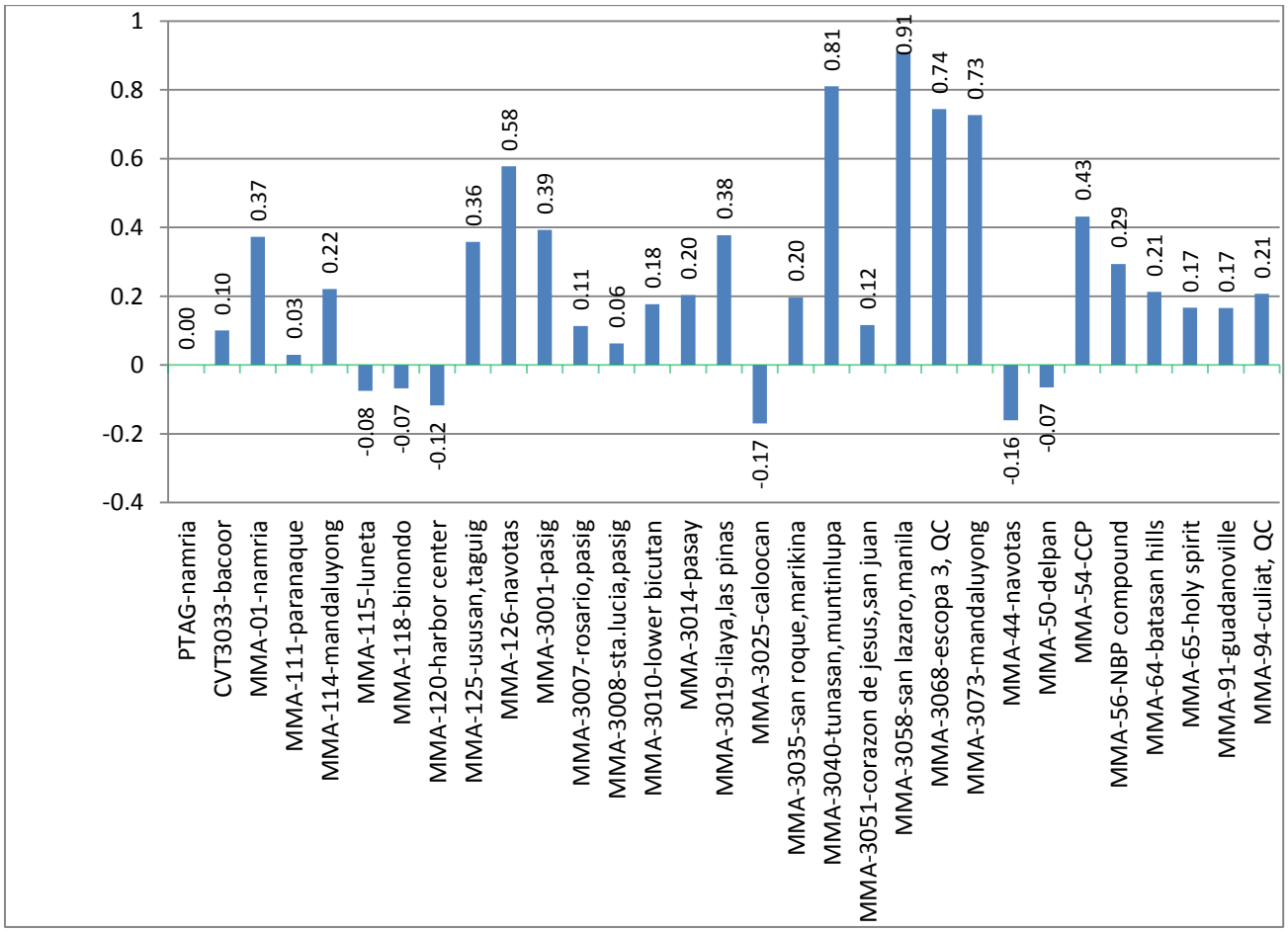

Figure 12. Graphical representation of the changes in Ellipsoidal Heights of PRS92 stations in Metro Manila from 1992 to 2009

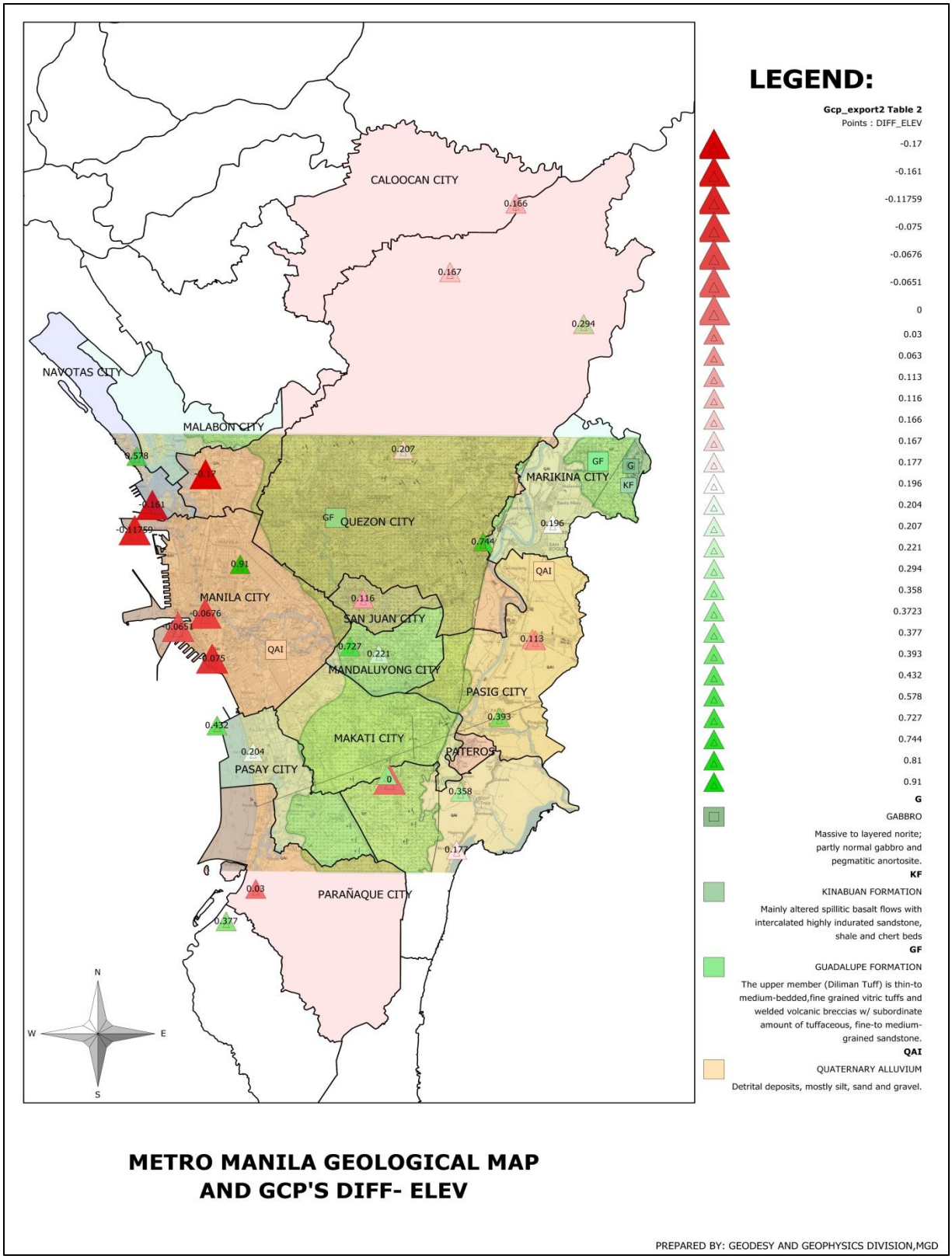

Figure 13. Map showing the location of GCPs that subsided. Red big triangles are areas where high subsidence occurred.

