The Hydrological Atlas of Austria – comprehensive transfer of hydrological knowledge and data to engineers, water resources managers and the public

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Abstract The Hydrological Atlas of Austria (HAA) is presented as an effective and efficient tool to provide spatial hydrological information consistently for the whole country to engineers, water resources managers and the public. The information is cartographically communicated on 52 map sheets, with a total of more than 100 thematic maps. The structure of the atlas shows the different components of the hydrological cycle; it has chapters considering water and mass balances, and covers the themes of water management as well as those of water-related environmental issues. Being a dual-mode product, the printed version is accompanied by a digital, GIS-based version on CD-ROM, including convenient viewing software and the data sets in industry-standard GIS formats. Only one year after publication, a wide range of applications is reported, both by administrative institutions and civil engineers.

Key words hydrology; water resources; hydrological atlas; information system; GIS; Austria

INTRODUCTION

Protection and sustainable use of water resources requires comprehensive knowledge of the water cycle components and their spatial and temporal distribution, as well as information about human impacts and water quality. A synopsis of different hydrological topics and water management issues is important for a better assessment of possible developments.

In Austria, a national hydrological service was established as early as in 1893, and therefore extensive information, which has also been processed cartographically, is available for the whole of Austria. To a large extent this information is based on the work of the Central Hydrological Office (HZB), now called the Department of Water Balance, within the Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW). Various maps on the theme of water can also be found in atlases of the individual federal states (provinces) as well as in the Atlas of the Republic of Austria (1961–1977). However, these sources were not co-ordinated, they do not use common base maps, and are not compatible regarding time periods and spatial references. Further important suppliers of data relevant for hydrology are the Central Institute for Meteorology and Geodynamics (ZAMG), which is Austria's national weather service agency, and the Geological Survey of Austria. These institutions not only supply data with different spatial and temporal extent and in different formats, they also follow different policies regarding public and professional access to their data.

Naturally, if access to comprehensive and consistent data is costly or involves major effort, decision makers will often do without information that is not absolutely required, and thus take the risk of making sub-optimal decisions.

The symposium circular of the IHP-UNESCO conference on *The Role of Hydrology in Water Resources Management* raised the question: How can hydrologists promote the compilation and use of integrated sets of data and information in the process of planning and managing hydraulic and water management projects? A possible answer is presented by the *Hydrological Atlas of Austria* (HAA), which is a dual mode cartographic product, i.e. it contains a wide range of spatial hydrological information, both in a high-quality printed edition and in a digital, GIS-based version (BMLFUW, 2007). As such, it relates to the formulation of the question above in a very literal sense:

- It **promotes** appreciation of comprehensive hydrological information amongst a wide professional public.
- The HAA project triggered the **compilation** of consistent, regionalised hydrological information for the whole country.
- Especially through its GIS-based version, which contains fully documented GIS-data sets in an industry-standard format, it supports the **use** of the data to estimate initial parameters of hydrological models, to provide long-term and regional reference information for local modelling results, and more.
- It contains **integrated sets of data and information** which are consistent within a layer and between different layers. The content is presented by more than 50 map themes, which are organised into 10 chapters, ranging from basic information to the elements of the water cycle, water management and environmental issues. An internet link provides one-click-access to the time series database of the Austrian hydrological service directly from the maps.
- The data sets are in a scale and format useful for **planning and managing hydraulic and water management projects**. The scale of the maps is 1:1 000 000, which also determines the density of information and spatial resolution of the GIS data sets. This scale is appropriate for regional hydrological studies and can serve as overview and reference information in a wide range of water management projects.

This paper discusses the technical concept of the HAA, relevant administrative and legal issues as well as its potential to support planning and management of water resources.

Objectives

The *Hydrological Atlas of Austria* focuses on the country as a whole and not on individual hydrological catchments. Access to spatial hydrological knowledge, compiled by observation, analysis and research, should be made easier for a larger public. The *Hydrological Atlas of Austria* (HAA) therefore pursues the following objectives:

- A homogenous presentation of hydrological information and water management issues for the whole country.
- A compilation of hydrological analyses and statistics in order to supply civil engineers, working in hydrology and water management, with base data.
- The provision of the GIS data sets used for the maps, as well as additional information related to the maps, in a digital format. It is expected, that a wider group of users will utilize a uniform, consistent data basis for hydrological investigations and that these investigations will therefore be more efficient and easier to prepare and compare.
- To increase public awareness to the fact that water is a precious resource. Accompanying teaching material supports the use of the HAA in secondary schools and other institutions of further education.

