National Infrastructure of Spatial Information – Spatiotemporal Conception of Data Model According to Water Framework Directive

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Abstract

The conception of National Infrastructure of Spatial Information in Slovakia follows the European initiatives of INSPIRE (Infrastructure for Spatial Information in Europe). Implementation of INSPIRE is conditioned by use of many international standards and initiatives in the field of data models, technological tools and information communities. For this purpose, The European Commission and The European Parliament have issued a collection of informational directives. Directive 2000/60/EC, called Water Framework Directive (WFD), is among them. WFD establishes a framework for Community action in the field of water policy oriented on the protection of surface waters and groundwaters.
Implementation of WFD in the field of Geographical Information Systems (GIS) requires the proper data model design of geographical database for storing and processing of geographical data necessary for water protection. This paper begins with the presentation of the relational data model of such database. However, the main intention of the paper is to incorporate the temporal aspect of geographical information into the spatial data model design and thus to introduce the spatiotemporal conception of geographical database according to FWD.
Spatiotemporal data models are used more and more often in GIS in recent years. They enable to represent a closer approximation to the real world, but on the other hand, such models must be based on a thorough understanding of how objects behave in reality. Temporal aspect of geographical information is especially very important in the databases of the environmental character as the attribute values of geographical features might be quite changeable. The geographical database for protection of surface waters and groundwaters is of such example and the paper presents the spatiotemporal object-oriented data model of this database.

1 Introduction

Spatial data, geographical information and Geographical Information Systems (GIS) are the subjects of interest of important European activities. Slovak Republic observes this trend with big interest. The Geodesy, Cartography and Cadastre Authority (GCCA) introduced the conception of National Infrastructure of Spatial Information (NISI) and defined Automated Information System of Geodesy, Cartography and Cadastre (AISGCC) consisting of three subsystems - 1) Cadastral Information System (CIS), 2) Information System of Geodetic Control (ISGC), 3) The Fundamental Base of Geographical Information

System (FBGIS). FBGIS defines the principles for harmonization of geographical information about topographical landscape elements on national level [7, 14, 15, 17].

The conception of NISI presented by GCCA follows the European initiatives INSPIRE [5, 11] focused on the creation of the European Spatial Information Infrastructure (ESII) and their functions - serving integrated and user oriented services for spatial information processing. These services should allow users to identify and access spatial and geographical information from wide range of national and international sources by the form of their mutual and functional sharing. INSPIRE intends to create ESII based on the following principles:

- effective and one-off data collection,
- seamless combining spatial information from different sources and their mutual sharing,
- sharing data from different control levels,
- availability and extensive use of geographical information,
- easy assignment of availability and suitability of geographical information according to specific task groups,
- clarity and interpretability of geographical information for the purpose of cartographic interpretation and visualisation.

Implementation of INSPIRE is conditioned by use of many international standards and initiatives in the field of data models, technological tools and information communities (OpenGIS Consortium, World Wide Web Consortium - W3C, International Standardisation Organization - ISO, European Committee for Standardisation - CEN, Dublin Core Metadata Initiative, etc.) [5]. For this purpose, The European Commission and The European Parliament have issued a collection of informational directives [2, 3, 4]. Directive 2000/60/EC, called Water Framework Directive (WFD), is among them. WFD establishes a framework for Community action in the field of water policy oriented on the protection of surface waters and groundwaters.

Implementation of WFD in the field of Geographical Information Systems requires the proper data model design of geographical database for storing and processing of geographical data necessary for water protection. This paper begins with the presentation of the relational data model of such database. However, the main intention of the paper is to incorporate the temporal aspect of geographical information into the spatial data model design and thus to introduce the spatiotemporal conception of geographical database according to FWD.

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2 Data Model According to WFD

In our previous work [12] we introduced the definition of geographical information system for water protection according to WFD (**W*FD*GIS**) as follows:

***W**FD**GIS** is interoperable geographical information system for generating complex geographical information about hydrological system elements and other landscape elements in a chosen scale by means of data structures, methodological procedures, informatical and technological tools, for providing water protection in integrated environment of INSPIRE and NISI.*

Geographical database represents model of reality. The reality is implemented into geographical database in 3 levels: conceptual model, logical model and physical model [8, 9, 10]. Implementation document of WFD [19] specifies the conceptual model. Therefore, we will concentrate on logical data model of geographical database (geographical database model

– GDBM, further) in the next text. Elements and relations define GDBM. Model elements are represented in feature catalogue, whereas relations are represented in relational data model.

