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Geomatics in hydrogeology

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Design and construction of hydrogeological information systems is now a necessity. For proper functionality of these systems, it is necessary to create them in accordance with widely accepted international standards regarding geospatial information. Geomatics research tools allow for creation of basic models of hydrogeological data, consistent with these standards. The models can be based upon classification of types and subtypes of hydrogeological features, as well as upon basic and derived classes of hydrogeological objects. The basis for this classification can be differentiation between features and objects, as well as between fuzzy features (objects) and fiat features (objects), or the analysis of their spatial dimensionality.

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INTRODUCTION

Geological and hydrogeological information, in the same sense as the term information is defined by computer science, is the basic matter that a hydrogeologist deals with while drawing up the results of observation, research and measurements. From the formal point of view, this work is based upon collection, verification, evaluation, ordering, gathering, analysing, synthesising, as well as sending, visualization and rendering access to hydrogeological, and, to some extent, geological information. From the point of view of computer science, most of these activities are defined as reversible or irreversible processing. Putting it simply, it is possible to say that all of these activities are supposed to convert data to information, and then information to knowledge. The way in which these activities are performed, depends upon methodological, technical and technological means that are accessible and, as a consequence, the results obtained also depend upon the same factors. Within the last twenty years, we have dealt with significant development of these means, which has been possible mainly thanks to computer science. Geomatics, as a discipline of knowledge dealing with geospatial information, owes its current research abilities in port to the development of computer science, since most methods and techniques that make up the research apparatus are derived from it.

Geospatial information, defined as information concerning phenomena implicitly or explicitly associated with a location relative to the Earth, encompasses about 80% of all information (Schell, 1999). It can be assumed that in geology and hydrogeology, almost 100% of all information has spatial reference with respect to Earth, that is, consists almost completely of geospatial information. Therefore, it can be the subject of research based upon methodologies and techniques of geomatics. A reliable example of changes, caused by application of geomatics, is the comparison of methodologies used nowadays for geological and hydrogeological information with classical methodologies, used in the period before the emergence of computer science.

In accordance with the title, the problems presented here pertain to geospatial hydrogeological information. However, since hydrogeology is a part of geology, it is impossible to properly present hydrogeological issues without taking into consideration issues of geology. Therefore, simplicity, all further references to hydrogeology will be understood as referring also to geology, to the extent necessary in order to properly present issues of hydrogeology. Another simplification of terminology pertains to the term geoinformation and the adjective geospatial. Since geomatics deals exclusively with geospatial information (geoinformation), in such cases the prefix geo- can be omitted, unless it leads to ambiguity.

CLASSICAL FORMS OF HYDROGEOLOGICAL INFORMATION

During the period before emergence of computer science, information in hydrogeology was presented in several forms, resulting from usage of paper as the information carrier:

— Text as a form of verbal description (non-graphical form). Every study, scientific publication, technical project or report includes such a component, which is often its basic part, holding all other parts together and offering explanation for them.

— A table, including numerical data (non-graphical form). This is most often used to present ordered results of field measurements or laboratory research. The location of elements in the table includes information which links this element with information assigned to adequate columns and lines.

— A datasheet, including fields of various types and in various arrangements (non-graphical form). A typical example of such a form is a borehole datasheet, including various text and numerical information, e.g. description of the geological profile of borehole with marked aquifers. The datasheet arrangement, in this case, defines the information structure, that is, the set and distribution of data that can be included in it.

— Photograph or image (graphical form). Photographs of a given area from various aspects: underground, ground-based, air or satellite, as well as laboratory photographs and photos of specimens (micro- or macroscopic). Included in this group are also any other images, taken at a specific location, using any remote sensors in various ranges of any kind of radiation.