Contents

The structure of the atlas shows the different components of the hydrological cycle, has various chapters considering water and mass balances, and covers the themes of water management as well as those of water-related environmental issues. Each chapter contains 2–11 map themes with detailed explanation sheets in German and in English. A list of the map themes is presented in Table 1. Within a chapter, generally a hierarchy of map themes is present, starting with the monitoring networks, followed by base maps like long-term means and supplemented by more specific topics, like extremes, variability or trends. The basic map scale is 1:1 million and also the GIS data sets in the digital version have a corresponding density of information. Where the map themes refer to long time averages or similar statistical evaluations, the time period spans the years from 1961 to 1990, i.e. the current standard reference period as recommended by the World Meteorological Organisation (WMO).

Table 1 List of chapters and map themes in the HAA.

1 Basic information	5.4 Standardized mean specific flood discharge
1.1 Topographic overview map	5.5 Low flow
1.2 Rivers and lakes	5.6 Water temperature
1.3 Basin divides	5.7 Mean annual depth of runoff using water balance data
1.4 General soil map	5.8 Specific low flow
1.5 Land cover	5.9 Event runoff coefficients
1.6 Mean annual air temperature	5.10 Seasonal trends in runoff
2 Precipitation	**6 Groundwater**
2.1 Precipitation stations	6.1 Groundwater stations – groundwater table and springs
2.2 Mean annual precipitation - Modelled with uncorrected data	6.2 Hydrogeology
2.3 Mean annual areal precipitation using water balance data	6.3 Long-term trends of the groundwater table
2.4 Variability of precipitation	6.4 Mean depth to groundwater table
2.5 Heavy convective storms – precipitation during 15 minutes	6.5 Mean annual fluctuation of the groundwater table
2.6 Heavy convective storms – precipitation during 60 minutes	6.6 Thermal and mineral waters
2.7 Heavy convective storms – precipitation during 180 minutes	**7 Water balance**
2.8 Maximum observed daily precipitation	7.1 Water balance regions, climatic water balance and runoff characteristics
2.9 Duration of dry spells	7.2 Seasonal water balance
2.10 Extreme multi-day precipitation	7.3 Seasonal trends in the water balance
2.11 Seasonal trends in precipitation	**8 Mass balance**
3 Evapotranspiration	8.1 Water quality stations
3.1 Evaporation stations	8.2 Biological water quality of rivers
3.2 Mean annual potential evapotranspiration	8.3 Hydrochemistry according to Piper – Furtak
3.3 Mean annual areal actual evapotranspiration using water balance data	8.4 Areal soil loss by water
4 Snow and glaciers	8.5 Hydrochemical geogenic background values of near-surface groundwater bodies
4.1 Snow observation stations and monitored glaciers	**9 Water management**
4.2 Snow depth and snow cover	9.1 Hydro-electric power plants
4.3 Glacier change in the 20th century	9.2 Waste water emissions into surface water and hazardous sites
5 Rivers and lakes	**10 Water and environment**
5.1 Water level and discharge gauging stations	10.1 River-type-specific stretches – current status
5.2 Drainage density	10.2 Natural characteristics of rivers
5.3 Seasonality of precipitation and runoff	

