UNIFICATION OF ELEVATION DATUM FOR WATER RESOURCE MANAGEMENT IN A RIVER BASIN

Irwan Syafri
Researcher on Experimental Station for River
ResearchCenter for Water Resources
Ministry of Public Works
Jl. Solo-Kartosuro km7 Pabelan, Surakarta 57101
Phone.: (0271) 719429, Facs.: (0271) 716406
irwansyafrijogja@yahoo.com

Abstract

In the water resource management of a river basin, elevation values used in various calculations, hydraulic analysis, river building planning, flood control, irrigation planning and others must refer to the same elevation datum. The most suitable elevation datum in the water resource management of a river basin is geoid, and the most suitable elevation system is orthometric elevation system. The unification of elevation datum consists of the determination of its point origin, tide observation, and the installation of elevation datum network. The point origin is a permanent peg called peil installed next to the location of sea surface tide observation.Minimum tide observation is 29 days. Elevation datum network is a benchmark, installed systemically along the left and the right sides of the main river, tributary,around the irrigation development area, dam plan location, and others. The calculation of the height difference between benchmarks is conducted using precise levelling method.
Keywords: unification, height, elevation, orthometric, datum, geoid, ellipsoid, origin point.

INTRODUCTION

Based on the Law of the Republic of Indonesia Number 7 of 2004 on Water Resource Management, the water resource management is defined as an attempt to plan, conduct, monitor, and evaluate the implementation of water resource conservation, the empowerment of water resource, and the control of water destructive force. In the article 4 of the Government Regulation of the Republic of Indonesia Number 42 of 2008 on Water Resource Management, it is stated that water resource management is implemented based on the policy of the management of water resource, river basin, and water resource management strategic plan.

River basin is an area unit of water resource management in one or moreCatchment Areasand/or small islands with the width less than or equal with 2,000 km2. The number of river basins in Indonesia based on the Decree of the President of the Republic of Indonesia Number 12 of 2012 on the Establishment of River Basin is 131, consisting of 5 cross-country river basins, 29 cross-province river basins, 29 nationally strategic river basins, 53 cross-regency/municipal area river basins, and 15 regent/municipal river basins.

In the water resource management of a river basin, the elevation values used in various calculation, hydrolic analisys, river building planning, flood control, irrigation planning and others must refer to the same elevation datum.*Datum* is the singular form of latin word *data*, which means things known, or considered, or assumed. Elevation is height of a point on a reference plane. Literally, elevation datum is datum of a reference plane used as basis for height calculation. Generally, there are 2 (two) reference planes used as basis of height calculation, namely geoid and ellipsoid. Geoid is equipotential plane of earth gravitational field coinciding with the mean sea level (MSL). Ellipsoid is an ellipse rotating on its minor axis. Based on the reference plane used, there 2 (two) elevation systems, those are physical elevation system and geometric elevation system,

Physical Elevation System

Physical elevation system is an altitude system using geoid reference plane. The height of H toward geoid is calculated along plumb line which is through the point. The physical elevation is obtained using levelling measurement equipped with gravity measurement.
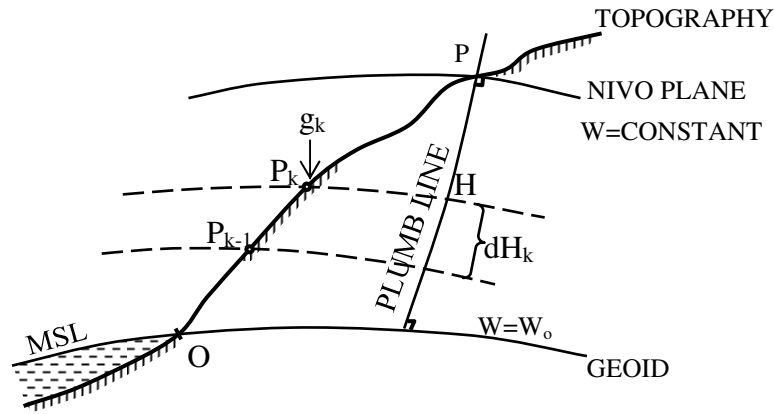
Figure 1 Geopotential number