— Map (graphical form). A two-dimensional, horizontally oriented (x, y) graphical picture, consisting of points, lines, surfaces, symbols and inscriptions, which is the expression of our idea of spatial relations between phenomena which are the subject of the map. It is assumed that there is an unambiguous and exact relation, consistent with the established frame of reference and mapping, between reality and the graphical image. In the geomatic sense, traditional hydrogeological maps do not significantly differ from any other cartographical representations, and their only distinguishing feature is the necessary portrayal of three-dimensional hydrogeological reality in two-dimensional form.

— Cross-section (graphical form). A two-dimensional, vertically oriented (x, z) graphical picture, which is subject to the same rules as a hydrogeological map. It is a form peculiar to geology, and thus it plays an important role in hydrogeology, as an auxiliary tool, which complements the map as an attempt to portray three-dimensional reality using two-dimensional tools.

— Sketch (graphical form). Any graphical picture, used to express the spatial relations, treated much less rigorously than the map and the cross-section.

Such information is typically recorded on paper, which makes changes such as supplements, corrections and updates, difficult, and normally requires this the creation of a new paper document. This form thus practically cannot be modified or processed.

DIGITAL RECORDING OF HYDROGEOLOGICAL INFORMATION

Digital recording, in this case, is understood as recording of information, using a durable or non-durable carrier, and employing standard rules of encoding based upon binary numbers. The digital recording may be applied to traditional forms of hydrogeological information, as listed above. In this case its only advantage is an ability to modify this information, which is in itself desirable: text, and numerical and graphical data can be easily complemented, corrected and updated.

Digital recording of information, however, opens up some new possibilities, which can be summarised as the computer data processing of hydrogeological information. Processing in this case is understood as the operation of specific algorithms included in the software. Thus, it is possible to derive new information, more suitable to a given situation, that is free of errors or internal inconsistency, is selected according to specific criteria, and is expressed and encoded in a form more suitable for a given application. In order for hydrogeological information to be processed by computer, a number of conditions have to be met, which are not met in case of traditional forms, even when recorded in the computer in digital form:

— The method of encoding of hydrogeological information should meet specific standards, allowing this information to be entered in various IT systems. These standards encompass three encoding levels: encoding of elementary information fragments, that is, the representation of characters, numbers and geometric forms; encoding of information structure, specified in the data model, and encoding of the encoding rules, that is, the language used to encode the data model.

— Separation of hydrogeological information content from its form of portrayal. If these are not separated, the information record is just an image, as in a traditional hydrogeological map. The digitally recorded (encoded) hydrogeological information does not have to and should not have a graphical form. It should be a record of a fragment, separated on the basis of specific rules, of hydrogeological reality (a hydrogeological feature), which includes only its own natural attributes, as well as functions (methods), pertaining to this fragment of reality. Portrayal of hydrogeological information is not needed for processing; this is only needed when the information is presented to a person, who is interested in it, for instance, a hydrogeologist, using the computer monitor screen or printed paper. Therefore, all graphical attributes pertaining to the method of feature representation, such as colours, line types and characters, typical of a traditional paper map are not directly related to hydrogeological information, but to its portrayal.

— The information structure must be suitable for the method of processing to be applied to this information. This structure is defined in the data model, and various data models can be used for the same hydrogeological information. For instance, a specified data model, assumed to record the hydrogeological borehole profile, can allow for correlation of features included in various profiles on the basis of lithological research results, and at the same time con prevent correlation of these features on the basis of hydrogeological research results. In such cases, a different data model must be used, or the previously used model has to be developed further.

— Hydrogeological information as data should be provided with an adequate description in the form of metadata, that is, data about data. This pertains particularly to the spatial and temporal range, the subject, frame of reference and mapping, precision of the data, the degree of verification, degree of processing, for instance — whether it is primary data, raw, interpreted, interpolated data, data describing a conceptual or a hypothetical model, as well as its topicality, completeness and consistency. Metadata is essential both for the person, who uses the data, and for other IT systems that receive and process the data.

If a hydrogeological information meets the conditions listed above, it can be treated fully as geospatial information and it can be subject to research, using methods that are the research tools of geomatics.

