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A Design of a Hydrological Database for the EU Water Framework Directive

Stefanía Guðrún Halldórsdóttir

Prepared for The University of Iceland, The Icelandic Centre for Research and The National Energy Authority

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Abstract:

The connection between geographical information and scientific data in a modern database system is becoming very sophisticated. The geographical data are kept in a relational database connected to all kinds of other data. The Water Framework Directive (WFD) is a EU legislation that requires all inland and coastal waters to have reached “good status” by 2015. It addresses inland surface waters, estuarine and coastal waters and groundwater.

In this thesis the Water Framework Directive will be considered as the requirement for a hydrological database. The database consists of geographical data, representing the hydrological network and actual hydromorphological data.

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ÚTDRÁTTUR Á ÍSLENSKU

Þetta verkefni snýst um gerð gagnagrunns með þarfir íslenskra stjórnvalda í huga. Markmiðið með því verkefni er að hanna landfræðilegan og vatnafræðilegan gagnagrunn með tilliti til Vatnatilskipunar Evrópusambandsins. Gerð er grein fyrir hvers konar landfræðileg gögn eru nauðsynleg til þess að hægt sé að framfylgja Vatnatilskipuninni. Gögn sem til eru, eru borin saman við tilskipunina og gerð grein fyrir hverju þurfi að bæta við, hvað þurfi að laga og hvað sé hægt að nota óbreytt. Vatnafræðilegur gagnagrunnur er tengdur staðfræðilegum gagnagrunni og búið til landfræðilegt upplýsingakerfi er þjónar framangreindum markmiðum.

Vatnakerfi í landfræðilegum gagnagrunni þurfa að hafa vissa eiginleika til þess að hægt sé að nota þau í Vatnatilskipuninni og við vatnafræðilegar greiningar. Sýnt er í þessari ritgerð hvernig hægt er að tengja saman landfræðileg gögn og vatnafræðileg gögn í gagnagrunni. Ætlast er til þess að framsetning gagna vegna Vatnatilskipunarinnar fari mikið til fram á kortum, en nú um stundir eru stafræn kort nátengd gagnagrunnum þar sem landfræðileg gögn eru geymd í vensluðum gagnagrunni, og tengd vatnafræðilegum gögnum þar.

ABSTRACT

The connection between geographical information and scientific data in a modern database system is becoming very sophisticated. The geographical data are kept in a relational database connected to all kinds of other data. The Water Framework Directive (WFD) is a EU legislation that requires all inland and coastal waters to have reached “good status” by 2015. It addresses inland surface waters, estuarine and coastal waters and groundwater.

In this thesis the Water Framework Directive will be considered as the requirement for a hydrological database. The database consists of geographical data, representing the hydrological network and actual hydromorphological data.

In chapter one there will be an introduction to the project, and to the test area.

The second chapter provides an overview of the database theory, database design and the database system used for the hydrological database.

The third chapter is about the objectives of the Water Framework Directive.

In the fourth chapter the implementation of an integrated river basin management is discussed. Further, it considers the river basins and sub-basins, and the database design for the river basin system.

In the fifth chapter the process of identification of water bodies is described. It discusses the requirements for the hydrological network in the geographical database, and to what degree the existing data meet these requirements.

The sixth chapter presents the general scientific data model, and how information and knowledge are linked to the data.

In chapter seven some conclusions are drawn. It is also discussed in this chapter how the database can be used in the future, and what has to be done to maintain a hydrological database with both scientific data and consistent hydrologic network.

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1 INTRODUCTION

The Water Framework Directive (2000/06/EC) is considered one of the most important environmental directives of the European Union (EU). Iceland’s day-to-day relationship with the EU is governed by the European Economic Area (EEA) agreement. It is expected that the Water Framework Directive (WFD) will become part of the EEA agreement [1].

A Common Implementation Strategy for the WFD (known as the CIS) was agreed upon by the European Commission, Member States and Norway in May 2001. The aim of the CIS is to allow, as far as possible, the coherent implementation of the WFD, whilst focusing on methodological questions relating to achieving a common understanding of the technical and scientific implications of the Directive. Guidance documents, recommendations for operational methods and other supporting information may be developed, but the implementation of the Directive will be the responsibility of the Member State. As such, these documents are informal and non-legally binding in character, but should limit any risks associated with the application of the WFD [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]. Here these documents will be used as a guide in order to design a hydrological database for the WFD.

The objective of this project is to develop an environmental database for a pilot project in Iceland to test the CIS-guidelines, and see how the WFD could be implemented on a catchment’s scale in Iceland. The pilot catchment will be the Ölfusá-Hvítá river basin, and the database will take all accessible data in order to design the database. This spatial database approach provides the opportunity to link all data together on a catchment level, and it will make all analysis of the data easier, for example to employ database technology like data mining as well as providing a decision support system in the context of the WFD.

Figure 1 shows a map of the pilot river basin.

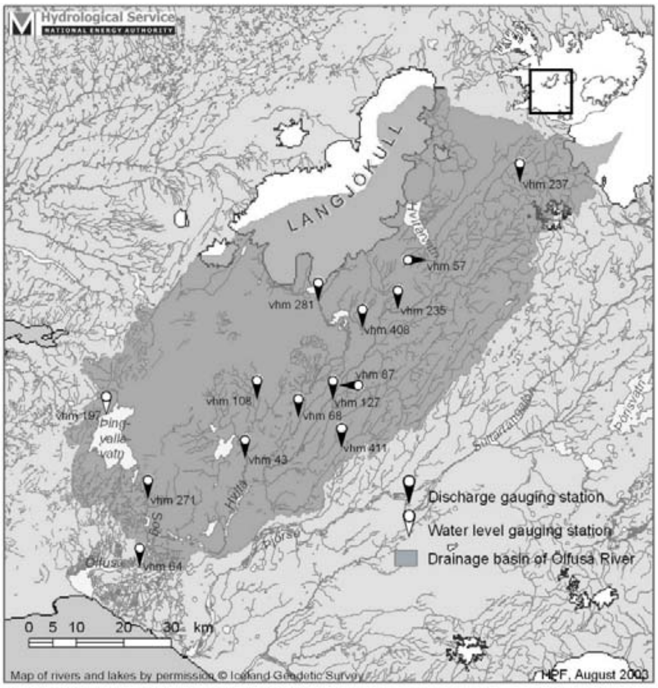


Figure 1: *The pilot river basin in Iceland [12].*

The first step will be to study wether the existing hydrological and geographical data meet the requirements of the Water Framework Directive. The database used in this study is the hydrological database of the Hydrological Service of the National Energy Authority in Iceland [13]. The next step will be to identify what kind of hydrological data is relevant in the context of the Water Framework Directive, and to design a database which includes the required hydrological element. Here it will be considered how the existing hydrological data can be made useful for the implementation of the WFD.

To compare the existing geographical data with the data required by the WFD, data models will be used. To analyze what kind of hydrological data is needed the guidance documents will be used, and then the database will be designed using Unified Modelling Language [14] and relational models [15].

2 DATABASE DESIGN

A primary goal for information technology systems today is to support efforts to manage organizational knowledge. Knowledge is not the same thing as data or information, although it uses both. Data are simple, absolute facts and figures that, in and by themselves, may be of little use. Information is data that have been linked with other data and converted into a useful context for specific use. Knowledge goes a step further; it is a conclusion drawn from the information after it is linked to other information and compared to what is already known. Knowledge, as opposed to information and data, always has a human factor. It is a critical cultural mindset that encourages collaboration and knowledge sharing in order to flourish. History has shown that knowledge management often requires major culture change [16]. An integrated database is, therefore, a fundamental element for knowledge management. The data has to be available, easily accessible and linked together in the database.

Databases are central elements in the using of computers today. Database engineering may be divided into some sub-processes, like domain analysis, requirement specification, design and implementation [17].

Building the database for effective use is not the same as building it as a data storage. It should be possible to read from the system requirement what data will be accessed frequently, what data will only be displayed and which data will be used for processing [18].

3 OBJECT ORIENTED DATA MODELLING

The application of object oriented concepts to databases was stimulated by the problems of redundancy and sequential search in the relational structure. For geographical data their use has been stimulated by the need to handle complex spatial entities more intelligently than as simple points, lines or polygon overlays. In a relational structure, each entity is defined in terms of its data records and the attributes and their values. In object oriented databases, data are defined in terms of a series of unique objects which are organized into groups of similar phenomena (known as object classes) according to any natural structuring. Relationships between different objects and different classes are established through explicit links [19]. Most of the spatial database systems which have been designed for spatial purposes have been built according to the relational approach. However, this approach is not powerful enough to be used as a basis for spatial database systems. Object-oriented benefits comply with the requirements of spatial systems [20]. The object oriented approach allows more complex objects and modelling to be constructed than may be undertaken using a relational network or hierarchical structures and so offers great potential for spatial data handling [19]. Here the object oriented concept will be used to model the data on the conceptual level. First the data is represented in an object-oriented model by using Unified Modeling Language (UML) [14], the UML models will then be translated into relational models for the internal level, that is the actual tables inside the database.

3.1 The UML

The UML [14] is a language for visualizing, specifying, constructing, and documenting the artefact of a software intensive system. UML is based on object oriented programming, and the concept *association* in UML has been used with the name *a relation* in development of database systems for many years. Nearly all the facilities connected to associations in UML have been adapted from database theory. Therefore, UML is well suited for defining database systems [17]. In the guidance document for the implementation of Geographical Information Systems (GIS-CIS)[4] a set of requirements is expressed for geographical information, and here the same standard will be applied. There the UML has become the recommended standard methodology [4].

The data models which aim to satisfy the requirements are primarily in the same way by the Directive itself, but are also based on commonly agreed definitions resulting from discussions in the GIS-CIS [4].

Here classes will be used to show the relation between the objects in the database. There are three kinds of class relationships. An association is a structural connection between classes; it is shown with a straight line that connects them. An association can contain roles, which are the faces that classes present to other classes. An association can show multiplicity. This indicates how many objects associated with each class can be present within the association. The multiplicity expression can take several forms, including the following:

- a fixed value (such as 1 or 3)
- an asterisk (*), which means “many”
- a range of values (for instance, 0...1 or 3...*)
- a set of values (for example 1,3,5,7) [14]

Figure 2 shows examples of an association with roles and multiplicity. In the figure, one river water body can have many river segments and one river segment is assigned to only one river water body.

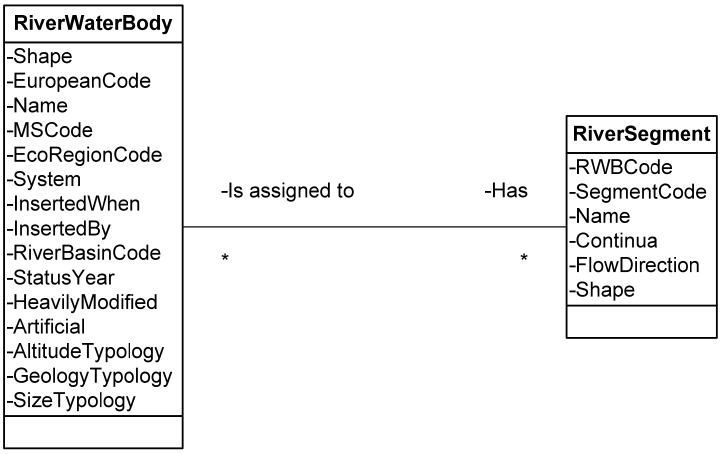


Figure 2: *Association with roles and multiplicity.*

In figure 2 the attributes are shown in the class, but in some models the association is the most important thing in the model, and the attributes are not included.

To show inheritance generalization is used. It refers to a relationship between a general class (the superclass or the parent) and more specific version of that class (the subclass or child). A subclass inherits the attributes and operations from one superclass or from more than one superclass. The UML notation for a generalization is a line with an open triangle at one end. The class next to the diamond is the parent/superclass; the class at the other end of the line is the child/subclass [14].

3.2 The Relational Model

The foundation of modern database technology is without question the relational model; it is the foundation that makes the field a science. The relational model is concerned with three aspects of data; data structure (or objects), data integrity, and data manipulation (or operators). The objects are basically the tables; the integrity portion has to do with primary and foreign keys; and the operators are join, project etc. [15].