Potential through point P is W_P and potential through point O is W_O. If point O is a point located on geoid, and point P is a random point on earth, the potential difference of $dW = W_O - W_P$ which is called geopotential number and notated as C, thus:

$$C = W_O - W_P = \int_O^H g \,.dH \qquad \qquad \ldots\ldots\ldots\ldots(1)$$

Since dH and g are continuous functions of a position, the integral of the above equation practically becomes:

$$Cij = \sum_{k=1}^{j} \bar{g}k \,.dH_k \qquad \qquad \ldots\ldots\ldots\ldots(2)$$

where $\bar{g}_k : \tfrac{1}{2}(g_k - 1 + gk)$

in general it can be written as:

$$C = \bar{g}\,.H \quad \text{or}$$

$$H = \frac{C}{\bar{g}} \qquad \qquad \ldots\ldots\ldots\ldots(3)$$

The equation above is the formula for height. Number of geopotetsial C is measured in geopotential unit or g.p.u.

1 g.p.u. = 1 k.gal.meter = 1000 gal.meter

Because g = 0.98 k.gal,   C= 0.98 H

Next, by entering 3 (three) different *g* values in the above equation, it is then known 3 (three) types of physical elevation, namely dynamic height, orthometric height, and normal height.

Dinamic Height

In dynamic height, for the average value of gravity $\bar{g}$, a standard normal gravity value for the corresponding area is taken, which is the closest normal gravity value to the average gravity value of the area. For global dynamic height, normal gravity value on latitude 45 is usually used.

$$H^{din} = \frac{C}{\tau o} \qquad \qquad \ldots\ldots\ldots\ldots(4)$$

For Indonesia:

$$H^{din} = \frac{C}{978,032 \, gal} \qquad \qquad \ldots\ldots\ldots\ldots(5)$$

Dynamic height datum is geoid, but dynamic height is not geometric distance between geoid and the corresponding point.

$l_i \neq l_1 \neq l_2 \neq l_3$, but
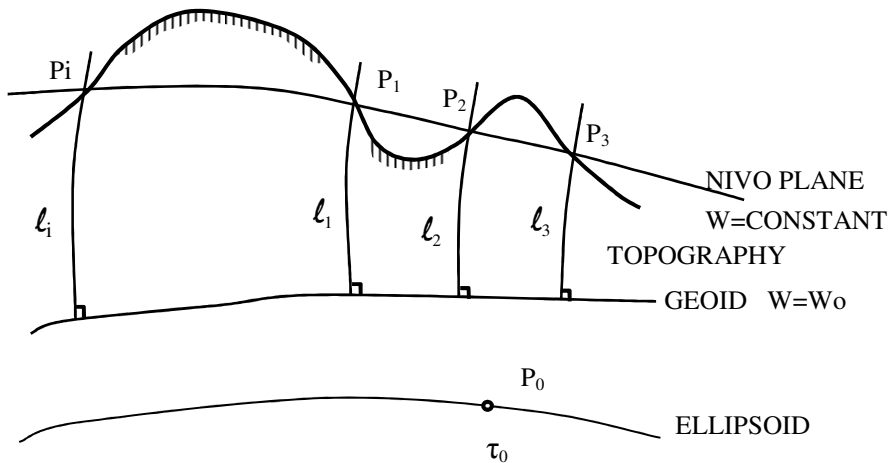$H_i{}^{din} = H_1{}^{din} = H_2{}^{din} = H_3{}^{din}$

Figure 2 Dynamic Height

From the equation above, we can formulate a dynamic height difference between point A and B as follows.

$$H_{AB}^{din} = H_B^{din} - H_A^{din}$$

$$= \frac{1}{\tau_O}(C_B - C_A) = \frac{1}{\tau_O} \int_A^B g \,.\, dn.$$

$$= \frac{1}{\tau_O} \int_A^B (g - \tau_O + \tau_O)\, dn$$

$$= \int_A^B dn + \int_A^B \frac{g - \tau_O}{\tau_O}\, dn$$

$$\delta H_{AB}^{din} = \delta n_{AB} + DC_{AB} \qquad\qquad\qquad \ldots\ldots\ldots\ldots(6)$$

Where DC_{AB} = number of dynamic correction calculated using the formula below.

$$DC_{AB} = \sum_A^B \frac{g - \tau_O}{\tau_O}\, dn \qquad\qquad\qquad \ldots\ldots\ldots\ldots(7)$$

dn is height difference of levelling measurement result.