2.1 Feature Catalogue

Implementation document [19] defines the set of feature classes and feature types and their positional, thematic and time representation. This gives the specification of feature catalogue content, which defines the set of elements of **W*FD*GIS** geographical database. We then define the form of feature catalogue as a hierarchical data structure on the basis of specification types of features. We distinguish following hierarchical levels of feature specification in feature catalogue (Table 1):

- feature classes,
- feature types,
- feature attributes,
- attribute values.

Feature classes	Feature types		Attri-butes	Attrib. values
	Full name	Abbreviation		
Water bodies	River water body	*RWbody*	*	*
	River water segment	*RWsegment*	*	*
	Lake water body	*LWbody*	*	*
	Lake water segment	*LWsegment*	*	*
	Groundwater body	*GWbody*	*	*
Administra-tion units	Ecoregion	*Ecoreg*	*	*
	Subbasin	*Subbasin*	*	*
	River basin	*Rivbasin*	*	*
	River basin district	*RBD*	*	*
	Competent authority	*Compauth*	*	*
Monitoring network	Surface monitoring station	*SWstn*	*	*
	Groundwater monitoring station	*GWstn*	*	*
	Monitor GW bodies	*GWmon*	*	*
	Monitor LW bodies	*LWmon*	*	*
	Monitor RW bodies	*RWmon*	*	*
Ecological status	Groundwater status	*GWstatus*	*	*
	Surface water status	*SWstatus*	*	*
	Fresh water ecological classification	*FWeccls*	*	*
	Physico-chemical classification	*Pchemcls*	*	*
Prot. areas	Protected area	*Protarea*	*	*

Table1 Specification of feature classes and feature types according to WFD.

A clear feature catalogue definition is a condition of GIS data models harmonisation. They have to be interoperable in the environment of national and international infrastructure of spatial information [12]. Harmonisation of geographical informational sources is defined by OpenGIS platform (Open Geodata Interoperability Specification) on the data, technological and society base [16]. Feature catalogue is the definition of data model elements, independent of technological platform. Besides, it declares the definition of geographical and spatial features of certain informational society (attribute and their values domains specification). Feature catalogue is therefore understood as effective tool for harmonisation of informational sources.

2.2 Relations

According to WFD [19], 20 feature types create the **W**$_{FD}$**GIS** database data model. They are represented in relational data model by relational tables. Table columns - fields present set of thematic attributes according to feature type definition in feature catalogue. Set of fields with the same domain of unique values (primary keys) define relations between tables.

Relational data model is shown in Figure 1. Out of total 25 relations in this model, 7 relations are created by both *RWbody* and *LWbody,* and 5 relations by *GWbody*, which seem to be the most important elements in database.

All elements of data model (feature types) come into relationship. Therefore, the condition of GDBM consistency is fulfilled from the relationships' viewpoint. But, the functionality of GDBM is in reality conditioned by the definition of common value domain of primary keys. This issue is written in more detail in [12, 13].