3.3 Relations

A relation has two parts, a heading and a body. The heading is a set of attributes, the body is a set of tuples. The relation is defined through keys. The primary key of a relation is just a unique identifier for that relation. However, primary keys are really only a special case of the more fundamental concept candidate key. The candidate key must be unique, and every relation does have at least one candidate key, because relations do not contain duplicate tuples. The reason for candidate keys being so important is that they provide the basic tuple-level addressing mechanism in a relational system. Relations that do not have a candidate key are bound to display strange and anomalous behavior in certain circumstances. It is possible for a given base relation to have more than one candidate key. In such a case, the relational model has historically required that exactly one of those candidate keys be chosen as the primary key for that base relation. If there is only one candidate key, it should be designated the primary key for the base relation in question. Hence every base relation has always had a primary key. The primary key must not have null value and the value must be unique. The relation between two tables is defined through the foreign key and a candidate key. Foreign keys are defined to be sets of attributes. By definition, every values of a given foreign key is required to appear as a value of the matching candidate key. However, the converse is not a requirement; the candidate key corresponding to some given foreign key might contain a value that does not currently appear as a value of that foreign key. That is, a foreign key value represents a reference to the tuple containing the matching candidate key value. Foreign-to-candidate key matches are sometimes said to be the “glue” that holds the database together. The referencing relation is the relation that contains the foreign key and the relation that contains the corresponding candidate key is called the referenced relation [15].

3.3.1 Normalization

A relation is said to be in a particular normal form if it satisfies a certain prescribed set of conditions. For example, a relation is said to be in first normal form (1NF) if and only if it satisfies the condition that it contains scalar values only [15].

If the relational schema is correct, then the table design should be already normalized. However, a brief look at normalization is worthwhile, and in order to evaluate an existing database, the normalization rules must be kept in mind.

A table is normalized, or in first normal form (1NF), if and only if its attributes are single valued and fixed. In other words, a 1NF table has a fixed number of columns, and each entry in a row-column position is a simple value (possibly null).

A table is in second normal form (2NF) if and only if it is in 1NF and every non-key attribute is (functionally) dependent on the whole of a key (not just part of it) [21].

A table is in third normal form (3NF) if and only if, for all time, each tuple consists of a primary key value that identifies some entity, together with a set of zero or more mutually independent attribute values that describe that entity in some way. Two or more attributes are mutually independent if none of them is functionally dependent on any combination of the others. Such independence implies that each such attribute can be updated independently of all the rest [15].

3.4 The Database System

In general, databases fit into one of two categories, online transaction process (OLTP) and decision support systems (DSS), with some overlap inherent in most systems. OLTP databases are characterized by high data change activity, such as inserts or updates, which are typically performed by a large user base. DSS databases are used to generate report information from large volumes of data, and the user population is smaller than in the case of OLTP. The key feature of a DSS system is a fast access to large amounts of data [22]. The database used in this research is both OLTP and DSS, it is an Oracle database with ArcSDE (spatial data engine) from ESRI. The ArcSDE enables GIS products to work with vector or raster data in Oracle. This means that spatial data is stored in the Oracle database engine just like the rest of the organization’s data [23]. ArcSDE is a server software product used to access in a massive way large multi-user geographic databases stored in relational database management systems (RDBMSs). It is an integrated part of ArcGIS, which is an information system for geographic data. Its primary role is to act as the GIS gateway to spatial data stored in a RDBMS[24]. The database system is shown in figure 3.

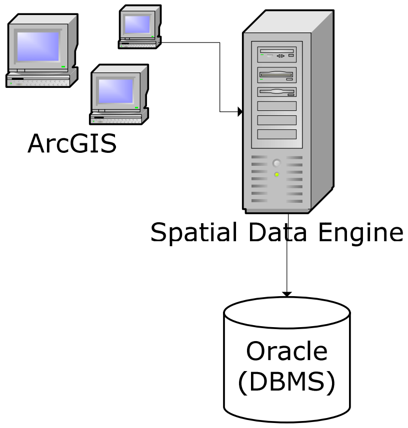


Figure 3: *The database system.*

The important thing about this architecture is that spatial data can be managed through the Database Management System and through the ArcGIS system. Oracle server processes interact with Oracle clients, such as ArcSDE. They are responsible for processing SQL statements and reading and writing user data [22].

4 INTEGRATED RIVER BASIN MANAGEMENT

The WFD is a comprehensive piece of legislation that sets out clear objectives for all waters in Europe, including inland waters, surface water, groundwater and coastal waters up to one sea mile from the coast. The main goals of the WFD are the protection and improvement of the aquatic environment and the contribution to sustainable, balanced and equitable water use. It is an ecological and holistic water status assessment approach; river basin planning; a strategy for elimination of pollution by dangerous substances; public information and consultation and finally, financial instruments [25]. The European Environment Agency's (EEA) reports [26] draw attention to the fact that the general pollution situation has not markedly improved since the 1980s and groundwater as well as smaller water resources are specially threatened by further deterioration. However, the true state of European water resources and aquatic ecosystems is unknown, and the WFD will require an assessment system for the first time, delivering reliable and comparable ecological status data for all waters, regardless of the European region concerned. The Directive aims at achieving good water status for all waters by 2015 [2]. The EEA-EFTA states will have to implement major aspect of the WFD, and it is evident that also Iceland has to prove good status for all waters by 2015 [1]. The key actions each member state needs to take have been declared and the action demands large amount of environmental data and good environmental data management.

In the WFD the river basin district is the main administrative and geographical unit for the management of river basins. Groundwaters and stretches of coastal waters must be associated with a river basin district. Each member state is required to produce a River Basin Management Plan (RBMP). River basin districts are created in such a way as to compose not only the surface runoff through streams and rivers to the sea, but the total area of land together with the associated groundwaters and coastal waters. The RBMPs are the central administrative tools, and the member states are required to ensure that they cover the following elements:

- A general description of the characteristics of the River Basin District, i.e. maps of the location and boundaries of water bodies (surface and groundwater) and of the eco-regions and surface water body types found in the river basin.
- A summary of significant pressures and impact of human activity on the status of surface water and groundwater, including an estimation of point and diffuse source pollution and a summary of land use.
- Protected areas are to be identified and shown in a map form.
- A presentation in a map form of the results of the monitoring programmes for the status of surface water (ecological and chemcial), groundwater (chemical and quantitative) and protected areas. A map of the monitoring networks shall also be included.
- A list of the environmental objectives established under Article 4 for surface waters, groundwaters and protected areas.
- A summary of the economic analysis of water use [16].

Those elements will be used to analyze a water body in order to assign water body ecological status. Whereas the river basin is the geographical area related to the hydrological system, the river basin districts must be designated by the Member States in accordance with the directive as the main unit in the RBMPs, where the water body is a coherent sub-unit in the river basin district to which the environmental objectives of the directive must apply. The identification of water bodies is, first and foremost, based on geographical and hydrological determinants [12].

Figure 4 shows a UML model on how the river basin district is associated with river basins, transitionalwaters and coastal waters, which is identified under Article 3(1) [2] as the main unit for management of river basins [4].

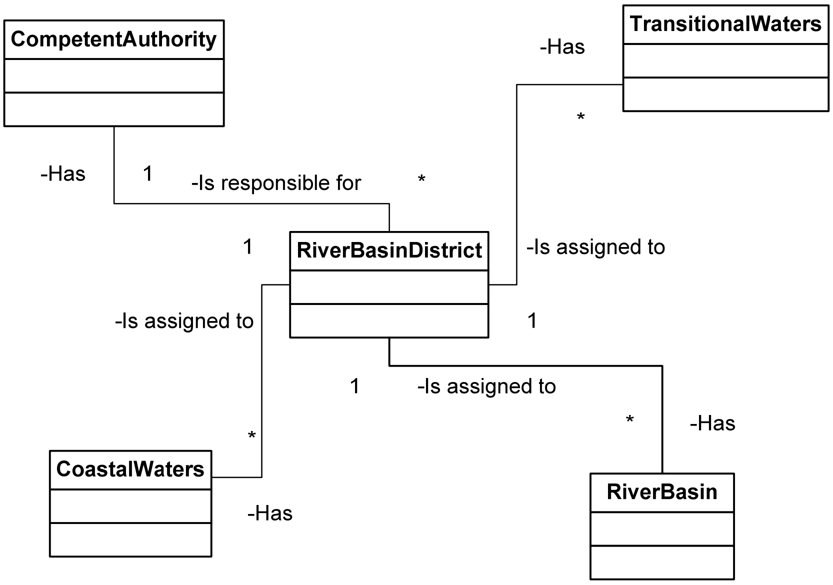


Figure 4: *UML model of how the river basin district is associated with river basins, transitional waters and coastal waters.*

These elements can be polygons in the geographical database, which are linked to the lines and the polygons that represent the rivers and the lakes. Figure 5 shows how the river basin is linked to the river water body and the lake water body.

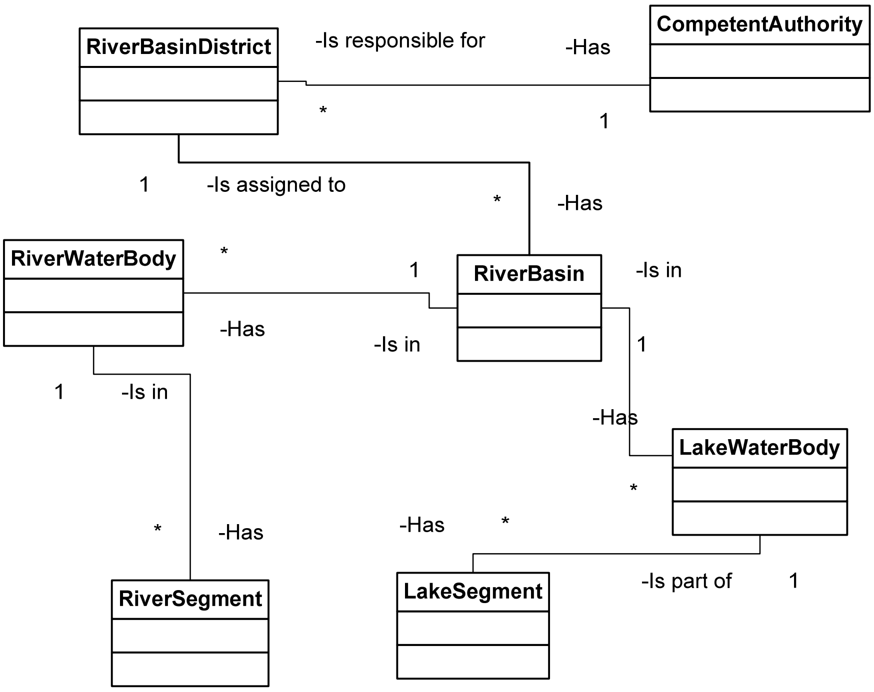


Figure 5: *UML model of the river basin part, and how it is associated with the river water body and the lake water body.*

Each lake water body can have many lake segments and each river water body can have many river segments [4].

In this pilot project river Ölfusá will be one river basin, because the river basin district is an administrative unit, whereas the river basin is a hydrological unit. The river basin districts have not been identified in Iceland. The river basin Ölfusá has several sub-basins, and the river basins used here are defined by the 1.250 000 watershed map of Iceland, which was developed at the Hydrological Service. It is not necessarily always containing the right water boundaries, but it is the best countrywide watershed map available. The river segments are from the database of the National Land Survey of Iceland. Here it will be studied how the existing hydrological database meets the requirements of the concepts shown in figures 5 and 6, and what action has to be taken in order to improve the existing geographical and hydrological data for the Water Framework Directive.

4.1 River Basins and Sub-basins

Runoff occurs when precipitation or snowmelt moves across the land surface – some of which eventually reaches natural or artificial streams and lakes. The land area over which rain falls is called the catchment and the land area that contributes surface runoff to any point of interest is called a watershed. A large watershed can contain many smaller sub-watersheds. The tract of land (both surface and subsurface) drained by a river and its tributaries is called a drainage basin. A watershed supplies surface runoff to a river or a stream, whereas a drainage basin for a given stream is the tract of land drained by both surface runoff and groundwater discharge [27]. In the Water Framework Directive the hydrographical concept of a river basin depends only on topographical conditions: “*the area of land from which all surface runoff flows through*

a sequence of streams and, possibly, lakes into the sea at a single river mouth, estuary or delta" [2].
All the basins and sub-basins taken together fully cover the river basin district. The basins and sub-basins are derived from the hydrological system, whereas the river basin district is designated as the main unit for the management of river basins. While this layer is non-mandatory it provides the basic entities for the river basin management and the presentation of it is recommended. The sub-basin is the area of land from which all surface run-off flows through a series of streams, rivers and, possibly, lakes to a particular point in a water course [4]. Figure 6 shows the relational model of the river basins.