Orthometric Height
Orthometric height of point (P) is geometric distance measured along plumb line between geoid and the corresponding point (P). This geometric height is the generally reasonable and widely used height.
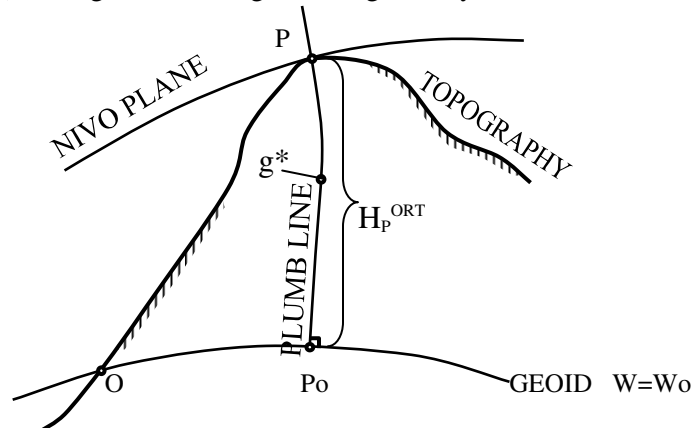

Figure 3 Orthometric height

The formula of orthometric height is:

$$H^{ort.} = \frac{C}{g*} \qquad \qquad \text{............(8)}$$

g* is average gravitational value along plumb line PP$_O$.
According to Helmert the value is:
g*   : g + 0,0424 H

If levelling measurement between two points or more is conducted, height difference *dn* is obtained. To change levelling height difference to orthometric height difference, orthometric correction applies to the result of the levelling measurement.
The orthometric correction is calculated using formula as follows.

$$OC_{AB} = \sum_{A}^{B} \frac{g - \tau_O}{\tau_O} dn + \frac{g_B^* - \tau_O}{\tau_O} H_A \frac{g_A^* - \tau_O}{\tau_O} H_B \qquad \qquad \text{............(9)}$$

If the levelling measurement is conducted in the relatively confined area, where nivo planes are considered parallel to each other, orthometric correction is usually ignored.
From the equation above, it is obvious that to calculate the orthometric correction, gravity data are needed. Therefore, in precise levelling measurement, gravity measurement is also usually done.

If the gravity data are unavailable, orthomethric correction can be calculated using theoretical gravity data with the formula as follows.
OC   : -h (δ Ø)* (0,0053 sin 2 Ø) sin 1"
h   : average height between two points
δØ   : latitude difference between two points, positive if its direction is from equator to pole.
Ø   : average value is used

Normal Height

Normal height is theoretical, so it is never used for practical need. The form is as follows.
$$H^N = C / \tau* \qquad \qquad \text{...........(10)}$$
$\tau*$ is average normal gravity along plumb line which can be measured as follows.
$$\tau* = \tau [1-(1+ f + m -2f \sin^2 \phi) H/a + H^2/a^2] \qquad \qquad \text{...........(11)}$$
$$m = \infty^2 a / \tau_E \qquad \qquad \text{...........(12)}$$

Geometric Elevation System

Geometric elevation system is the altitude system using ellipsoid plane. The height used is *h* height (geodetic height). The height of *h* toward referenced ellipsoid is calculated along normal line n' which is through the point. Geometric elevation is obtained using satellite method, such as GPS. The illustration is shown below.
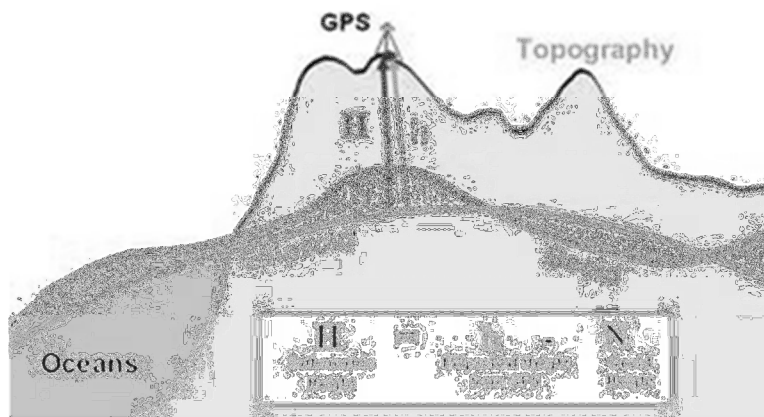

Figure 4 Geometric Height

The unification of elevation datum of river basin is an attempt to disseminate the elevation values toward the same datum to all areas of a river basin in order to be in one elevation system.