VII. CONCLUSION

Based on the results of the leveling survey, we can conclude that parts of Metro Manila have subsided for the last 38 years. Figure 14 shows the areas that subsided in Metro Manila. Considerable subsidence occurred in the following areas:

- NAVOTAS 1.2005m or 3.159cm/yr
- CALOOCAN 0.7620m or 2.005cm/yr
- TONDO 0.6762m or 1.779cm/yr
- BINONDO 0.3971m or 1.045cm/yr
- SAMPALOC, MANILA 0.3624m or 0.954cm/yr
- MALABON 0.3777m or 0.994cm/yr
- PATEROS 0.3366m or 0.886cm/yr.

New elevations of BMs at MSL series 2008 were computed for the Metro Manila area (Appendix 4). This accounts for the combined ground subsidence and SLR. A new relief map of Metro Manila is shown in Figure 15.

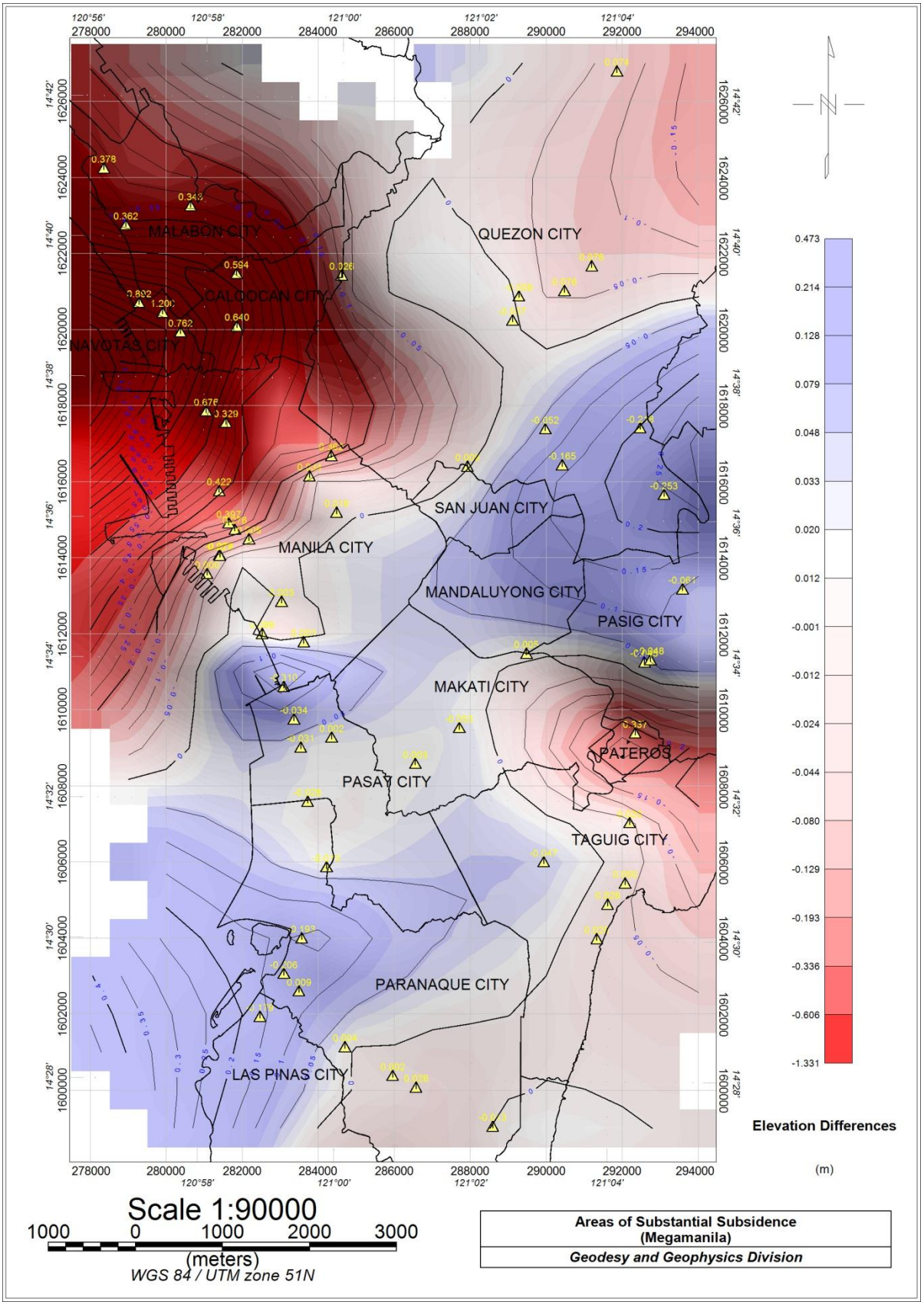

Figure 14. Map showing the areas that subsided. High red intensity indicates high subsidence.

