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## **THE EVOLUTION OF MATHEMATICAL BASES OF POLISH TOPOGRAPHIC MAPS DURING THE RECENT 80 YEARS**

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The beginnings of contemporary Polish topographic cartography are associated with the Military Geographical Institute (WIG) established in July 1919. The first works of the Institute focused on standardising the geodetic base on the whole territory of the country. The independent Polish state came out of the era of partitions with ten legacy coordinate systems based on four reference ellipsoids. The new, uniform coordinate system, known as the “Borowa Gora coordinate system” and the next flat coordinate system in the WIG projection were adopted in 1928.

The political change after World War II at first included all the topographic maps into classified documents, among them maps made before the War. Then, the authorities in 1953 introduced a new coordinate system “1942.” This system was used for the production of military topographic maps not available to civilian users. In 1968, the system “1965”

was introduced for design and business purposes, and in 1980—the “GUGiK-80” system was implemented.

Further evolution in Poland brought about the declassification of the system “1942” in 1990 which was used for the production of some of the civilian topographic maps, and the introduction of the system “1992” intended for the new type of topographic maps made from 1994 on. Since the mid-90s, the Polish Army publishes topographic maps in the NATO standards using the UTM flat coordinate system. This coordinate system is also employed for the production of a civilian 1:50,000 topographic map coming out since 2003.

The multiple changes of the coordinate systems and map types which were frequently introduced during the recent eight decades are responsible for the fact that the resource of contemporary topographic maps in Poland is not homogenous and up-to-date and this, in turn, causes a number of problems when it comes to using those maps.

#### 1. “Borowa Gora” coordinate system

The state coordinate system “Borowa Gora” was introduced in Poland in 1928. This system was used for the production of topographic maps in scales 1:25,000 and 1:100,000.

Bessel’s ellipsoid of 1841 was adopted as a reference surface for this system with the origin at the village of Borowa Gora outside Warsaw.

The quasi-stereographic single-zone projection of the WIG was used in its form modelled on Roussilhe’s projection. This is a conformal double projection which consists on projecting Bessel’s ellipsoid onto a sphere and then onto a plane. The linear scale of 0.9995 was adopted for the projection’s principal point ( $B_0=52^\circ$ ,  $L_0=22^\circ$ ).

A cartesian flat coordinate system was adopted in which axis X covers the image of the central meridian  $L_0=22^\circ$ , and axis Y runs perpendicularly to axis X at the origin. Values  $X_0=500$  km,  $Y_0=600$  km were adopted for the system’s starting point.

#### Map grids:

- graticule—in map sheets made of the sheet’s inner frame complemented by minute frame;
- kilometre grid—in 1:25,000 maps, every 4 cm (=1km), in 1:100,000 maps—every 2 cm (=2 km).

## 2. “1942” coordinate system

The state coordinate system “1942” was introduced in Poland in 1953. Being associated with national defence, this system was classified from its very beginning and used only in military topographic maps, until 1990 when it was declassified. The Military Topographic Service prepared and printed maps using this system until 1997. In the years 1990-1995, “1942” topographic maps were also published in a civilian version in scales 1:10,000 (part of the sheets), 1:50,000 (the other part of the sheets), 1:100,000 (tourist version) and 1:200,000.

Here, the Krasowski ellipsoid was adopted as the reference surface with an origin on the geoid at the Pulkovo suburb of St. Petersburg.

The Gauss-Krüger projection was used, that is, a conformal projection of a spheroid on a plane in narrow, 6-degree meridional zones. Poland’s territory covers three such zones with central meridians 15°, 21° and 27° eastern longitude. These zones overlap with zones 33, 34 and 35 adopted for the division into the 1:1,000,000 International World Map sheets. Every central meridian in the zone projects with no linear distortions. The lines of constant linear distortion are parallel to the images of axial meridians of the individual zones reaching values close to +50 cm/1km at the zone borderlines.

The flat cartesian coordinate system was adopted where each zone has a separate system built on the same principle, that is, axis X covers the image of the central meridian in the zone, and axis Y—covers the image of the equator. At the starting points of each coordinate system (intersection of the zone’s central meridian with the equator) the of the zone, the shift value was adopted as  $X_0=0$  km,  $Y_0=N500$  km where N is the number of the projected zone counted eastwards from Greenwich (in Poland, respectively, 3, 4, and 5).

