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Jacek Florek dr inż. rmflorek@cyf-kr.edu.pl
12 662 4172 [signature]

# AREA-STORAGE CAPACITY CURVE OF HISTORIC ARTIFICIAL WATER RESERVOIR OTTERGRUND, SLOVAKIA – ASSESSMENT OF THE HISTORICAL DATA WITH THE USE OF GIS TOOLS

J. Fuska[1], D. Kubinský[2], K. Weis[3], L. Lackóová[4], J. Pokrývková[1], M. Leitmanová[4], T. Panagopoulos[5]

[1] **Department of Water resources and Environmental Engineering, Slovak University of Agriculture in Nitra, Hospodárska 7, 949 76 Nitra, Slovakia**

[2] **Department of Ecology and Environmental Sciences, Constantine the Philosopher University, Tr. A. Hlinku 1, 949 74, Nitra, Hospodárska 7, 949 76 Nitra, Slovakia**

[3] **Department of Geography and Geology, University of Mathias Bel in Banská Bystrica, Tajovského 40, 974 01 Banská Bystrica**

[4] **Department of Landscape Planning and Land Consolidation, Slovak University of Agriculture in Nitra, Slovakia**

[5] **Research Centre for Spatial and Organizational Dynamics, University of Algarve, Portugal**

**Contact of first author: fuska.jakub@gmail.com**

## ABSTRACT

The main goal of this work was to verify the historic data of historic artificial water reservoir Ottergrund, Banská Štiavnica district, which is inscribed in the UNESCO world heritage list. Main focus was set to area-storage capacity curve, that describe the water surface area and water storage volume at particular elevations of the water level. There is historic map with the display of reservoir bottom contours and area-storage capacity curve in paper format. These data were analysed and compared with the results of the calculation of area-storage capacity curve that was performed with the use of new tool with name "ASC_Curve", which is based on Python script. This tool utilizes arcpy site package and it works with the TIN model of water reservoir bottom. In case of water reservoir Ottergrund we created the TIN model of the historic bottom; input data for the TIN model creation was the historic contour plan. The results of the analysis have shown that the storage capacity calculated with the use of the developed ASC_Curve tool is 97% of the volume mentioned in the historic map. Analysis has also show the minor mathem
data in historic contour plan. This tool can
capacity conditions of the water reservoirs
to obtain the data to produce the TIN mode

obvious info 1

ArcPy explan f.e. arcgisscipting package module 2

Keywords: area-storage capacity curve,

**1 - obvious information, please skip**
**2 - ArcPy explain f. e. "arcgisscripting package module", it would be good to explain what ArcPy is**
**3 - .... can also be used for .....**

**1.OK**
**2. Explained in details at page 5**
**3. OK**

## INTRODUCTION

Erosion processes that occur in the watershed are causing the siltation of water reservoir (Halaj et al., 2013). Changes of the reservoir bottom morphology can be caused also by processes of shoreline erosion (Pelikán and Šlezingr, 2015). Processes of the accumulation of the sediment cause the variety of negative effects; such as loss of the reservoir storage capacity due to siltation and affecting of the biota and ecological water quality (Ahmed and Sanchez 2011, Pradhan et al. 2011, Jurík et al. 2015). However, pollution caused by various human activities is far more dangerous to the environment (Policht-Latawiec et al., 2015) as the sediments are ultimate source of potential chemical and biological pollutants. (Apitz et al., 2005). The processes of the water reservoir siltation causes the annual loss of the reservoir storage capacity of 0.5-1% of the total storage capacity worldwide (White, 2010). This process can lead to the disappearing of the particular lakes (Choiński and Ptak, 2009). Water reservoirs belong to surface waters that are the primary water source (Tárnik, Igaz, 2015) and they are strongly affected (water quality and quantity) by the activities in the reservoir catchment area (Kaletová, Mandalová, Stradiot, 2013).

**x - causes the global .... in the range between 0,5-1% ..**

Analysis of the water reservoir water volume is [illegible] us purposes, such as storage capacity or fish density (Cross and Moore, 20[illegible] e can be calculated with the various different method, such as calculation with [illegible] of the reservoir bottom (Kress et al., 2005), calculation of the storage capacity change can be also performed as the comparison of two raster elevation models (Ceylan et al., 2005).