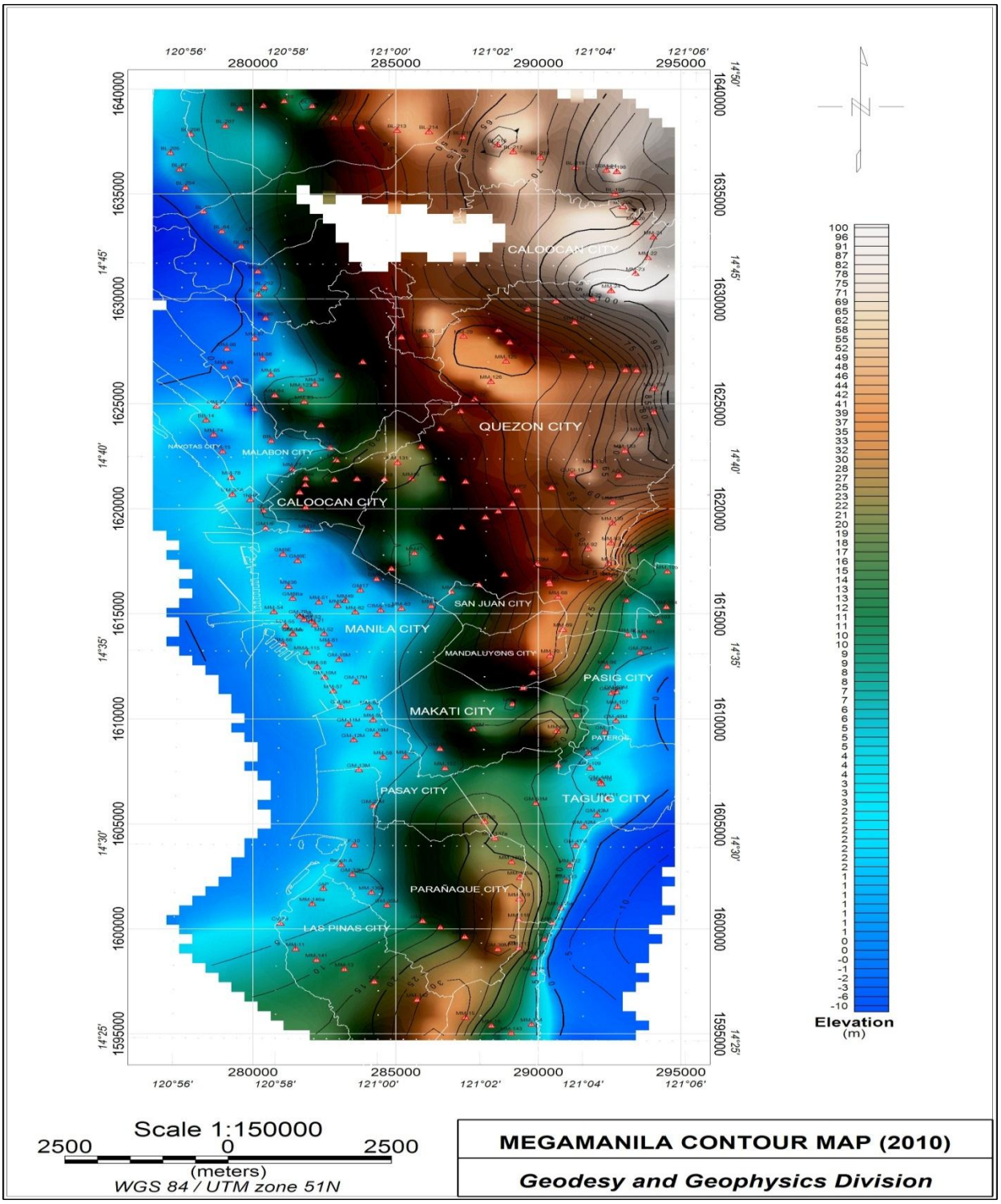

Figure 15. Relief Map of Metro Manila showing the new elevations computed above the MSL series 2008 with the outline of municipal boundaries in white. This map can be used by city planners, lot owners and developers in decision making.

VIII. RECOMMENDATIONS

1. First Order Geodetic Leveling should be done every five (5) years to monitor any changes in the ground level of Metro Manila.
2. Marikina and Cainta should be included in the five-year re-leveling project as well as secondary level lines that cross the level loops.
3. At least two (2) benchmarks per municipality should be included in the GPS survey network for proper ellipsoidal height monitoring in Metro Manila.
4. GPS observations should be conducted annually at the TBM of each Tide Station in the country to properly monitor the changes in ellipsoidal heights of the TBMs. This will determine the stability of the TBMs without performing the leveling survey.

APPENDICES

APPENDIX 1

LIST OF RECOVERED BENCHMARKS

Loop No.	***Station Name***
Loop 1	GM-6Ba, GM-6E, RI-2, CC-1, 560-4A, GM-16, GMP-2, MM-5, GM-7H, GM-17
Loop 2	BB-13, BB-14 ,BB-15, GM-3Fa,BM-1 NHA, CC-3, GM-14F, GM-5E
Loop 4	BL-80, BL-83, BL-84, BL-85, BL-87, BL-3103, BBM-94
Loop 6	W2-A, QUCI-13A, MMA-96, GMA-67M, MM-6, MMA-98
Loop 7	AQ-1
Loop 8	BM-66, GM-1A,GM-6Ba, GM-7B, GM-21, GM-9Ab, GM-9M, GM-10M, GM-11M, GM-12M, GM-13M, GM-16M, GM-17M, GM-19M, MMA-115
Loop 9	GM-27M, GM-26M, GM-56M, GM-R7, GM-23M, GM-N4, CIMA-18a
Loop 10	ML-3, OS-2, GM-49M, GM-51M, GM-27M
Loop 11	GM-68M, GM-70M
Loop 12	GM-48M-S, GM-T1, GM-44M, GM-43M, GM-42M, GM-41M, GMW-13
Loop 13	GM-37M, GM-36M, GM-35M, GM-33M, Beach-A, F-10, GM-22M, GM-13M
Loop 14	JAP, MM-140a, CV-58, MM-11, MM-13, D-9, MM-15, MM-16

APPENDIX 2

LIST OF ESTABLISHED BENCHMARKS

Loop No.	***Station Name***
Loop 1	MM-36,MM-37,MM-38,MM-39,MM-40,MM-41,MM-42,MM-43,MM-44,MM-45,MM-46,MM-47,MM-48,MM-49,MM-50,MM-51
Loop 2	MM-74, MM-75, MM-76, MM-77, MM-78, MM-79
Loop 3	MM-80, MM-81, MM-82 ,MM-83, MM-84, MM-85, MM-86, MM-87, MM-88, MM-89
Loop 4	BL-198, BL-199, BL-200, BL-201, BL-202, BL-203. BL-204, BL-205, BL-206. BL-207. BL-208. BL-209, B;-210, BL-211, BL-212, BL-213, BL-214, BL-215, BL-216, BL-217, BL-218, BL-219, MM-20, MM-21, MM-22, MM-23, MM-24, MM-25, MM-26
Loop 5	MM-122, MM-123, MM-28, MM-29, MM-30, MM-31, MM-33, MM-34
Loop 6	MM-121, MM-124, MM-125, MM-126, MM-127, MM-128, MM-129, MM-130, MM-131, MM-132, M-133, MM-134, MM-135, MM-136, MM-137
Loop 7	MM-138, MM-139, MM-93
Loop 8	MM-54, MM-55, MM-56, MM-57
Loop 9	MM-51, MM-52, M-53, MM-54, MM-58, MM-59, MM-60, MM-61, MM-62, MM-63, MM-64,MM-65, MM-66, MM-73
Loop 10	MM-67, MM-68, MM-69, MM-70, MM-71, MM-72, MM-91, MM-92, MM-93, MM-94, MM-95, MM-96, MM-97, MM-98, MM-99, MM-100, MM-102
Loop 11	MM-101, MM-102, MM-103, MM-104, MM-105, MM-106
Loop 12	MM-107, MM-108, MM-109, MM-110, MM-110, MM-111, MM-112, MM-113, MM-114,MM-115a, MM-116
Loop 13	MM-138a, MM-139a
Loop 14	MM-140A, MM-141, MM-142, MM-143, MM-144, MM-115

