E-HypeWeb: Service for Water and Climate Information - and Future Hydrological Collaboration across Europe?

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Abstract. The hydrological scientific and operational communities are faced with new challenges. There is a demand for detailed water information for large regions and new environmental issues to deal with, which request advanced technical infrastructure merged with up-dated hydrological knowledge. Traditionally, the hydrological community is disaggregated. In this paper we suggest a collaborative approach and invite both researchers and operational agencies to participate in the development of a common European core service providing free access to water information. We present the idea of starting from the new E-HYPE model and its advanced technological infrastructure and open source cod, using a bottom-up approach.

Keywords: catchment hydrology,modeling,pan-European,technical infrastructure,open source community,E-HYPE

1 Introduction

Information about water quantity and/or quality is required by any societal sector dealing with natural resources, ecosystem services, or watercourses. Accordingly several European directives deal with water access and status, e.g. the Water Framework Directive, WFD (2000/60/EC) and the Marine Strategy Framework Directve, MSFD (2008/56/EC). Hydrological predictions by numerical models are often used to produce water information and related decision-support for societal safety or production efficiency. The predictions may be used for e.g. early warning services, hydropower regulation, infrastructure planning, agricultural practices, water allocation, shipping guidance, environmental control, or climate change adaption.

Both scientifically and operationally, the water community in Europe is diverse and disaggregated. Traditionally, hydrological model systems have often been site specific for water bodies and catchments, or small enough to be manageable by a single actor. Because of the economic interests in the water business, many commercial companies have developed their own tools for specific assessments and forecasts. Often institutes have specialized on a single model concept for decades [1] giving answers to a few questions. SWAT [2] and HBV [3] are examples of models that are frequently used for specific catchments in Europe, and sometimes also for operational transnational use in large river basins [4]. New challenges, however, have appeared for European water authorities related to new policies for environmental control, climate change adaption and uncertainty analyses. Today's requirements on hydrological models are going in the direction of higher spatial and temporal resolution for larger regions. Developing such tools requires a lot of resources, both when it comes to technical infrastructure, computational power and hydrological knowledge.

Setting up an integrated hydrological modeling and monitoring system is maybe not only a national concern today as information is requested also for pan-European issues and cooperation would reduce costs. This has been recognized since decades among meteorologists and oceanographers, who are sharing both code development and operational systems in the international collaborations of e.g. HIRLAM/ALADIN, MACC, HIROMB, NEMO and MYOCEAN. The experiences show that it is not only beneficial for scientific and technical development, knowledge and data exchange, but it is also economically sound to share the costs of both development and maintenance of these large systems between several partners. These cooperations could serve as blue-prints for the hydrological community, when increasing ambitions to cover the whole European domain and developing a core service for hydrological information.

The most ambitious European collaboration around a common hydrological model code is probably the SHE initiative that started some decades ago, between European institutes in Denmark, UK and France [5]. For transnational analyses, some hydrological models have recently been applied for the pan-European domain, such as VIC [6], WaterGap [7, 8], WASMOD [9] and LISFLOOD [10, 11]. However, none of the mentioned initiatives combines collaborative code development and operational production in common.

In this paper we present and suggest a platform that will enable intensified collaboration among water scientists as well as operational institutes, to provide water information with high resolution for Europe. This will presumably speed up the work with European directives in the European Union, as included model components, databases, simulation platforms, and model results are suggested to be open access for all member states. Such a collaborative core service could also enable a flora of commercial decision support systems appointed to specific needs of end-users.

2 Material and Methods

2.1 The HYPE Model

The Hydrological Predictions for the Environment (HYPE) model is a dynamic, semi-distributed and process-based model based on well-known hydrological and nutrient transport concepts [12]. It can be used for both small and large scale assessments of water resources and water quality.

In the model, landscape is divided into classes according to soil type, vegetation and altitude. The soil representation is stratified and can be divided in up to three layers, each with individual characteristics and hence calculations. The model simulates water flows, transport and turnover of nitrogen, phosphorus and inert trace substances. These substances follow the same pathways as water in the model: surface runoff, macro pore flow, tile drainage and groundwater outflow from the individual soil layers. Rivers and lakes are described separately with routines for turnover of nutrients in each environment. Model coefficients are global, or related to specific characteristics of Hydrological Response Units (HRU), i.e. combinations of soil type and land-use. Internal model components are checked using corresponding observations from different sites [13]. The HYPE model code is structured so that the model can be easily applied with high spatial resolution over large model domains, which is also facilitated by linking coefficients to physical characteristics and by the multi-basin calibration procedure [14].