**OK**

Water storage capacity and water surface area of reservoir is the function of the water level elevation, this function is described by „Area and capacity curve" (U.S. Bureau of Reclamation, 1987) or „Area-storage capacity curve" (Issa et al., 2015) or „Elevation-area and elevation-capacity curves" (U.S. Department of the Interior, 2001), In Slovakia, the name „bathygraphic curve" is used (Jurík et al., 2011). This curve describes the water surface area and amount (volume) of water at the given water level elevation in the form of graph or table.

Water surface area is calculated as the surface of the contour with the examined elevation (planimetry, GIS or CAD solution). Water volume is usually calculated as the sum of partial volumes {Equation 1.} calculated between two contours with the use of the prismatic method as the multiplication of the contour elevation difference and average area of the contours (top and bottom contour of the examined partial water volume) {Equation 2}.

$$V_{n,total} = \sum_{n=1}^{i} V_{n,partial}\,[m^3] \quad \{1.\}$$

$$V_{n,partial} = \frac{S_{n-1} + S_n}{2}\Delta H = S_{average}.\Delta H\,[m^3] \quad \{2.\}$$

where:

$V_{n,total}$ = total water volume at the given water level $[m^3]$

$V_{i,partial}$ = partial volume of the $n-th$ part of water volume $[m^3]$

$S_{i-1}$ = Surface area of the previous contour $[m^2]$

$S_i$ = Surface area of the examined contour $[m^2]$

$\Delta H$ = Elevation difference of the contours $[m]$

**OK**

(Jurík et al., 2011)

## MATERIALS AND METHODS

### Study site

Historic water reservoir Ottergrund is located in the cadaster of Banská Štiavnica town, Slovakia (Figure 1). T OK is enlisted in UNESCO world heritage list as the technical monuments in the mining area "Historic Town of Banská Štiavnica and the Technical Monuments in its x Vicinity". Ix past the reservoir was used as the source of the water for the purposes of mining and as the drinking water supply. Dam crest elevation is 800.5 m above sea level (m ASL) and x it is the water reservoir located at the highest elevation in the Štiavnicke Vrchy area (Hydroconsult, 1991).

x - use one of the form consistently f.e. it's

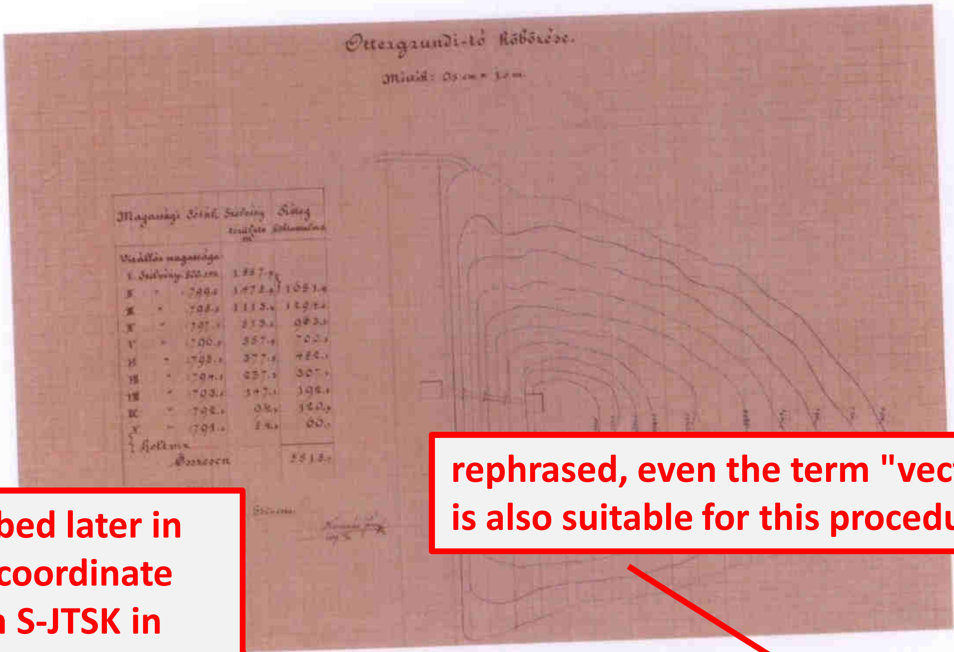

Figure 1 Location of the water reservoir Ottergrund

### Input data

Historic contour map (Fig. 2) and area-storage capacity curve was used as input data for the TIN model creation and further analysis. This map was created in the year 1889 and it is drawn at the milimetre paper (Kamenár, J., 1889).