APPENDIX 3

DIVERGENCE VALUE OF EACH LEVEL SECTION

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 1							
GM-6Ba	MM36	655.93	-0.32401	0.32244	-0.3232	1.6	
MM36	GM6E	1282.56	0.55433	-0.55557	0.5550	1.2	2.8
GM6E	MM37	1488.68	0.18761	-0.18819	0.1879	0.6	3.4
MM37	CC1	1123.00	5.94153	-5.93833	5.9400	-3.2	0.2
CC1	MM38	748.29	4.81959	-4.81737	4.8184	-2.2	-2.0
MM38	RI-2	649.08	-1.52200	1.52300	-1.5225	-1.0	-3.0
RI-2	5604a	411.74	2.88500	-2.88400	2.8845	-1.0	-4.0
5604a	GPS1	1081.69	2.11656	-2.11315	2.1148	-3.4	-7.4
GPS1	MM39	763.40	2.79982	-2.79728	2.7986	-2.5	-10.0
MM39	GM16	941.22	3.57641	-3.57403	3.5752	-2.4	-12.4
GM16	MM40	995.11	-2.47805	2.47502	-2.4765	3.0	-9.3
MM40	MM41	1047.21	-4.21927	4.21827	-4.2188	1.0	-8.3
MM41	MM42	830.21	14.48242	-14.48271	14.4826	0.3	-8.0
MM42	GMP2	1889.78	11.82941	-11.82705	11.8282	-2.4	-10.4
GMP2	MM5	946.59	-3.12247	3.12160	-3.1220	0.9	-9.5
MM5	MM43	828.32	-5.17516	5.17460	-5.1748	0.6	-9.0
MM43	MM44	546.01	-5.45253	5.45520	-5.4538	-2.7	-11.6
MM44	MM45	962.32	-7.29855	7.29982	-7.2992	-1.3	-12.9
MM45	MM46	880.85	-9.24048	9.23731	-9.2389	3.2	-9.7
MM46	MM47	1099.66	-2.97729	2.97818	-2.9777	-0.9	-10.6
MM47	MM48	1179.97	1.79808	-1.80199	1.8000	3.9	-6.7
MM48	GM7H	710.59	-8.66653	8.66438	-8.6654	2.2	-4.6
GM7H	GM17	793.49	-0.35922	0.35693	-0.3580	2.3	-2.3
GM17	MM49	726.22	-0.11908	0.12051	-0.1198	-1.4	-3.7
MM49	MM50	520.36	0.03590	-0.03460	0.0352	-1.3	-5.0
MM50	MM51	693.19	-0.20666	0.20691	-0.2068	-0.3	-5.3
MM51							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 2							
MM-38	MM-77	1.17	-8.92953	8.92855	-8.9290	1.0	
MM-77	BB-13	1.55	-0.92391	0.92407	-0.9240	-0.2	0.8
BB-13	MM-76	1.89	-2.42863	2.43041	-2.4295	-1.8	-1.0
MM-76	MM-79	1.06	-0.22622	0.22262	-0.2244	3.6	2.6
MM-79	MM-75	1.33	1.81404	-1.81450	1.8142	0.5	3.1
MM-75	BB-14	0.74	1.27561	-1.27884	1.2773	3.2	6.3
BB-14	MM-74	0.92	-2.82245	2.82286	-2.8226	-0.4	5.9
MM-74	BB-15	0.87	0.62704	-0.62379	0.6254	-3.2	2.7
BB-15	MM-78	1.47	0.90204	-0.89791	0.8999	-4.1	-1.5
MM-78	GM-3FA	1.11	0.01459	-0.01428	0.0144	-0.3	-1.8
GM-3FA	1NHA	1.10	0.77407	-0.77615	0.7752	2.1	0.3
1NHA	CC3	1.15	2.48268	-2.47856	2.4806	-4.1	-3.8
CC3	GM14F	1.20	-1.28796	1.29133	-1.2896	-3.4	-7.2
GM14F	GM5E	1.42	-2.94359	2.94159	-2.9426	2.0	-5.2
GM5E	GM-6E	0.62	0.71735	-0.71661	0.7169	-0.7	-5.9
GM-6E							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 3							
MM-79	MM-89	1.01	-0.27626	0.27841	-0.2773	-2.2	
MM-89	MM-88	1.01	0.48395	-0.48324	0.4836	-0.7	-2.9
MM-88	MM-87	1.14	0.28758	-0.28600	0.2868	-1.6	-4.4
MM-87	MM-86	1.00	-0.02014	0.02198	-0.0210	-1.8	-6.3
MM-86	MM-85	0.85	2.07848	-2.08020	2.0793	1.7	-4.6
MM-85	MM-84	1.00	5.81205	-5.81227	5.8121	0.2	-4.3
MM-84	MM-83	1.19	3.38838	-3.38751	3.3880	-0.9	-5.2
MM-83	MM-82	1.25	-3.15678	3.15425	-3.1555	2.5	-2.7
MM-82	MM-81	1.14	-4.56903	4.56657	-4.5678	2.5	-0.2
MM-81	MM-80	0.66	13.21948	-13.22287	13.2211	3.4	3.2
MM-80	GPS-1	0.91	-1.27206	1.27009	-1.2710	2.0	5.1
GPS-1							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 4							
MM-87	BL-80	1.04	0.00377	-0.00060	0.0022	-3.2	
BL-80	BL-201	0.54	3.35733	-3.35980	3.3586	2.5	-0.7
BL-201	BL-202	0.97	-2.56837	2.56555	-2.5669	2.8	2.1
BL-202	BL-203	0.79	-0.41411	0.41000	-0.4120	4.1	6.2
BL-203	BL-83	1.33	0.96389	-0.96437	0.9642	0.5	6.7
BL-83	BL-84	1.01	-0.05391	0.05217	-0.0530	1.7	8.4
BL-84	BL-85	1.18	-0.59607	0.59588	-0.5959	0.2	8.6
BL-85	BL-204	1.31	0.28357	-0.28603	0.2848	2.5	11.1
BL-204	BL-87	0.96	1.76276	-1.76034	1.7616	-2.4	8.7
BL-87	BL-205	0.90	-0.97671	0.97346	-0.9750	3.2	11.9
BL-205	BL-206	1.12	1.70640	-1.71038	1.7084	4.0	15.9
BL-206	BL-207	1.29	1.65789	-1.65630	1.6571	-1.6	14.3
BL-207	BL-208	1.01	1.40681	-1.40640	1.4066	-0.4	13.9
BL-208	BL-209	0.86	2.62014	-2.61962	2.6198	-0.5	13.4
BL-209	BL-210	0.79	4.06479	-4.06179	4.0632	-3.0	10.4
BL-210	BL-3103	1.07	-10.63588	10.63212	-10.6340	3.8	14.1
BL-3103	BL-211	1.02	29.99795	-29.99334	29.9956	-4.6	9.5
BL-211	BL-212	1.12	10.17335	-10.17086	10.1722	-2.5	7.0
BL-212	BL-213	1.25	4.11056	-4.11121	4.1108	0.7	7.7
BL-213	BL-214	1.12	-1.23758	1.24209	-1.2398	-4.5	3.2
BL-214	BL-215	1.23	6.98173	-6.98336	6.9826	1.6	4.8
BL-215	BL-216	1.29	27.47328	-27.47615	27.4747	2.9	7.7
BL-216	BL-217	0.65	-17.91793	17.91536	-17.9166	2.6	10.3
BL-217	BL-218	1.00	5.59611	-5.59749	5.5968	1.4	11.6
BL-218	BL-219	1.26	10.51670	-10.52127	10.5190	4.6	16.2
BL-219	BBM-94	1.01	14.51418	-14.51182	14.5130	-2.4	13.9
BBM-94	BL-198	0.950	-2.9507	2.9487	-2.9496	1.9	15.8
BL-198	BL-199	1.093	-4.5600	4.5598	-4.5600	0.2	16.0
BL-199	BL-200	0.715	-19.0059	19.0039	-19.0048	2.0	18.0
BL-200	MM-20	0.990	16.4504	-16.4542	16.4522	3.8	21.8
MM-20	MM-21	0.963	10.9523	-10.9512	10.9518	-1.1	20.7
MM-21	MM-22	1.106	0.8624	-0.8620	0.8622	-0.4	20.3
MM-22	MM-23	0.740	-0.9807	0.9809	-0.9808	-0.2	20.1
MM-23	MM-24	1.447	9.0102	-9.0144	9.0124	4.3	24.4
MM-24	MM-25	0.849	-2.6244	2.6258	-2.6252	-1.4	23.0
MM-25	MM-26	1.263	-23.2454	23.2420	-23.2437	3.4	26.4
MM-26							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 5							
MM-84	MM-123	1.06	-0.91068	0.90935	-0.9100	1.3	
MM-123	MM-34	0.56	-2.11430	2.11450	-2.1144	-0.2	1.1
MM-34	MM-33	0.91	2.08146	-2.07776	2.0796	-3.7	-2.6
MM-33	MM-122	1.09	7.41657	-7.41926	7.4179	2.7	0.1
MM-122	MM-31	1.81	20.60153	-20.60305	20.6022	1.5	1.6
MM-31	MM-30	0.89	17.08064	-17.07992	17.0802	-0.7	0.9
MM-30	MM-29	1.38	-16.34723	16.34291	-16.3450	4.3	5.2
MM-29	MM-28	1.29	0.94522	-0.94832	0.9468	3.1	8.3
MM-28	MM-124	0.91	0.60591	-0.60283	0.6044	-3.1	5.3
MM-124	MM-125	0.95	-4.23102	4.23189	-4.2314	-0.9	4.4
MM-125	MM-126	1.12	11.80935	-11.80858	11.8090	-0.8	3.6
MM-126	MM-127	1.03	-5.83488	5.83381	-5.8344	1.1	4.7
MM-127	MM-128	0.82	-4.91036	4.91316	-4.9117	-2.8	1.9
MM-128	MM-129	1.12	-2.72067	2.72213	-2.7214	-1.5	0.4
MM-129	MM-130	1.09	-11.42079	11.41866	-11.4198	2.1	2.6
MM-130	MM-131	1.21	5.18195	-5.18576	5.1838	3.8	6.4
MM-131	MM-39	1.95	-6.82371	6.82919	-6.8264	-5.5	0.9
MM-39							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 6							
GMP2	W2-A	1.92	5.32598	-5.32885	5.3274	2.9	
W2-A	QUCI-13	1.04	13.35895	-13.35670	13.3578	-2.3	0.6
QUCI-13	MM-132	0.93	-2.45674	2.45674	-2.4567	0.0	0.6
MM-132	MM-133	1.33	16.33397	-16.33406	16.3340	0.1	0.7
MM-133	MM-134	1.00	-1.25211	1.25331	-1.2528	-1.2	-0.5
MM-134	MM-135	1.08	14.53190	-14.53065	14.5312	-1.3	-1.7
MM-135	MM-136	1.13	1.39674	-1.39644	1.3966	-0.3	-2.0
MM-136	MMA-96	1.19	-24.40912	24.40892	-24.4090	0.2	-1.8
MMA-96	67M	0.67	-3.46690	3.46729	-3.4671	-0.4	-2.2
67M	MM-6	0.97	-11.43584	11.43953	-11.4376	-3.7	-5.9
MM-6	MMA-98	0.84	-0.87399	0.87413	-0.8740	-0.1	-6.1