DISCUSSION

Elevation Datum of River Basin

Up to now the elevation datum of river basins in Indonesia varies to one another. In table 1 below is the elevation datum of river basins in Java.
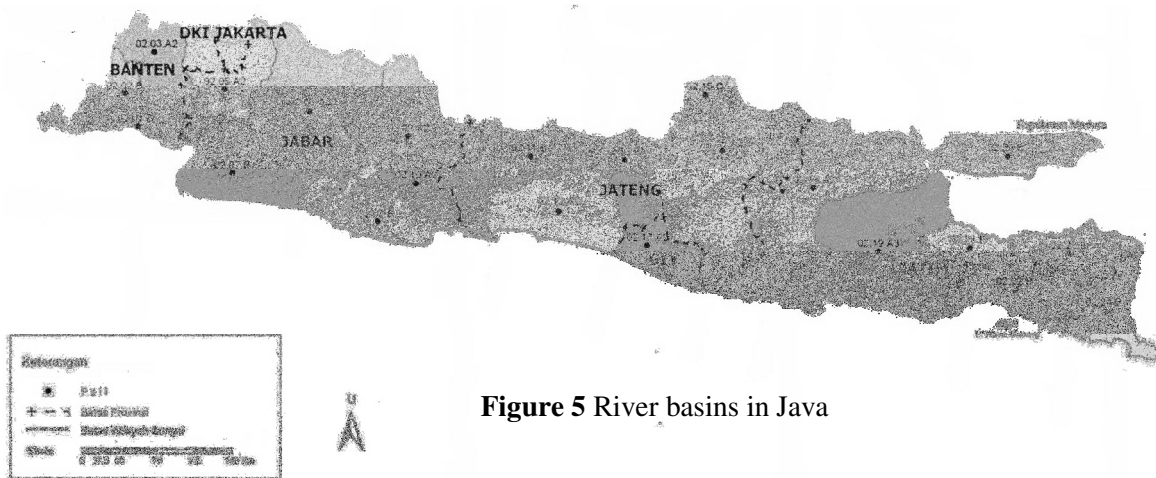

Figure 5 River basins in Java

Table 1. Elevation Datum of River Basins in Java

No	Code	Name of River Basin	Elevation Datum		
			Reference Plane	Datum Origin	
				Name	Location
1	02.01.B	Cibaliung – Cisawarna RB	MSL	Priuk Peil	TanjungPriuk Port
2	02.02.B	Ciliman – Cibungur RB	MSL	Priuk Peil	TanjungPriuk Port
3	02.03.A2	Cidanau – Ciujung – Cidurian RB	MSL	Priuk Peil	TanjungPriuk Port
4	02.04.A2	Kepulauan Seribu RB	Local	Priuk Peil	TanjungPriuk Port
5	02.05.A2	Ciliwung – Cisadane RB	MSL	Priuk Peil	TanjungPriuk Port
6	02.06.A3	Citarum RB	MSL	Priuk Peil	TanjungPriuk Port
7	02.07.B	Cisadea – Cibareno RB	MSL	Cilacap Peil	TanjungIntanP ort
8	02.08.B	Ciwulan – Cilaki RB	MSL	Cilacap Peil	TanjungIntanP ort
9	02.09.A2	Cimanuk – Cisanggarung RB	MSL	Cirebon Peil	CirebonPort
10	02.10.A2	Citanduy RB	MSL	Cilacap Peil	TanjungIntanP ort
11	02.11.B	Pemali – Comal RB	MSL	Semarang Peil Baru (SPB)	TanjungEmas Port
12	02.12.A3	Serayu – Bogowonto RB	MSL	Cilacap Peil	TanjungIntanP ort
13	02.13.B	Bodri – Kuto RB	MSL	Semarang Peil Baru (SPB)	TanjungEmas Port
14	02.14.C	Kepulauan Karimunjawa RB	Local	-	-
15	02.15.C	Wiso – Gelis RB	MSL	Semarang Peil Baru (SPB)	TanjungEmas Port
16	02.16.A3	Jratunseluna RB	MSL	Semarang Peil Baru (SPB)	TanjungEmas Port
17	02.17.A2	Progo – Opak – Serang RB	MSL		
18	02.18.A2	Bengawan Solo RB	MHHW	SHVP	TanjungPerak Port
19	02.19.A3	Brantas RB	MHHW	SHVP	TanjungPerak

