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BALTICA Volume 19 Number 2 December 2006 : 58-63

# Mapping of Quaternary groundwater in Latvia – a review of different approaches

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Delina, A., Seglinš, V., 2006. Mapping of Quaternary groundwater in Latvia – a review of different approaches. Baltica, Vol. 19 (2), 58–63. Vilnius. ISSN 0067-3064.

**Abstract** The last decade's hydrogeological studies produce a number of highly specialised maps and data sets and nowadays this process is speeded up by introduction of modern computer technologies. There are numbers of cartographic exercises addressed to Quaternary groundwater, but they do not reflect the current knowledge. It is proposed to present complicated hydrogeological data for society in schematic map of hydrogeological districts of Latvia and groundwater usage potential.

***Keywords*** *Quaternary groundwater, major ions, mapping, hydrogeology, Latvia.*

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## INTRODUCTION

Investigations of Quaternary groundwater are carried out in Latvia more than hundred years. There have been different scope of investigations, but the main are natural composition of groundwater, groundwater flow systems, their interaction with surface waters and aquifer properties (Delina 2005). One way to present results of these investigations was compilation of different maps and graphs, which differed significantly in the initial parameters, mapped parameters and level of complicity. Initially these were just the maps showing groundwater flow directions and content of major ions at some sites. Later number of specific and complex hydrogeological maps was compiled, but the initial data set used for compilation of five or more maps did not differ much and this can't be recognised as successful development. Introduction of computer techniques and Geographic Information System (GIS) provides easy way for mapping of various parameters or their combinations. However, content, aim and the usage of the mapped data should be evaluated carefully. The aim of the study was to analyse and assess mapping exercises of the previous years, focusing on the mapped parameters, legend and complicity of the map.

## MATERIAL AND METHODS

The subject of the study is Quaternary groundwater: mapping and data presentation of hydrogeological parameters of Quaternary groundwater in regional investigations. The study focused on analysis of published and archive Quaternary hydrogeological maps, as well as on investigations of Quaternary groundwater in the region, mainly in Latvia. Number of groundwater vulnerability maps, maps showing natural composition of Quaternary groundwater and different hydrogeological maps showing various areas of the Baltic Sea region, North–West of Russia and other regions of the World, compiled during the last fifty years (Arhangelskiy 1966; Dzens–Litovskiy 1967; Kondratas 1969, 1979; Grigelis 1982; Paczyński 1993; British Geological Survey 1994; USGS 2000), were reviewed and analysed. The analysis focused on the studied groundwater parameters, methods used for the compilation of the maps, legends applied and generalisation of the results in both, specific and complex hydrogeological maps.

The historical hydrogeological maps tend to be very simple, showing that studied and mapped parameters are quite similar, with little differences. Content of major ions in Quaternary groundwater in Latvia was studied in details with simultaneous *in situ* measurements of groundwater pH and electric conductivity

(EC) values so that level of difference of these parameters could be identified. Verification of mapping results on other parameters, e.g. groundwater level, hydraulic conductivity, flow directions in plan and section, is needed and it is foreseen to be the next step of this study.

## HYDROGEOLOGICAL MAPS

Any type of graphical presentation, e.g. a map, is traditional and obvious way to demonstrate data of various professional groundwater investigations that was mostly performed in the hydrogeological maps. Conventional set of these maps included general map illustrating deposits and sediments containing Quaternary groundwater, water table and groundwater flow systems, as well as supplementary maps and illustrations showing recharge conditions, hydraulic conductivity of the sediments, depth of water table etc. The quality of the maps mainly depended on scale and the reliability of initial data, but the experience of the hydrogeologist had great importance as well. On the other hand, the weakness like history of data set, presentation manner and prevailing concepts should be mentioned.