2.2 The European HYPE Model Set-up (E-HYPE)

So far, the HYPE model has been set up pan-European for water, while nutrients are only modeled for the Baltic Sea basin (Balt-HYPE), se Table 1. The E-HYPE model calculates water balance, hydrological processes (snow, glaciers, soil moisture, flow paths, groundwater contribution, and lake dampening) and final routing to the surrounding sea, i.e. the Atlantic, Mediterranean, Black and Baltic Seas. The model domain covers most of the European continent, from the British Isles to the Ural Mountains, and from Norway to the Mediterranean Sea.

It serves as an operational high-resolution model and production system delivering daily data. This achievement was possible thanks to readily available regional and global databases, which are handled in a specially designed system of methods for automatic generation of model input data, WHIST [15]. The first version was uncalibrated but a second version is currently (spring 2011) being set up and calibrated against observed time-series.

2.3 HYSS

The source code of HYPE is embedded in the HYdrological Simulation System (HYSS, 2.3), which is the infrastructural part of the model source code. HYSS handles the simulation instructions, provides the hydrological model with variables containing data on the model set-up, time and current forcing data (i.e. precipitation and air temperature) and writes the result files. It also provides variables for model state, model parameters and output, which are used and set by the model. In this way, the hydrological algorithms are separated from the model infrastructure in its own module. HYSS can thus be coupled to several different hydrological modules with different model structures and process descriptions. HYSS leaves it to the hydrological process code to define parameters and output variables, and calculate state variables during a time step. Currently, HYSS only handles ASCII-files which are used both for input data and output.

Table 1. Model application set-up and input data.

	Balt-HYPE	E-HYPE1.0[1]
Areal extent	1.8 million km2	9.6 million km2
Med. Sub basin area	325 km2	120 km2
No. Sub-basins	5128	57436
Topography/routing	Hydro1K [17]	Hydrosheds [16],(Hydro1K for latitude $> 60°$
Forcing Data	ERAMESAN 1980-2004 [18], Resolution = 11 km.	ERAMESAN 1980-2004 [18], Resolution = 11 km.
Landcover	Globcover 2000	Globcover 2000
Soil-types	ESDB [19]	ESDB [19]
Runoff data	GRDC[20], BHDC[21]	GRDC EWA[22], BHDC[21]
# calibration stations	35	Not calibrated
# validation stations	121	16 (river mouths only)

[1] Version 2.0 will cover 8.9 million km2, 36 314 sub basins and use Corine land cover [23]

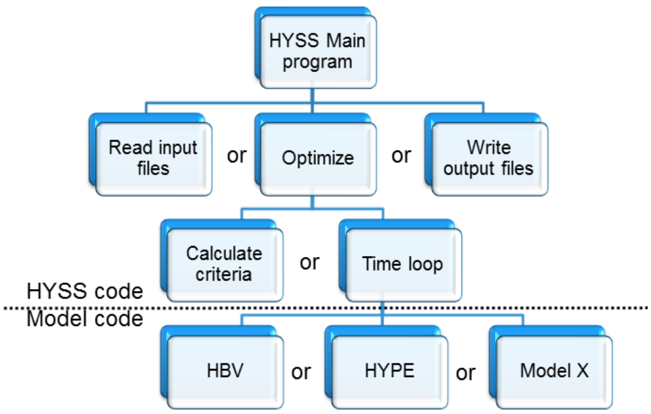

Fig. 1. Schematic picture of HYSS and its linkage to hydrological algorithms

2.4 E-HypeWeb and Balt-HypeWeb

E-HypeWeb is a publically available web service with open access where you can easily download daily and monthly simulations of discharge (m3/s) for one or several sub basins in Europe or river outlet to the sea. Data for download can be chosen by either specifying a sub basin ID or selecting areas from a map. Balt-HYPE is restricted to river outlets but also includes data of nutrient transport to the sea.

E-HypeWeb allows both zooming and panning in the maps shown in the web browser. To make the application reasonably fast the maps for different zoom levels are pre generated using cloud technology with access to several servers and parallel processing is achieved.