					Port
20	02.20.B	Madura – Bawean RB	Local	-	-
21	02.21.B	Welang – Rejoso RB	Local	-	-
22	02.22.B	Bondoyudo – Bedadung RB	Local	-	-
23	02.23.B	Pekalen – Sampean RB	Local	-	-
24	02.24.B	Baru – Bajulmati RB	Local	-	-

Elevation datum of each river basin in Java varies. Some use Mean Sea Level (MSL), some use Mean Higher High Water (MHHW), and some others use local elevation datum. The river basins in Java which use MHHW are Bengawan Solo river basin and Brantas river basin. MHHW used in Bengawan Solo river basin and Brantas river basin is known as Surabaya Haven Vloed Peil (SHVP). Local elevation datum is obtained by determining and agreeing with the elevation value of an area, and the elevation value is then used as a reference of various elevation measurement. However, local elevation datum is not physically or mathematically defined, so it cannot be used as an elevation reference for all river basin areas in question.

There is no elevation datum of river basins in Java using ellipsoid. But, it must be remembered that the height toward ellipsoid (geometric height) obtained using GPS measurement is the height of a point toward the ellipsoid surface. Meanwhile, the ellipsoid surface is not equipotential plane of earth gravity, but just earth model without physical reality. On the other side, water flow is related to earth gravity. As a result, the geometric height cannot be used as the elevation system in water resource management of a river basin.

Unification of Elevation Datum

Water flow is related to earth gravity, and elevation datum which is equipotential plane of earth gravity is geoid. Geoid coincides mean sea level. Consequently, the most suitable elevation system used as elevation system in water resource management of a river basin is orthometric elevation system.

For a river basin using orthometric elevation system, every time the height of the points in the river basin will be measured, it must be started from the mean sea level. However, it will not be efficient. Therefore, the unification of the elevation datum of the corresponding river basin is conducted by disseminating the elevation values toward the mean sea level to all of the river basin areas in order that all of those areas will be in one elevation system and there is an elevation representation toward the mean sea level in all areas of the corresponding river basin. The initial stage which is conducted in the unification of elevation datum of a river basin is determining the Origin Point. Physically, the origin point is in form of permanent peg made of reinforced concrete construction usually called peil. Peil is installed near the sea level tidal observation location. The height of this peil is determined toward the mean sea surface in the area. Mean sea level is obtained by doing sea surface observation for 29 days. Then, a harmony analysis or other analyses are conducted to obtain mean sea level. The peil height toward mean sea level equals the difference of peil height from mean sea level.
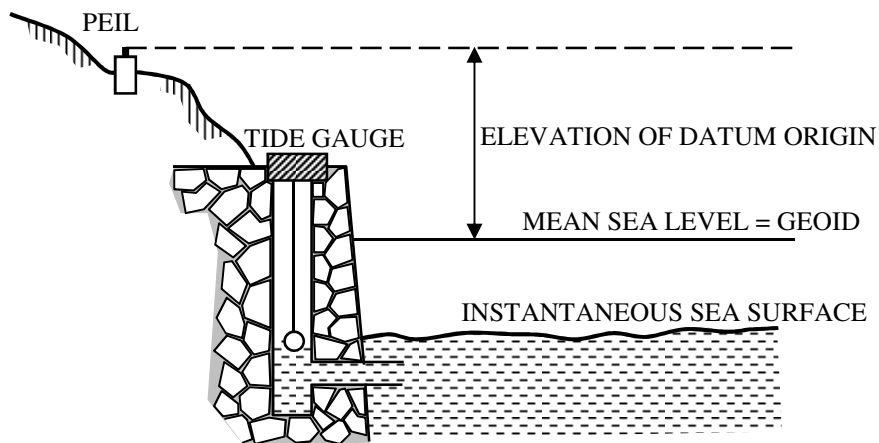

Figure 6. Determination of Peil height toward Mean Sea Level.