This is correct name in accordance to UNESCO, see http://whc.unesco.org/en/list/618

„it is“ is in correct form



rephrased, even the term "vectorization" is also suitable for this procedure

Described later in text – coordinate system S-JTSK in Křovák projection was used

…contour map with the area-storage capacity curve in the table format

…storic map

Historic map was scanned with 600 DPI resolution in TIFF format. Afterwards the particular contours with the semi-automatic vectorization [1] in R2V Software (R2V User's Manual, 2008) were vectorized [2] and the elevation from the historic map was added to each contour. Vectorized contour map was registered to the Slovak national coordinate system S-JTSK Křovák East-North, registration of the contour plan was performed in ArcMAP 10.2 with the ortophotomap of the location – ESRI ArcGIS reference cartographic base map and basic topographic map of Slovak republic in scale 1: 10000 from WMS server (www.sazp.sk). Registration was performed with the use of the suitable points that were available to identify at historic map and ortophotomap – position of the outlet structure manipulation building, spillway channel and dam crest.

1 ?
projection
2 ?
vectorized

pilothouse,
control room

In case of water reservoir Ottergrund the historic map also contained the table of the area-storage capacity cur… the ASC table has shown minor … mathematical …rdance to equation (1… …ed from Verification o… …as the input data – … …servoir. contour with … …del was The TIN mo… …oses we afterwards a… …cpy site created the … …manded package for … elevations and storing the data in plain text file for further processing.

rephrased to "building of outlet structure" - this refers to small building on the dam of reservoir, In this building is located the equippment for the manipulation and control of outlet structure.

"ASC_Curve" script is developed to be stored and run from the folder containing the TIN model (or more models). ASC_Curve automatically gathers minimum and maximum elevation from TIN model, path to the folder and name of the analysed TIN model. Afterwards the user can set the boundary elevations (minimum and maximum) and the interval of the water depth division – elevation difference for analysis of the reservoir. ASC_Curve allows the user to set the option of the calculation direction (from the top to the bottom or from bottom to the top). This option is to offer the solving of two main types of its further use:

1. Analysis will be performed for the identical water depths with increasing tendency (from minimal elevation of TIN in direction to the top) – in this case the ASC_Curve can analyse the TIN model and offer the results for the demanded water depths - that means the ASC_Curve will analyse the amount of water in accordance to the water depths (Fig. 4,a)
2. … asing … the … level … ~~s are~~ … area development at the same water level elevations in both time stages (Fig. 4,b)

rephrased to "water volume and water surface area"

*surface covered by water or water capacity

..surface covered by water... or ... water capacity...

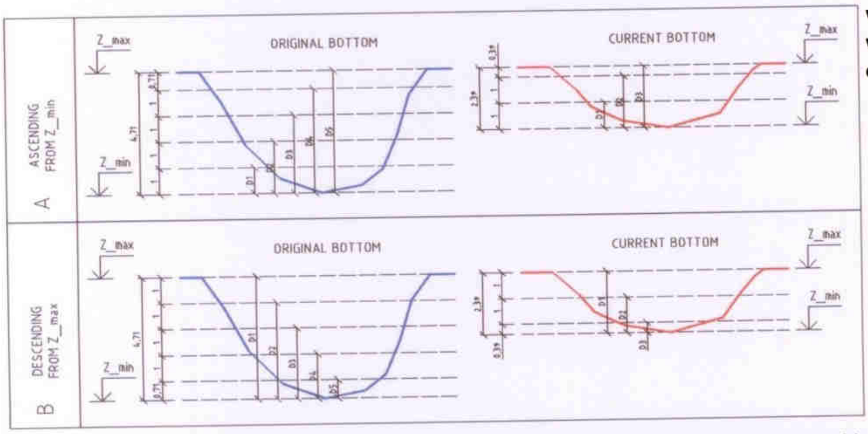



**Figure 4 Direction of the ASC_Curve script calculation: a. from lowest elevation to provide whole numbers of the water depths; b. from highest elevation to provide equal elevation of the water le… …original (historical) and current status of the reservoir bottom**

Number 800.542 is from year 1889 and we cannot find any reason or explanation – the map data has also shown mathematical errors in volume calculations, but the true reason of this value is unclear and it would be only wild guess that we would state here

## RESU…

Historic… …as ten contour… …ontour 792.5 m… …ations, but ther… …e ASC table is… …ailable docume… .