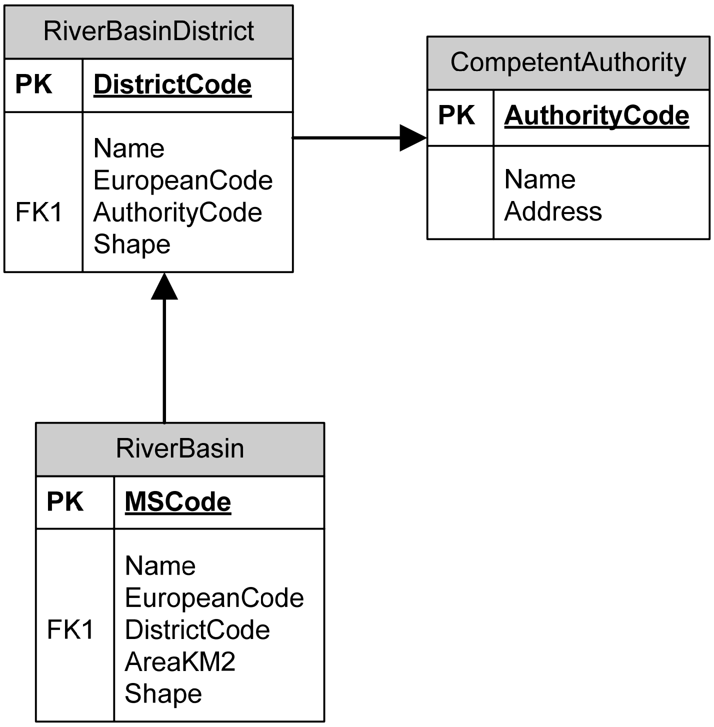


Figure 6: *Relational model of the river basin system [4].*

In the database of the Hydrological Service the river basin system is hierarchical. The catchment is represented by three letters, here called VOD_ID. The first letter indicates one of the four regions, north, east, south and west. The regions are then divided into superclasses, shown by the second letter and finally the catchments are defined by the third letter (figure 7).

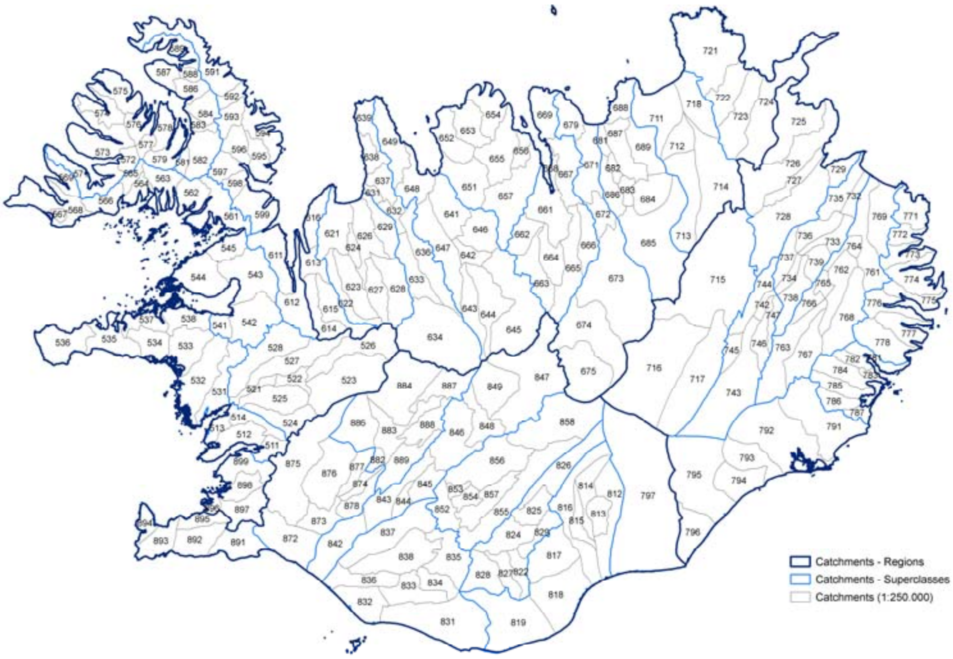


Figure 7: *The river basins.*

The main purpose in the beginning with defining these catchments was to sort the projects that the department was working on. The basics in the division is however river basins, both main-basins and sub-basins. The main rule is that the main basins have nine numbers for its sub-basins and the lowest number in the area. The main-basins are different in size and in some cases the main-basins include eighteen sub-basins (e.g. Þjórsá and Hvítá), but other main-basins have only nine sub-basins [28]. The tables for the River Basin are shown in figure 8.

RiverBasin	
PK	**MSCode**
	Shape Name EuropeanCode DistrictCode AreaKM2

RIVER BASIN	
	OBJECTID AREA VOD_ID SHAPE

Figure 8: *River basin table from the GIS-guidance document[4] compared to the existing RIVER BASIN table in the hydrological database.*

The field VOD_ID can be used as the MSCode, which is a unique code for a river basin within the member state, and the fields shape and area for the geometry are identical. The water body is linked to the parent river basin with the river basin code. The EuropeanCode is a unique code for a river basin at EU level, and the DistrictCode is for the river basin district the basin belongs to. This information will be filled in as the work on the Water Framework Directive progresses.

5 IDENTIFICATION OF WATER BODIES

Within the river basin the water body is a coherent sub-unit that will be used for reporting and assessing compliance with the Directive's principal environmental objectives, but it should be avoided to sub-divide the water bodies to smaller and smaller water bodies. The Directive only requires such sub-division of surface water and groundwater that emerges as necessary for the clear, consistent and effective application of its objectives [12]. The member states shall provide a map for each river basin district illustrating the classification of the ecological status for each body of water [2]. Figure 9 shows the class diagram for the water body. Every UML class becomes a table and every UML attribute in a class becomes a column in a table. The general feature is the abstract class water body, and the groundwater body and surface water body inherit from the WaterBody abstract class. The fresh water body and the saline water body inherit from the surface water body.

The LakeWaterBody and RiverWaterBody classes inherit from the abstract class FreshWaterBody. TransitionalWaters and CostalWaters feature classes inherit from the abstract class SalineWaterBody[4].

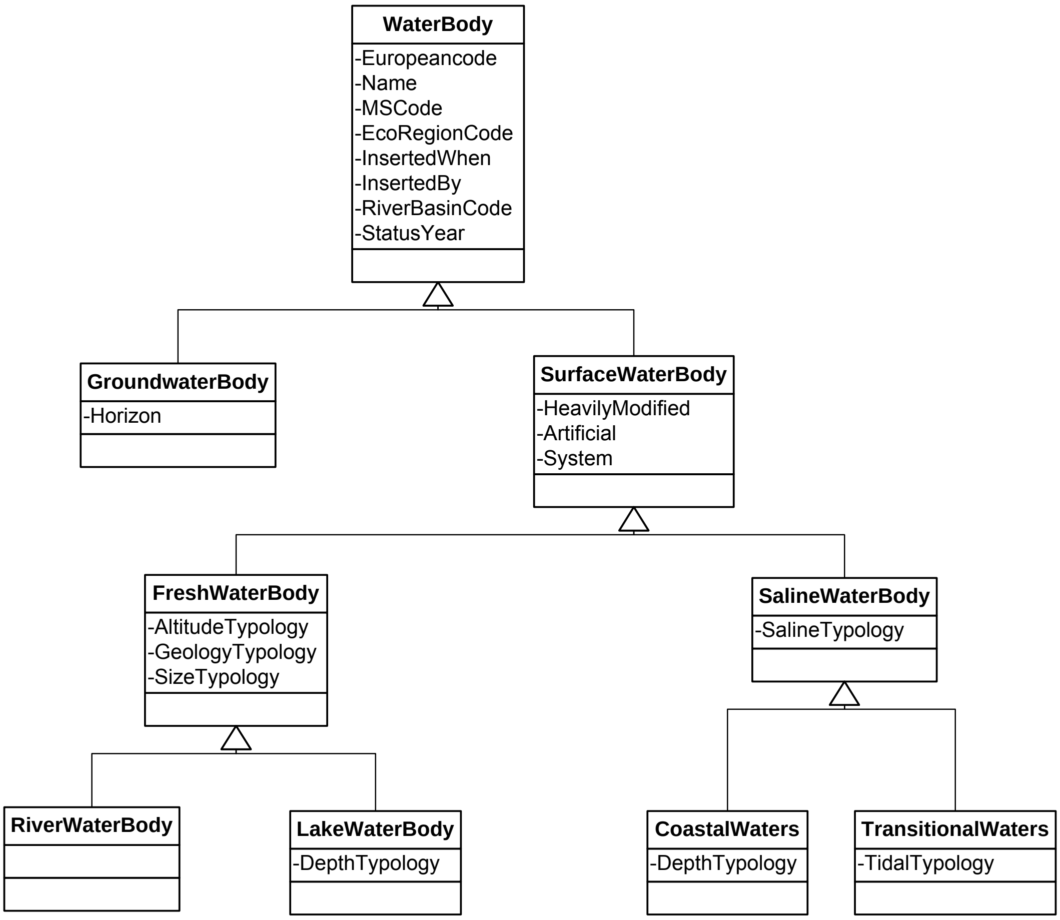


Figure 9: *The class diagram for water bodies.*

Each water body has segments, river segments or lake segments. For the database for Ölfusá, the river basins have already been presented, the river and lake segments exist in the database, but the link between the segments and the river basin is the water body, which has to be identified and created in the database. The coastal water body, the transitional water body and the groundwater body must also be created.

According to the WFD a surface water body can be a lake, a reservoir, a stream, a river or a canal, part of a stream, river or canal, transitional water or a stretch of coastal water. It should be a discrete and significant element of surface water. Water bodies with different characteristics should not overlap, and each water body must be of one category or another. The boundary of a water body may be established where two different categories meet, the categories are rivers, lakes, transitional waters and coastal waters. Physical features like river junctions are also significant, but there are also considerations regarding pressures, impacts and different uses that can be employed for identifying meaningful water body boundaries. In short, a water body must be capable of being assigned to a single ecological status class regarding local circumstances.

The following steps are suggested in delineating surface water bodies:

- Identify the boundaries of the surface water categories, like rivers, lakes, transitional waters and coastal waters.
- Identify the boundaries of the surface water types in each river basin district.
- Identify boundaries using distinct physical features that are (a) likely to be significant in the context of aquatic ecosystem characteristics, and (b) are consistent with the examples of discrete and significant elements of surface water given in the Directive’s definition.
- Identify boundaries on the basis of other relevant criteria.
- Identify as non-heavily modified water body or as heavily modified water body.

This process must be dynamic, and all changes to the environment must lead to a new water body identification process [12]. Figure 10 shows the relational model for the tables that should be present for the freshwater database including their attributes. Tables that are geographical are the RiverSegment, LakeSegment and RiverBasin. The river segment is a line segment and the lake segment is a polygon. Lakes and rivers are termed as LakeWaterBody and RiverWaterBody in the model to allow for the subdivision of individual lakes and rivers into distinct bodies. LakeWaterBody and RiverWaterBody are therefore not a feature class by itself, it is rather a list of the individual LakeSegments (polygons) and RiverSegments (lines) which make it up [4].