BASIC TERMS AND DEFINITIONS

Issues presented here pertain to several terms used in geomatics and, speaking more precisely, its ontological and semantic basis, applied to hydrogeological information. In order to present these issues clearly, it is necessary to explain, how these terms are understood here:

— Geomatics — the discipline of knowledge and technology, which deals with the issues of collection, gathering, maintenance, analysis, interpretation, transfer and usage of geospatial information, that is, information related to places, the position of which is specified with respect to Earth (Michalak, 2000*b*; 2001*a*).

— Geospatial information — information, in the sense defined by computer science, but, unlike any other kind of information, this is related to a specific place (fragment of space) and, as a result, data specifying the position of this place with respect to Earth is its essential component.

— Geospatial feature — the basic element (atom) of geospatial information. It has geospatial attributes (geometric and topological), such as shape, extent, position, relation to other features. The term feature is often confused with the term object, but feature can be an object, however, it does not have to be (Mark *et al*., 2001). Since in geomatics all features are geospatial, the adjective geospatial is usually omitted, and a shorter term — feature is used.

— Object — a real or an abstract entity (instance), distinguishable in the modelled reality, which has a name, unambiguous identification, clearly defined boundaries, attributes and other features, such as the type of internal structure or the structure of related data. These components (members) of the object characterise: its state (through values of attributes and associations) and its behaviour (through operators and methods, that is, functions) (Subieta, 1998). In geomatics, it is assumed that an object is an instance of class, which is based upon the paradigm of object-orientation, derived from UML (Unified Modelling Language), which is adapted here for description of conceptual models (OMG, 2001). In cartography, the definition of an object is different, close to the popular understanding of this word, for instance: military, sports, tourist object *etc.* (Gaździcki, 2001).

— Attribute — a property of a feature or an object, defined by the name of this property and the scope of values that can be ascribed to this name in order to characterise this property.

— Geospatial attribute — a property (characteristic), resulting from the fact that a feature occupies specific places in reality in the geospatial sense. Most often it is assumed that the term geospatial also includes time, which means that it is equivalent to the term temporal-geospatial. Examples of such attributes are: size, shape, position, geospatial association (e.g. ...is placed within extent of…), geospatial relations with respect to other features (e.g. distance or type of proximity).

— Non-geospatial attribute — all other attributes that are not related to spatial reference. These attributes may belong both to geospatial features and to other non-geospatial objects and instances. Very often in geomatics, this kind of attribute is named a thematic attribute.

— Feature geometry — a subset of geospatial attributes of a feature, pertaining only to those characteristics which depend upon the applied spatial reference system (SRS). For instance, the shape of Antarctica is different on different maps of the world.

— Feature topology — a subset of geospatial attributes of a feature, pertaining only to those characteristics, which do not depend upon the applied SRS. For instance, the fact that Warsaw is located by the Vistula River and its district — Praga — is located on the right bank of this river. The issues of association of one feature or object with another as a part, belonging to an entity, is dealt with by merology, and if this association has a spatial sense, by merotopology (Smith and Mark, 1998).

— Fuzzy (object, feature or attribute) — an object, feature or attribute is specified as fuzzy in cases when the boundaries, attributes or their values are not sharp, that is, there is a visible ambiguity with regard to boundaries, attributes or their values. Examples are: a boundary of a mountain or a syncline, air temperature or river volume, hydrodynamic or hydrochemical field, a zone of fluctuations of a water table level or a zone of a capillary rise.

— Fiat (object, feature or attribute) — an object, feature or attribute is described as fiat, if it is not naturally distinguishable from the surrounding reality. In geomatics, this usually pertains to definition of boundaries, which are arbitrarily defined on the basis of a specific hypothesis, or without taking into consideration conclusions resulting from observation (Smith, 2001). An example can be an administrative unit (a commune or district), a gulf boundary on the open sea side or boundaries of a continuous geological or hydrogeological unit, such as a monocline or a groundwater reservoir. Contradiction of the term fiat is genuine in this sense.