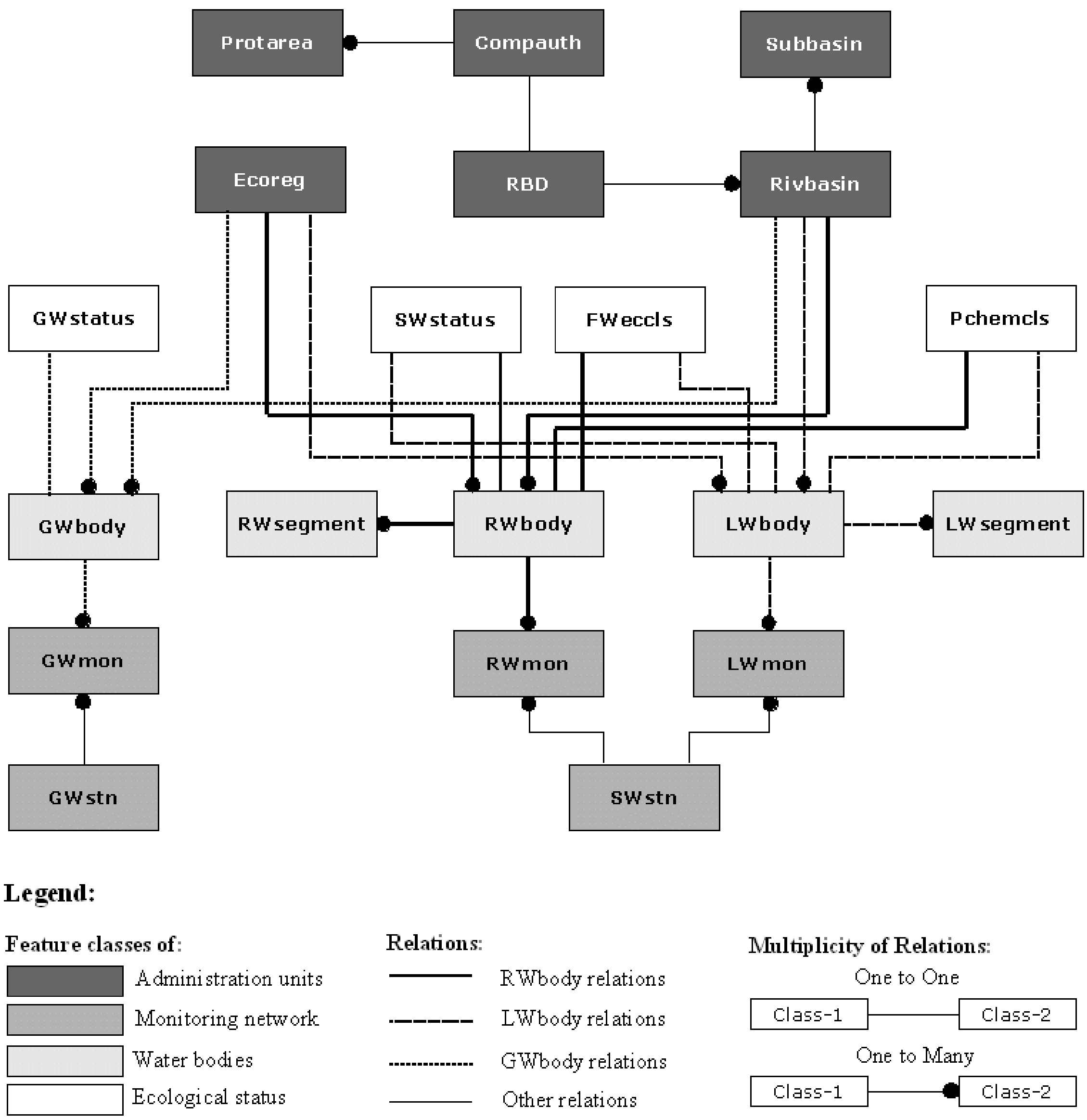

Figure 1 Relational data model of geographical database according to WFD.

3 Implementing Temporal Aspect Into Data Model

A spatiotemporal information system is defined as an information system where the spatial localization and temporal history of the real world system are of the interest to creator [18].

We will discuss the problem of implementing temporal dimension into data model on the example of object-oriented model of geographical database for water protection [1]. We come out from a hierarchical definition of **W**$_{FD}$**GIS** feature catalogue and from the conception in implementation document [19]. The principle of attribute inheritance between the more specific classes and the more general classes is used. They are in mutual relation through generalization or association. All features in one feature class can be only of the same topological dimension. Every feature has a unique identifier in the database (Figure 2).

To implement the temporal dimension in the object-oriented schema, feature classes and association and generalization links may be **T** or **S**-marked. A class that is **T**-marked has properties that vary over time. A feature class that is **S**-marked is a spatial feature and thus has a location. If a feature class is **ST** marked, it means that the location of such features may also vary over time. Hence, a feature class may be both **T**-marked and **S**-marked, but not **ST**-marked if it has a static location, but has other properties that vary over time. Subclasses inherit all markers from their superclasses, and are only marked if additional properties that deserve a mark are added to the feature class. A generalization link is **T**-marked if the instance of the subclasses may change in type. An association link may be **T**-marked if the link only exists during a part of the time for which both involved features co-exist. If, on the other hand, a link between two temporal feature classes is not **T**-marked it means that the link exists as long as both features co-exist. If an association link is **S**-marked it means that the link is spatially dependent, i.e. is a topological link.

