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Developing A Hydrologic Information System: Towards Promoting Sustainable Standardization

Abbas Fayad

Ibrahim Alameddine

Majdi Abou Najm

Mutasem El-Fadel

DEVELOPING A NATIONAL HYDROLOGIC INFORMATION SYSTEM: A STEP TOWARDS PROMOTING HYDROLOGICAL STANDARDIZATION IN A DEVELOPING COUNTRY

FAYAD, ABBAS(1), ALAMEDDINE, IBRAHIM (1), ABOU NAJM, MAJDI (1), EL-FADEL MUTASEM (1)
(1): Department of Civil and Environmental Engineering, American University of Beirut, Riad El Solh, Beirut, Lebanon

Water quantity and quality monitoring plays a key role towards the development of a sustainable water sector. Most developing countries lack the required infrastructure needed to monitor and manage their surface and groundwater systems. As such, water quantity and quality data if present are often fragmented, intermittent, not freely shared, lack appropriate metadata, and are stored in formats that hinder establishing seamless coupling with hydrological models. In Lebanon, governmental institutions responsible for water monitoring have invested little in terms of hydroinformatics, resulting in a fragmented and disjoint hydrological information system. Most data, when available, are stored locally with little attention placed on defining and maintaining metadata on the collection protocols, geographic referencing, measurement accuracy, resolution, detection limits, and data censorship. These limitations have made the development and adoption of sound management solutions for the water sector in Lebanon challenging. To alleviate these shortcomings, a National Hydrologic Information System (NHIS) based on the ArcHydro data model was developed. The NHIS has centralized available hydrological and water resources information; coupled spatial coverages with their respective time series data on flow, water demand, meteorology, and water quality; and standardized metadata. Additionally, the developed system ensures support for hydrologic modeling and water resources analysis. A loose coupling between the system and the Water Evaluation And Planning (WEAP) hydrological model was developed and tested on the Upper Litani River Basin. Generated model simulations were in turn exported back and integrated within the NHIS as time series records.

INTRODUCTION

Water scarcity is one of the main challenges facing Lebanon. The current situation is characterized by diminishing water resources, increasing water demand by all sectors, inefficiencies in the water supply systems, and increasing water pollution [1]. In addition to the environmental and water shortage dilemmas, there is a lack in the quantification and qualification of surface and ground water resources, which curtails the proper management of the sector [2]. At present most of the available information regarding water budget and water resources use in Lebanon is fragmented and outdated. Despite the importance of water

resources data and information in planning, the country's research community and the state's water agencies lack a system that allows for the storage and dissemination of hydrologic data. This situation is due to both technical and administrative constraints. From a technical perspective, most available data are difficult to sort, have limited metadata, and are in various non-harmonized formats. Moreover, institutional policies often limit access to available data.

The need to properly assess the status of the hydrologic and water resources system in Lebanon has never been more pressing, as the country's renewable water resources continue to be overexploited and as future climate change predictions point to a drier future along the eastern Mediterranean coastline. The effectiveness of analyzing the hydrologic processes and managing the water sector in the face of these challenges is highly dependent on the quality and quantity of the available data.

As such, the need for a dynamic hydrologic information system (HIS) that is capable of handling hydrological data over space and time is crucial. In this paper, we describe the steps taken towards the development of an integrated hydro-informatic system that can be used in data syntheses, hydrologic analysis and modeling, and water resources assessment. This integrated system makes use of the conceptual framework of the HIS developed by Maidment [3].

Similar HIS systems are in use worldwide for sharing, supporting, and enhancing data quality and for the analysis of hydrologic processes [4, 5].

METHODOLOGY

A National Hydrological Information System (NHIS) was developed for Lebanon. The system aims to offer solutions to many of the existing problems related to data assimilation and management at the national level. As a first step, the available national data on hydrology were collected from different stakeholders. Yet the assimilation of the data was constrained given that data came in a variety of formats. Archived observatory data, such as time series of river flows and climate variables prior to the 1970's, were in paper format. Recent flow and meteorological data were in spreadsheet format, while some data from some governmental bodies and local universities were stored in shapefiles, rasters, and Access databases. In an effort to harmonize the data, spatially related feature were organized into a set of predefined feature datasets. Metadata files were generated for each feature class and raster. The metadata files documented the collection protocols, the geographic referencing, measurement accuracy, resolution, detection limits, source of data, year of collection, and data censorship.