The major set of hydrogeological data had been obtained more than twenty years ago during geological and hydrogeological mapping. Nowadays limited number of detailed hydrogeological investigations is carried out and most current work is based on aquifer properties determined long time ago. Separate groundwater studies carried out today applying modern investigation methods and technologies show (see Levins & Gosk 2004) that historic data were reliable and representative and might be used in routine hydrogeological calculations. On the other hand, the methods used in previous investigations do not provide enough information for current needs increasing by new legislative environment and basic conditions of scientific based studies. Some of these cons can be identified as: only larger aquifers were studied in details and several minor aquifers were studied as one complex. Currently only dynamic parameters could be calculated based on these historic data, but it is problematic to perform the mass transport calculations in correspondence to certain conditions.

### Quaternary groundwater vulnerability maps

Compilation of complex maps was another way to present hydrogeological information. There was particular methodology for each map, but the main tendencies was that number of hydrogeological as well as geological or hydrological parameters were combined and mapped as one or few complex parameters. One of the examples of complex maps is the map of Quaternary groundwater vulnerability.

At the end of 1990s map of relative vulnerability was compiled (Delina 2004). This map was the result of the overlay of several maps that demonstrated distribution of values for most important factors influencing groundwater vulnerability: map of Quaternary deposits, map of nature areas, map of groundwater recharge and map of thickness of unsaturated zone. The resulting map (Fig. 1) shows spatial distribution of areas of different vulnerability classes and is easy to use for spatial planning needs. The disadvantages of this vulnerability map are bound to the initial data maps. Most of the maps used in the overlay are generalised: distribution of mapped parameter is obtained interpolating and extrapolating data in limited number of observation points. The only exception is the Quaternary map, which is based on detailed field investigations and a lot of data and which has the greatest impact on distribution of vulnerability classes.

Therefore already presented groundwater vulnerability map has limited added value and current methodology of compilation of groundwater vulnerability map is suitable just for a regional scale 1:1,000,000 and larger to be applied for National Development planning, general infrastructure planning etc. From our point of view no improvements can be achieved if the existing initial data are replaced by newer data and only limited upgrading is proposed. The methodology

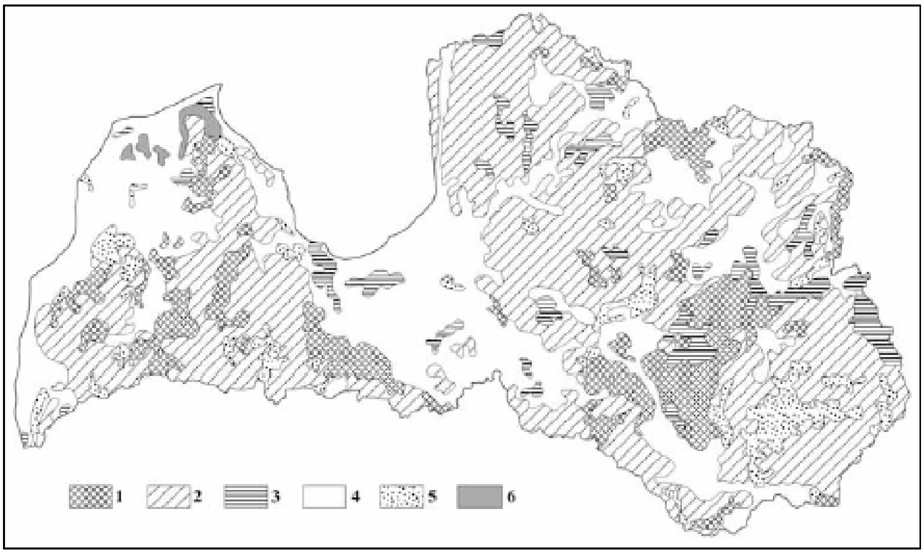


Fig. 1. Natural vulnerability of Quaternary groundwater (Delina 2004). Vulnerability classes: 1 – very low, 2 – low, 3 – intermediate, 4 – high, 5 – very high; 6 – outcrops of Pre-Quaternary deposits (Devonian).

of the modern vulnerability map as well as for maps used as overlays should be changed significantly.