TYPES OF HYDROGEOLOGICAL SPATIAL INFORMATION

Most often, from the point of view of geomatics, hydrogeological spatial information does not differ significantly from the same information pertaining to other disciplines, especially when these disciplines are part of the earth sciences. As a result, we deal here with the same types of information, but in geological disciplines there are also very peculiar types and characteristics of information. The most peculiar characteristic of geological spatial information is its three-dimensionality. Outside geology, there are very few disciplines, in which it is necessary to take three-dimensionality into consideration, and mostly these are disciplines associated with the lithosphere, e.g. geophysics and mining, or with the earth's atmosphere, e.g. physics of the atmosphere, meteorology and aerial navigation.

One from of geological spatial information is hydrogeological information, comprising descriptions of geological structures, expressed as models, taking into consideration geometric and topological relations in 3D space. The differences here between standard ways of expressing information and digital ways are the greatest.

Another typically geological or hydrogeological type of spatial information is the recording of results obtained from a borehole. This type of information, characterised by a very particular structure, has no equivalents in other disciplines. The most typical characteristic of spatial information obtained on the basis of drilling, is its complex structure, which typically varies within an individual borehole. This is a typical case, when the recording of this information in a relational database encounters significant difficulties, and application of an object model and an object database gives significantly better results.

FEATURES AND OBJECTS IN HYDROGEOLOGY

The terms feature and object are often treated as synonymous. However, in the terminology of ISO 19100 norms (ISO/TC211..., 2001) and in OpenGIS specification (The OpenGIS..., 1999), the meaning of these terms is different. The term object is understood here as in the definition given above (OMG, 2001). From this perspective, several entities can be distinguished in the real world that significantly differ from their surrounding and have identity — these are genuine objects. Equivalents of genuine objects can be components of a formalised, abstract conceptual model — abstract objects. In computer science, a certain programming entity, can be an object which is the equivalent of an abstract in a conceptual model, and therefore of genuine object in the real world. Such an object is often named a class instance, and it can be e.g. an aggregate of data and methods, though an object in the programming sense can also be something that has no equivalent in reality. The definition of the term object*,* adapted here, means that a number of other terms are related to this term, such as: attribute, link, class, abstract data type, encapsulation, message, method, and polymorphism (Subieta, 1998).

The term feature is a relatively new term, which originated in scientific circles associated with OGC (OpenGIS Consortium). It relates to something that exists in reality (phenomenon) and is visibly distinguishable from its surrounding in the spatial (more specifically, geospatial) sense. It can be an object in the sense explained above — a real object, or a corresponding abstract or programming object, but it can also be something that cannot be described as an object, because it does not meet the conditions set out in the definition. An example of a feature-object can be a house, a car, a tree or a planet, and an example of a feature-non-object is a spot on a satellite image, a depression of a surface, a syncline, a groundwater recharge area or an atmospheric high-pressure area. An essential characteristic of a feature is its continuity in time and space, as well as at least one characteristic that allows one to distinguish it from the surroundings. It can be said that a feature is a certain place in space and time, in which, for some reason, something different exists or something looks different. The reason can be an object that is located there, or something else. The term spatial feature is related to other terms, such as position, extent, shape, duration, geometry, topology and merology. In hydrogeology, as in geology, features that are not objects in most cases can be defined as forms (Mark and Smith, 2001). A form can be a syncline or a monocline, an artesian basin or a hydrogeological window, and in geomorphology, for instance, a river terrace scarp.

