Status of the UELN/EVRS Data base and Results of the last UELN adjustment

Martina Sacher[1], Tassi Belyashki[2], Gunter Liebsch[3], Johannes Ihde[4]

Abstract

Since the last UELN report in 2002 the United European Levelling Network (UELN) could be extended to South East Europe due to the integration of the Bulgarian network. The first order levelling network of Bulgaria consists of 36 nodal points and 57 measurements between them. The connection to the UELN is realized by 6 levelling lines between the networks of Romania and Bulgaria. The paper provides information about the Bulgarian levelling network as well as some results of the latest UELN adjustment (UELN-95/17).

1. Bulgarian National Levelling Network

1.1. Overview

The Bulgarian National Levelling Network comprises I, II, III and IV order networks. The networks of 1st and 2nd order are being measured with higher precision. They are used for engineering as well as for scientific purposes, e.g. determination of vertical crustal movements, investigations of the sea surface topography, etc.

The establishment of the Bulgarian National Levelling Network started in 1920 and up to now two re-levellings were carried out. (Table 1)

Table 1 Cycles of measurements in Bulgaria

Cycle	Period	Length of lines (km)	Number of loops	Instruments
I	1920 - 1930	4200	18	Carl Zeiss III
II	1953 - 1957 1963 - 1965	3500 5000*	8 18*	Carl Zeiss III and Ni 004
III	1974 - 1984	5630	23	Ni 002

* including the previous measurement (1953-1957)

The datum of the first Levelling Network was defined by the mean sea level of the Black Sea. It was realized using sea level observations of the tide gauge Varna during the period July 1928 - December 1930. The height of the mean sea level at that time was equal to a height of 68.2 cm above the zero point of the tide gauge in Varna.

In 1958 the Unified Precise Levelling Network (UPLN) of the former socialist countries was established. It was based on the datum of the tide gauge Kronstadt in the Baltic Sea. Bulgaria contributed the part of its First order Levelling Network measured in the period 1953-1957 to this East-European network.

In accordance to the UPLN the datum of the national levelling network was changed to the Kronstadt system. The heights of the points were calculated in the system of normal heights.

The measurements for the most recent levelling network (cycle III) were carried out from 1974 to 1984. Both the Bulgarian part of the re-levelling of the UPLN in 1983 and the extension of the UELN are based on these observations.

1.2. Levelling network cycle III (1974-1984)

The network was measured in two stages. In the first stage (1974-1980) five large loops covering the whole territory of the country were measured. These loops and six levelling connections between Bulgaria and Romania were contributed to the 2nd realisation of the UPLN. Those connections were carried out between Vidin (BG) and Calafat (RO), Nikopol and Turnu Magurele, Ruse and Djurdju, Sillistra and Calarash (all those over the Danube River), Cardam and Negru Voda, Duranculak and Vamma Veke. The connecting lines were measured between 1974-1977.

In the second stage (1981 to 1984) new levelling lines were included in those five loops and the levelling network gained its current shape. In the years 1962 and 1963 about 300 fundamental subsurface benchmarks were built as basement for a reliable monumentation of the first and second order levelling network. Additional benchmarks were built in the following years. Nowadays, 330 subsurface benchmarks exist.

[1] Bundesamt für Kartographie und Geodäsie, Außenstelle Leipzig, Karl-Rothe-Str. 10-14, D-04105 Leipzig, Germany;
Tel.: +49 342 5634 423, Fax: +49 341 5634 415; E-mail: martina.sacher@bkg.bund,de
[2] Reasearch Institute in Geodesy and Photogrammetry, 215 „Tsar Boris III" blvd., 1618 Sofia, Bulgaria;
Tel.: 855-0117, E-mail: t_belyashki@yahoo.com
[3] Bundesamt für Kartographie und Geodäsie, Außenstelle Leipzig, Karl-Rothe-Str. 10-14, D-04105 Leipzig, Germany;
Tel.: +49 342 5634 429, Fax: +49 341 5634 415; E-mail: gunter.liebsch@bkg.bund.de
[4] Bundesamt für Kartographie und Geodäsie, Richard –Strauss-Allee 11, 60598 Frankfurt am Main, Germany;
Tel.: +49 69 6333 250, Fax: +49 69 6333 425, E_mail: johannes.ihde@bkg.bund.de

The heights of the benchmarks in the first order National Levelling Network were calculated in normal heights based on the zero level of the tide gauge Kronstadt. The measured height differences were corrected using Bouguer's gravimetric anomalies. The anomalies were extracted from maps with an accuracy of 2 mgal.