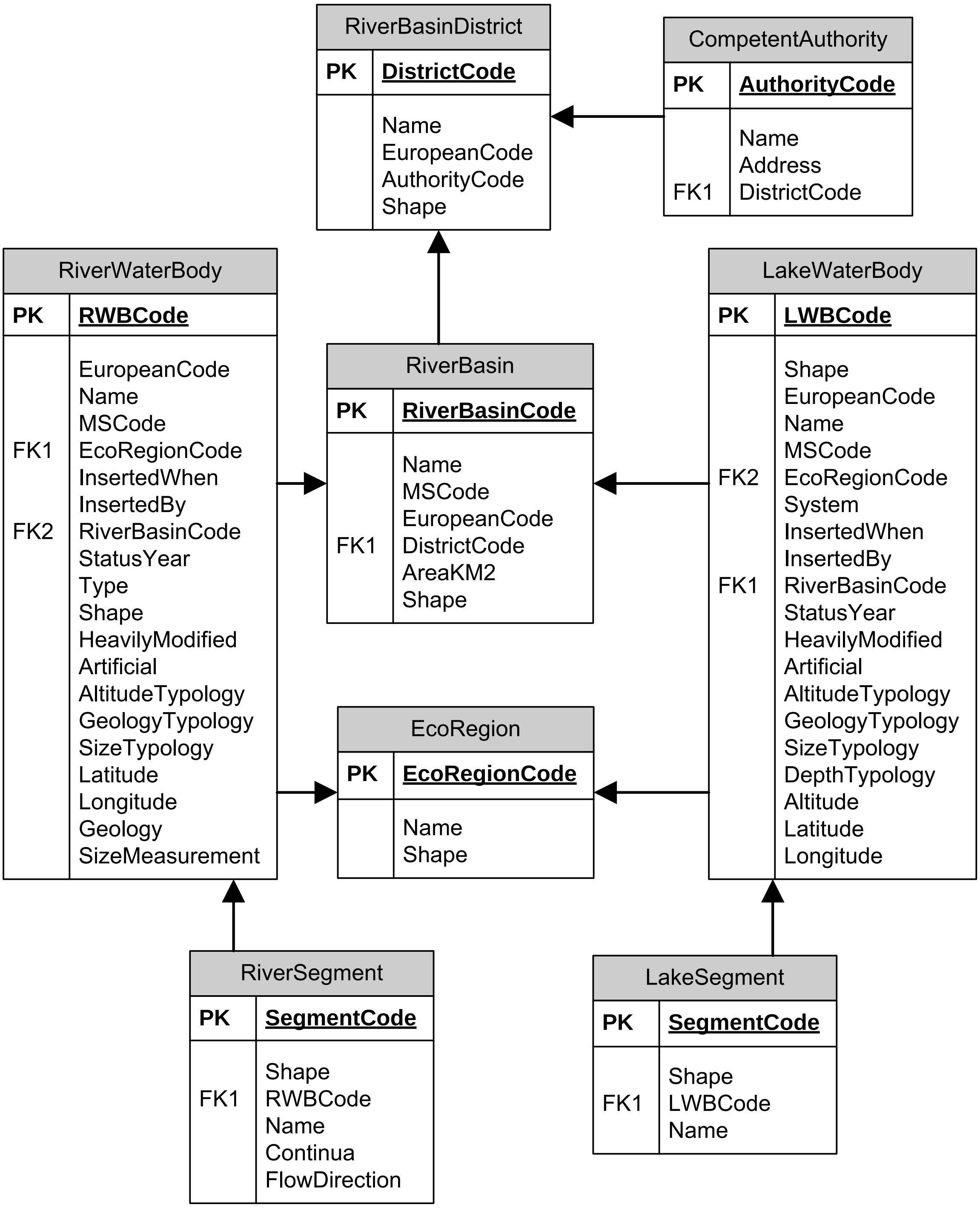


Figure 10: *The relational model for the freshwater database.*

For the purpose of the Directive each river basin is assigned to an individual river basin district. The water body is assigned to the river basin, but since groundwater and coastal water do not fully follow a particular river basin, they shall be assigned to the nearest or most appropriate river basin district [2] (figure 10 and figure 11). A water body must also be assigned a single ecological status, and each river basin district must have a competent authority.

The WFD only requires those subdivisions of surface water and groundwater that are necessary for the clear, consistent and effective application of its objectives.

Subdivisions of surface water and groundwater into smaller and smaller water bodies that do not support this purpose should be avoided. A "water body" must be capable of being assigned a single ecological status [4].
Each groundwater body, transitional and coastal water should be linked directly to the river basin district, as shown in figure 11.

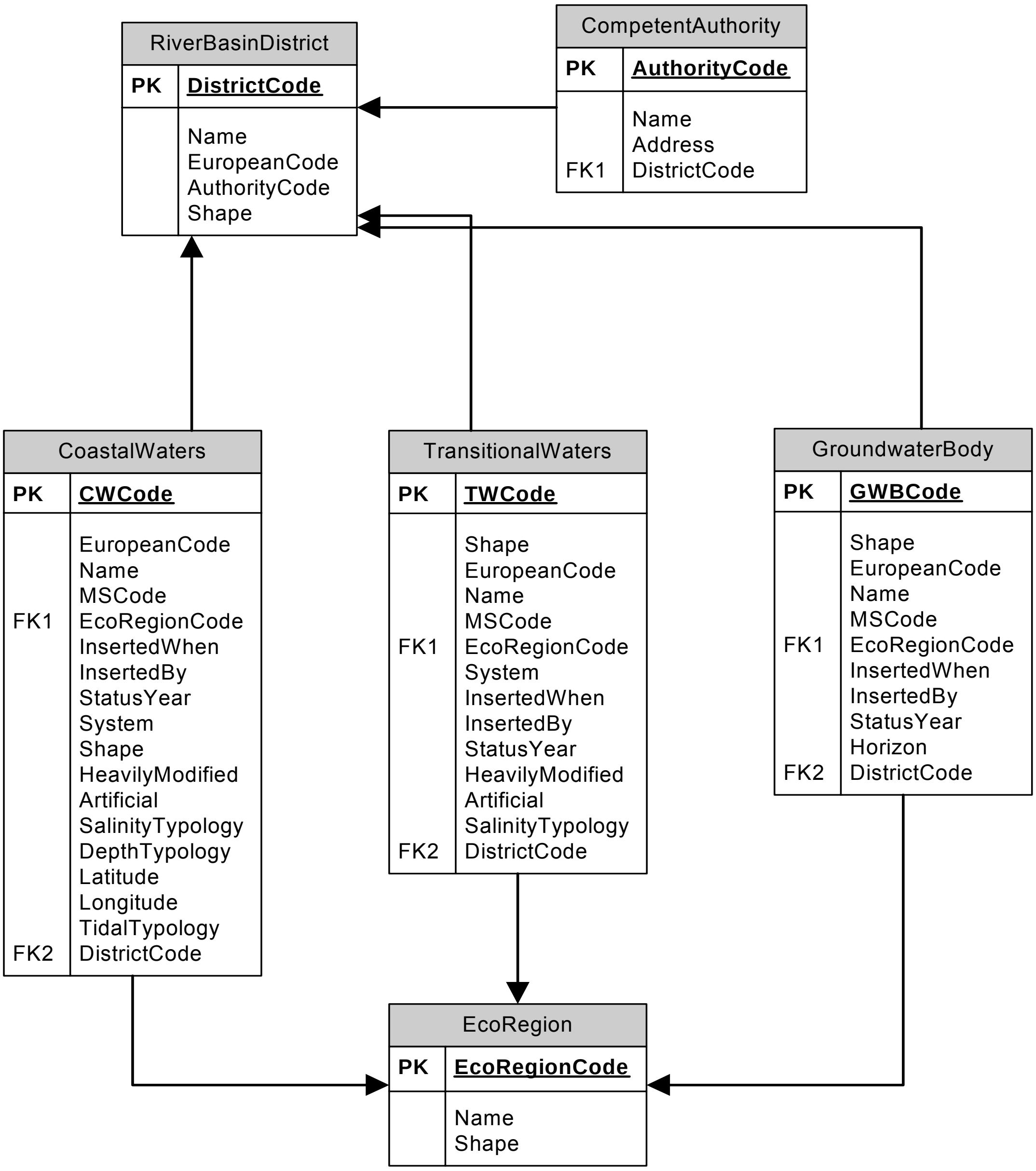


Figure 11: *The relational model for the groundwater body, coastal waters and transitional waters.*

The maps provided for each river basin district must illustrate the ecological status for each body of water in color code, shown in table 1.

Table 1: *Colour code for the ecological status of the water body [4].*

Classification of the body of water	Ecological status classification Colour Code
High	Blue
Good	Green
Moderate	Yellow
Poor	Orange
Bad	Red

Since each water body must have an ecological status assigned, each water body must be presented as a geographical unit [4].

5.1 Identification of river water body

Each river water body may consist of several component river segments. The class RiverWaterBody is therefore not required to be a feature class, instead it is a list of the RiverSegment features which make it up, as shown on figure 12. The river segments are, therefore, simple line features with nodes at the endpoint [4].

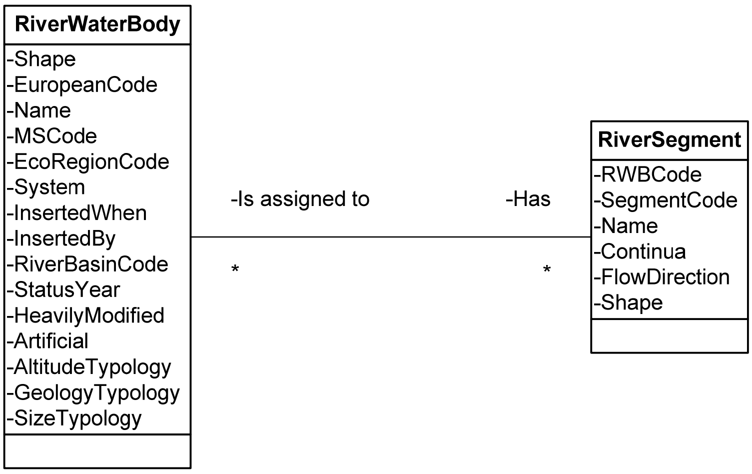


Figure 12: *The river water body can have many river segments.*

The existing river network in the database is at a 1:250 000 scale, originating from the National Land Survey in Iceland. The table in the database that includes the river segment is shown in figure 13 with the corresponding river segment derived from the GIS-CIS [4]. The table RiverSegment is only to identify the information that should be present in the database. The table RIVERSEGMENT is the existing table in the database, to compare what already exists and what is missing (figure 13).

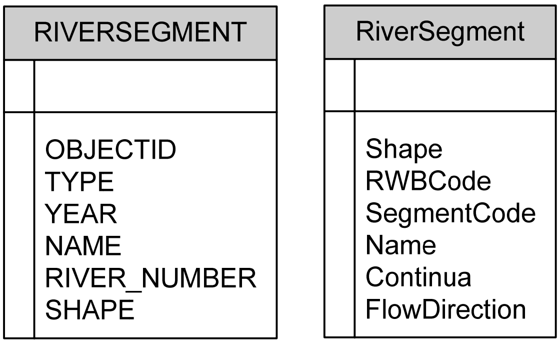


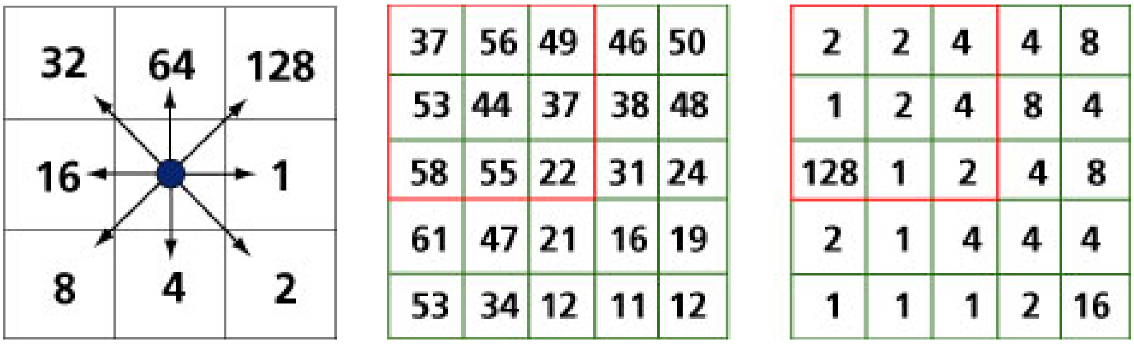
Figure 13: *The table RIVERSEGMENT (derived from VMGIS.BLAD1_9VATN_ARC) represents the existing table in the database. RiverSegment contains the required attributes.*

The RWBCode is a unique code of the river water body to which this segment belongs, and corresponds to the field RIVER_NUMBER in the database. The SegmentCode is the OBJECTID. The Continua field indicates whether the river segment is an imaginary link segment to maintain network topology, for example this would be true if the river segment was only a connection through a lake. The continua do not exist in the database, meaning that the river segments break up if there is a lake between. Neither existing river segments do have flow direction. The network topology, both continua and flow direction must be established in the database in order to use the existing geographical data for the identification of water bodies. This can be obtained by using DEM and software in ArcGIS to assign flow direction to the river segmet presupposing that the river segments are properly joined together. Figure 14 shows river segments without continua and with continua and nodes.

Figure 14: *On the left there are river segments without continua. On the right there are river segments with continua and nodes.*

If there is no continua the river segments do not have an imaginary link, and a network topology is not maintained. The existing river segments do not have nodes, and nodes must be added in order to connect the existing river segments.