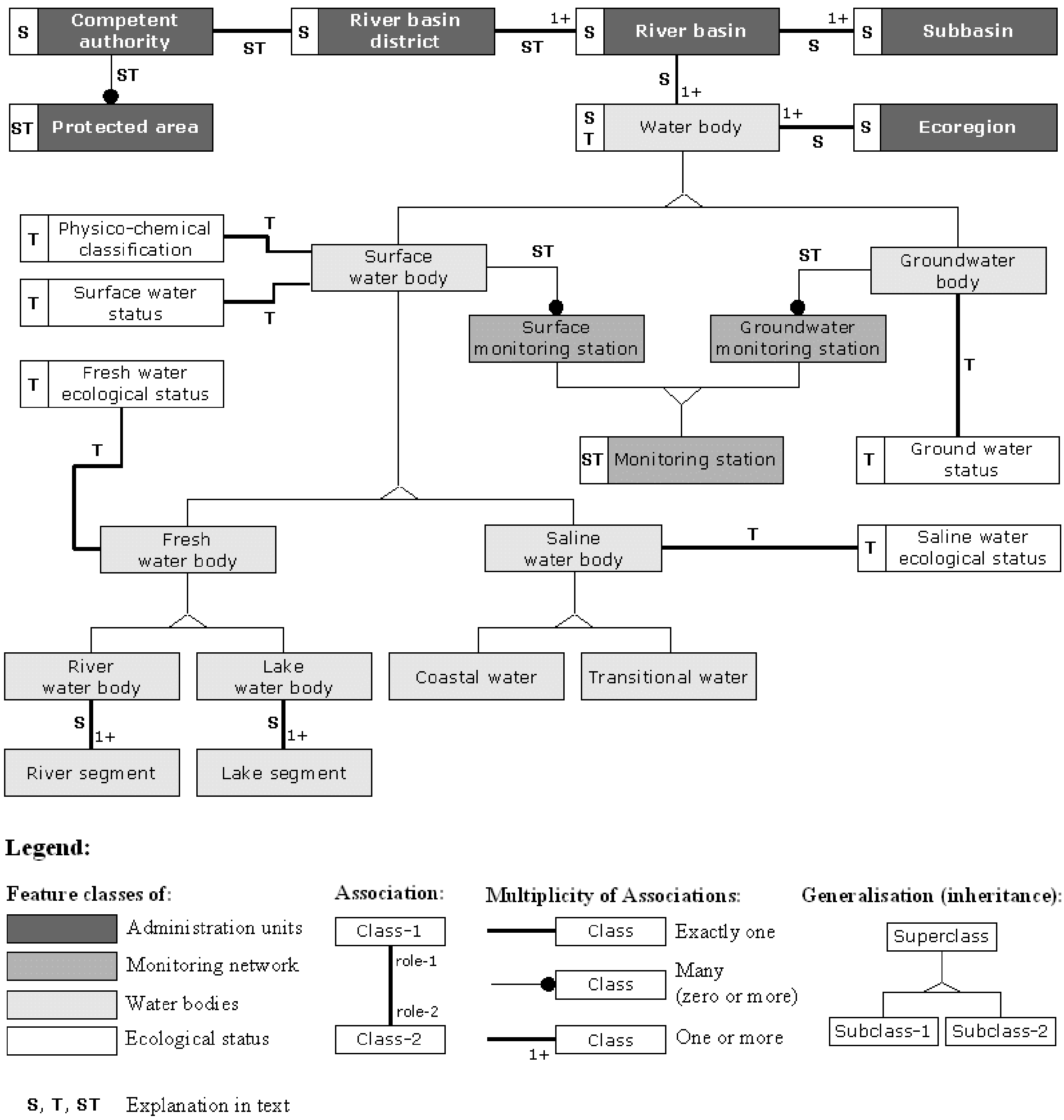

Figure 2 Object-oriented spatiotemporal data model of geographical database according to WFD.