Table 2 Parameters of the levelling network cycle III

Loops	23
Levelling lines	55
Length of the levelling lines	5630 km
Average loop perimeter	360 km
Average levelling line length	102 km
Nodal points	33
Levelling points	4530
Loops measuring interval Minimal Maximal Average	 1 yrs 9 yrs 5 yrs
Average epoch of the Levelling Network	1979
Accuracy of the Levelling Network (for 1 km double measured distance)	
Mean error (m)	±0.40 mm
Mean accidental error (η)	±0.38 mm
Mean systematic error (σ)	0.09 mm
Mean error after adjustment of the Network	±1.21 mm
Mean overall line error (M) $M = \pm\sqrt{\eta^2 L + \sigma^2 L^2}$	±9.67 mm

The Levelling Network was adjusted without constraints based on the fundamental subsurface benchmark No28 close to Varna.
This benchmark was chosen because:

- it was built in 1932 after special investigation of the stability of the region. The stability of the benchmark was monitored by repeated levellings. These levellings confirm the high stability of the benchmark.
- the values of its height obtained from the two adjustments of the Unified Precise Levelling Network (1958 and 1983) differ only by 2 mm.

Table 2 summarizes some characteristic parameters of the levelling network, the measurements as well as the adjustment.

1.3. Tide gauge observations for determination of the National Levelling Network datum

Four tide gauges on the Bulgarian Black Sea coast are used for geodetic applications. They are located in Varna, Bourgas, Akhtopol and Irakli. The tide gauges in the towns of Varna and Bourgas have been operated since 1928. Observations of the tide gauge Varna were used to realize the levelling datum of the first National Levelling network (cycle I). The tide gauge in Varna is situated in the harbour area. The instrument is manufactured by "A.Ott" GmbH, Germany. The charts register the sea level variations in a scale of 1:5 and are changed once a week. The tide pole is rigidly attached at the stilling well beneath the recording drum. The recordings of the tide gauge and the tide pole are checked with respect to their equality. The zero point of the tide pole represents the datum of the observations.

The daily mean value is extracted from the daily record of the sea level, using the whole continuous tidal profile. The high and low levels are registered every day together with the relevant times. The monthly mean and the annual mean levels are calculated too. Missing observations from one tide gauge are reconstructed after the method of comparison of the recordings to those of neighbouring tide gauge stations. This is applicable because all of them are located in a coastal area with similar hydro-meteorological conditions.

Because of tectonic and technogenic reasons the tide gauge site in Varna is influenced by considerable local subsidences. Therefore, special levelling loops were observed in order to monitor the magnitude of this subsidence with respect to more stable areas. The levelling loop between the tide pole, the tide gauge bench mark and a benchmark of the national levelling network on the wall of a stable building in the centre of Varna has a length of 7 km and is observed every year. The observations verify a continuous subsidence of the tide gauge benchmark with respect to the reference benchmark.

A second larger levelling loop (length 28 km) connects the tide gauge and the reference benchmark with the fundamental subsurface benchmark No 28. This point is situated out of the zone where active vertical movements are observed. Till 1983 this loop has been measured every year. Now it is measured once in ten years. In this way a full chronological overview of the stability of the tide gauge installation with respect to the datum point of the Bulgarian levelling network is obtained. Altogether, the tide pole has sunk by 0.544 m since 1928. The trend of the velocity is about -8.2 mm/year (see Figure 1).

The influence of this local subsidence on the sea level record can be seen in Figure 2. The original tide gauge observations of Varna show an apparent rise of the sea level of 9.8 mm/year. After the correction of the measurements the trend of the records is considreably smaller (1.5 mm/year).