The flow direction can be derived from a digital elevation model grid. Water will flow in the direction of the steepest descent, where a slope is defined by elevation decrease per unit travel distance. The flow can be along the diagonal or in the rectilinear directions through the sides of the cell. The flow direction code indicates the cell – out of the eight neighbour cells – towards which the water flows [29]. Figure 15 shows flow direction code on the left, digital elevation model in the middle, and the derived flow direction grid on the right.



37	56	49	46	50
53	44	37	38	48
58	55	22	31	24
61	47	21	16	19
53	34	12	11	12

2	2	4	4	8
1	2	4	8	4
128	1	2	4	8
2	1	4	4	4
1	1	1	2	16

Figure 15: *Flow direction derived from a digital elevation model grid [29].*

The flow accumulation is calculated from the flow direction grid. The flow accumulation grid records the number of cells that drain into an individual cell in the grid. The individual cell itself is not counted in this process. The derived flow direction grid is shown in figure 16 [29].

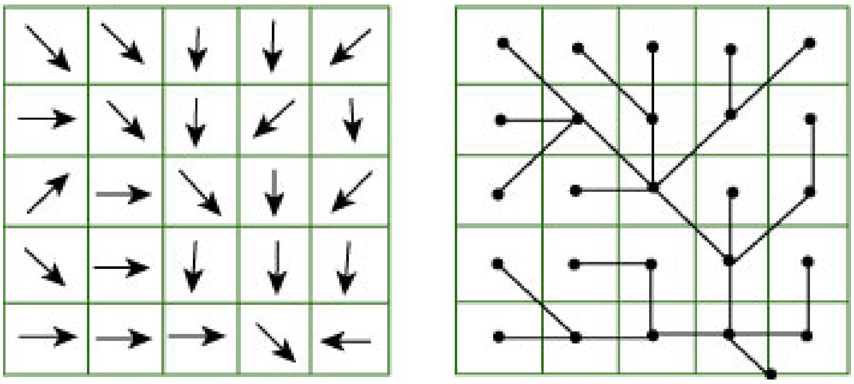
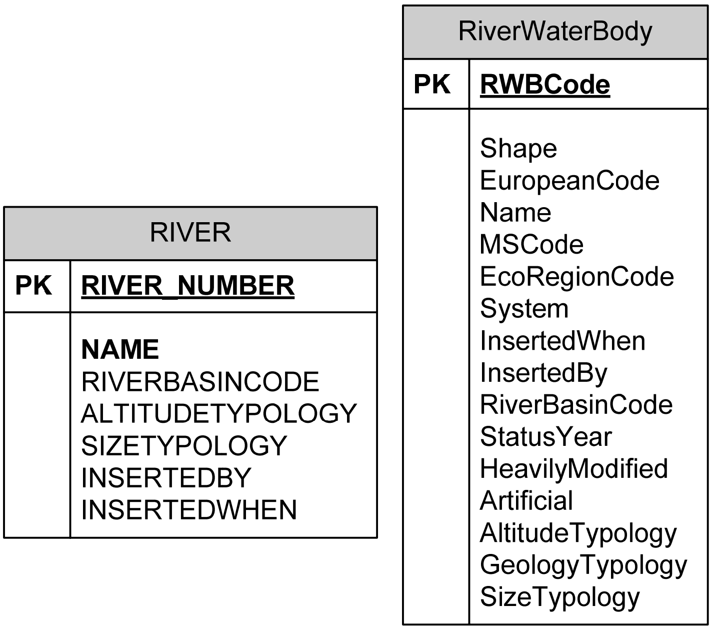


Figure 16: *Physical representation of flow direction grids. The left grid has directional arrows, and the right one shows a flow network [29].*

The database for river segments has not got the required attributes for the WFD. Flow direction, nodes and continua must be added.
The next step is to compare the information needed for the river water body to the information available in the database. Figure 17 compares the data available about the river water body and the attributes required in the WFD for the river water body. The left table RiverWaterBody is only to show what information should be available for the WFD.



RIVER	
PK	**RIVER_NUMBER**
	NAME RIVERBASINCODE ALTITUDETYPOLOGY SIZETYPOLOGY INSERTEDBY INSERTEDWHEN

RiverWaterBody	
PK	**RWBCode**
	Shape EuropeanCode Name MSCode EcoRegionCode System InsertedWhen InsertedBy RiverBasinCode StatusYear HeavilyModified Artificial AltitudeTypology GeologyTypology SizeTypology

Figure 17: *The table RIVER (derived from VM.VATNSFALL) represents the existing table in the database. RiverWaterBody contains the required attributes*

Since the water body is the main unit to be classified on the map of the river basin management, the river water body is a collection of river segments, and information about the river segments, connected to the river basin, which is a polygon. The corresponding table RIVER is a registry from the database of the Hydrological Service. The existing table contains attributes that correspond to the required attributes Name, RiverBasinCode, AltitudeTypology, SizeTypology, InsertedBy and InsertedWhen. The field RIVER_NUMBER contains a unique number for each river, and can be used as the RWBCode. It is a link to the river segment.

Some of the information needed for the river water body can be obtained from the table RIVERS, but there is a lot of information missing, which has to be added for the Water Framework Directive. Each water body should be assigned a single ecological status class regarding local circumstances, and the rivers do not necessarily represent the water body.

Although not all of the required attributes exist in the database, a river water body can be delineated. An example shown in figure 18 is of river Brúará (green) and the river Hvítá (blue).

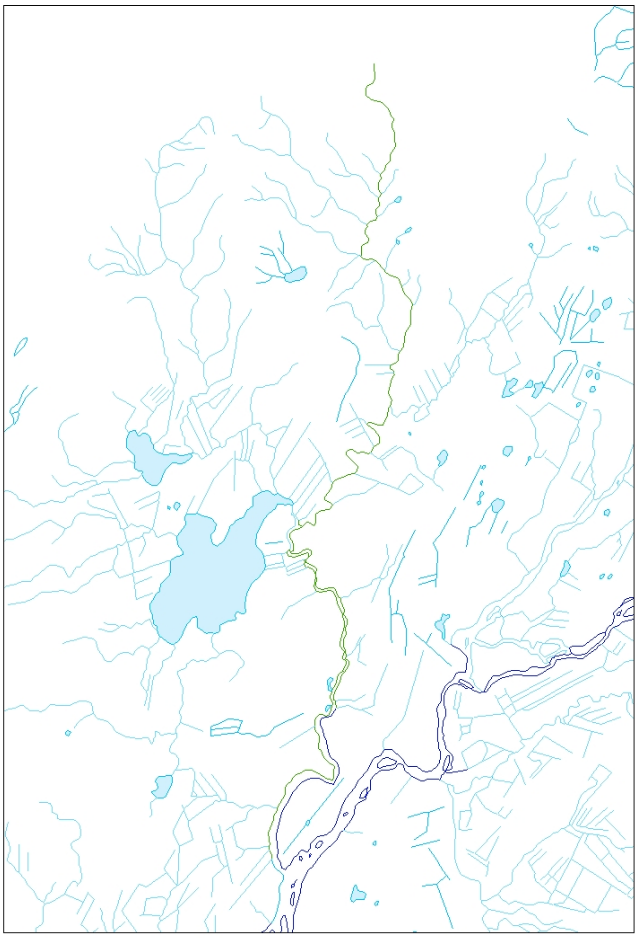


Figure 18: *River water body Brúará is green and river water body Hvítá is blue.*

The river Brúará belongs to one surface water category. Physical features (geographical or hydromorphological) that are likely to be significant in relation to the objectives of the Directive should be used to identify discrete elements of surface water. The boundaries should be identified using distinct physical features that are (a) likely to be significant in the context of aquatic ecosystem characteristics, and (b) are consistent with the examples of discrete and significant elements of surface water given in the Directive's definition. The boundaries can also be identified on the basis of other relevant criteria. Then the river water body must be identified as a non-heavily modified water body or as a heavily modified water body. The river Brúará is a spring fed river, and that is a physical feature that can be used to identify Brúará as a single river water body.

The size typology given in Annex II (System A) implies that rivers with catchment areas greater than 10 km^2 are water bodies that fall under the requirements of the Directive and might need to be included within the water status assessment and monitoring [8].

In the database there are 653 rivers that meet these criteria, shown in figure 19.

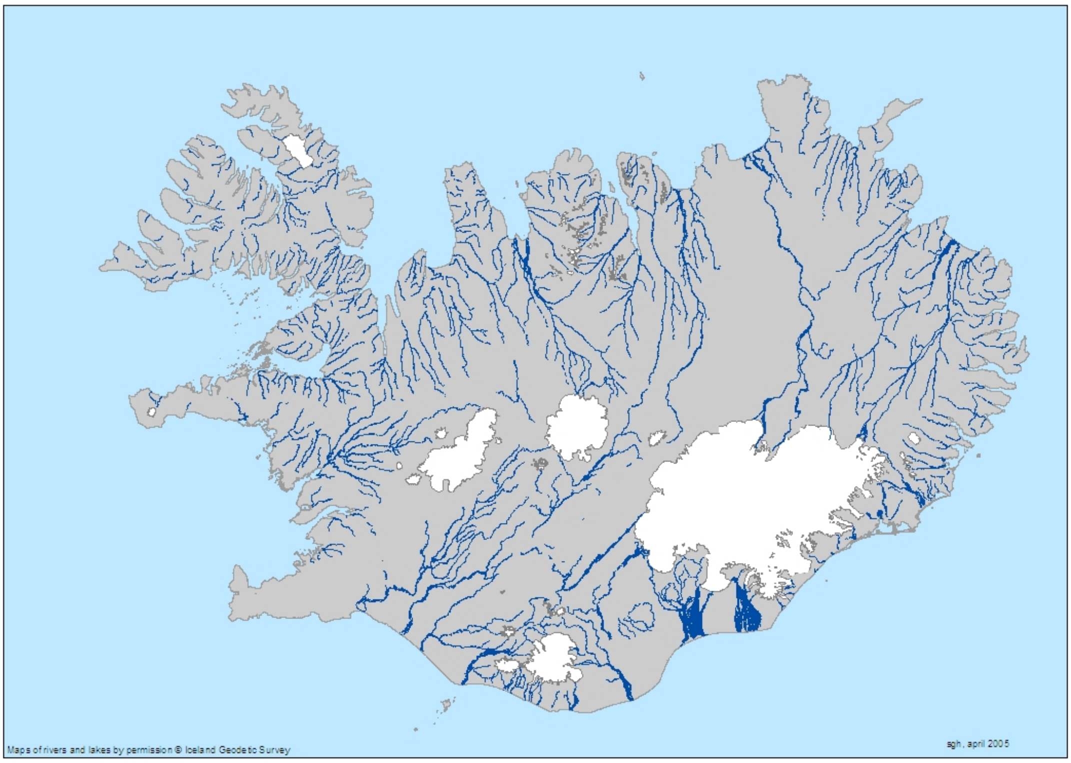


Figure 19: *Rivers with catchment areas greater than 10 km² in Iceland[13].*

5.2 Identification of Lake Water Body

Each lake water body may consist of several component lake segments. The class LakeWaterBody is not, therefore, required to be a feature class, instead it is a list of the LakeSegment features which make it up, as shown on figure 20. The lake segments are, therefore, area (polygon) features, and should have nodes at inlets and outlets, thus providing a connectivity to the RiverSegment (line) features and to any internal "continua" segments defined. This is done via the SegmentCode[4].

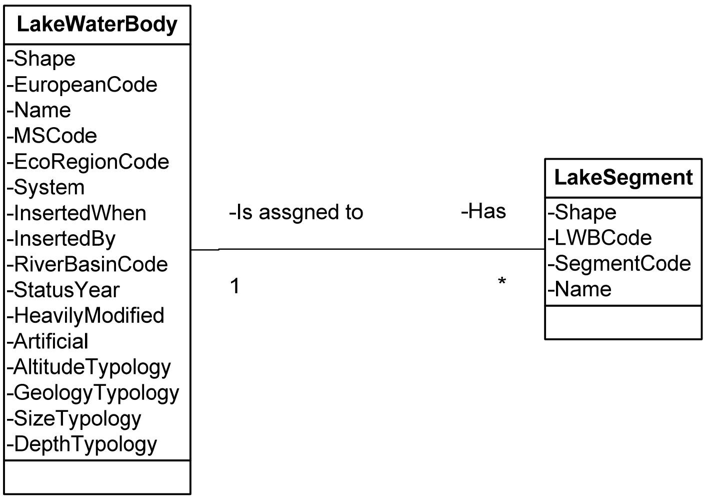


Figure 20: *The lake water body can have many lake segments.*

The existing map of lakes in the database is at the scale of 1:250 000 originating from the National Land Survey in Iceland. The table in the database that includes the lake segment is shown in figure 22 with the corresponding lake segment derived from the GIS-CIS [4]. The table LakeSegment is only to identify the information that is required in the hydrological database for the Water Framework Directive. Figure 21 shows the table LAKESEGMENT, which is the existing table in the database, and the table LakeSegment, which contains the required attributes.