MMA-98	MM-137	1.67	15.89588	-15.89779	15.8968	1.9	-4.1
MM-137	MM-26	1.72	12.27055	-12.27299	12.2718	2.4	-1.7
MM-26	MM-121	1.02	-10.37374	10.37322	-10.3734	0.5	-1.2
MM-121	MM-28	1.88	-29.70988	29.70920	-29.7095	0.7	-0.5
MM-28							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 7							
MM-132	AQ-1 (tbm)	1.16	10.42359	-10.42275	10.4232	-0.8	
AQ-1 (tbm)	MM-138	1.37	-11.21262	11.21405	-11.2133	-1.4	-2.3
MM-138	MM-139	0.97	-7.51700	7.52080	-7.5189	-3.8	-6.1
MM-139	MM-93	0.98	0.12520	-0.12549	0.1253	0.3	-5.8
MM-93							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 8							
BM-66	GM-1A	0.80	2.10713	-2.10427	2.1057	-2.9	
GM-1A	MM-55	0.46	-0.65995	0.65765	-0.6588	2.3	-0.6
MM-55	MM-54	0.79	-0.58726	0.58783	-0.5876	-0.6	-1.1
MM-54	GM-6BA	0.96	-0.41849	0.41997	-0.4192	-1.5	-2.6
GM-6BA	GM-7BA	1.04	-0.08353	0.08575	-0.0846	-2.2	-4.8
GM-7BA	GM-7B	0.31	-0.77527	0.77381	-0.7745	1.5	-3.4
GM-7B	MM-53	0.69	0.91370	-0.91103	0.9124	-2.7	-6.0
MM-53	GM-21	0.26	0.30166	-0.30122	0.3014	-0.4	-6.5
GM-21	MM-52	0.46	-0.25804	0.25852	-0.2582	-0.5	-7.0
MM-52	MM-61	1.51	-0.64563	0.64604	-0.6458	-0.4	-7.4
MM-61	GM-16M	1.29	0.41671	-0.41279	0.4148	-3.9	-11.3
GM-16M	GM-17M	0.72	0.37529	-0.37197	0.3736	-3.3	-14.6
GM-17M	MM-60	1.12	-0.10236	0.10604	-0.1042	-3.7	-18.3
MM-60	MM-59	0.83	0.29326	-0.29069	0.2919	-2.6	-20.9
MM-59	GM-19M	0.71	0.33151	-0.32984	0.3306	-1.7	-22.5
GM-19M	MM-58	1.11	-0.09482	0.09553	-0.0951	-0.7	-23.2
MM-58	GM-13M	1.47	0.66619	-0.66709	0.6666	0.9	-22.3
GM-13M	GM-12M	1.48	-1.27003	1.26952	-1.2697	0.5	-21.8
GM-12M	GM-11M	0.77	0.10746	-0.10837	0.1079	0.9	-20.9
GM-11M	GM-9M	0.89	1.19046	-1.19130	1.1908	0.8	-20.1
GM-9M	MM-57	0.78	-0.60497	0.60675	-0.6058	-1.8	-21.9
MM-57	GM-10M	0.74	0.26091	-0.25821	0.2595	-2.7	-24.6
GM-10M	MM-56	0.80	-0.49000	0.49254	-0.4912	-2.5	-27.1
MM-56	MMA-115	0.82	1.60560	-1.60439	1.6050	-1.2	-28.3
MMA-115	GM-9ab	0.54	-0.84215	0.84074	-0.8414	1.4	-26.9
GM-9ab	BM-66	1.15	-1.71862	1.72282	-1.7207	-4.2	-31.1
BM-66							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 9							
MM-58	MM-73	0.84	2.06277	-2.05935	2.0610	-3.4	
MM-73	GM-27M	1.30	1.28366	-1.28509	1.2844	1.4	-2.0
GM-27M	GM-26M	1.47	9.63665	-9.63836	9.6376	1.7	-0.3
GM-26M	MM-72	1.80	-7.49305	7.49089	-7.4920	2.2	1.9
MM-72	GM-56M	0.82	5.12965	-5.12689	5.1282	-2.8	-0.9
GM-56M	MM-71	0.90	21.13178	-21.13283	21.1323	1.1	0.2
MM-71	MM-70	1.01	3.06007	-3.06190	3.0610	1.8	2.0
MM-70	MM-69	1.27	-3.70585	3.70590	-3.7058	0.0	1.9
MM-69	MM-68	1.64	7.52547	-7.52322	7.5244	-2.2	-0.3
MM-68	GM-R7	0.68	-4.52957	4.52894	-4.5292	0.6	0.3
GM-R7	MM-67	0.11	-0.63229	0.63354	-0.6330	-1.3	-0.9
MM-67	GM-23M	0.96	4.93208	-4.93548	4.9338	3.4	2.5
GM-23M	MM-66	1.26	-12.46754	12.46937	-12.4684	-1.8	0.6
MM-66	GM-N4	1.01	-19.52787	19.52951	-19.5286	-1.6	-1.0
GM-N4	MM-65	1.07	-2.45432	2.45638	-2.4554	-2.1	-3.1
MM-65	MM-64	0.90	-1.88326	1.88260	-1.8830	0.7	-2.4
MM-64	MM-63	1.05	-2.27160	2.27292	-2.2723	-1.3	-3.7
MM-63	CIMA-18a	0.73	-0.73929	0.74023	-0.7397	-0.9	-4.7
CIMA-18a	MM-62	0.95	0.57415	-0.57362	0.5738	-0.5	-5.2
MM-62	MM-51	1.36	-0.44260	0.43961	-0.4412	3.0	-2.2
MM-51	GM6Ba	0.99	0.15202	-0.15230	0.1522	0.3	-1.9
GM6Ba							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 10							
GM-23M	MM-91	1.04	1.76691	-1.76889	1.7679	2.0	
MM-91	MM-92	0.88	7.31071	-7.31240	7.3115	1.7	3.7
MM-92	MM-93	0.94	0.53588	-0.53535	0.5356	-0.5	3.1
MM-93	ML-3	1.01	7.04330	-7.04696	7.0452	3.7	6.8
ML-3	MM-94	1.42	-30.93888	30.93457	-30.9368	4.3	11.1
MM-94	0S-2	1.27	-18.64359	18.64141	-18.6425	2.2	13.3
0S-2	MM-95	1.65	-1.03710	1.03932	-1.0382	-2.2	11.1
MM-95	MM-96	1.71	-0.74138	0.73866	-0.7400	2.7	13.8
MM-96	GM-49M	1.82	0.34133	-0.34328	0.3423	1.9	15.7
GM-49M	MM-97	1.68	4.08067	-4.07838	4.0796	-2.3	13.5
MM-97	MM-98	1.21	22.17232	-22.17172	22.1720	-0.6	12.9
MM-98	MM-99	2.09	-25.14276	25.14536	-25.1440	-2.6	10.3
MM-99	GM-51M	1.93	2.74508	-2.74767	2.7463	2.6	12.8
GM-51M	MM-100	2.13	12.25805	-12.25516	12.2566	-2.9	10.0
MM-100	MM-102	2.60	-14.91120	14.91587	-14.9135	-4.7	5.3
MM-102	GM-27M	1.12	-1.89501	1.89626	-1.8956	-1.2	4.0
GM-27M							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 11							
GM-49M	GM-68M	0.18	-2.07277	2.07348	-2.0732	-0.7	
GM-68M	GM-70M	2.09	1.36126	-1.36008	1.3606	-1.2	-1.9
GM-70M	MM-101	0.84	1.92439	-1.92189	1.9231	-2.5	-4.4
MM-101	MM-103	0.94	1.32870	-1.32951	1.3292	0.8	-3.6
MM-103	MM-104	0.74	0.18398	-0.18260	0.1832	-1.4	-5.0
MM-104	MM-105	1.70	0.71493	-0.71745	0.7162	2.5	-2.4
MM-105	MM-106	1.61	2.01819	-2.01766	2.0180	-0.5	-3.0
MM-106	MM-93	1.18	38.51052	-38.51279	38.5116	2.3	-0.7
MM-93							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 12							
GM-49M	MM-107	0.78	-2.20410	2.20457	-2.2044	-0.5	
MM-107	GM-48M-S	0.58	-0.52985	0.52953	-0.5296	0.3	-0.2
GM-48M-S	GM-T1	0.80	2.03666	-2.03626	2.0364	-0.4	-0.6
GM-T1	MM-108	1.27	-1.88260	1.88578	-1.8842	-3.2	-3.7
MM-108	MM-109	0.74	-0.19346	0.19165	-0.1925	1.8	-1.9
MM-109	GM-44M	1.21	1.86091	-1.86216	1.8616	1.3	-0.7
GM-44M	MM-110	0.14	-2.25691	2.25713	-2.2570	-0.2	-0.9
MM-110	MM-111	0.60	0.49469	-0.49381	0.4942	-0.9	-1.8
MM-111	GM-43M	0.85	0.27648	-0.27580	0.2761	-0.7	-2.5
GM-43M	GM-42M	0.72	-0.68907	0.68871	-0.6888	0.4	-2.1
GM-42M	GM-41M	0.95	-0.20347	0.20369	-0.2035	-0.2	-2.3
GM-41M	MM-112	1.12	3.84879	-3.84921	3.8490	0.4	-1.9
MM-112	MM-113	1.12	-1.31821	1.31429	-1.3162	3.9	2.0
MM-113	MM-115a	0.84	-2.05360	2.05191	-2.0527	1.7	3.7
MM-115a	MM-114	0.79	2.07514	-2.07553	2.0753	0.4	4.1
MM-114	W-13	0.81	-1.30902	1.30930	-1.3092	-0.3	3.8
W-13	MM-116	1.48	2.68642	-2.68551	2.6860	-0.9	2.9
MM-116	MM-117	0.78	21.75928	-21.75986	21.7596	0.6	3.5
MM-117	MM-118	1.36	1.15354	-1.15550	1.1545	2.0	5.5
MM-118	MM-119	0.82	2.61707	-2.61495	2.6160	-2.1	3.3
MM-119	MM-135a	1.10	-3.81038	3.80932	-3.8098	1.1	4.4
MM-135a	MM-136a	1.25	-7.05238	7.05208	-7.0522	0.3	4.7
MM-136a	MM-137a	1.26	-4.05378	4.05042	-4.0521	3.4	8.1
MM-137a	MM-100	1.10	4.86366	-4.86322	4.8634	-0.4	7.6
MM-100							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 13							
MM-117	GM-39M	1.06	3.70828	-3.70839	3.7083	0.1	
GM-39M	MM-138a	1.32	-12.37101	12.37518	-12.3731	-4.2	-4.1
MM-138a	GM-37M	0.95	-4.18299	4.18143	-4.1822	1.6	-2.5
GM-37M	GM-36M	0.96	-5.61143	5.61033	-5.6108	1.1	-1.4
GM-36M	GM-35M	1.21	-3.92539	3.92823	-3.9268	-2.8	-4.2
GM-35M	MM-139a	0.76	-2.82222	2.82383	-2.8230	-1.6	-5.8
MM-139a	GM-33M	1.22	1.67831	-1.67651	1.6774	-1.8	-7.6
GM-33M	Beach A	0.91	-3.02179	3.02165	-3.0217	0.1	-7.5
Beach A	F-10	1.12	0.88958	-0.89097	0.8902	1.4	-6.1
F-10	GM-22M	2.09	1.41484	-1.41736	1.4161	2.5	-3.6
GM-22M	GM-13M	2.05	-1.53144	1.53156	-1.5315	-0.1	-3.7
GM-13M							