The quality of the different layers varied significantly. As such, topological editing was applied at the feature dataset level to remove errors related to polygons overlapping, lines intersecting, and polygon and lines with dangles. Similarly, statistical analyses were conducted to identify potential outliers and/or the coding used for missing data. This heterogeneity in data format highlights the lack of standardization and the limited interoperability of the existing data. As such, the developed NHIS aimed at standardizing data handling and unifying the data storage model.

RESULTS

As a first step towards standardizing river basin representation, the NHIS incorporated the concept of unique Hydrologic ID (HydroID) that structured existing data at the national level in a hierarchical framework. The system emulates the USGS's Hydrologic Unit Code (HUC)

cataloging system. The entire country was divided into 5 major basin areas (Table 1). A basin's HydroID was further divided into three nested layers as shown in Figure 1. Each hydrologic unit represented a unique combination of soil, land cover, and geologic formation. This system contrasts with the existing system that defines basins and their subdivisions by their common names; a process that restricts data indexing, hinders joining/linking operations, and prohibits the automated aggregation of data.

Table 1. The developed HydroID system for Lebanon by region and river basin

Region HydroID	Basin HydroID	River Basin Name	Region
010000	010000	Litani	Bekaa/South
020000	020000	Assi	Bekaa
030000	030000	Hasbani	Bekaa
040000	040100	El Kebir	North
	040200	El Ostouene	
	040300	Arka	
	040400	El Bared	
	040500	Abou Ali	
	040600	El Jouz	
050000	050100	Ibrahim	Mount Lebanon
	050200	El Kelb	
	050300	Beirut	
	050400	Damour	
060000	060100	Awali	South
	060200	Sainik	
	060300	El Zahrani	
	060400	Abou Assouad	

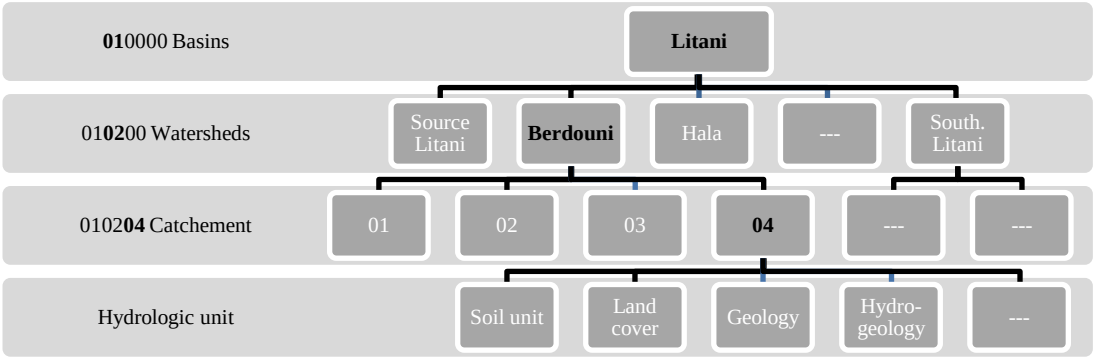

Figure 1. Example of the adopted basin hierarchy based on HydroID

The ArcHydro data model [6] was adopted within the NHIS, primarily for its ability to support time series data within a geospatial framework. All hydrographic and hydro-time series datasets were based on the ArcHydro schematic model and were populated with existing national records. Time series data were linked to their hydrologic features using the appropriate feature HydroID. The ArcHydro tools were also used in the processing of watersheds, namely watershed delineation and stream segmentation. The generated geodatabase was able to integrate different forms of water features such as hydro networks (stream and rivers feature classes), hydro areas (basin, watershed, and drainage feature classes), hydro points (catchment pour points and outlets), hydrographic features (water bodies, dams, monitoring points), and hydro times series (hydrologic records). The hydro points, networks, and areas were created using ArcHydro tools based on a digital elevation model (DEM) built on the national topographic maps (1:20,000).