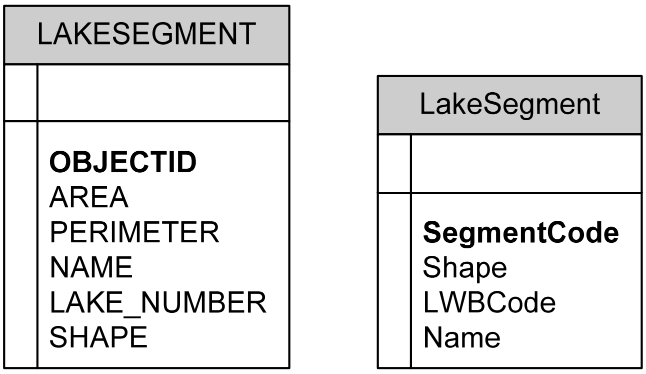
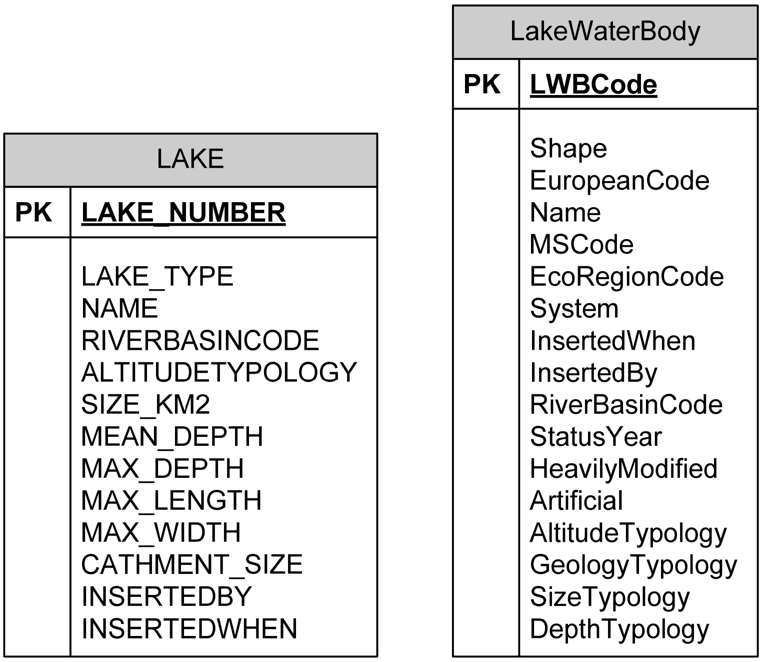


Figure 21: *The table LAKESEGMENT (derived from VMGIS.BLAD1_9ST) represents the existing table in the database. LakeSegment contains the required attributes.*

The LWBCode is a unique code of the lake water body to which this segment belongs, and corresponds to the field LAKE_NUMBER in the database. The SegmentCode is the OBJECTID. The attributes Name and Shape exists already in the database. The requirements for the lake segment are not as many and as complicated as those for the river segments, because the network topology is maintained in the river network. The existing table for the lake segment in the database can be used, and must be linked to the lake water body (figure 22).



LAKE	
PK	**LAKE_NUMBER**
	LAKE_TYPE NAME RIVERBASINCODE ALTITUDETYPOLOGY SIZE_KM2 MEAN_DEPTH MAX_DEPTH MAX_LENGTH MAX_WIDTH CATHMENT_SIZE INSERTEDBY INSERTEDWHEN

LakeWaterBody	
PK	**LWBCode**
	Shape EuropeanCode Name MSCode EcoRegionCode System InsertedWhen InsertedBy RiverBasinCode StatusYear HeavilyModified Artificial AltitudeTypology GeologyTypology SizeTypology DepthTypology

Figure 22: *The table LAKE (derived from VM.STODUVATN) represents the existing table in the database. LakeWaterBody contains the required attributes.*

The lake water body is a collection of river segments, and information about the river segments, connected to the river basin, which is a polygon. The existing table LAKE is a registry from the database of the Hydrological Service. The missing attributes in the database are the geological typology, artificial and heavily modified. The existing information about the depth, the size and the altitude can be used to meet the requirements. The DepthTypology is based on the mean dept and the SizeTypology on the surface area [2]. Figure 23 shows the lakes Laugarvatn and Apavatn that could be identified as two different lake water bodies.

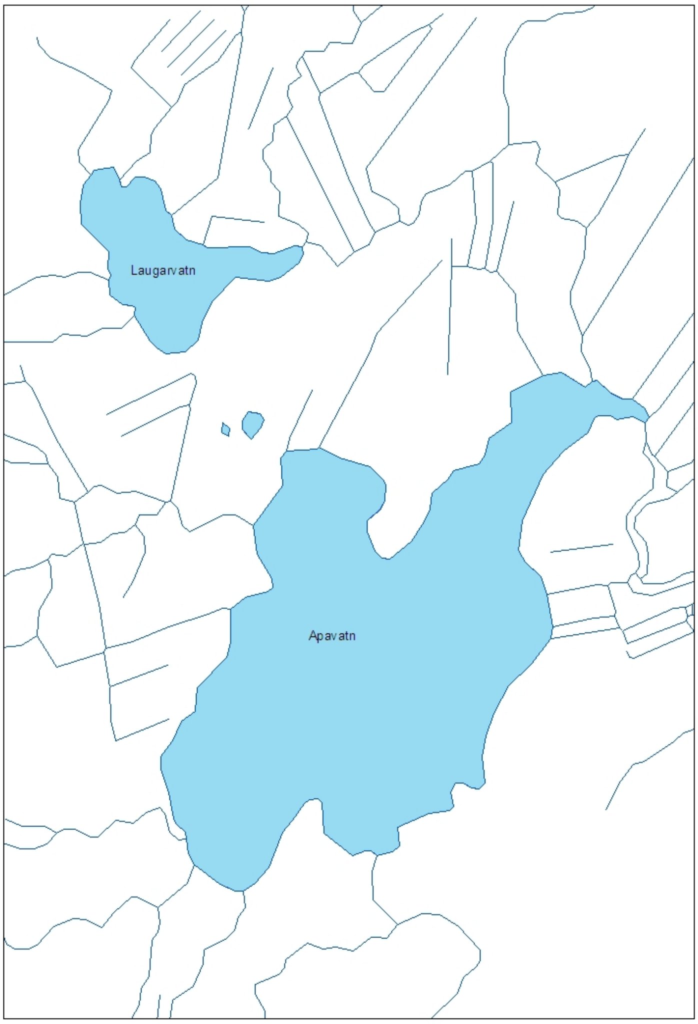


Figure 23: *The lakes Laugarvatn and Apavatn are distinct geographical features in the database.*

The attributes in the database about the lakes Laugarvatn and Apavatn are shown in table 2.

Table 2: *Attributes from the table LAKE in the database [13]*

	Laugarvatn	**Apavatn**
LWBCode	2252	2250
Name	Laugarvatn	Apavatn
InsertedBy	ke	ke
InsertedWhen	20-OCT-97	20-OCT-97
RiverBasinCode	876	876
AltitudeTypology	LOW	LOW
SizeTypology	0,5 to 1 km²	10 to 100 km²
DepthTypology	< 3 m	< 3 m

The existing geographical data and the attribute table for the lakes can be used in the hydrological database for the WFD to identify lake water bodies.

The size typology given in Annex II (System A) implies that lakes greater than 0.5 km^2 in surface area are water bodies that fall under the requirements of the WFD and might need to be included within the water status assessment and monitoring [8].

In the database there are 360 lakes that meet these criteria. They are shown in figure 24.

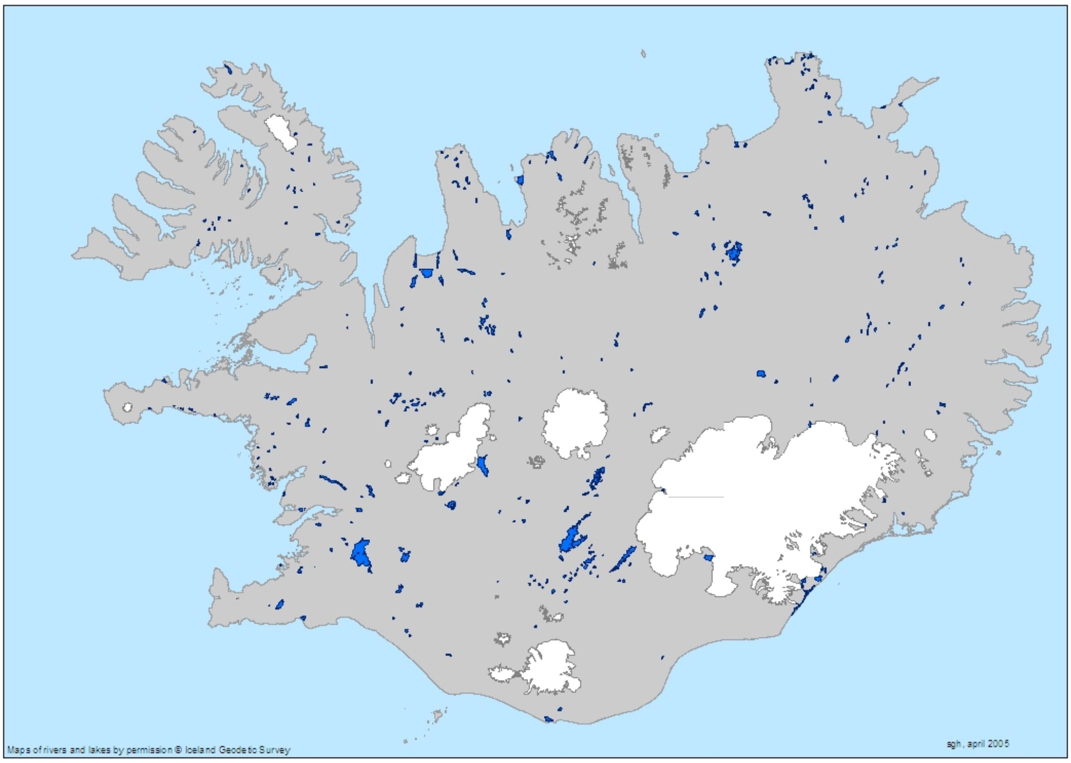


Figure 24: *Lakes greater than 0,5 km*^{2} in surface area in Iceland (13).

5.2.1 Identification of Bodies of Groundwater, Transitional Waters and Coastal Waters

One key purpose of the WFD is to bring the member states to prevent further detoriation of, and to protect and enhance the status of aquatic ecosystems. They have to recognize their water needs, and become conscious of how the terrestrial ecosystems are directly dependent on aquatic ecosystems. The first step in the identification of the bodies of groundwater requires a general interpretation of the term aquifer, in respect to what constitutes a significant flow of groundwater and what volume of abstraction would qualify as a significant quantity. Figure 25 shows how this could be identified. It is necessary to take geological characteristics of the area into account when defining groundwater flow. A Member State may wish to deliniate a water body boundaries that coincide with the boundaries between the geological strata, but then it must ensure that the assessment of the quantitative status will not be affected. Unlike surface water bodies, the delineated boundaries of groundwater will rarely coincide exactly with river basins. Therefore, groundwater bodies must be assigned to a river basin district [12]. This must be achieved through a relationship in the database.