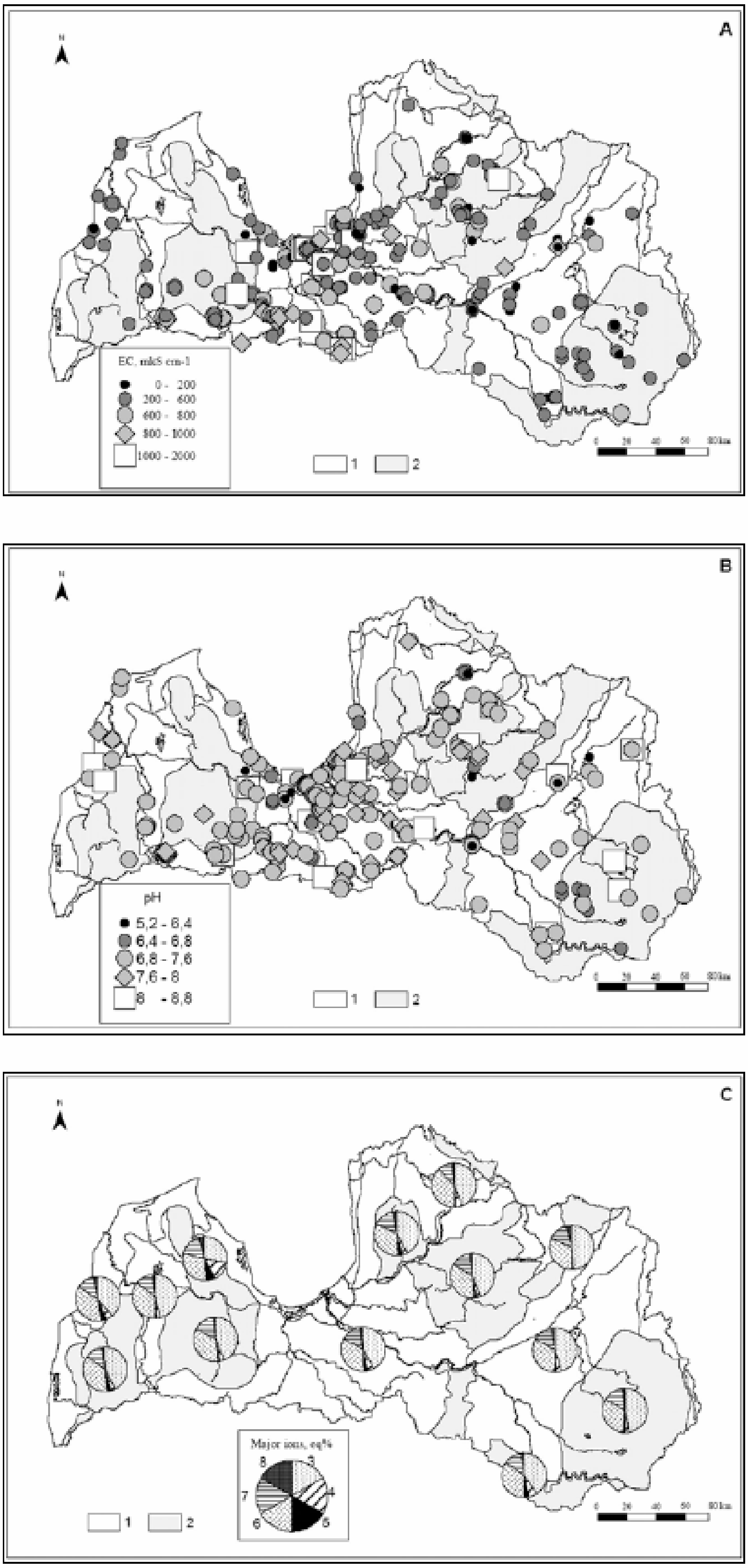


Fig. 2. Natural composition of Quaternary groundwater: A – electrical conductivity, B – pH values, C – major ions within nature areas. 1 – lowlands, 2 – highlands, 3 – bicarbonates ($HCO_3$), 4 – sulphates ($SO_4$), 5 – chlorides (Cl), 6 – calcium (Ca), 7 – magnesium (Mg), 8 – sodium and potassium (Na+K).