Implementation

The initiative to develop the *Hydrological Atlas of Austria* (HAA) came from the Austrian Hydrological Society (OEGH) on the occasion of its establishment in 1994. In 1997, and after a number of intensive preliminary discussions, the Department of Water Management, Hydrology and Hydraulic Engineering (IWHW) within the BOKU – University of Natural Resources and Applied Life Sciences, Vienna, drew up a feasibility study on behalf of the Central Hydrological Office (HZB), which acted as the agency responsible for the project and as a representative of the publisher BMLFUW. As a result, prototypes were developed both in a classical printed edition and a digital GIS-based version. Based upon these, the preparation of the HAA began in the summer of the year 2000. The IWHW was responsible for the project management and the co-ordination of the work done by the contracting agency, map authors and the compilers of the cartographic elaboration, which was done at the IWHW in consultation with the Institute of Geography and Regional Planning at the University of Vienna, Austria. The authors of individual maps represent the leading Austrian institutions in the fields of the respective topics. Thus the HAA has become a true collaborative product of Austria's hydrologists, a fact that is an indicator of the high quality of the results and of wide public acceptance. Quality assurance was achieved by a scientific advisory board, which was recruited from all institutions interested and competent in the field of water. The atlas is published by the Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW). This reflects its responsibilities, its main principle of sustainability, as well as its idea of considering itself as being the "Ministry of Life".

THE PRODUCT

The HAA is a collection of thematic maps, consisting of both a classical printed edition and a digital GIS based version.

Printed edition

The printed atlas was conceived as an expandable loose-leaf-style map collection, which has been published in parts. The goal was to present a high-quality cartographic product, conveying hydrological information by meaningful and visually attractive maps. The maps have been designed to facilitate easy interpretation, with detailed and unambiguous legends, and have base topography and hydrography extending well beyond the borders of Austria to provide regional context. Each map is supplemented by detailed text, which clearly and succinctly explains the data and analytical methods used in the preparation of each map, an explanation of the principal characteristics of each map's contents, and descriptions of the problems associated with mapping some of the variables at scales of 1:1 000 000 and 1:2 000 000. Each section's text also cites and lists the relevant literature, enhancing the general reference value of the atlas. Also, in order to address prospective international customers, maps and explanation sheets are written in German and in English. This is particularly important within Europe, because member countries of the European Union need reliable, comparable results of investigations on their water resources, with special emphasis regarding the requirements of the Water Framework Directive.

Digital, GIS-based version

The digital, GIS-based version of the atlas provides a comprehensive collection of hydrological information in a uniform, consistent format for a large group of users and is conveniently available on CD-ROM. It contains data and records which were used for the printed maps and enables further work with GIS, as well as additional texts, tables and graphic information linked with the maps. Specific viewing software guarantees a user-friendly application. The digital HAA is a custom-made GIS viewer that was developed in Visual Basic, using the developer's tools of MapObjects LT2 (ESRI) for displaying maps. Functionality that displays additional information on a spatial object in a map, like showing the recorded time series at a gauge when clicking the gauge on the map ("hotlink" functionality), is implemented in this environment with very little effort.

In these times of data warehouses and WEB-GIS it may seem anachronistic to provide the HAA on CD-ROM. The feedback from the users shows how they appreciate the concept for two reasons: (a) The information contained in the HAA is not rapidly changing and therefore there is no need for continuous updates. The ensurance that (once installed on a personal laptop) all the information is reliably accessible anytime is valued more highly by the users than being right up-to-date. (b) The simplicity and convenience of the usage conditions: The unlimited right to use the data for all purposes (except digital re-distribution) is acquired with the purchase of the HAA.

DATA STRUCTURES

The original concept of the digital HAA was to provide all relevant data sets in a widely useable data format, i.e. in ESRI shape file format, together with a simple viewer without analytical GIS functionality. The files on the CD can be opened using ArcGIS, ArcView or almost any other GIS software without difficulty, so users interested in pursuing GIS applications of the atlas contents should have no problem doing so. Despite use of the industry standard format and extensive metadata associated with each data set, it turned out that users expected retrieval of areal information related to watersheds of varying size, depending on the scale of their current problem. Such complex queries involving analysis of network topology were not within the scope of a simple GIS viewer and even posed difficulties for experienced users of high-end GIS products. It was decided to develop consistent base data sets of the drainage network and watersheds where the hierarchy of stream segments and watersheds is coded into a single attribute that would allow the required hierarchical selections and aggregations with simple attribute-based criteria.