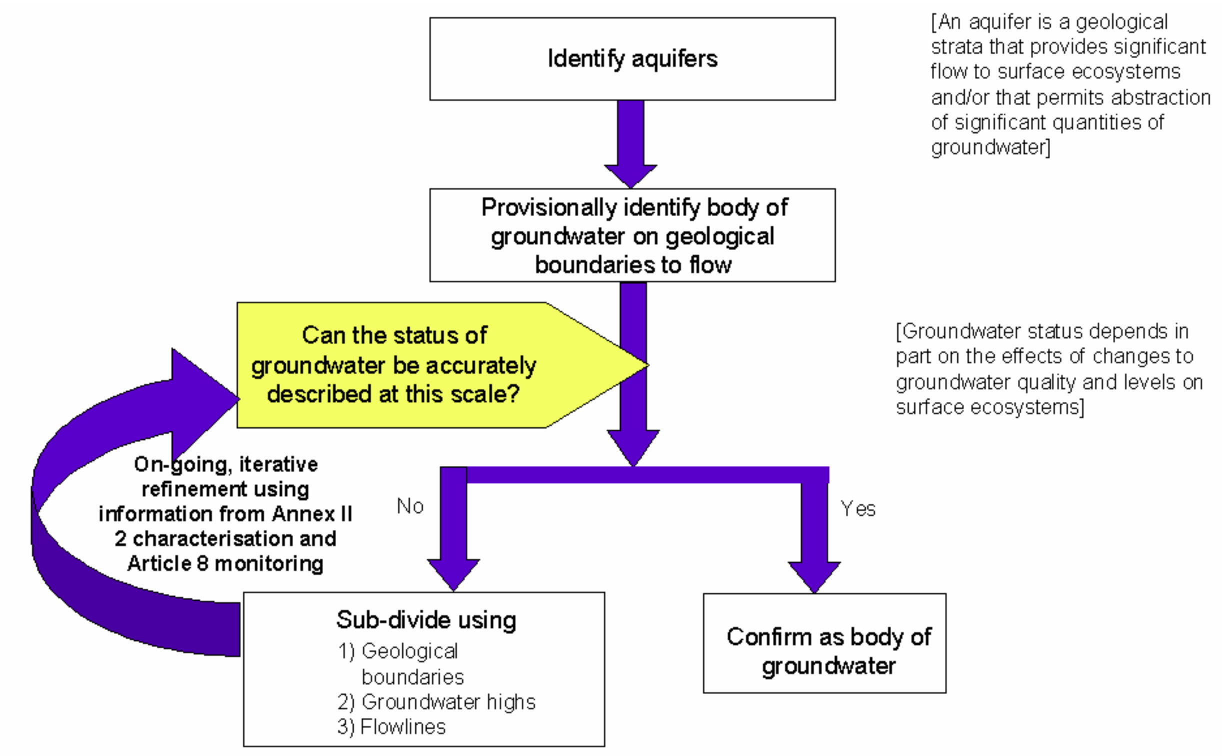


Figure 25: *Summary of the suggested hierarchial approach to the identification of bodies of groundwater [12].*

The groundwater body feature class inherits from the WaterBody abstract class (figure 10). Body of groundwater means "*a distinct volume of groundwater within an aquifer or aquifers*". The Member State must provide information on pressures, overlying strata and dependent surface water and terrestrial ecosystems. Information on geological and hydrogeological characteristics must be provided if the groundwater bodies are considered to be at risk. The model presented in the GIS-CIS is 2-dimensional (i.e. planar) polygon features. The boundaries of groundwater will rarely coincide exactly with river basins, but must be assigned to a River Basin District. The groundwater body in the database is only an example, it must be assigned the attributes according to the GroundwaterBody in the water framework directive. The table THINGV_BERGLEKT has the name of the groundwater body, it should be placed with all other groundwater bodies in Iceland in one layer, hence one table. The only groundwater bodies available in the database at the present are from Thingvellir and Skagafjordur. Here the example from Thingvellir will be used (figure 26 and figure 27).

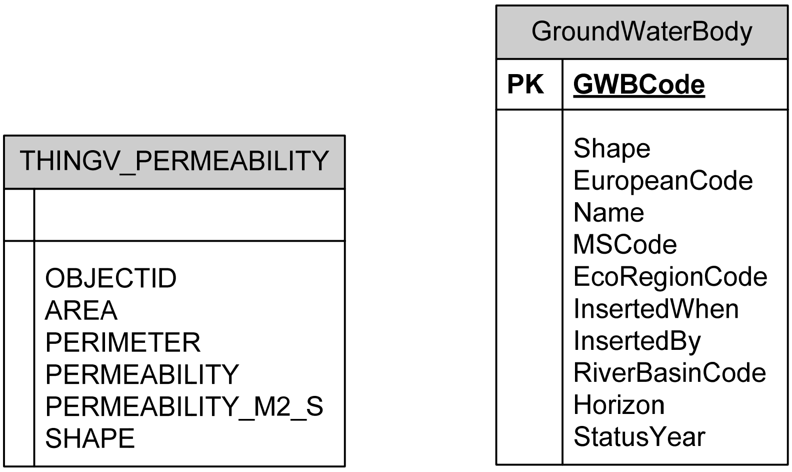


Figure 26: *The table THINGV_PERMEABILITY derived from VMGIS.THINGV_BERGLEKT) represents the existing table in the database. GroundWaterBody contains the required attributes.*

The existing table does not have the information about horizon, as required in the WFD. The horizon is a unique identifier for the horizon, where separate, overlying bodies exist. The geographical unit groundwater does not have to be homogeneous in terms of its natural characteristics, or the concentrations of pollutants or level alterations within it.

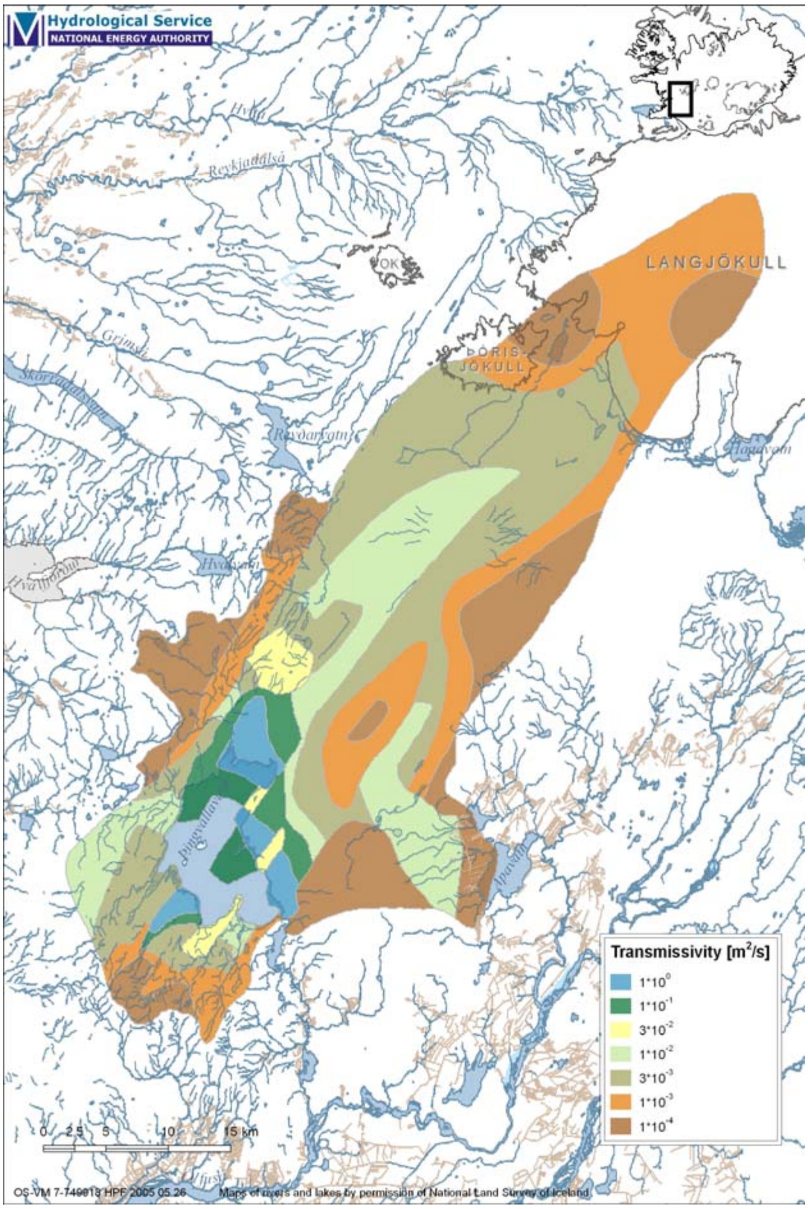


Figure 27: *The transmissivity in the Thingvellir area [13].*

The groundwater bodies should be delineated in a way that enables an appropriate description of the quantitative and chemical status of groundwater [12]. Thus, the table for the groundwater body must be connected to the status and the monitoring station. This connection is shown in figure 28.

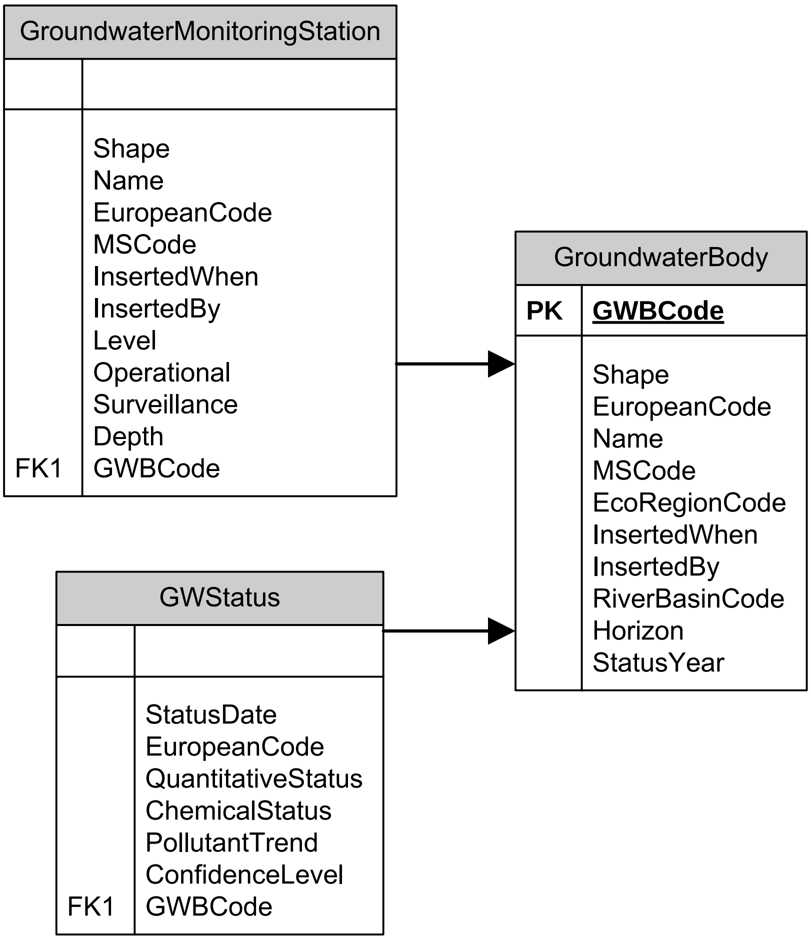


Figure 28: *The relational model of the groundwater monitoring station, the groundwater body and the groundwater status*

For groundwater a water level monitoring network is required which will provide a reliable assessment of the quantitative status of all groundwater bodies or groups of bodies including an assessment of the available groundwater resource. The level gauge network alone will not be able to achieve this assessment. In terms of groundwater chemical status, surveillance and operational monitoring are required. An additional objective of groundwater surveillance and operational monitoring is to provide information that can be used in the assessment and in establishing the presence of long term trends in pollutant concentrations. Surveillance monitoring data should also be used to assess long term trends in natural conditions [8]. The volumes and flow rate are determined by the geology of the region. The character and arrangement of rocks and soils are important factors, and these are often highly variable within a groundwater reservoir. Groundwater protection and management practices must be based on an understanding of groundwater sources, the manner in which groundwater is distributed below the earth’s surface, geologic, topologic, and soil characteristics of the region, and the interconnections between groundwater and surface water sources [27]. The Water Framework Directive states that there is need for a greater integration of qualitative and quantitative aspects of both surface waters and groundwaters, taking into account the natural flow conditions of water within the hydrological cycle. It also states that the quantitative status of a body of groundwater may have an impact on the ecological quality of surface waters and terrestrial ecosystems associated with that groundwater body [2].

According to figure 26 (flow diagram), the first step is to identify the aquifers. The Directive's definition of an aquifer requires two criteria to be considered in determining whether geological strata qualify as aquifers. If either of the criteria is met, the strata will constitute an aquifer or aquifers. The criteria are:

- Could > 10 m^3 a day as an average, or sufficient to serve 50 people, be abstracted.
- Would removal of groundwater flow result in a significant diminution in the ecological quality of a surface water body or a directly dependent terrestrial ecosystem [12].

In the database there is no object for aquifers, they must be identified on digital maps in the database.