In hydrogeology, we deal with a great variety of feature types. To illustrate this variety, an analysis of types of spatial hydrogeological features has been conducted on the basis of the set of terms included in the Polish "Hydrogeological Dictionary" (Kleczkowski and Różkowski, 1997). Among 1192 terms defined in this dictionary which pertain to hydrogeology, 276 are associated with spatial feature types. Representative examples of such terms are: hydrodynamic field, groundwater reservoir, protection area, groundwater contour line, depression cone, underground watershed, aquifer, aquifer bottom, water vein, hydrogeological unit, spring, piezometer, well and hydrogeological system. Among these 276 terms related to feature types, there are 55 synonyms, which can be omitted in order to simplify the analysis. Among the remaining 221 terms, 126 can be described as terms referring to subtypes, for instance, hydrogeological test borehole is a subtype of the type hydrogeological borehole. Also in this case, in order to make the analysis simpler, terms referring to subtypes have been omitted, and finally the number of terms analysed amounted to 95. Individual terms, relating to the main types of hydrogeological features, were checked with regard to the following characteristics:

— Is the spatial feature an object, in particular, is a specific feature type associated with a specific class of objects? For instance, there can be a class of objects named hydrogeological boreholes and thus such types of features can be associated with this class. An example of the opposite case is the well active zone feature type, since this zone does not meet the requirements of the definition of the object (more specifically, of a class of objects), and, as a result, it is only a feature type.

— Is the feature fiat or does it include fiat elements? In the terms analysed here, fiatness is most often closely associated with fuzziness, since in most cases fuzziness is the reason for fiatness, for instance, the fuzziness of a boundary is the reason for fiatness of the course of this boundary.

— Is the feature genuine or partially genuine, that is, do at least some of the criteria serving as the basis for distinguishing it from the surroundings have physical sense? This condition can be met also in the case when only the object, to which this feature pertains, is genuine. An example can be a groundwater table as a partially genuine feature and a hydrogeological unit as space (spatial feature), which includes a hydrogeological

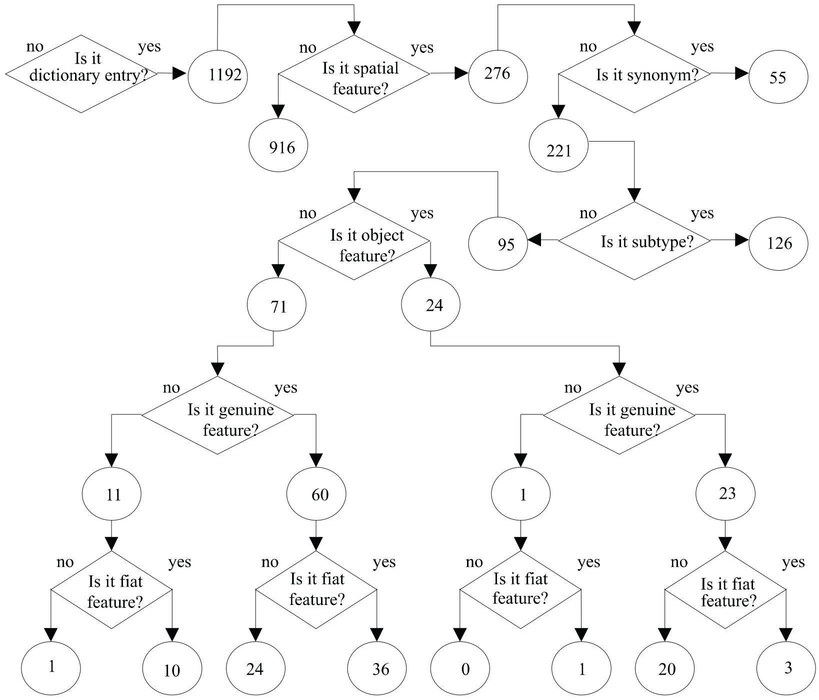

Fig. 1. Selection diagram of Polish "Hydrogeological Dictionary" terms in respect of base types of spatial features

system, understood as a complex hydrogeological object. A non-genuine feature is, for instance, a protection area.

— Is the feature fuzzy? Almost all features that are not associated with objects are fuzzy features in hydrogeology, and vice versa — almost all object features are sharp (non-fuzzy).

— Is the feature complex? A complex feature consists of other features, for instance a groundwater formation or a pumping test set of wells.