In acco… …s with the ASC… …e of 1

* 42 glitch or setting

possible explanation can be: it's a glitch in the data or an effect of certain setting ...?

meter with the calculation from the highest elevation to lowest. Results were processed in MS Excel in table (Tab. 1) and graph format (Fig. 5).

Result of the ASC_Curve analysis was significantly different from the volume data in the ASC table in historic map (Tab. 2). These differences were also achieved in the surface area data calculation – this led us to conclusion that the georeferencing of historic map raster was added led to the distortion of the raster input – this distortion resulted in deformation of (Fig. 2.) ntours. To eliminate this error we performed the new georeferencing with the different approach. We used the grid of the millimetre paper – 1 cm raster represents 2 m (scale 1:500). We recreated the point grid field with distance of points 2 x 2 m in the ArcMAP 10.2 and the scanned map was georeferenced to these points with the use of millimetre paper grid nodes. Afterwards we shifted and rotated the referenced map to fit the visually identical points at the ortophotomap (dam, buildings at the shoreline). This newly referenced map was afterwards vectorised manually in ArcMAP 10.2. Then the ASC_Curve tool was used again to process the TIN model to obtain the water surface area and water storage capacity (Tab. 1, Tab. 2).

**Table 1 Parameters of bathygraphic curves from historic map and from the analysis of TIN models**

| Water level elevation [m ASL] | Historic data | | | | | Data from TIN model (ortophotomap referenced) | | Data from TIN model (millimeter paper referenced) | |
|---|---|---|---|---|---|---|---|---|---|
| | Water level area [m$^2$] | Volume data from table in map | | Recalculated volume (prismatic method) | | | | | |
| | | Partial volume [m$^3$] | Total volume [m$^3$] | Partial volume [m$^3$] | Total volume [m$^3$] | Water level area [m$^2$] | Total volume [m$^3$] | Water level area [m$^2$] | Total volume [m$^3$] |
| 791.6 | 54.3 | 0 | 0 | 0 | 0 | 41.1 | 0.0 | 48.6 | 0.0 |
| 792.5 | 94.1 | 66.7 | 66.7 | 74.2 | 74.2 | 81.6 | 53.9 | 95.9 | 63.6 |
| 793.5 | 147.7 | 120.9 | 187.6 | 120.9 | 195.1 | 130.6 | 159.3 | 152.6 | 186.9 |
| 794.5 | 237.3 | 192.5 | 380.1 | 192.5 | 387.6 | 202.2 | 324.3 | 237.6 | 380.4 |
| 795.5 | 377.8 | 307.5 | 687.6 | 307.6 | 695.2 | 322.9 | 583.7 | 379.1 | 684.8 |
| 796.5 | 587.9 | 482.8 | 1170.4 | 482.9 | 1178.0 | 502.7 | 992.1 | 591.4 | 1164.2 |
| 797.5 | 813.2 | 700.5 | 1870.9 | 700.6 | 1878.6 | 700.4 | 1591.4 | 822.9 | 1868.4 |
| 798.5 | 1113.4 | 963.3 | 2834.2 | 963.3 | 2841.9 | 953.6 | 2414.9 | 1121.3 | 2836.4 |
| 799.5 | 1475.9 | 1294.6 | 4128.8 | 1294.7 | 4136.5 | 1256.8 | 3515.8 | 1480.6 | 4131.8 |
| 800.5 | 1887.9 | 1681.9 | 5810.7 | 1681.9 | 5818.4 | 1607.8 | 4949.3 | 1893.8 | 5820.0 |