From BM to BM		DISTANCE (km)	DIFFERENCE OF ELEVATION			DISCREPANCY	
			Forward Line (m)	Backward Line (m)	Mean (m)	Partial (mm)	Total Accumulated (mm)
LOOP 14							
Beach A	JAP	1.32	0.83168	-0.83106	0.8314	-0.6	
JAP	MM-140a	0.95	0.51067	-0.51200	0.5113	1.3	0.7
MM-140a	CV-58	1.50	-1.40743	1.40534	-1.4064	2.1	2.8
CV-58	MM-11	1.37	4.52214	-4.51995	4.5210	-2.2	0.6
MM-11	MM-141	0.90	1.84250	-1.84316	1.8428	0.7	1.3
MM-141	MM-13	1.05	3.20532	-3.20409	3.2048	-1.2	0.0
MM-13	D-9	1.21	3.31090	-3.31457	3.3127	3.7	3.7
D-9	MM-142	1.75	14.59942	-14.59860	14.5990	-0.8	2.9
MM-142	MM-15	1.96	2.08039	-2.08418	2.0822	3.8	6.7
MM-15	MM-16	1.01	-17.47153	17.46880	-17.4702	2.7	9.4
MM-16	MM-143	0.81	-4.77832	4.77936	-4.7788	-1.0	8.4
MM-143	MM-144	1.23	-4.88634	4.88266	-4.8845	3.7	12.1
MM-144	MM-115	2.44	0.47236	-0.47330	0.4728	0.9	13.0
MM-115	MM-116	0.86	1.94584	-1.94663	1.9462	0.8	13.8
MM-116							