According to feature catalogue, there are following feature classes (in italic) in object-oriented data model, divided into water bodies, monitoring network, ecological status, administration units and protected areas:

The feature class *Water body* has both spatial and temporal character, as it includes the attributes like ***InsertedWhen*** and ***YearStatus***. All *Water bodies* are subdivided into *Surface water bodies* and *Groundwater bodies*. The abstract class *Surface water body* is classified on the first level into *Fresh water body* and *Saline water body*. Feature class *Fresh water body* is subdivided on the lower level into feature classes *River water body* and *Lake water body*. On the lowest classification level we differentiate *River segments* and *Lake segments*. They are in one-to-many (1 : N) association link with *River water body* and *Lake water body*. The feature class *Saline water body* is analogously on the lower level classified into the feature classes

Transitional waters and *Coastal waters*. All these feature classes are in generalization link with *Water body*, and thus inherit the **T** and **S** markers.

Monitoring stations form the basis of the assessment of water ecological status. Abstract class *Monitoring station* can be on the lower level subdivided into *Surface monitoring station* and *Groundwater monitoring station*. Monitoring stations are point features, which location may change during period. Since a station may serve multiple functions, it is not appropriate to define distinct subtypes. Besides, they may monitor multiple water bodies. Monitoring stations therefore have many-to-many (M : N) relationships with water bodies.

For each type of water body, parameters of its ecological status can be defined, thus form the feature classes *Ecological status* of relevant water bodies, with which they are linked via the unique identifier. Thus there exist feature classes *Groundwater status*, *Surface water status*, *Fresh water ecological classification* and *Saline water ecological classification*. Besides, to all feature classes of surface waters belong the feature class *Physico-chemical classification*. For each of these elements, the attribute ***StatusDate*** is recorded, allowing multiple status reports to be made for the same water body over time.

Administration units include *Subbasin*, *River basin, Water basin district*, *Competent authority* and *Ecoregion*. The first two have natural character and fixed location. *Water basin district* is the main unit for management. There should be established a *Competent authority* for each river basin district, responsible for implementation of WFD. Their delimination may very over a long time period. According to WFD, the area of Europe is subdivided into 25 *Ecoregions* for fresh water bodies, or 6 *Ecoregions* for saline water bodies.

Feature class *Protected area* is not exactly defined in WFD, but we suggest in our data model to associate it to *Competent authority.* We will include it into the group of administration units feature classes.

The relational model in Figure 1 is created by the transformation of described object-oriented data model. For practical reasons of WFD implementation into conditions of Slovakia, the saline water bodies were omitted.

4 Conclusion

Historically, research in GIS has focused on application issues of digital cartography such as how to represent and manipulate spatial data structures in computers. The traditional representation schemes for geographical information systems have utilized cartographic primitives such as points, lines and areas. However, modern computers are capable of representing more information and knowledge about the real world than the paper map model is able to convey, such as the temporal perspective of spatial information [18].

The object-oriented approach is a popular approach in GIS modeling in general but also in spatiotemporal modeling. Apart from the advantages of the object-oriented model in traditional GIS, [6] list 4 main advantages of an object-oriented model in temporal database:

- The complete history of an entity can be encapsulated into one single object.
- Since the complete history of an entity can be represented as a single object, queries become less complicated, because they do not consider the dispersion of the entity over many tuples.
- Since complex object queries are executed efficiently, the corresponding temporal data should be handled efficiently as well.
- Handling of temporal and non-temporal data can be accomplished in a uniform way.

Spatiotemporal data models are used more and more often in GIS in recent years. They enable to represent a closer approximation to the real world, but on the other hand, such models must be based on a thorough understanding of how objects behave in reality. Temporal aspect of geographical information is especially very important in the databases of the environmental character as the attribute values of geographical features might be quite changeable. The geographical database for protection of surface waters and groundwaters is of such example.

References

[1] BOROŠ, R.; MIČIETOVÁ, E.: Data Model Conception of Geographical Database for the protection of Surface Waters and Groundwaters. In: Proceedings of 15th Cartographical Conference, Zvolen, Slovakia, 2003, p. 25-34.