Preparation of input data sets

For the HAA, vector data sets of the stream channels, watershed divides and streamgauges had been prepared, corresponding in spatial detail and accuracy to printed maps on a scale 1:500 000 to 1:1 million. The data set of watershed divides delineates 5420 basins with an average area of about 17 km^2. These layers were carefully edited geometrically to establish correct cross-layer topological relationships. As an example, stream junctions must also be nodes in the watershed divides layer, and streamgauges must be nodes in the streams layer. Each stream segment must have exactly one watershed and *vice versa*. Next, a "hydro network" was created from these layers, using the Arc Hydro framework data model (Maidment, 2002) in ArcGIS and the tools coming with Arc Hydro. This object oriented model establishes a topological network and cross-layer topological relationships between watersheds, streams and junctions. The network topology defines the flow direction, connectivity and upstream/downstream relationships of stream segments.

However, the Arc Hydro framework data model and the tools are based on the ArcGIS Geodatabase (Zeiler, 1999), which is a proprietary format. In order to avoid proprietary data formats in the HAA, a shapefile version was created which maps cross-layer relationships and network topology into the attribute tables of three shapefiles. A "Hydrojunction" shapefile collects all stream junctions (nodes), including streamgauges. The stream segments are held in a "Hydroedge" line shapefile and the watersheds are in the polygon shapefile "Watershed". A unique feature identifier "HYDROID" is used for mapping networks as well as cross-layer relationships (Fürst & Hörhan, 2009).

Hierarchical coding system

So far, the Arc Hydro attributes make it conceptually simple to navigate in the network, but without specific network tools it still needs a procedural approach to identify and select, e.g. all watersheds upstream of a selected junction. Also, the data structures do not yet support recognition of the stream and watershed hierarchy.

A Pfafstetter coding system uniquely identifies each stream segment, captures information on the network topology, and inherently recognizes the stream and basin hierarchy. This coding system was first published in the literature by Verdin & Verdin (1999). The main idea is to use one digit (1 to 9) per level in the hierarchy. Since a stream can usually have more than nine tributaries, only the four tributaries with the largest catchment area are selected at a particular level. They receive even digits (2, 4, 6, 8) and the inter-basins and source stream receive the odd digits. This scheme is applied recursively until all stream segments are coded.

A strict application of the Pfafstetter rules would allow a fully automatic procedure to code a complete basin upstream of a given stream junction. For coding all rivers within Austria's territory, however, several constraints had to be considered. First, Austria drains into three major river basins: the Danube, the Rhine and the Elbe, with the majority (95%) contributing to the Danube basin. This area is less than 10% of the whole catchment area of the Danube. It is therefore important to harmonize a national coding system with existing coding conventions of 20 countries in the Danube basin. This implies that the codes must be able to respect political and administrative borders as well as basin hierarchy. Such an initiative was started by the Cooperation of the Danube countries (Brilly, 2000). The agreement and recommendation was to use the methodology and rules as set up by LAWA (1993) for Germany. For the major sub-basins, high-level codes were assigned by Brilly (2000), considering both harmonization between the Danube countries and consistent mapping of the basin's stream hierarchy. To map stream hierarchy down to an arbitrary level, the high-level pre-assigned codes have to be extended by further digits.

The coding procedure for a sub-basin of the Danube is then generally: (1) Determine the pre-assigned code according to Brilly (2000). (2) Hierarchically assign further digits of the code, following the Pfafstetter rules as modified by LAWA (1993).

A schematic example how to add one level to the code is given in Fig. 2 for the River Enns, a major tributary of the Danube, which has a pre-assigned code of 1194. Its tributary Palten, which is the second (counted from the spring) of the four largest tributaries, is code 11944 and the interbasin between Palten and Salza is 11945. Also note here the major difference to the original Pfafstetter coding: The order of numbering is downstream from the source to the mouth instead of upstream.