APPENDIX 4

LIST OF NEW ELEVATION OF BENCHMARKS REFERRED TO BM 66 AT MSL 2008 DATUM

BM No.	Elevation (m)	BM No.	Elevation (m)	BM No.	Elevation (m)
0S-2	7.8886	CC3	5.4890	GM-7B	0.8863
1NHA	3.0075	CIMA-18a	1.4610	GM-7Ba	1.6609
5604a	14.2817	CV58	2.2334	GM-7H	2.2446
67M	61.7556	D9	15.1160	GM-9ab	3.0269
AQ1	69.0357	F10	3.1867	GM-9M	3.1013
BB13	3.0695	GM-10M	2.7548	GMN4	8.8115
BB14	3.5110	GM-11M	1.9107	GMP2	42.3810
BB15	1.3152	GM-12M	1.8029	GM-R7	36.5079
BBM94	93.7059	GM-13M	3.0728	GMT1	5.7534
Beach-A	2.2960	GM14F	4.2003	GPS1	16.3958
BL-198	90.7561	GM16	22.7685	JAP	3.1278
BL-199	86.1960	GM-16M	1.6103	ML3	57.4683
BL-200	67.1911	GM17	1.8861	MM-100	22.5613
BL-201	4.2715	GM-17M	1.9838	MM-101	7.6634
BL-202	1.7045	GM-19M	2.5017	MM-102	7.6475
BL-203	1.2924	GM1A	3.4116	MM-103	8.9928
BL-204	1.8920	GM21	2.1000	MM-104	9.1762
BL-205	2.6784	GM-22M	4.6035	MM-105	9.8929
BL-206	4.3866	GM-23M	40.8086	MM-106	11.9113
BL-207	6.0436	GM-26M	15.3893	MM-107	4.2473
BL-208	7.4501	GM-27M	5.7517	MM-108	3.8686
BL-209	10.0698	GM-33M	5.3174	MM-109	3.6758
BL-210	14.1329	GM-35M	6.4623	MM11	6.7548
BL-211	33.4943	GM-36M	10.3886	MM-110	3.2797
BL-212	43.6663	GM-37M	15.9990	MM-111	3.7737
BL-213	47.7770	GM-39M	32.5535	MM-112	7.0047

BM No.	Elevation (m)	BM No.	Elevation (m)	BM No.	Elevation (m)
BL-214	46.5371	GM-3FA	2.2315	MM-113	5.6880
BL-215	53.5195	GM-41M	3.1563	MM-114	5.7098
BL-216	80.9941	GM-42M	3.3602	MM-115	5.1391
BL-217	63.0774	GM-43M	4.0494	MM-115a	3.6349
BL-218	68.6741	GM-44M	5.5368	MM-116	7.0856
BL-219	79.1930	GM-48M	3.7174	MM-117	28.8448
BL-3103	3.4988	GM-49M	6.4520	MM-118	29.9986
BL80	0.9129	GM-51M	10.3050	MM-119	32.6143
BL83	2.2564	GM-56M	13.0254	MM-121	67.2471
BL84	2.2033	GM5E	1.2588	MM-122	15.2549
BL85	1.6073	GM-68M	4.3789	MM-123	7.8714
BL87	3.6535	GM6Ba	1.7456	MM-124	38.1446
BM66	1.3060	GM6E	1.9762	MM-125	33.9134
CC1	8.1024	GM-70M	5.7401	MM-126	45.7226
MM-127	39.8837	MM33	7.8346	MM69	33.5130
MM-128	34.9728	MM34	5.7556	MM70	37.2189
MM-129	32.2524	MM36	1.4218	MM71	34.1580
MM13	11.8035	MM37	2.1630	MM72	7.8977
MM-130	20.8335	MM38	12.9202	MM73	4.4681
MM-131	26.0184	MM39	19.1937	MM74	0.6889
MM-132	58.6128	MM40	20.2912	MM75	2.2329
MM-133	74.9479	MM41	16.0717	MM76	0.6413
MM-134	73.6960	MM42	30.5538	MM77	3.9921
MM-135	88.2282	MM43	34.0829	MM78	2.2160
MM-135a	28.8045	MM44	28.6287	MM79	0.4177
MM-136	89.6258	MM45	21.3289	MM80	17.6666
MM-136a	21.7517	MM46	12.0895	MM81	4.4456
MM-137	65.3396	MM47	9.1111	MM82	9.0134
MM-137a	17.6990	MM48	10.9103	MM83	12.1689
MM-138	57.8194	MM49	1.7657	MM84	8.7810