**Natural composition of Quaternary groundwater – major ions**

Natural composition of Quaternary groundwater is characterised as fresh water with dominance of bicarbonate calcium magnesium ions, amount of total dissolved solids is 0.3–0.5 g/l (Dzilna 1970; Delina 2006). The detailed study of groundwater pH and EC in situ and major ions composition in laboratory, and analysis of the results shows that there is no significant difference in distribution of pH, EC and major ions (Fig. 2) values in Latvia. These data demonstrates that dominating pH values are 6.8–7.6 and dominating EC values are 200–600 µS $cm^{-1}$, but there are no consequences or contrasts in distribution of the data. The characteristic distribution of major ions within the nature areas (Fig. 2C) is similar in all Latvia with no contrast to be successfully demonstrated on maps. This proves that simple visualisation methods of natural composition of groundwater in Latvia conditions used before could not provide different results.

In Latvia case there is no new knowledge available that could be obtained further analysing major ions in groundwater, their distribution and relations to each other. Detailed analysis of major ions of Quaternary groundwater (Delina 2006) demonstrates that new data on major ions in groundwater, where modern sampling and laboratory analysing methods were applied, are similar to those obtained from proper data in earlier investigations during previous 30–40 years.

The new knowledge on natural composition of Quaternary groundwater from recent, still on–going studies (Levins & Gosk 2004) lies in the analysis of minor ions and trace elements in groundwater. But the analysis of minor ions and trace elements should be applied on the local scale, as direct regional interpretation of the data will not be correct from the methodology point of view (Appelo & Postma 2005). Great amount of fact data should be obtained and analysed locally before regional analysis could be done and therefore, current priority should be addressed to groundwater flow systems and their interaction with surface water and confined aquifers.

## DISCUSSION

Recent interpretation and presentation of hydrogeological data is problematic because existing data and maps are growing old, there are no common requirements and methodology for map development as it was before and the alternation of generation of hydrogeologists is going on in Latvia as well as in other Baltic States making new product development more complicate in the future, and it should be taken into account. The users of hydrogeological information might be divided into two groups – professionals and map makers with good knowledge on groundwater systems and hydrogeological issues, and society as end users with limited knowledge on groundwater and overall perception of maps. Assuming different requirements of professionals and society to the groundwater maps, the most viable solution might be if separate maps are prepared for those groups of users.

Information on natural composition of groundwater traditionally was shown by the prevailing anion(-s). But the current investigations and earlier studies point out that there are no substantial differences in the distribution of major ions in Quaternary groundwater, and further studies on distribution of major ions will not add knowledge on natural composition of groundwater. The latest investigations of I. Levins and E. Gosk (2004) on minor ions and trace elements in shallow groundwater show that number of new information and understanding will be gained in these studies not only on chemical composition of groundwater, but also on groundwater flow systems. Studies of natural composition of groundwater in future should focus on minor ions and trace elements and processes related to them. In that case the *in situ* studies of physical chemical parameters (pH, ORP, EC, DO, t), increasing our knowledge about processes in groundwater, is of great importance (Appelo & Postma 2005).