### Map grids:

- graticule— in map sheets made of the sheet’s inner frame complemented by minute frame;
- kilometre grid—in 1:10,000 maps, the grid lines are found every 10 cm (=1km), in 1:25,000 maps—every 4 cm (=1 km), in maps: 1:50,000, 1:100,000 and 1:200,000—every 2 cm (respectively, 1 km, 2 km and 4 km in the field). Sheets 2°

away from the zone's borderline additionally received extensions of the adjacent zone's kilometre grid at the external frame.

### 3. "1965" coordinate system

Since the state coordinate system "1942" was secret, a "1965" flat coordinate system was adopted for non-military needs. It was used for making topographic maps for economic purposes. After 1970 these were 1:10,000 maps and after 1977—maps in scales 1:25,000 and 1:50,000.

The "1965" system divided the Polish territory into 5 zones: four comprising several provinces each and one comprising the Katowice Province as it was before the 1975 administrative reform. Krasowski ellipsoid was used as the reference area.

Projections: > for zones I, II, III, and IV, a multiple quasi-stereographic projection was adopted. The linear scale at the central point of each zone is equal to 0.9998 (linear distortion -20 cm/1km). The zero linear distortion lines are circles with radius about 178.7 km, that is, almost at the edge of each zone. For zone V, the Gauss-Krüger projection was used with the central meridian in zone  $L_0 = 18^{\circ}57'30''$  and linear scale on that meridian equal to 0.999983 (linear distortion -1.7 cm/1km). This zone has two zero distortion lines parallel to the zone's central meridian and some 35.5 km distant from it, which also places it at the edge of the zone.

Flat cartesian coordinate systems: > every zone has a separate cartesian coordinate system. Axes X of these systems are not directed precisely towards geographical north. Each zone gets a different rotation angle sometimes reaching up to several degrees.

#### Map grids:

> graticule— maps done in the "1965" system had no graticule (images of selected meridians and parallels) which prevents the identification of the actual orientation of the map sheets,

– kilometre grid – in 1:10,000 maps, the grid lines are found every 10 cm (= 1 km), while in the 1:25,000 and 1:50,000 maps—every 4 cm (= 1 km and 2 km, respectively).

#### 4. “GUGiK-80” coordinate system and projection

With the inconvenience of the hardly homogenous “1965” coordinate system for maps in scales smaller than 1:50,000, the Head office of Geodesy and Cartography (GUGiK) in the years 1978-1980 worked out a projection that offered a basis for the introduction of a homogenous cartesian coordinate system for topographic maps in scales 1:100,000, 1:200,000 (this map has never been produced) and 1:500,000. However, the state censorship ordered that the kilometre grid is erased from the “GUGiK-80” maps, hence they are described as maps made in the “GUGiK-80” projection, not “GUGiK-80” coordinate system. A shortcoming of these maps was that they were totally unrelated to topographic maps done in the system “1965.”

The proposed system is uniform for the whole Polish territory. Krasowski ellipsoid was adopted as the reference surface.

The adopted projection named “GUGiK-80,” is a modified multiple quasi-stereographic version of the pre-war WIG projection. The principal point of this projection has geodetic coordinates:  $B_0=52^\circ 10'$  and  $L_0=19^\circ 10'$ . The scale at this point is equal to 0.99971 (linear distortion -29 cm/1km). Zero linear distortion is found on the circle whose radius is about 215 km. Maximum linear distortion—at the south-eastern end of Poland where it is slightly over +70 cm/1km.

Cartesian flat coordinate system: > origin of the adopted system matches with the image of the principal point in the “GUGiK-80” projection, the axis X overlaps with the image of meridian  $19^\circ 10'$ , and axis Y runs ortogonally towards axis X at the projection’s principal point. For the system’s origin, coordinates  $X_0=500$  km,  $Y_0=500$  km were adopted.

Map grids:

– graticule—in 1:100,000 maps, the graticule lines run every 3' longitude and every 2' latitude, while in 1:500,000 maps—every 30'. Maps done with the “GUGiK-80” projection, show a graticule deliberately moved and slightly turned in relation to its actual orientation. The resulting graticule shifts in relation to the picture shown in the map vary, sometimes reaching up to 90 m,

– kilometre grid—maps using the “GUGiK-80” projection have no kilometre grid shown.

#### 5. “1992” coordinate system

Civilian topographic maps of a new type in scales 1:10,000 and 1:50,000 were prepared and published from 1995 to 2002 using a new system of cartesian flat coordinates “1992.” This coordinate system was in 2003 used for the development of a uniform topographic data base.