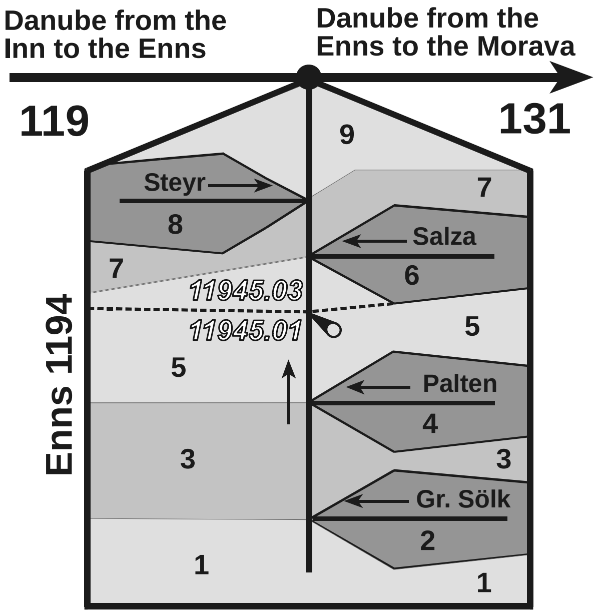

Fig. 1 Application of the modified Pfafstetter code for one level.

For the small shares in the Rhine and Elbe basins, an analogous procedure was applied, although these codes do not claim to be compatible with a possibly already existing coding scheme for these basins.

Since the data sets were prepared to have exactly one watershed per stream segment and *vice versa*, the same code, which is stored in an attribute named “Hydrocode”, is assigned to a watershed and the associated stream segment. The 5242 features in the current data set are identified by hierarchical codes with a maximum length of 10 digits. Refinements to capture more details like in topographic maps of scale 1:50 000 can be added consistently, either for selected watersheds or the whole country, without changing the existing codes.

EXAMPLE APPLICATIONS

Map based presentation of water balance results

A seasonal, spatially-distributed water balance was developed for whole of Austria using a continuous, semi-distributed water balance model (Kling *et al.*, 2005). The results were computed for the watersheds and published in the HAA, both in a series of printed map sheets and in the GIS based version. The spatial distribution of a water balance variable is well demonstrated by contour maps, but often a user wants to know the water balance of a region of interest, which is usually a sub-watershed. This requires selection of the region and then to spatially aggregate the desired variables. The long-term mean water balance elements, depth of precipitation P, evapotranspiration E and runoff depth R, are expected to fulfil the balance equation P = E + R for any selected region. Instead of providing smooth contour maps of these quantities, the water balance results are stored as attributes with the watersheds shapefile. The hierarchical Hydrocode can therefore be used to select the relevant watersheds and it is a simple task to perform an area-weighted aggregation of the water balance figures for the selected region. In the digital HAA, a “hotlink” tool is associated with the water balance layers, which allows selecting the upstream watershed of a point (actually a part of a basin) or streamgauge by simply clicking on it. The region is highlighted on the map display and with another mouse click an evaluation can be displayed (Fig. 2).

With the same concept, also a mean monthly water balance can be evaluated and visualised for any selected region (Fig. 3).