[2] Directive 2000/60/EC of the European Parliament and of the Council.
http://europa.eu.int/eur-lex/en/consleg/pdf/2000/en_2000L0060_do_001.pdf

[3] Directive 85/337/EEC of the Council of the European Communities.
http://europa.eu.int/comm/environment/eia/full-legal-text/85337.htm

[4] Directive 2001/42/EC of the European Parliament and of the Council.
http://europa.eu.int/comm/environment/eia/full-legal-text/0142_en.pdf

[5] INSPIRE Architecture and Standards Position Paper. Architecture and Standards Working Group, 2002.
http://inspire.jrc.it/home.html

[6] KÄFER, W.; RITTER, N.; SCHÖNING, H.: Support for Temporal Data by Complex Objects. In: Proceedings of the 16th Conference on Very Large Databases (VLDB'90), Brisbane, Australia, 1990, p. 24-35.

[7] Koncepcia tvorby, aktualizácie a správy Základnej bázy geografického informačného systému do roku 2005. Úrad geodézie, kartografie a katastra Slovenskej republiky, Bratislava, 2002.
www.geodesy.gov.sk/koncepcie/zbgis2005/cele.htm

[8] KRCHO, J.; MIČIETOVÁ, E.: Geoinformačný systém o geografickej sfére a komplexný digitálny model priestorovej štruktúry ako jeho integrálna súčasť. Geografický časopis, 3, 1989, p. 249-273.

[9] KRCHO, J.; MIČIETOVÁ, E.: Štruktúra a úrovne integrity geografického informačného systému. Geografický časopis, 4, 1989, p. 369-388.

[10] MIČIETOVÁ, E.: Geografický informačný systém (GIS): štruktúra, integrita, interoperabilita, implementácia. In: Sborník 14. Kartografické konference, Plzeň, Czech Republic, 2001.
http://gis.zcu.cz/kartografie/konference2001/sbornik/

[11] MIČIETOVÁ, E.; BOROŠ, R.: Geographical Informational Resources, International Standards and National Infrastructure of Spatial Information in Slovak Republic. In:

Proceedings of 5th Czech-Slovak-Polish Conference, Prachatice, Czech Republic, 2003 (in print).

[12] MIČIETOVÁ, E.; BOROŠ, R. : Integrity and Interoperability of GIS Data Model for Water Protection According to Water Framework Directive. Meteorological Journal, 7, 2004, p. 25-37.

[13] MIČIETOVÁ, E.; BOROŠ, R. : Geographical Database Model of Hierarchical Hydrological System. Aktivity v kartografii, 2004, p. 86-94.

[14] MIČIETOVÁ, E.; KONEČNÝ, M.: Geographical Informational Resources, International Standards and National Infrastructure for Spatial Information in Slovak Republic. In: Digital Earth - Information Resources for Global Sustainability. Proceedings of the 3rd International Symposium on Digital Earth, Brno, Czech Republic, 2003, p. 510-517.

[15] NIKŠOVÁ, N.; VOJTIČKO, A.: Koncepčné zámery tvorby, aktualizácie a poskytovanie výstupov zo ZBGIS na roky 2001 až 2005. Geodetický a kartografický obzor, 47/89, 8-9, 2001, p. 186-191.

[16] OPEN GIS CONSORTIUM. OGC Technical Committee Policies and Procedues, Wayland, Massachusetts, 1997.
http://www.opengis.org/techno/development.htm

[17] PHALER, G.; KONEČNÝ, M.; MIČIETOVÁ, E. : Technical Report – GIS. Technical Assistance to GCCA Institution Building Component. Phare SR 9906.04.01.0006, pp 109. dep. UGKK SR ,2003.

[18] RENOLEN, A. : Modelling the Real World: Conceptual Modelling in Spatiotemporal Infromation System Design. Transactions in GIS, 2000, 4(1), p. 23-42.

[19] Water Framework Directive – Common Implementation Strategy. European Communities, 2002.
http://www.eau2015-rhin-meuse.fr/fr/ressources/documents/guide_sig.pdf