The detailed understanding of hydrogeological conditions also increases reliability of groundwater vulnerability assessment. The current general maps of intrinsic vulnerability do not fulfil the requirements of the spatial planners and developers, hydrogeologists, environmentalists and other experts for the detailed information on sustainability of groundwater quality. Besides, currently available data in Latvia are not sufficient for more detailed evaluation of groundwater vulnerability. Great example is detailed hydrogeological mapping experience in Denmark. These studies (Thomsen & Sondergaard 2004; Thomsen *et al.* 2004; Jorgensen *et al.* 2005) show that introduction of transient electromagnetic method methods in

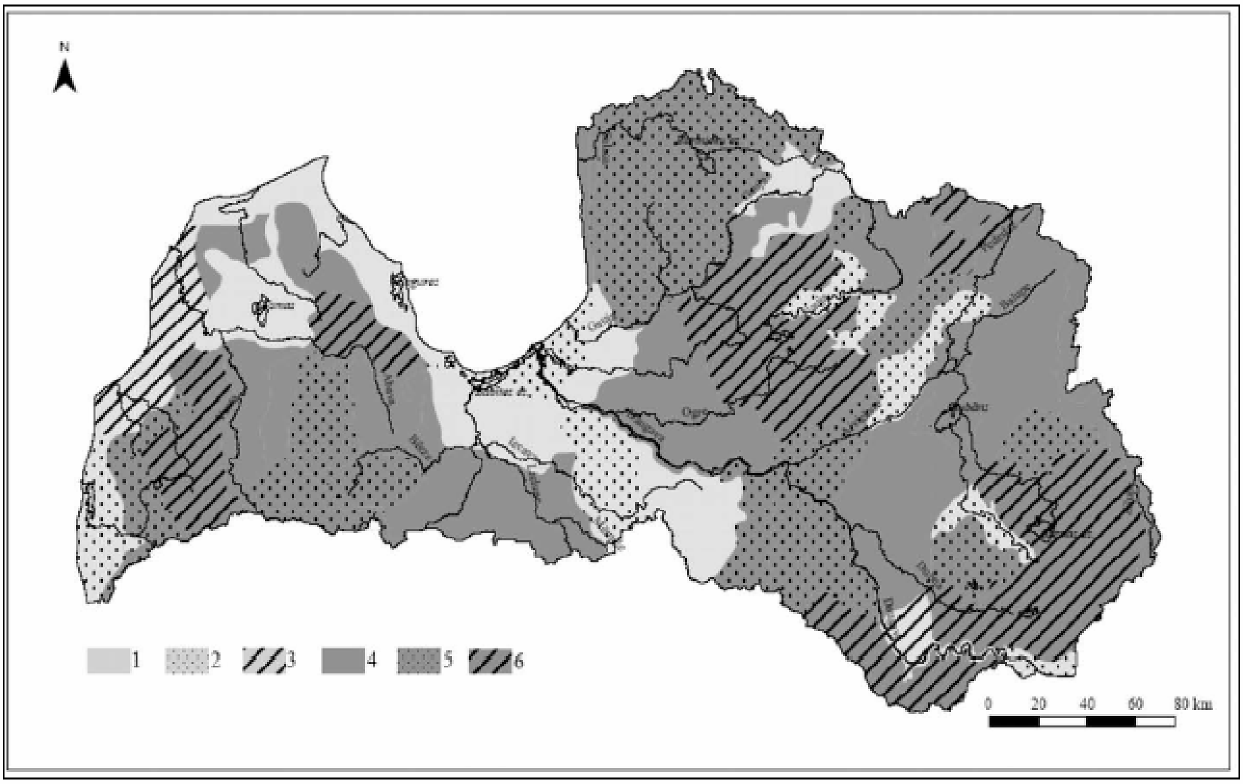


Fig. 3. Hydrogeological districts of Latvia. 1 – areas with continuous water table aquifer and no or very rare interglacial aquifers, 2 - areas with continuous water table aquifer and few interglacial aquifers, 3 - areas with continuous water table aquifer and many sporadic or few continuous interglacial aquifers, 4 - areas with sporadic water table aquifer and no or very rare interglacial aquifers, 5 - areas with sporadic water table aquifer and few interglacial aquifers, 6 - areas with sporadic water table aquifer and many sporadic or few continuous interglacial aquifers.