BM No.	Elevation (m)	BM No.	Elevation (m)	BM No.	Elevation (m)
MM-138a	20.1814	MM5	39.2582	MM85	2.9689
MM-139	50.2993	MM50	1.8006	MM86	0.8896
MM-139a	3.6401	MM51	1.5933	MM87	0.9107
MM-140a	3.6399	MM52	1.8418	MM88	0.6239
MM-141	8.5984	MM53	1.7986	MM89	0.1403
MM-142	29.7160	MM54	2.1649	MM91	42.5764
MM-143	9.5503	MM55	2.7526	MM92	49.8876
MM-144	4.6661	MM56	2.2637	MM93	50.4233
MM15	31.7988	MM57	2.4957	MM94	26.5315
MM16	14.3289	MM58	2.4072	MM95	6.8504
MM20	83.6380	MM59	2.1718	MM96	6.1103
MM21	94.5895	MM6	50.3146	MM97	10.5318
MM22	95.4514	MM60	1.8799	MM98	32.7037
MM23	94.4704	MM61	1.1959	MM99	7.5594
MM24	103.4824	MM62	2.0346	MMA-115	3.8685
MM25	100.8570	MM63	2.2006	MMA-96	65.2178
MM26	77.6129	MM64	4.4730	MMA-98	49.4413
MM28	37.5326	MM65	6.3560	QUCI-13	61.0686
MM29	36.5866	MM66	28.3401	RI2	11.3973
MM30	52.9325	MM67	35.8749	W13	4.4007
MM31	35.8528	MM68	41.0372	W2A	47.7099

APPENDIX 5

LIST OF ELEVATION OF OLD BMS REFERRED TO BM 66 AT MSL 1970 DATUM (New Survey)

BENCHMARK NAME AND LOCATION	ELEVATION
A. Mabini& C-3 Road intersection, Caloocan _ **CC-1**	8.6284
C-3 Road, Caloocan _ **CC-3**	6.015
Sampaloc, Caloocan _ **560-4A**	14.8077
Hagonoy, Taguig _ **GM-43M**	4.5754
Lower Bicutan, Taguig _ **GM-41M**	3.6823
Lower Bicutan, Taguig _ **GM-42M**	3.8862
Sta. Ana, Taguig _ **GM-44M**	6.0628
Aurora Blvd., San Juan _ **GM-N4**	9.3375
Bagumbayan, San Juan _ **OS-2**	8.4146
Cembo, Makati _ **GM-56M**	13.5514
Dasmariñas, Makati _ **GM-27M**	6.2777
Fort Bonifacio, Makati _ **GM-51M**	10.831
McKinley road corner EDSA, Makati _ **GM-26M**	15.9153
Concepcion, Malabon _ **BB-15**	1.8412
HulongDuhat, Malabon _ **BB-14**	4.0370
Tinajeros, Malabon _ **BB-13**	3.3955
Malate, Manila _ **GM-10M**	3.2808
Malate, Manila _ **GM-17M**	2.5098
Malate, Manila _ **GM-9M**	3.6273
Binondo, Manila _ **GM-7B**	1.4123
Binondo, Manila _ **GM-7BA**	1.869
Ermita, Manila _ **GM-16M**	2.1363
Liwasang Bonifacio, Manila _ **GM-21**	2.626
Port Area, Manila _ **BM-66**	1.832
Port Area, Manila _ **GM-1A**	3.9376
Sampaloc, Manila _ **GM-17**	2.4121
Sampaloc, Manila _ **GM-7H**	2.7706
South Port District, Manila _ **GM-9AB**	3.5529
Sta. Mesa, Manila _ **CIMA-18A**	1.987
Tondo, Manila _ **GM-5E**	1.7848
Tondo, Manila _ **GM-6BA**	2.2716
Tondo, Manila _ **GM-6E**	2.5022
La Huerta, Parañaque _ **F-10**	3.7127
San Dionisio, Parañaque _ **Beach A**	2.822
San Dionisio, Parañaque _ **GM-33M**	5.8434

BENCHMARK NAME AND LOCATION	ELEVATION
Sucat, Parañaque _ **GM-35M**	6.9883
Sucat, Parañaque _ **GM-36M**	10.9146
Sucat, Parañaque _ **GM-37M**	16.525
Sucat, Parañaque _ **GM-39M**	33.0795
Tambo, Parañaque _ **GM-22M**	5.1295
Caniogan, Pasig _ **GM-68M**	4.9049
Capasigan, Pasig _ **GM-49M**	6.978
Mabunga, Pasig _ **GM-70M**	6.2661
Balintawak, Quezon City _ **GM-16**	23.2945
Cubao, Quezon City _ **GM-23M**	41.3346
Diliman, Quezon City _ **GM P-2**	42.9090
Diliman, Quezon City _ **W2-A**	48.2369
Diliman, Quezon City _ **QUCI-13A**	61.596
Fairview, Quezon City _ **MM-6**	50.8452
Fairview, Quezon City _ **MM-5**	39.7844
EDSA, Quezon City _ **GM-R7**	37.0339
Libis, Quezon City _ **ML-3**	57.9943
Sto. Rosario Silangan, Pateros _ **GM T-1**	6.2794
Daniel Fajardo, Las Piñas _ **JAP**	3.6538
Bagumbayan, Navotas _ **GM-3FA**	2.7575
Dagat-Dagatan, Navotas _ **1NHA**	3.5335
Baclaran, Pasay _ **GM-13M**	3.5988
Roxas Blvd. & Sen. Gil Puyat Ave. intersection, Pasay _ **GM-11M**	2.4367
Roxas Blvd. & Libertad intersection, Pasay _ **GM-12M**	2.3289
Taft & Libertad intersection,Pasay _ **GM-19M**	3.0277

Appendix 6 – Difference in Elevation between Benchmarks of Old Survey

Appendix 7 – Difference in Elevation between Benchmarks of New Survey (ML-3 Fixed)

Appendix 8 – Difference in Elevation between Benchmarks of New Survey (BM-66 Fixed)

Appendix 9 – Difference in Elevation between Old and New Survey (ML-3 Fixed)

Appendix 10 – Difference in Elevation between Old and New Survey (BM-66 Fixed)