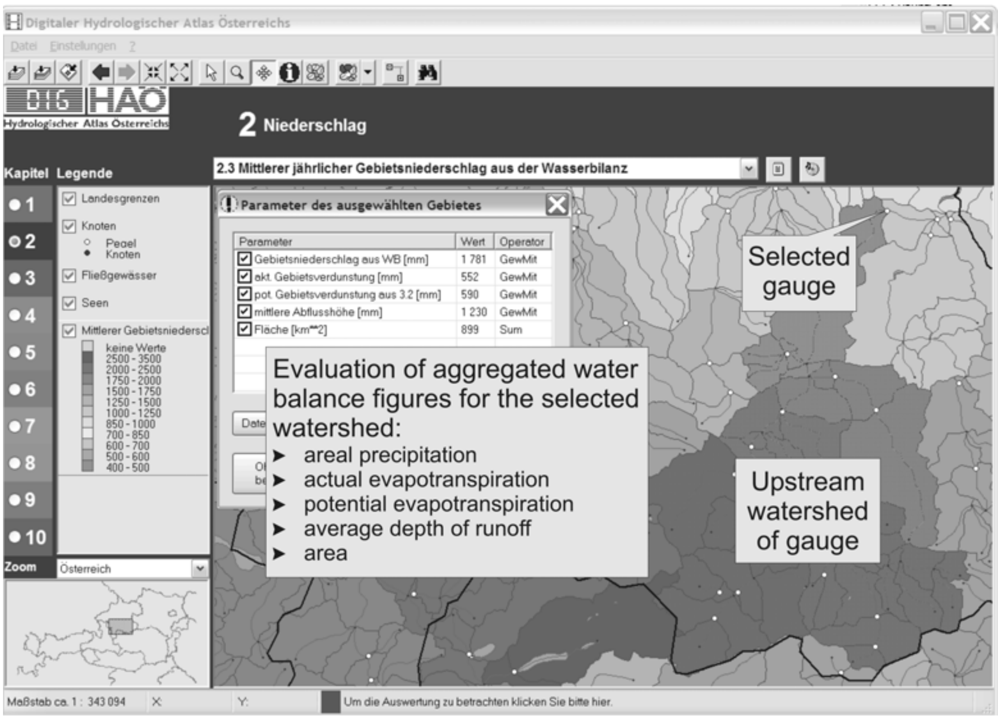

Fig. 2 Aggregating water balance variables for an arbitrary watershed in the digHAO.

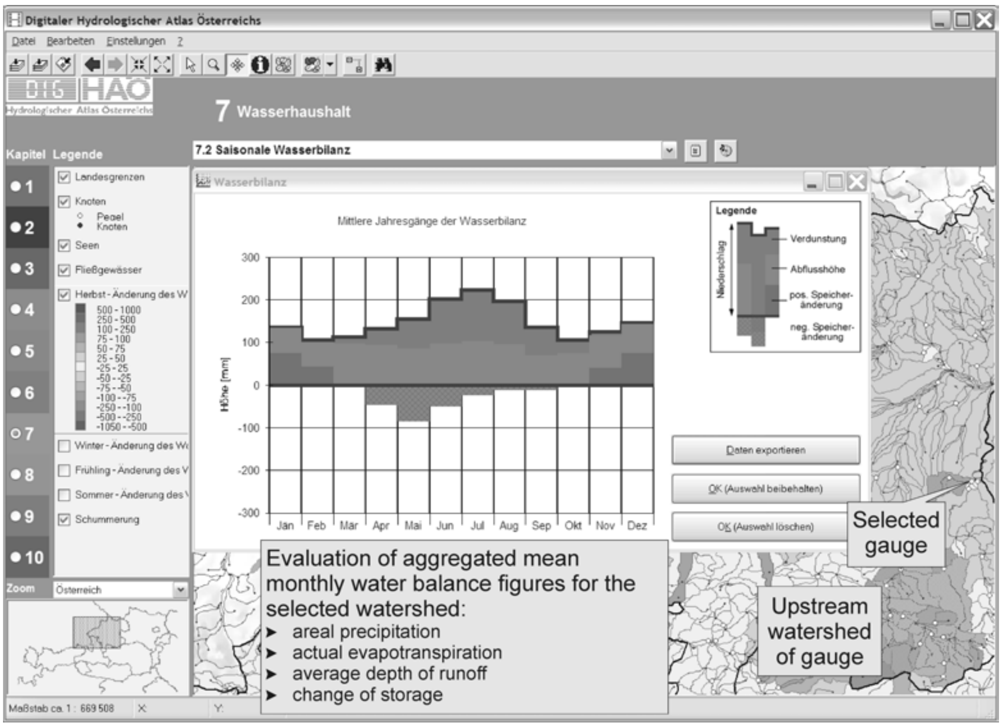

Fig. 3 Visualisation of mean monthly water balance for the River Steyr watershed.