Table 1. Grouping criteria of Quaternary hydrogeological sections.

| Criteria | Description of the group of sections |
|---|---|
| Distribution of water table aquifer | Continuous water table aquifer. Groundwater is bound to continuous, thick (ca. 10–20 m) layers of sand, sand and gravel and silty sand. |
| | Sporadic water table aquifer. Shallow groundwater is found in local, rather thin (ca. 1–3 m) layers of sand, sand and gravel and silty sand that overlay low permeable sediments or the shallow groundwater is bound to the sand and silt lenses in the upper part of the glacigenic till loam sediments. |
| Distribution of interglacial semi–confined aquifers | Limited distribution of interglacial aquifers; rare, local up to 5–10 m thick water saturated lenses or layers of sand, sand and gravel and silty sand are found in the glacigenic till loam sediments. |
| | Some, local 5–15 m thick interbeddings of sand, sand and gravel and silty sand are found in glacigenic till sediments. |
| | Number of interglacial aquifers, local and continuous; thickness 15-25 m, made of sand, sand and gravel and silty sand sediments. |

detailed hydrogeological mapping also helps to rise groundwater vulnerability issues to the next level, significantly increasing understanding of composition of unsaturated zone and water table aquifer and the water flow systems there.

Observed variations in interpretation of hydrogeological data allowed compilation of many specialised maps, suitable just for professionals or very limited number of users. Combining existing data in different sets might produce some other hydrogeological maps, but they will not increase knowledge on hydrogeological conditions and groundwater systems of the area, as well as will not ease the understanding of the groundwater systems for general public. The same refers to the application of digital methods in groundwater mapping: digital methods applied in basic geological mapping currently in Latvia just rearranges existing data without any added value and can't be recognised as ones to be developed in the future.

The visualisation method would provide main hydrogeological data presented as schemes or schematic maps. An example of the schematisation of complicated hydrogeological conditions might be the map of hydrogeological districts (Fig. 3). Analysis of several thousands of hydrogeological sections lead to the conclusion that six types of hydrogeological sections could be identified (Delina 2006). The criteria for selection of typical sections were distribution of water table aquifer and interglacial semi-confined aquifers (Table 1). Analysing spatial distribution of these typical sections, the map of hydrogeological districts was compiled.

The map schematically indicates areas of different complexity of hydrogeological section and conditions. Based on the information of earlier studies, these typical sections could be bound to the information on available groundwater resources, e.g., larger groundwater resources are found in areas, where continuous water table aquifer and several semi-confined aquifers are distributed.

## CONCLUSIONS

Existing Quaternary hydrogeological maps and data presentation methods are not suitable for modern society as knowledge end-users, and new mapping should be developed by professionals, taking into account that several hydrogeological parameters, e.g., composition of major ions are very similar in whole Quaternary section in the Latvia.

There are several opportunities to develop Quaternary hydrogeological mapping exercises; one of possibilities could be schematic mapping of groundwater usage potential. This map could be compiled overlaying three existing maps: natural composition of groundwater, distribution of typical hydrogeological cross-sections and groundwater vulnerability. The resulting map might be suitable for multi-purpose easy use. The map simultaneously can provide general information on chemical composition of Quaternary groundwater, potential resources and their vulnerability. However, compilation of proposed map is not an easy task, and from our experience it is recommended to develop it step by step in discussions with potential user groups, e.g., teachers, students, farmers etc.

### Acknowledgements

The study is supported by the EU ESF and Latvian Council of Science. The authors are grateful to Professor Algimantas Grigelis for his great editorial help and support, as well as to the reviewers, Professor Algirdas Klimas, Lithuania, and Professor Hans Jürgen Voigt, Germany, for their circumstantial and precious comments, remarks and suggestions.

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