**Table 2 Comparison of the water volume from historic map and from the analysis of TIN models**

| Water level elevation [m ASL] | Water volume | | | | |
|---|---|---|---|---|---|
| | Original historic data [m$^3$] **Recalculated historic data [m$^3$]** | OPM referenced [m$^3$] | MMP referenced [m$^3$] | OPM referenced | MMP referenced |
| | | | | % of original historic data **% of recalculated historic data** | |
| 791.6 | 0 | 0 | 0 | - | - |

| | 0 | | | - | - |
|---|---|---|---|---|---|
| 792.5 | 66.7 | 53.9 | 63.6 | 80.7 | 95.4 |
| | **74.2** | | | **72.6** | **85.7** |
| 793.5 | 187.6 | 159.3 | 186.9 | 84.9 | 99.6 |
| | **195.1** | | | **81.7** | **95.8** |
| 794.5 | 380.1 | 324.3 | 380.4 | 85.3 | 100.1 |
| | **387.6** | | | **83.7** | **98.1** |
| 795.5 | 687.6 | 583.7 | 684.8 | 84.9 | 99.6 |
| | **695.2** | | | **84.0** | **98.5** |
| 796.5 | 1170.4 | 992.1 | 1164.2 | 84.8 | 99.5 |
| | **1178.0** | | | **84.2** | **98.8** |
| 797.5 | 1870.9 | 1591.4 | 1868.4 | 85.1 | 99.9 |
| | **1878.6** | | | **84.7** | **99.5** |
| 798.5 | 2834.2 | 2414.9 | 2836.4 | 85.2 | 100.1 |
| | **2841.9** | | | **85.0** | **99.8** |
| 799.5 | 4128.8 | 3515.8 | 4131.8 | 85.2 | 100.1 |
| | **4136.5** | | | **85.0** | **99.9** |
| 800.5 | 5810.7 | 4949.3 | 5820.0 | 85.2 | 100.2 |
| | **5818.4** | | | **85.1** | **100.0** |
| Average for all elevations: | | | | 84.6 | 99.4 |
| | | | | **82.9** | **97.4** |
| Note: OPM - orthophotomap; MMP - millimetre paper | | | | | |

**Added map of reservoir bottom in vector format (vectorized contours and TIN model). This article deals only with the comparison of our numerical calculation with the numerical calculation from year 1889 – the differences are significant only in the case of ortophotomap-georeferenced map, which is wrong. Correctly referenced map (map referenced to the points in grid 2m x 2m) shows quitesufficient and similar results of our fashion of calculation with the use of our ArcPy script**

**It would be helpfull to provide a current map (digital) for the described reservoir bacuse the oroginal map (Fig. 2.) and general map is not giving a much chance to recognize differencies in the hights. Allso spatial distribution of the capacity changes would then be perceived.**

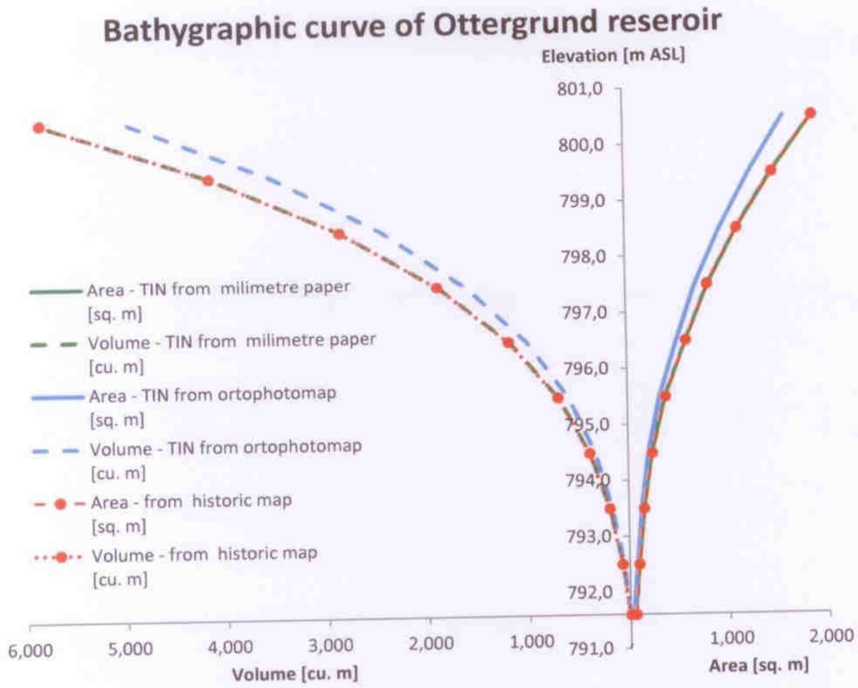



**Figure 5 Area-storage capacity curves of the water reservoir Ottergrund**

In accordance to the results of the analysis of the second referencing we can state that the analysis of the ASC_Curve tool resulted in average to 3 % smaller water volumes compared to the conventional prismatic method of the calculation of the area-storage capacity. This result makes the newly developed ASC_Curve tool available and useful tool for the area-storage capacity curve calculations of the current status. TIN model created from spatially referenced depth-point hydroacoustic surveying can be used for the calculations of the current water volume (Byrnes et al. 2002, USACE 2013, Fuska 2015).