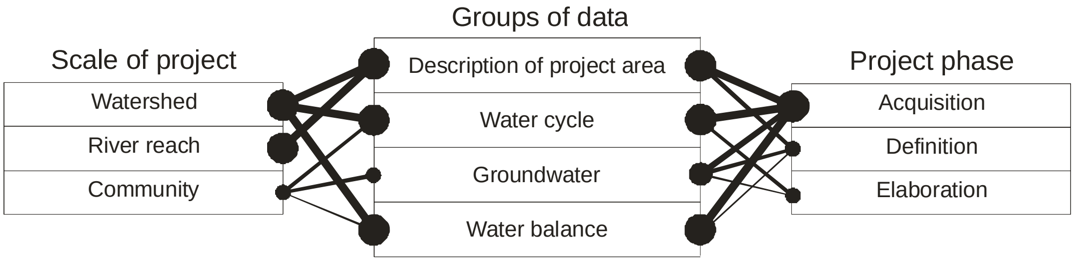

Fig. 4 Relationship between groups of data in the HAA and scale of project and project phase in engineering projects

Applications in water resources administration

The federal water authorities report a variety of tasks that make use of the HAA, including:

– Up-to-date and more consistent maps of the federal hydrographic networks in the Hydrological Yearbook, which is published every year.
– Mean annual reference information satisfying the reporting requirements of the European Water Framework Directive. The report on the current state used the gauge data, long-term mean flow, low flow and mean water balance data from the HAA.
– A reference for the assessment of extreme hydrological events.
– The data sets of the rivers and basin divides were used as an input in a national flood risk assessment.
– The starting point for basic and background information for presentations, publications and calls for tenders.
– Use of HAA evaluations and queries in expertise on design rain depths, water balance inquiries, low flows, runoff coefficients, and others.
– Training of staff.

Applications by civil engineers

Engineering consultants in the field of hydrology and hydraulic engineering report an almost immediate return on investment when using the HAA. The intensity of use depends on the spatial scale of a project and on the project phase (Fig. 4). The larger the spatial extent of a project, the more information can be extracted from the atlas. Considerable benefits are gained from the HAA during acquisition and definition of projects, because the ease of access to a comprehensive set of relevant data facilitates well-founded project formulation and tendering.

SUMMARY AND CONCLUSIONS

The value of the HAA is at least two-fold. As a **project**, it stimulated the country-wide consistent compilation of a wide range of hydrological information, bringing together the competent national experts in hydrology and related fields. An important element is a spatially and seasonally differentiated water balance that is based on and consistent with the relevant basic information in the atlas. As a **product**, this concerted effort resulted in a map-based representation of Austria's hydrology in which consistency is maintained within and between the different maps.

The wealth of information is presented in a dual-mode high quality cartographic product in printed and digital versions. While the maps in the printed version ensure an aesthetically attractive and informative look at the whole country, the digital version supports more detailed, regional-scale analysis. The largest practical value is provided by the convenient availability of the GIS data sets on CD-ROM. Convenience, in this context, refers to the ease of use of industry-standard data sets, as well as to the generous conditions of use, which include unlimited use of all data sets.

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REFERENCES

BMLFUW (ed.) (2007) *Hydrologischer Atlas Österreichs. 3. Lieferung*, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Vienna, Austria.

Brilly, M. (2000) Danube River basin coding. Slovenian IHP Comittee, Ljubljana, Slovenia.

Fürst, J. & Hörhan, T. (2009) Coding of watershed and river hierarchy to support GIS based hydrological analyses at different scales. *Computers & Geosciences* **35**, 688–696.

Kling, H., Nachtnebel, H. P. & Fürst, J. (2005) Karte 7.1: Bilanzierungsgebiete, klimatische Wasserbilanz und Abflussverhältnisse (Map 7.1: Water balance regions, climatic water balance and runoff characteristics). In *Hydrologischer Atlas Österreichs (Hydrological Atlas of Austria)*, 2nd instalment (ed. by BMLFUW). Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Vienna, Austria.

LAWA (1993) *Richtlinie für die Gebietsbezeichnung und die Verschlüsselung von Fließgewässern*, 19 pp. Länderarbeitsgemeinschaft Wasser (LAWA), Düsseldorf, Germany.

Maidment, D. R. (ed.) (2002) *Arc Hydro - GIS for Water Resources*. ESRI Press, Redlands, California, USA.

Verdin, K. L. & Verdin, J. P. (1999) A topological system for delineation and codification of the earth's river basins. *J. Hydrol.* **218**, 1–12.

Zeiler, M. (1999) *Modeling our World. The ESRI Guide to Geodatabase Design*. ESRI Press, Redlands, USA.