— Is this a base type of feature? That is, is it possible to divide it into subtypes? For instance, a hydrogeological zone can be horizontal (zone of groundwater flow) or vertical (saturated zone), and the vertical hydrogeological zone can have many subtypes — in this case, there are 13 of these. There are 8 subtypes of horizontal zones. Nesting of subtypes in such cases creates a hierarchical structure.

— In addition, the spatial dimensionality of individual feature types was analysed. Is the feature distinguished from 3D, 2D or 1D space? Is the feature 0D (e.g. point), 1D (e.g. line), 2D (e.g. surface) or 3D (e.g. solid)? In this case, the condition, according to which the feature cannot be characterised by a greater number of dimensions than the space with in which it is distinguished, applies.

Graphical results of this analysis, limited, for the sake of clarity of the diagram, to the first two questions, are presented in Figure 1. The criteria included in all questions, listed above, allow for grouping of all 95 types of features, and as a result 52 feature groups are obtained. As many as 31 groups include only one feature type, and the 3 most numerous groups include only 6 types. This indicates a great diversity of hydrogeological feature types. Other observations lead to the following conclusions:

— All types of features, related to objects, are distinguished within 3D space, and their dimensionality is very different: 8 point features — 0D, 6 line features — 1D, 1 surface feature — 2D and 9 spatial features — 3D.

— Among non-object features, 50 are distinguished within 3D space, 20 within 2D space and 5 within 1D space. Some of these features are not unambiguously dimensional, that is, they can be distinguished within various spaces: 2D within 3D and at the same time 1D within 2D, e.g. groundwater system boundary or underground watershed can be a surface in space and a line on the surface.

— Most non-object, non-fuzzy features are terms belonging to the area of groundwater dynamics or hydrology.

— 4 object, fuzzy features (more specifically, ones containing fuzzy elements) are water-management systems, health resorts, groundwater circulation systems and hydrogeological systems. If we take into consideration the fact that a health resort is also a complex system, it is possible to assume that fuzziness of objects in hydrogeology pertains only to complex systems. This can be explained by the fact that a complex object consists of an imprecisely stated number of objects, which is the reason for fuzziness.

Due to the particular properties of the subject of geological and hydrogeological research — the lithosphere — in geology and hydrogeology we rather deal with features than with objects. Such geological terms as bed, facies, formation, sediment or fault, as well as hydrogeological terms, such as aquifer and groundwater table, cannot be treated as objects. However, in the computer system, features can be represented by objects as data structures. A number of analyses shows that treating data aggregates, describing geospatial geological and hydrogeological features, as objects, obtains much better results than the application of any other type of data model (Michalak, 1997*a*, *b*). The reason for this is the great diversity and complexity of geological and hydrogeological information.

Examples are the specific types, mentioned above, such as the geological structure model and the borehole datasheet.

FUZZY HYDROGEOLOGICAL FEATURES

Many features that we deal with in hydrogeology are fuzzy features. This fuzziness may pertain to spatial and temporal boundaries, as well as non-geospatial characteristics, typical for a given feature.

Apart from fuzziness that could be described as genuine in hydrogeology, we often deal with apparent fuzziness, resulting from lack of precise information, caused by difficulties in accessing the feature and thus the information regarding this feature. This can be shown by a number of examples:

— A lake most often is not a fuzzy feature, since usually its boundaries are clearly visible, sharp and thus easily determined.

— Wetness is a feature that is easily accessible, but it is difficult to mark its boundaries, since the shift between the wet area and the dry area is often gradual, thus the boundaries cannot be unambiguously set — often the only thing we can be sure of is where the wetness is and where dry ground is. It can be said that this is a genuine fuzzy feature.

— A fossil coral-reef located deep under the ground, is characterised by sharp geospatial boundaries, but access to this feature and to the information regarding the location of its boundaries may be very limited. In many cases, we are only able to tell that there is the reef in one location, and that there is no reef in another. The probability of existence of reef at points lying on the line connecting these two locations is a continuous linear function, and on the basis of this we can say that our knowledge, regarding the position of the boundary, is fuzzy. This situation is similar to the genuine fuzzy feature, but the reason here are the difficulties in accessing information, regarding the position of the boundary, which is not fuzzy, but it is not directly accessible for observation. This can be regarded a case of apparent fuzziness.