This tool was developed by J. Fuska, D. Kubinský and K. Weis and it is free to download at the link http://bit.ly/1Oxbnh, original link is http://www.dkubinsky.sk/blog/veda-a-vyskum/automaticky-vypocet-plochy-a-objemu-vyvoj-nastroja-na-baze-python-skriptu-pre-arcgis.

corrected

This script is available for the use for the experts or public in non-governmental, academic or commercial use, but it is necessary to take in mind that developers do not take any responsibilities for the errors or damages caused by the use of this script. We do not guarantee the functionality and the use of this script is on the own responsibility and risk of the user.

correct this sentence

## CONCLUSION

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Assessment of the water reservoir Ottergrund storage capacity and water surface area performed with this study has shown the multiple aspects of this type of analysis. It is necessary to consider the quality of the input historic data due to possible deformations of historical paper maps (shrinkage) and the quality of the mathematical processing, but there is also the need of the quality of the

*2

read the last page

georeferencing as it may bring the distortion of the input data that will certainly affect the quality of the analysis outputs.

Area-storage capacity curve parameters can be easily calculated from the input TIN model in the ArcMAP 10.2 software with the use of newly developed tool ASC_Curve that was created as the Python script. This tool offers the fast and easy way of the area-storage capacity curve parameters calculation in comparison to the conventional prismatic method of the calculation – in case of the analysis of the Ottergrund water reservoir the ASC_Curve analysis calculated the water storage capacity only 3 % smaller than water storage capacity calculated with conventional prismatic method calculation.

Area-storage capacity curve can be used for the assessment of the historic data, but there is large potential mainly in the field of regular or current assessment of the storage capacity of the particular water reservoirs. Current research of water reservoirs worldwide is based on the use of echosounding equipment to provide digital elevation models such as the TIN model of the current reservoir bottom. With the use of the developed ASC_Curve tool there can be easily calculated and compared the development of the storage capacity and water volume for the purposes of irrigation, fish production and drinking or industrial water supply. As the morphology of the water reservoir is strongly affected by siltation with the material eroded and transported from the reservoir watershed, this tool can answer the question of the total amount of the material eroded and transported with the surface runoff to the water reservoir.

OK

**... the decelopment ot the storage capacity and water volume can be easily calculated for the purpose of irrigation.**

## ACKNOWLEDGEMENT


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- APVV-15-0562: Effective irrigation management as a device of changing climate
- APVV SK-PT-2015-0005: Establishing new scientific and research networking in the field of water reservoir storage capacity monitoring addressing the issue of climate change
- VEGA 1/0456/14: Management of the Soil Moisture Regime as a Tool for Climate Change Adaptation
- VEGA 2/0050/14: The impact of biological soil crust and microtopography on infiltration and flow of water in sandy soil


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reference changed to "www.sazp.sk. Basic topographic maps 1:10000. WMS server. http://nipi.sazp.sk/arcgis/services/podklady/zbgis10r/MapServer/WMSServer/?" to match the text at page 4


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this is missing

- U.S. Bureau of Reclamation, 1987 ?

*1,2
If the maps were provided those so called differencies as mentioned "orientation" and "shrinkage" could be explained to the reader.
I think those details are interesting.

this is missing

- Hydroconsult, 1981 ?

Added as this document is noted at page 2

NR – not referenced in the paper

OK

NR - means this is not referenced in the paper.

* 1,2
If the maps (current digital versions as explaind earlier in the text) were provided those so called differencies as mentioned "orientation" and "shrinkage" could be explained to the reader.
I think those details are interesting. (.. and it would ad to the value of this paper)

*1,2
Added mention about the physical shrinkage caused by temperature or air humidity during the longer time as the map is more than 100 years old