To disseminate the elevation values toward the mean sea level to all areas of a river basin, the installation of elevation datum network is performed. The elevation datum network is bench marks (BM). The understanding of BM here is permanent markers with the dimension 20cm x 20cm x 120cm, installed along the left and right sides of main rivers, the left and right sides tributaries, around the irrigation development areas, around the dam plan locations, and other locations. The distance between the installed BMs on the left and right sides of the river is 1 km.

To reduce the distance between bench marks along the left and right sides of a river, the permanent pegs with smaller size of 10cm x 10cm x 120cm are installed. In practice, the smaller pegs are called control point (CP). All BMs and CPs are given numbers systematically. In order that each BM and CP save the elevation value toward the mean sea level, the measurement of height difference toward peil is conducted. The measurement method used is levelling method. In order to find out the height of other points toward the average sea surface, all we need to do is just tie it to the closest BM or CP.

Figure 7 shows the example of the unification of the elevation datum of a river basin, in this case is Bengawan Solo river basin.
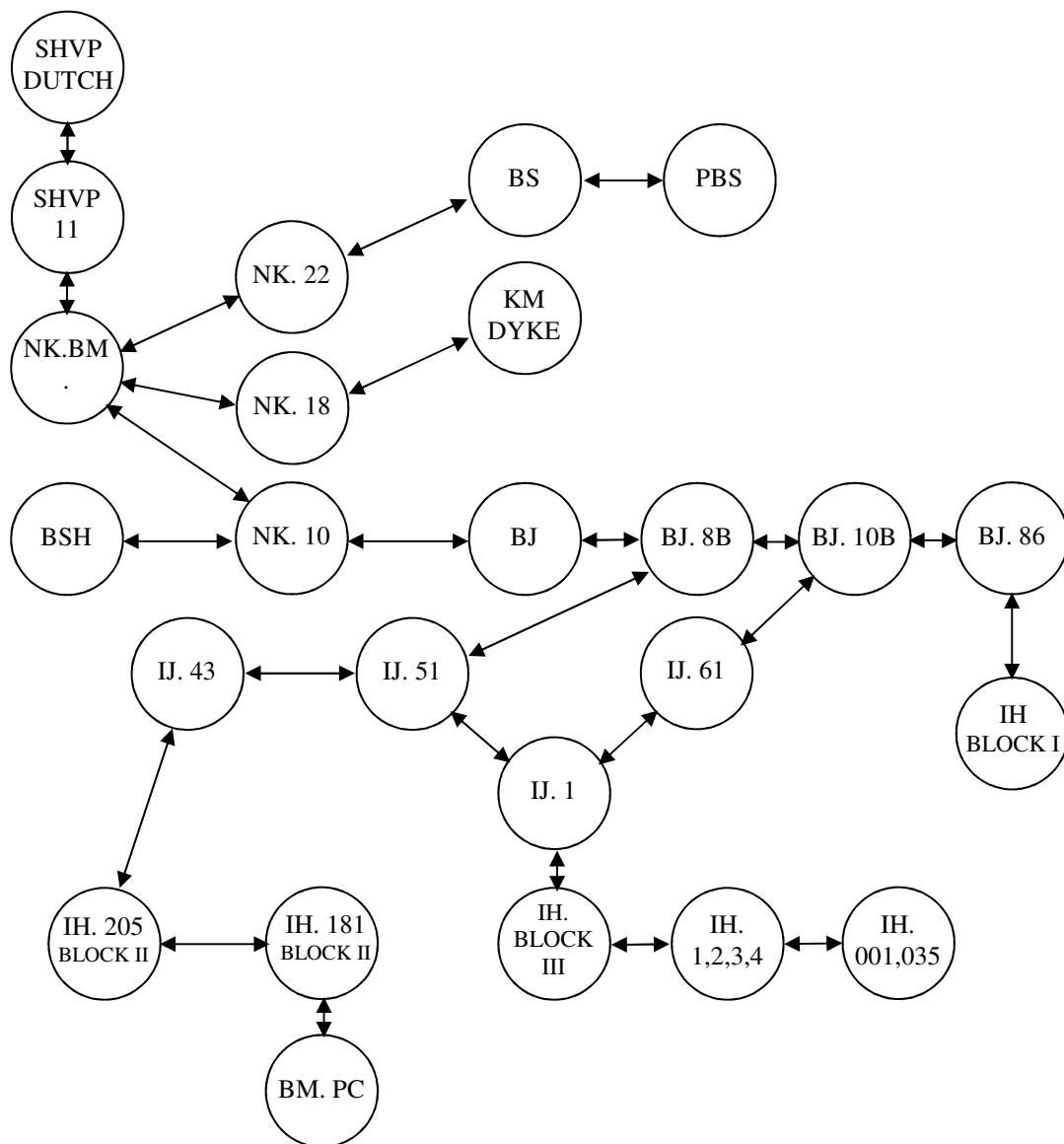