Altogether, the mean sea level in Varna has risen by about 10 cm since the datum realization of the first Bulgarian levelling network between 1928-1930.
The tide gauge in Bourgas is comparable to the one in Varna considering its location, operational style, instrument, surveillance, data processing, and geodynamical parameters. The sinking value of the tide staff is twice as less as that in Varna.

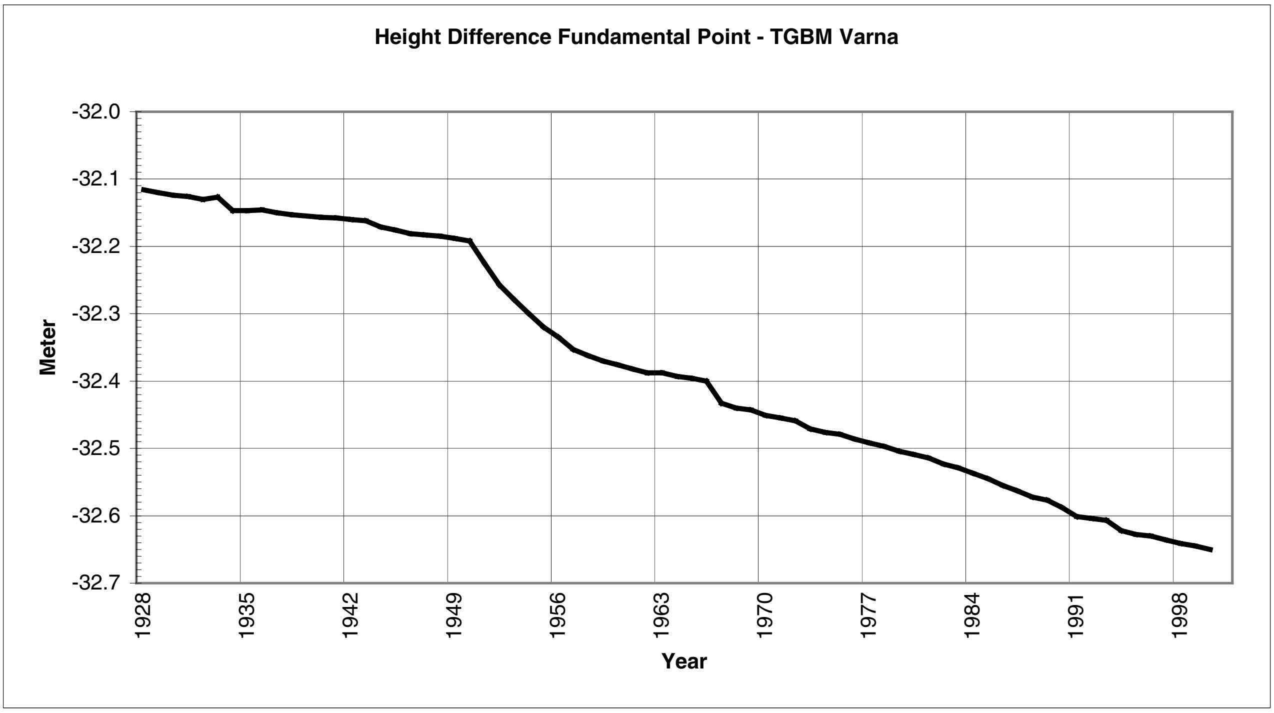


Figure 1 Subsidence of the tide gauge benchmark in Varna

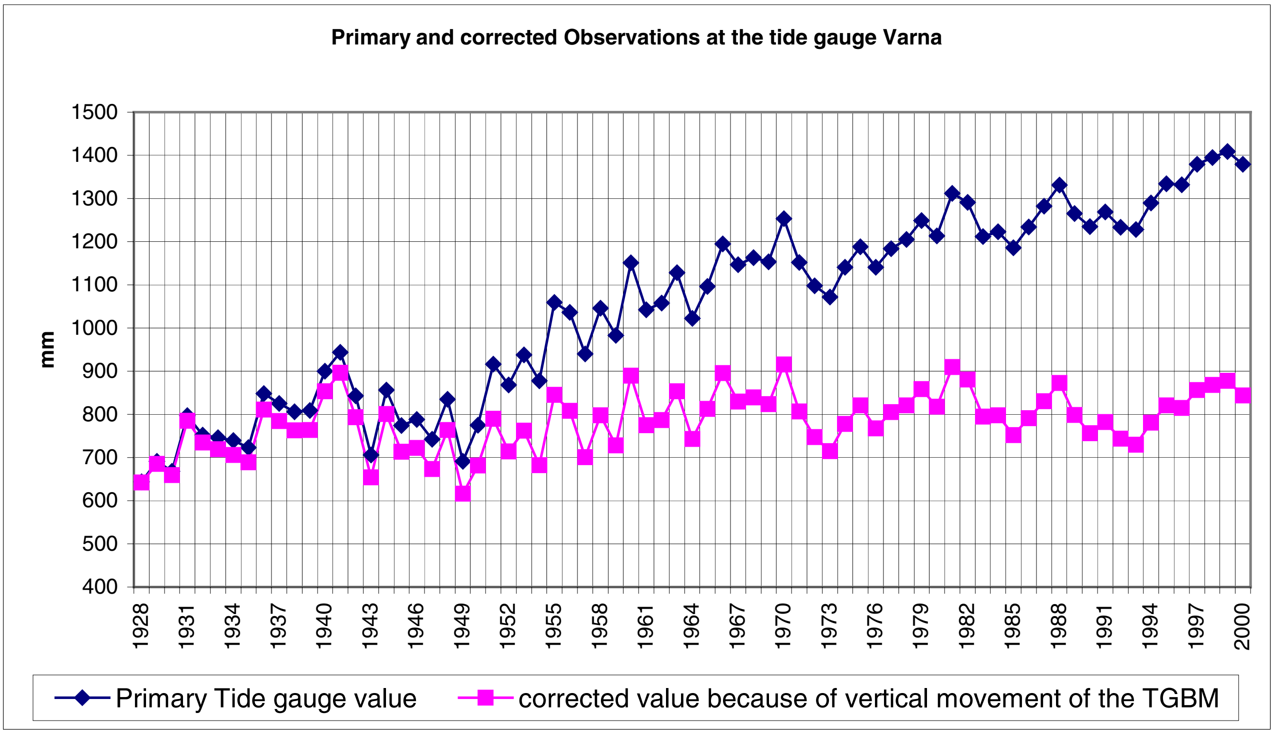


Figure 2: Primary observations at the tide gauge Varna and corrected values because of the subsidence of the TGBM

The other two tide gauges in the town of Akhtopol and in the locality Irakli came into operation in 1970. The first one is situated directly in the sea, between the breakwater and a solid rock. The second one is located on the beach and is connected to the sea by a long pipe inlet. The tide gauge instruments were built in Russia ("SUM" type). The tidal charts are changed every day. The variations of the sea level are recorded on the scale of 1:10.

The sites of these installations are also controlled by high-precision levelling. These regular measurements prove the very good stability of the tide gauge monumentation.

2. Integration of the Bulgarian Network in the UELN

2.1 Adjustment of the Bulgarian network

In order to check the validity of the geopotential number differences a test adjustment of the Bulgarian network was carried out. The adjusted geopotential numbers were compared with the results of the Bulgarian adjustment. The maximum difference of the adjusted geopotential number was 0.4 kgal·mm; the mean of the absolute value of the difference was 0.1 kgal·mm. These results (Table 3) are in agreement with the results of the Bulgarian adjustment described in the paragraph above.