The “1992” system is uniform all over the Polish territory. GRS 80 (Geodetic Reference system 1980) has been used as its reference surface.

The “1992” system employs the Gauss-Krüger projection in a meridional zone covering the whole area of the country (over  $10^\circ$ ), with the axial meridian  $L_0 = 19^\circ$  E, on which the linear scale is equal to 0.9993 (linear distortion -70 cm/1km). Similar distortions are found at the eastern and western outskirts of Poland. The zero distortion lines run about 240 km away from the axial meridian.

Cartesian flat coordinate system: – the origin of the system is the point at which the image of the axial meridian  $19^\circ$  (axis X) intersects with the image of the equator (axis Y), where this point has the coordinates:  $X_0 = -5300$  km,  $Y_0 = 500$  km.

#### Map grids:

> graticule—in the form of an inner frame of the sheet, complemented by the minute frame,

> kilometre grid—in 1:10,000 maps, the grid lines are found every 10 cm (= 1 km), and every 4 cm (= 2 km).

#### 6. “UTM” coordinate system

In 1994, the Polish Army Topographic Services began to print maps adopted for the NATO standards and, from 1998 on, they make only NATO-standard maps. Contemporary military topographic maps are available in the following scales: 1:25,000, 1:50,000, 1:100,000, while the general topographic maps are available in scales: 1:250,000

(operating map), 1:500,000 and 1:1,000,000. From 2003 on, the 1:50,000 map has been printed in its military and civilian versions.

Here, the WGS-84 ellipsoid was adopted as the reference surface as the 1984 worldwide geodetic system is built on it (WGS-84).

Projection—for maps in scales 1:25,000 to 1:250,000—uses the Universal Transverse Mercator UTM projection with  $6^\circ$ , meridional projection zones. At axial meridians (in the case of Poland:  $15^\circ$  and  $21^\circ$ ) the linear scale is 0.9996 (linear distortion - 40 cm/1 km). The lines of zero linear distortion are found about 180 km away from the axial meridian.

Cartesian coordinate systems: – every zone has a separate but identically constructed coordinate system. The systems' axes are: images of the axial meridians of the zones and the equator image. The point of their intersection stands for the starting points of the coordinate systems with coordinates: N = 0 km, E = 500 km.

Map grids:

- graticule—inner frame in the sheet, complemented with the grid ticks at intervals of 5' (in 1:25,000 and 1:50,000 maps), and every 10' (in 1:100,000 maps),
- kilometre grid—in maps, the intervals between grid lines correspond with the longitude of 1 km (in 1:25,000, 1:50,000 and 1:100,000 maps, they are shown every 4 cm, 2 cm and 1 cm).

## 7. Summary

During the recent 80 years, the mathematical basis of Polish topographic maps of various scales was based on the application of:

- 5 coordinate systems (“Borowa Gora,” “1942,” “1965,” “GUGiK-80,” “1992,” and “UTM”),
- 4 reference surfaces—ellipsoids:
  - Bessel (for maps done with the “Borowa Gora” system),
  - Krasowski (for “1942,” “1965,” and “GUGiK-80” maps),
  - GRS-80 (for “1992” coordinate system maps),

- WGS-84 (for “UTM” maps),
- 3 cartographic projections (in several variants):
  - quasi-stereographic (3 variants: for maps “Borowa Gora,” “GUGiK-80,” and in zones I, II, III, and IV of the “1965” coordinate system),
  - Gauss-Krüger (3 variants: for maps “1992,” “1942,” and zone V of the “1965” coordinate system),
  - Universal Transverse Mercator (for the “UTM” maps).

Frequent changes of the coordinate systems affected maps in various scales, as well as maps in the same scale but coming in various editions, e.g., sheets of the 1:10,000 maps were done in the “1942,” “1965,” and “1992” systems. This is why the existing resource of contemporary topographic maps shows not only a strong diversity but also inconsistency which makes the use of some cartographic materials difficult or quite impossible. Using maps done in various coordinate systems requires their conversion into a common system. Older conversions of map sheets often spoiled the precision of some topographic maps. Today, such conversions are done with computerised tools. The process of building a “1992” Topographic Data Base has been underway for several years now in which vector data are obtained from ortophotomaps. A 1:10,000 map is generated from this TDB. In the recent time, aerial photographs and satellite images were used to update the base VMAP LEVEL2 done in the “UTM” system and used for making 1:50,000 topographic maps in both, military and civilian versions.

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