Within the NHIS framework, we used the Stockholm Environment Institute's (SEI) Water Evaluation And Planning (WEAP) software, for data modeling and analysis [7, 8, 9]. Given the interest in modeling the impact of future climate change on the hydrology of Lebanon, the NHIS incorporated climatic time series rasters, as a separate TimeSeries raster dataset. The 50x50 km rasters represented 5 statistically downscaled GCM outputs (i.e. CGCM2, CSIRO2, ECHAM4, HADCM3, and PCM) and 4 IPCC scenarios (i.e. A1FI, A2, B1, and B2) derived from the work of Mitchell et al. [10]. The coupling between the NHIS and WEAP was established; yet WEAP's ability to solely deal with shapefiles presented some limitations. In an effort to automate the transfer of data between the NHIS and WEAP, a separate dataset was created within the NHG that accounted for WEAP's format requirements. On the other hand, model output from WEAP were seamlessly incorporated back into the geodatabase in the form of time series records that were attached to the appropriate gauging station by its unique HydroID. The loose coupling between the two systems was successfully tested on the Upper Litani River Basin.

A comparison between the developed NHIS and other HIS programs is shown in Table 2. As can be seen, the NHIS system contains most of the elements found in other international HIS systems. Yet, a major limitation with the existing system remains its inability to operate in a web-based environment and cater for multiple users.

Table 2. Comparison between different HIS

Features	LEB-NHIS	CUAHSI-HIS	WHYCOS-HIS	SAPHY-DATA
Model-oriented HIS	Yes	Yes	No	Partially
Incorporates a combination of hydrologic data, tools and simulation models that supports hydrologic analysis.	Yes	Yes	Partially	Partially
Makes use of hydrologic and water resources simulation models	Yes	Yes	Partially	Partially
Web-Based HIS	NO	Yes	Yes	NO
Applies to large, distributed information systems that have many owners, are complex and heterogeneous	NO	Yes	Yes	NO
Connection among different components is established by web services and/or local PC applications	Local	web services / local	web services	Auto-functions
GIS-Based HIS	Yes	Yes	Partially	Partially
Stores spatial data with linked attribute in a GIS database, where analytical functions are used to generate the needed information products	Yes	Yes	Partially	Partially
Data and information has been assimilated and stored on a local/server computer	Local	Local/ Server	Server	Server
Managing all available data and information using a Database (DB)/Geodatabase (GDB) and provide support for future data updating.	GDB	DB/GDB	DB	DB
Built to operate on the desktop PC level (single-user) or enterprise level (multiple-users) sharing access to the same database, GIS and modeling software.	Single-user	Multiple-users	Multiple-users	Multiple-users
Capabilities of a GIS in areas such as data manipulation and querying, modeling, analysis, and interpretation.	Yes	Yes	Partially	Partially
Representing phenomena that are inherently dynamic and vary greatly through time.	Yes	Yes	Yes	Yes
Data-oriented HIS	Yes	Yes	Yes	Yes
Provide access to different type of data (e.g. time series, spatial data, and information or unstructured data such as digital documents and pictures).	Yes	Yes	Yes	Partially
Distinguishes between different types of databases such as hydrologic, hydrogeologic, water resources etc.	Yes	Yes	Yes	Yes

CONCLUSION

A national HIS system was developed for Lebanon. The system facilitates spatial analysis, querying, and the handling of spatio-temporal hydrologic data. The NHIS also provides a suitable environment for handling continuous updates required to meet the current and future needs of its users. The NHIS was coupled with the WEAP hydrological model and the coupling was successfully tested on the Upper Litani River Basin. Future work on the NHIS will involve incorporating regionally downscaled climatic data from the Weather Research and Forecasting (WRF) [11] model and expanding on the current coupling with the WEAP hydrological model.

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