Table 3 Parameters of the adjustment

Number of fixed points:	1
Number of unknowns:	39
Number of measurements:	62
Degrees of freedom:	149
A-posteriori standard deviation referred to 1 km levelling distance in kgal·mm:	1.19
Mean value of the standard deviation of the adjusted geopotential numbers (≙ heights), in kgal·mm:	13.44
Average redundancy:	0.371

Table 4 Border connections between Bulgaria and Romania [in m] in west-east direction

Connec-tion	nat. height Bulg. [m]	nat. height Rom.[m]	difference [m]
1	31.529	31.696	0.167
2	23.872	24.038	0.166
3	19.184	19.326	0.142
4	14.285	14.394	0.109
5	161.684	161.821	0.137
6	27.221	27.314	0.093

For integrating the Bulgarian network in the UELN 6 connection lines to Romania are available. Table 4 shows the differences between the national height systems of Bulgaria and Romania at the connection point. The difference between both networks changes in the west-east direction from almost 17cm to about 11cm. The easternmost connection shows an extreme value that corresponds with the impermissible misclosure of the loop containing this connection line (see loop E in Table 5). The use of this bordering loop would increase the standard deviation of the adjustment by 0.25kgal·mm. For this reasons the border connection No. 6 (Durankulak) was eliminated from the UELN adjustment.

2.2 Results of the new adjustment version UELN-95/17

The adjustment version UELN-95/17 contains the previous UELN version plus the national first order levelling network of Bulgaria inclusive 5 connection lines to Romania (Figure 3).
Table 6 shows the parameters of the adjustment:

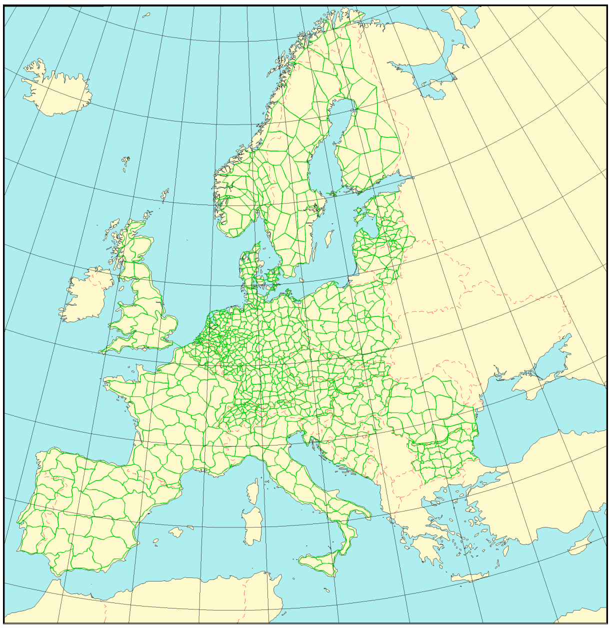
Table 6 Parameters of the UELN adjustment

Number of fixed points:	1
Number of unknowns:	3654
Number of measurements:	5130
Degrees of freedom:	1476
A-posteriori standard deviation referred to 1 km levelling distance in kgal·mm:	1.13
Mean value of the standard deviation of the adjusted geopotential numbers (≙ heights), in kgal·mm:	19.34
Average redundancy:	0.288

Table 5 Misclosures of the bordering loops

Loop	concerned border connections	circumference [km]	permissible misclosure at s_0 =1.2 [kgal·mm]	misclosure [kgal·mm]
A	1, 2	466	50.75	+10.66
B	2, 3	301	40.78	-38.32
C	3, 4	344	43.63	-32.91
D	4, 5	341	43.41	+24.93
E	5, 6	120	25.73	-50.47

The results of the variance component estimation are given in Table 7. The current content of the UELN data base is presented in Table 8 and Figures 3 and 4.