3 Results

The E-HYPE is a modeling tool that, on a daily timescale, and at a high spatial resolution:

- calculates water discharge *at all sub basin outlets on the European continent*
- calculates water discharge *to European Seas* (and nutrient load to the Baltic sea)
- can be used operationally to give *past* and *current* conditions and *forecast* all variables
- can be used as a tool for examining the effects of *climate change, land use change* and/or *nutrient reduction measures*, and
- uses quality-assured data and will soon be *calibrated* and *validated* against independent observations, according to sound scientific principles [24]

Pan-European analyses show that the model captures major hydrological variability for the continent 3. Comparisons of preliminary model results towards observed values [24] also show that the model is able to reconstruct dominant features of water quality and dynamics for the continent. Although, there is a need for more detailed input data and local adjustments to achieve more useful results for water authorities on the sub basin scale.

4 Discussion and Visions for the Future

When applied for Sweden, the HYPE model (then called S-HYPE) has shown to be a very useful tool both for hydrological forecasts (for early warning services and hydropower industry) and sustainable management of water resources [25], e.g. for nutrient reductions and climate change adaptation. The process to develop a similar hydrological core service for the entire European domain with free access to water information has just started. In accordance with earlier pan-European attempts, the first E-HYPE results clearly show that quality improvements are needed before the results can be useful for local multi-purposes. The strategy for further development must include better input data, local knowledge

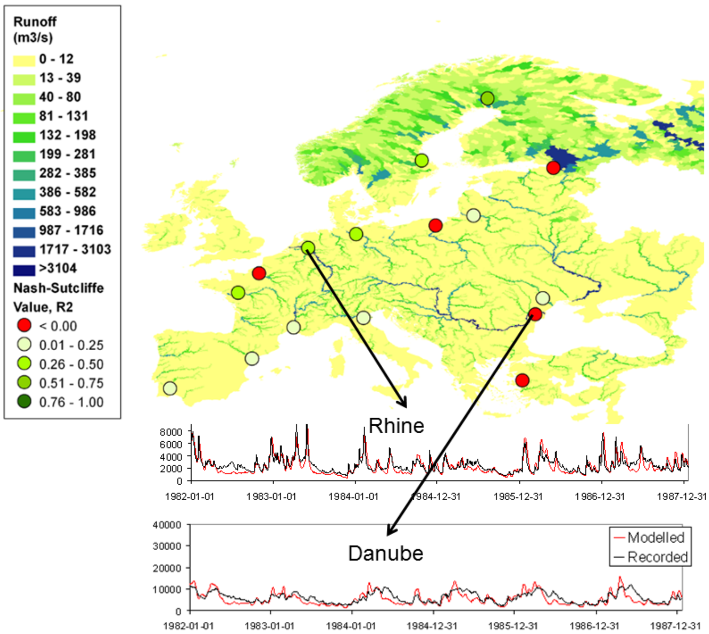

Fig. 2. First evaluation of time-series from the uncalibrated E-HYPE model vs. observations.

on dominant hydrological processes, and advanced technology. For successful implementation and cost efficient development we ask for a bottom-up approach and inclusion of e-science. Some of the main building blocks in such an ambition are presented in the three steps below.

4.1 Better Input Data

Attempts to improve the input data are performed in several on-going EU FP7 projects (see acronyms that follow). Within GEOLAND2 we will experiment with new satellite-based products regarding detailed land use, soil sealing, phenology and soil moisture. In CRYOLAND we will try satellite products for snow and glaciers. GENESIS contributes with information about aquifers, and SUDPLAN with methods for incorporation of local observations. EURO4M will contribute with more detailed forcing data and high-resolution precipitation products. In addition, the strategy is to initiate local collaboration and participatory modeling where input data can be improved for a specific domain of interest, and thereby contribute to the overall development.

4.2 Open Source Community

For efficient code development and inclusion of local knowledge on dominant hydrological processes for each part of such a large model domain, we will try the concept of an open source community. The code is then open and can be seen, changed and learnt from, and all code users are then treated as co-developers. It lies within the nature of an open source project to be highly modularized, and this allows for parallel development of independent components. Users/co-developers should be encouraged to submit additions to the software, code fixes, bug reports, and documentation etc. Early versions of the software should be released as soon as possible to increase chances of finding co-developers early.