Figure 7 Unification of the elevation datum of Bengawan Solo river basin
(data source: Monenco Company, 1984)

In **Figure 7,** we can see the stages of unification of the elevation datum of Bengawan Solo river basin, especially of lower solo area. SHVP is rob peil installed by dutch at SurabayaPort. SHVP peil refers to the mean higher high water plane. Peil SHVP is then used by Bengawan Solo Project as an origin point of the elevation datum. NK, BJ, IH, IJ, IH, KM, BSH, PBS, BS, PC, PL, SL, KTM, and JR are the names of bench marks installed gradually, and all have elevation values toward mean higher high water level. The unification of elevation datum of Bengawan Solo river basin has been conducted systematically. However, the implementation is not conducted in particular but together with other activities needing planning activity. The unification of the elevation datum of river basin should be well-planned, both in the datum used and BM dissemination location plan. The basis of the BM dissemination location selection is Implementation Planof the water resource management of the corresponding river basin.

CONCLUSION

The unification of elevation datum of river basin is conducted by disseminating the elevation values toward the same datum to all areas of a river basin to build the elevation datum network.

Elevation datum of each river basin in Java varies. Some use mean sea level, some use mean higher high water, and some others use local elevation datum.

Water flow is related to earth gravity, so the most suitable elevation datum in water resource management of a river basin is geoid, and the most suitable elevation system is orthometric elevation system.

The initial stage which is conducted in the unification of elevation datum of a river basin is determining the origin point.

The elevation datum network of river basin is bench marks installed along the left and right sides of main rivers, the left and right sides tributaries, around the irrigation development areas, around the dam plan locations, and other locations.

ACKNOWLEDGEMENT

I would like to extend my gratitude to Experimental Station for River, which has given facilities for me to complete this paper.

REFERENCES

Abidin, H. Z. 1995.*Penentuan Posisi Dengan GPS dan Aplikasinya (1ˢᵗ ed).* Bandung: PT Pradnya Paramita.

Syafri, I., Wuriyati, A. 1996. *Kondisi Datum Ketinggian Wilayah Sungai di Pulau Jawa.* Buletin Pusair No 23 Tahun VI. Bandung.

Minister of Law and Human Rights of the Republic of Indonesia. 2008. *Peraturan Pemerintah Republik Indonesia Nomor 42 Tahun 2008 Tentang Pengelolaan Sumber Daya Air.* State Gazette of the Republic of Indonesia Number 82 of 2008. Jakarta

Monenco Company. 1984. *Vertical Control System Identification.* Lower Solo Project (unpublished).

Soeprapto. 1993.*Pasang Surut Laut dan Chart Datum.* Yogyakarta: Department of Geodetic Engineering of Faculty of EngineeringGadjahMadaUniversity.

Joyosumarto, S. 1991. *Pengantar Geodesi.*Yogyakarta: School of Measurement Expert, Diploma III Program, Survey and Planning Department, PU-UGM.

StateSecretary of the Republic of Indonesia. 2004. *Undang-Undang Republik Indonesia Nomor 7 Tahun 2004 Tentang Sumber Daya Air.*State Gazette of the Republic of Indonesia Number 32 of 2004. Jakarta: State Secretariat.