October 2003

Figure 3 Configuration of the UELN-95/17

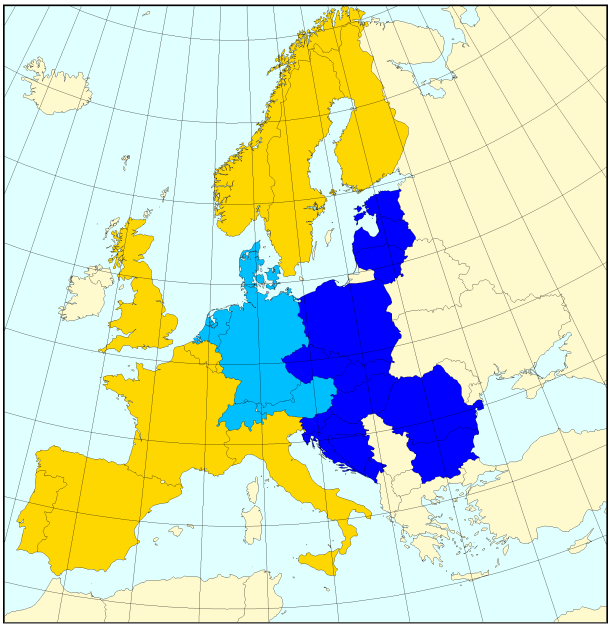


Figure 4 UELN-95/17 Status of the adjustment and enlargement

The mean difference between the adjusted UELN heights and the national heights in Bulgaria is 18 cm (see Figure 5). This vertical translation is caused by the different heigth datums of the UELN and the Bulgarian network (Amsterdam – Kronstadt). Some strains in the border connections to Romania result in a small inclination of the national Bulgarian levelling network in relation to the UELN. The inclination is equivalent to a height change of +1 mm per 100 km difference in the latitude and –2 mm per 100 km difference in the longitude.

Table 7 Results of the UELN-95/17 adjustment

Block	Number of obser-vations	Sum of redun-dancies = [pvv]	a posteriori standard deviation [kgal·mm]
Austria	144	39.065	0.81
Belgium	54	19.484	1.22
Switzerland	387	150.432	1.09
Germany	766	272.987	0.85
Denmark	1038	312.871	0.59
Spain	101	27.235	1.84
France	175	46.293	2.03
Italy	97	32.537	1.75
The Netherlands	935	163.949	1.08
Portugal	22	5.858	1.77
Great Britain	60	15.000	1.72
Norway	194	70.992	1.67
Finland	89	20.142	0.76
Sweden	122	34.865	1.74
Czech Republic	82	27.479	1.07
Hungary	60	13.710	0.51
Poland	221	63.387	0.96
Slovakia	74	18.562	1.42
Bosnia/Herz, Croatia, Slovenia,	79	19.395	0.90
Romania	90	31.486	1.75
Estonia	46	10.377	1.31
Latvia	159	35.559	1.67
Lithuania	72	20.092	0.94
Bulgaria	63	24.243	1.19
	5127	1476.000	

3. Outlook

In several countries of Europe new measurements of the first order levelling networks are going on or have been practically completed. The Scandinavian countries and the Netherlands announced the supply of their new levelling data for 2004. Additionally first discussions about the exchange of levelling data with Russia were conducted on the occasion of the visit of a Russian delegation at the BKG in February 2004. So the closing of the circle around the Baltic Sea in connection with the exchange of the whole old Scandinavian network block seems to be within reach.