An open source community also needs a dynamic decision making structure that makes strategic decisions depending on changing user requirements and also manage/release new code versions. The open code and system related to E-HYPE could be hosted and managed at SMHI to serve the needs of local and continental issues and demands.The community should also cooperate with other national services and end-users linked to the operational production systems for full implementation.

4.3 Hydrological Laboratory and New Technologies

The proposed modeling system will also be used as a “hydrological laboratory”. At present the HYSS system manage the HYPE and the HBV models, but the ambition is that more models should be plugged in relatively easily. This facilitates ensemble runs using several different models for the same domain and with the same input data. In addition, the HYPE model code is relatively easy to follow, which allows experiments with different hydrological algorithms. This would enable scientific elaboration of hydrological hypothesis and increase the knowledge base of European water systems.

New challenges in hydrological modeling include e.g. high spatial and temporal resolution, Monte Carlo simulations for uncertainty estimates, sensitivity studies, ensemble modeling, water quality estimates and climate change effects for the next coming hundreds of years. All these applications need high computational capacity. Hydrological models are traditionally run on PCs, but the new challenges thus ask for new technologies. Cloud services using several processors are already applied in the production system within SMHI hydrology to generate maps for the web products. Future modeling system may use this technology also to run the hydrological models themselves 3. This will soon speed up the computational time significantly.

Moreover, new technology is currently developed for visualization of E-HYPE results in decision support systems, for data extraction and automatic model calibration to local observation. This development is done in the EU FP7 preoject SUDPLAN and will result in interactive user interfaces, including model runs and data access.

All together, the step strategy could thus lead to improved quality, credibility through transparency, collective learning and international cooperation. Each step would benefit on linkage to new e-science to be efficient. If the overall development is successful, E-HYPE has a large potential to form a hydrological core service for Europe in the next coming years. This would then combine collaborative code development and operational production in the same service.

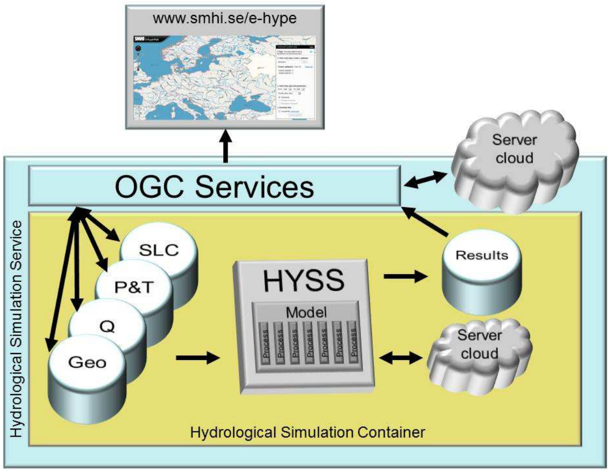

Fig. 3. Schematic picture of the future E-HypeWeb production system.

5 Conclusions

- A pan-European model is available, providing high-resolution water information with free access through a web product `http://www.smhi.se/e-hype`, and water and nutrient load to the sea through `http://www.smhi.se/balt-hype`
- The first preliminary model results show that the model is able to reconstruct dominant features of water quality and dynamics for the continent. However, collaborative development is needed both for producing more useful results for water authorities on the sub basin scale, and for further operational pan-European implementation.
- A three step strategy is developed for further development and implementation using a bottom-up approach. Focus is put on better input data, local knowledge on hydrological processes and advanced technology. Much of the work will rely on EU FP7 projects, an open source community, and hopefully new e-science. The ambition is to combine both collaborative code development and operational production in this new water service.