— Often in hydrogeology we have to deal with simultaneous genuine and apparent fuzziness. An example can be an aquifer, located at great depth, and often in such cases the horizontal extent of this aquifer is both apparently and genuinely fuzzy. Genuinely, since the stratum may end in a certain location due to gradual lithological changes, and apparently, when we have no direct access to the location, in which these changes take place.

HYDROGEOLOGICAL FIAT FEATURES

Fiatness, like fuzziness, can pertain to spatial and temporal boundaries, as well as to non-geospatial characteristics typical of a given feature. Fiatness, in this case, means the arbitrary definition of something that does not exist objectively in reality, but without it something that exists in reality cannot be properly defined or classified. Fiatness often pertains to the relation between a geospatial feature and something else, e.g. a non-geospatial object. Examples of fiat boundaries are horizons, boundaries of administrative units or boundaries of geodetic parcels. A good illustration is the case of a sea gulf. On the land side, the gulf is limited by a genuine, sharp boundary — the shoreline, but on the open sea side, there is no genuine boundary. Therefore, some arbitrary line is defined, which separates the gulf from the open sea. This is a typical example of a fiat boundary.

In hydrogeology, as in geology, most spatial boundaries are fuzzy, which is caused either by actual fuzziness of these boundaries, or by a lack of information regarding their actual position (apparent fuzziness), or by the necessity to separate a part that is not clearly defined from some entity. The method of determining such boundaries depends mainly upon the feature type and the knowledge that we have with regard to this feature. The most popular hydrogeological fiat features are, among others, subtypes derived from the primary type “area of (x) of groundwater”, e.g. area of (deficit) of groundwater, area of (protection) of groundwater *etc*. This group also includes all 21 subtypes of zones, e.g. zone of influence of a well and many other, such as depression cone, groundwater deposit, hydrogeological region and groundwater province.

FEATURE AS A COMPONENT OF HYDROLOGICAL INFORMATION CONCEPTUAL MODEL

The analysis presented here was conducted as part of preliminary work within the confines of the 9 T12B 025 18 research project, entitled structural and functional basic model for object systems of geospatial information in hydrogeology, based upon OpenGIS specification, CORBA and UML language. Its objective is to determine the types and subtypes for data aggregates that should be included in the data model. Assumption of object-orientation, based upon the paradigm derived from UML (Unified Modelling Language) for this model, results in the necessity of representation of non-object features (in accordance with the meaning adapted by geomatics) as objects corresponding with them, understood as programming entities (in accordance with the meaning provided in the definition of object, given above). In this sense, base types and subtypes of features are represented by base classes and derived classes of objects. As a consequence, a feature is treated as an instance of a feature type, and an object is an instance of a class.

Design and construction of hydrogeological information systems is now a necessity. For proper functioning of these systems, it is necessary to create them in accordance with widely accepted international standards and specifications (Michalak, 2001*b*). Therefore, the base model developed here will be based upon current work of the OpenGIS Consortium and adapted for normalisation purposes by the Technical Commitee ISO/TC 211 (Kuhn, 1997). The norms worked out by ISO/TC 211 will be adapted as European norms, and, as a consequence, as has been announced by the Polish Normalisation Commitee, they will also become Polish norms (Chowańska-Szwoch, 2000). One of the basic methodological problems is application of the XML metalanguage (eXtensible Markup Language) to hydrogeological information (Michalak, 2000*a*). However, these works and the related norms pertain only to the geospatial aspect, and the remaining, non-geospatial aspects of the base model, which are typical of hydrogeology, require application of solutions worked out and agreed upon by the hydrogeological community (Michalak, 1997*a*). From the point of view of computer science, this community is understood as the hydrogeological information community in the sense specified in the OpenGIS Abstract Specification (The OpenGIS..., 1999).

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