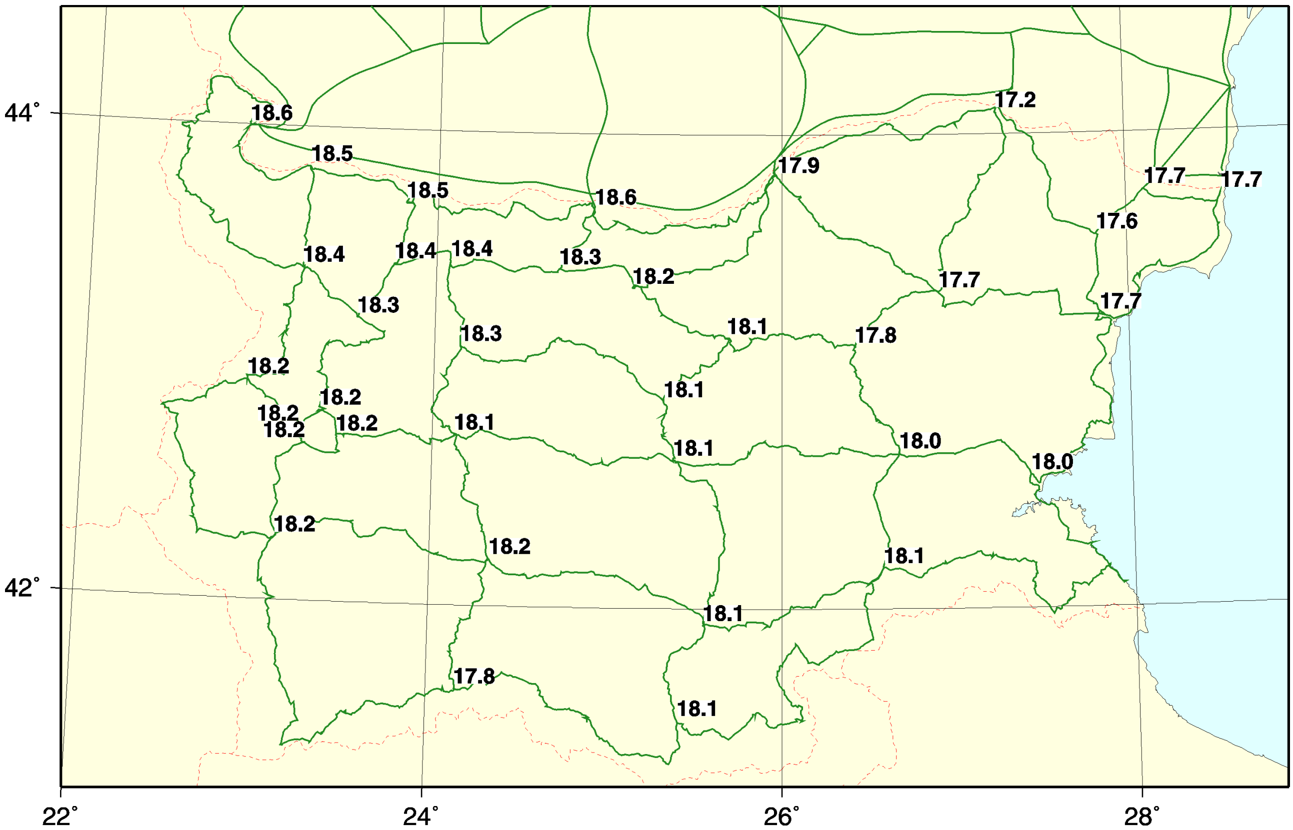


Figure 5 Levelling network of Bulgaria with differences between UELN heights and national heights in cm

Table 8 Contents of the UELN/EVS - Data Base

Country	Number of Nodal Points	Number of Observations	National Heights Available	Whole First Order Network	Epoch of Observation	Epoch of each Meas. known	Year of Input in UELN	Kind of Observations	Further Epochs
Austria	96	145	X	X	1966-1992	X	1995	ΔC	
Belgium	35	54			1969-1975		1980		
Bosnia/Herz. + Croatia	46	64	X	X	1970-1973	X	1998	ΔC, Δh	
Bulgaria	36	62	X	X	1974-1984	X	2003	ΔC, Δh	
Czech Republic	53	82	X	X	1973-1992	X	1995	ΔC, Δh	1939-1959
Denmark	738	1035	X	X	1982-1994	X	1998	ΔC	1885-1905, 1943-1961
Estonia	35	45	X	X	1959-1996	X	1999	ΔC, Δh	
Finland	67	89			1935-1972	X	1980	ΔC	
France	126	1785			1962-1969	X	1980	ΔC	
Germany	498	1508	X	X	1974-1992	X	1995	ΔC, Δh	East 1953-1959 West 1934-1964
Hungary	43	51		X	1975-1978	X	1995	ΔC, Δh	
Italy	64	97			1942-1971	X	1980	ΔC, Δh	
Latvia	126	158	X	X	1968-1988		1999	ΔC, Δh	
Lithuania	46	72	X	X	1933-1998	X	2000	ΔC, Δh	
Netherlands	842	932	X	X	1969-1975	X	1997	ΔC, Δh	1926-1940, 1950-1964, 1986-1996
Norway	120	194			1912-1978	X	1980	ΔC	
Poland	118	217	X		1973-1980		1996	ΔC	
Portugal	15	22			1943-1969	X	1980	ΔC, Δh	
Romania	65	89	X	X	1974-1986	X	1999	ΔC, Δh	
Slovakia	53	74		X	1973-1980		1996	ΔC	
Slovenia	11	15	X	X	1970-1973	X	1996	ΔC	
Spain	79	101			1925-1974	X	1980	ΔC, Δh	
Sweden	92	122			1950-1967		1980	ΔC	
Switzerland	232	380	X	X	1943-2001	X	2002	ΔC, Δh	3 additional epochs
United Kingdom	45	60			1951-1958		1980	ΔC	