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References

1. Arheimer, B., Lindström, G., Olsson, J.: A systematic review of sensistivities in the Swedish flood forecasting system. Atmospheric Research 100, 275–284 (2011)
2. Arnold, J.G., Fohrer, N.: SWAT2000: Current Capabilities and Research Opportunities in Applied Watershed Modelling. Hydrological Processes 19, 563–573 (2005)
3. Bergström, S.: Development and application of a conceptual runoff model for Scandinavian catchments. SMHI Reports RHO No. 7, Norrköping (1976)
4. Berglöv, G., German, J., Gustavsson, H., Harbman, U., Johansson, B.: Improvment HBV model Rhine in FEWS. Final report. SMHI Hydrology report No. 112, Norrköping (2009)
5. Refsgaard, J.C., Storm, B., Clausen, T.: Système Hydrologique Européen (SHE): review and perspectives after 30 years development in distributed physically-based hydrological modeling. Hydrology Research 41(5), 355–377 (2010)
6. Arnell, N.W.: A simple water balance model for the simulation of streamflow over a large geographic domain. Journal of Hydrology 217(3-4), 314–335 (1999)
7. Döll, P., Kaspar, F., Lehner, B.: A global hydrological model for deriving water availability indicators: model tuning and validation. Journal of Hydrology 270, 105–134 (2003)
8. Alcamo, J. Döll, P., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T., Siebert, S.: Development and testing of the WaterGAP 2 global model of water use and availability. Hydrological Schiences Journal 48(3), 317–338 (2003)
9. Widn-Nilsson, E., Halldin, S., Xu, C.: Global water-balance modelling with WASMOD-M: Parameter estimation and regionalization. Journal of Hydrology 340, 105–118 (2007
10. Feyen, L., Vrugt, J.A., Nualláin, B.Ó., van der Knijff, J., De Roo, A.: Parameter optimisation and uncertainty assessment for large-scale streamflow simulating with the LISFLOOD model. Journal of Hydrology 332(1), 276–289 (2007)
11. van der Knijff, J.M., Younis, J., De Roo, A.P.J.: LISFLOOD: a GIS-based distributed model for river-basin scale water balance and flood simulation. Intrnational Journal of Geographical Information Science 24(2), 189–212 (2011)
12. Lindström, G., Pers, C., Rosberg, J., Strömqvist, J., Arheimer, B.: Development and test of the HYPE (Hydrological Predictions for the Environment) model - A water quality model for different spatial scales. Hydrology Research 41(3-4), 295–319 (2010)
13. Arheimer, B., Dahné, J., Lindström, G., Marklund, L., Strömqvist, J.: Multivariable evaluation of an integrated model system covering Sweden (S-HYPE). IAHS publ. 345 (2011)
14. Donnelly, C., Dahné, J., Lindström, G., Rosberg, J., Strömqvist, J., Pers, C., Yang, W., Arheimer, B.: An evaluation of multi-basin hydrological modelling for predictions in ungauged basins. IAHS publ. 333, 112–120 (2009)
15. Strömqvist, J., Dahné, J., Donnelly, C., Lindström, G., Rosberg, J., Pers, C., Yang, W., Arheimer, B.: Using recently developed global data sets for hydrological predictions. IAHS publ. 333, 121—127 (2009)
16. Lehner, B., Verdin, K., Jarvis, A.: New global hydrography derived from spaceborne elevation data. Eos, Transactions, American Geophysical Union 89(10), 93–94 (2008)
17. US Geological Survey: Hydro1k Elevation Derivative Database. `http://edc.usgs.gov/products/elevation/gtopo30/hydro/index.html`

18. Jansson, A., Persson, C., Strandberg, G.: 2D meso-scale re-analysis of precipitation, temperature and wind over Europe - ERAMESAN Time period 1980-2004. SMHI Reports, Meteorology and Climatology no. 112, Norrköping (2007)
19. Joint Research Centre: Eurpoean Soils Database. http://eusoils.jrc.ec.europa.eu/ESDB_Archive/ESDB/index.htm
20. Global Runoff Data Centre: River Discharge Data. Koblenz, Federal Institute of Hydrology (BfG) (2009b)
21. BALTEX Hydrological Data Centre: BALTEX Hydrological Database. http://www.smhi.se/sgn0102/bhdc
22. Global Runoff Data Centre: European Water Archive (EWA). Koblenz, Federal Institute of Hydrology (BfG)
23. European Environment Information and Observation Network: Central Data Repository. http://cdr.eionet.eu.int (2003)
24. Donnelly, C., Dahné, J., Rosberg, J., Strömqvist, J., Yang, W., Arheimer, B.: High-resolutio, large-scale hydrological modelling tools for Europe. IAHS Publ. 340, 553–561 (2010)
25. Hjerdt, N., Arheimer, B., Lindström, G., Westman, Y., Falkenroth, E., Hultman, M.: Going public with advanced simulations. ISESS conference proceeding, this issue (2011)