4. References

AUGATH, W. (1994): *Proposals for a European Task Force on Vertical Datums within the EUREF-Subcommission.* Presented at the EUREF Symposium, June 8-10,1994, Warsaw. Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung, Heft Nr. 54, S. 171-175, München 1994.

AUGATH, W. (1996): *UELN-2000 - Possibilities, Strategy, Concepts - or: How should we realize a European Vertical System?* Presented at the EUREF Symposium in Ankara, May 22-25, 1996. Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung, Heft Nr. 57, S. 170-174.

BROUWER, F. J. J., DE MIN, E. J. (1994): *On the Definition of a European Vertical Datum.* EUREF Symposium in Warsaw, June 8-10, 1994, Poland. Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung, Heft Nr. 54, S. 176-183, München 1994.

EHRNSPERGER, W., KOK, J. J. (1986): *Status and Results of the 1986 Adjustment of the United European Levelling Network - UELN-73.* Paper contributed to the Symposium on Height Determination and Recent Crustal Movements in Western Europe, Federal Republic of Germany, Sept. 15-19, 1986.

LANG, H., SACHER, M. (1995): *Status and Results of the Adjustment and Enlargement of the United European Levelling Network 1995 (UELN-95).* EUREF Symposium Kirkkonummi, Finland, May 3-6, 1995. Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung, Heft Nr. 56, S. 86-96, München 1995.

LANG, H., SACHER, M. (1996): *Status and Results of the Adjustment and Enlargement of the United European Levelling Network 1995 (UELN-95).* EUREF Symposium Ankara, Turkey, May 22-25, 1996. Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung, Heft Nr. 57, S. 163-169, München 1996.

LANG, H., SACHER, M., SCHOCH, H. (1997): *Status and Results of the Adjustment and Enlargement of the United European Levelling Network 1995 (UELN-95).* EUREF Symposium Sofia, Bulgaria, June 04-07, 1997. Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung, Heft Nr. 58, S. 85-90, München 1997.

MARTI, U., SCHLATTER, A. (2002): *The new Height System in Switzerland.* IAG Proceedings of the Symposium on Vertical Reference Systems, Cartagena, Colombia, Springer-Verlag (in press)

SACHER, M., LANG, H., IHDE, J. (1998): *Status and Results of the Adjustment and Enlargement of the United European Levelling Network 1995 (UELN-95).* Presented at the EUREF-Symposium in Bad Neuenahr-Ahrweiler, 1998.

SACHER, M., IHDE, J., CELMS, A., ELLMANN, A. (1999): *The first UELN stage is achieved, further steps are planned.* Presented at the Symposium of the IAG Subcommission for Europe (EUREF) in Prague, June 2-4, 1999.

SACHER, M., IHDE, J., CORCODEL, S. (2000): *Status of the UELN/EVS Data base and Results of the Last UELN adjustment.* Report on the Symposium of the IAG Subcommission for Europe (EUREF), Tromsø, 22-24 June 2000, Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung, Heft Nr. 61, S. 126-131, München 2000.

SACHER, M., IHDE, J., MARTI, U.,C, SCHLATTER,A. (2003): *Status Report of the UELN/EVS Data base* Report on the Symposium of the IAG Subcommission for Europe (EUREF), Ponta Delgada, 5-8 June 2002, Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 29, S.140-146 Frankfurt am Main 2003

SCHOCH, H. (1995): *Beschreibung des Programmsystems HOENA*. Institut für Angewandte Geodäsie, Leipzig, März 1995 (not published).