Shared groundwaters must be assigned only to one River Basin District. The assignment of groundwaters has to be done to the nearest or most appropriate river basin district while coastal waters could be assigned to one or several districts [7]. Transitional waters are "bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows". Transitional waters will typically be estuaries, and modelled as polygon features. The use of river segments (as lines), to reach as far as coastal outlets, will maintain the network connectivity. The river coding system will extend to marine waters and will maintain hydrological connectivity relationships. Those river reaches, which are wholly within the transitional waters area, can be assigned database attribute values to identify them as transitional [4].

Coastal water means "*surface water on the landward side of a line, every point of which is at a distance of one nautical mile on the seaward side from the nearest point of the baseline from which the breadth of territorial waters is measured, extending where appropriate up to the outer limit of transitional waters "[2].*

Lakes, coastal waters and transitional waters are hydrologically connected through river networks [4].

The transitional and coastal waters are not a geographical object in the database as rivers and lakes, and must be identified on digital maps.

6 DATA FOR NORMATIVE DEFINITION OF ECOLOGICAL STATUS CLASSIFICATIONS FOR LAKES AND RIVERS

The WFD requires surface water classification through the assessment of ecological status. Biological as well as supporting hydromorphological and physico-chemical quality elements are to be used by Member States in the assessment of ecological status. Classification of ecological status is to be based on ecological quality ratios, which are derived from biological quality values. Figure 29 shows how the ecological status can be assessed for the supporting elements. To classify ecological status, the Directive stipulates that the lower of the values for the biological and physico-chemical monitoring results for the relevant quality elements should be used. This implies that Member States will need to establish methods/tools for assessing ecological status for both the biological and physico-chemical quality elements. Biological as well as supporting hydromorphological and physico-chemical quality elements are to be used by Member States in the assessment of ecological status [3].

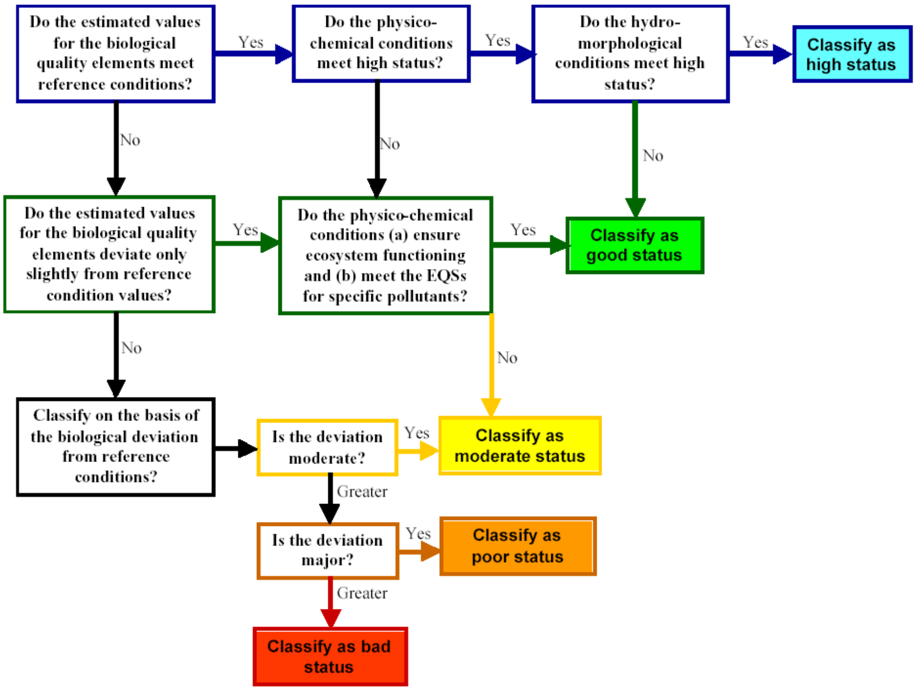


Figure 29: *Indication of the relative roles of biological, hydromorphological and physico-chemical quality elements in ecological status classification according the normative definitions in Annex V:1.2 [3].*

6.1 Hydromorphological Quality Elements

The WFD specifies quality elements for the classification of ecological status that include hydromorphological elements supporting the biological elements and chemical and physico-chemical elements supporting the biological elements. Supporting means that the values of the physico-chemical and hydromorphological quality elements are such as to support a biological community of a certain ecological status, as this recognizes the fact that biological communities are products of their physical and chemical environment. It is not intended that these supporting elements can be used as surrogates for the biological elements in surveillance and operational monitoring. The monitoring or assessment of the physical and physico-chemical quality elements will support the interpretation assessment and classification of the results arising from the monitoring of the biological quality elements. [8].

The hydromorphological elements supporting the biological elements are for rivers:

- Quantity and dynamics of water flow
- Connection to groundwater bodies
- River continuity
- River depth and width variation
- Structure and substrate of the river bed
- Structure of the riparian zone

The elements for lakes are:

- Residence time
- Connection to the ground water body
- Lake depth variation
- Structure and substrate of the lake bed
- Structure of the lake shore [2]

6.1.1 Hydrological regime

The hydrological regime plays a major role in the population dynamics of aquatic, riparian, and wetland species through influences on reproductive success, natural disturbance, and biotic competition. Modifications of hydrologic regimes can indirectly alter the composition, structure, or function of these species through their effects on physical habitat characteristics, including water temperature, oxygen content, water chemistry, and substrate particle sizes [30]. The Water Framework Directive states that in order to report high status of the hydrological regime, the quantity and dynamics of flow, and the resultant connection to groundwaters must reflect totally, or nearly totally, undisturbed conditions. The continuity of the river should not be disturbed by anthropogenic activities and allow undisturbed migration of aquatic organisms and sediment transport [2].

The interannual variability in runoff is high in most of the Icelandic rivers. The variability in atmospheric circulation causes to a large extent the variability in runoff. Seasonal snow cover, glaciers and groundwater play a large role in the hydrology of Iceland. The largest contribution to Icelandic runoff is by rivers fed directly by rain and snowmelt. However, glacial contribution to annual runoff is estimated to be approximately 20% of the total runoff and another 20% of the runoff is estimated to be groundwater. The distribution of precipitation between seasons, and temperature evolution throughout the year, determines how much of the precipitation falls as snow. It, therefore, determines whether a large fraction of the runoff will be snowmelt floods in the spring or whether autumn or winter floods will be larger. The summer and fall temperature affects how much glacial meltwater will be in the glacial rivers during the summer; the higher the temperature, the more meltwater. The different geophysical characteristics of watersheds in Iceland give an extra basis for variability. Groundwater storage masks some of the climate variability, while glaciers create their own variability of runoff through changes in mass balance, forced by climatic variations. Seasonal snow cover, glaciers and groundwater play a large role in the hydrology of Iceland. Rivers in Iceland are frequently divided into three categories by their origin: groundwater fed rivers, direct runoff rivers, and glacial rivers [31]. Seasonal profiles of three rivers of different origin are shown in Figure 30 [32].

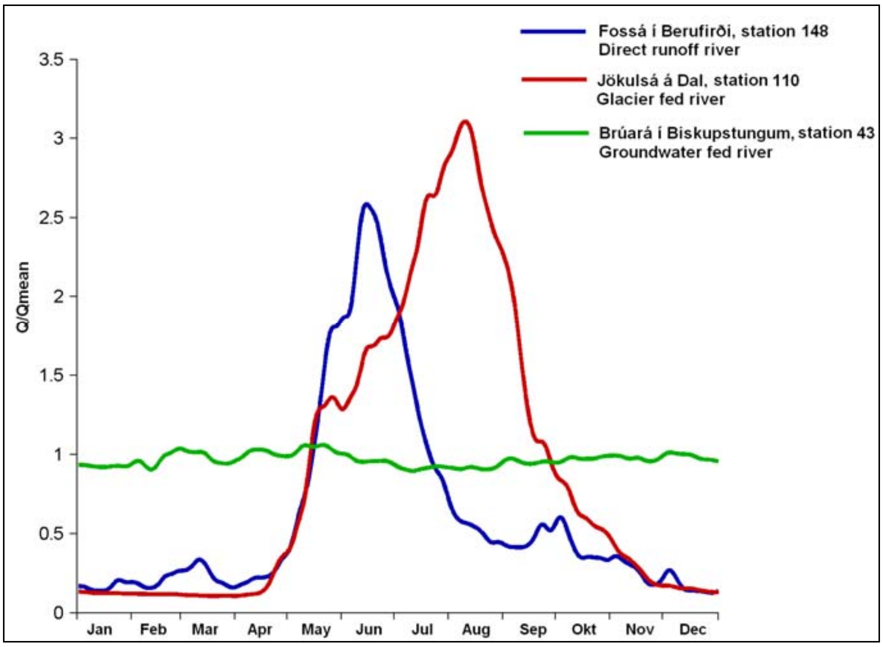


Figure 30: *Seasonal profiles of three rivers in Iceland [32].*

The runoff series are unevenly sampled data. They can be depicted in 3-D space, where the three coordinate axes are space, indexed by location L; time, indexed by T; and the variable being measured, indexed by V. So the value D can be written as D(L,T,V) to symbolize its dependence on these coordinate axes (figure 31). In the database, field names are used to represent variables.

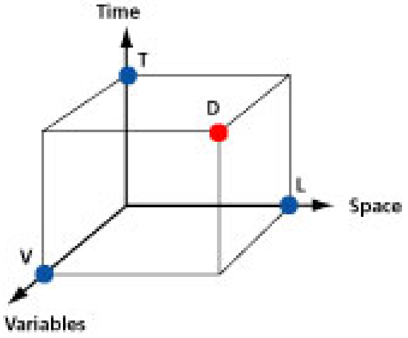


Figure 31: *Data for a variable measured at a particular point in space and time [29].*

Figure 32 shows a static structure for the runoff data in the hydrological database. The time series data is connected to a measurement, which is connected to the waterbody. The class Type contains the information about the type of time series.

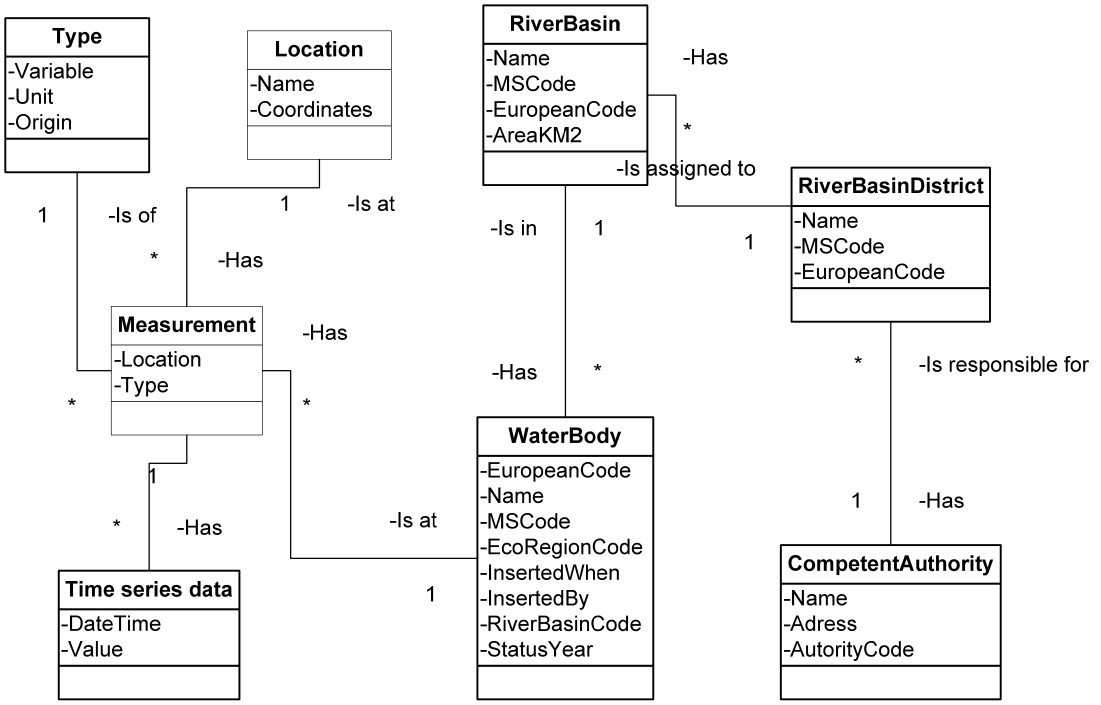


Figure 32: *UML model of the runoff data.*

Figure 33 shows the relational model of the tables for the runoff data. The table Time series data holds the value and the time. The table Measurement keeps information about the location and the type. The table Type contains information on unit, origin and variable. The table Location keeps information about the coordinates. Each measurement is linked to a water body, which is linked to a river basin (figure 33).

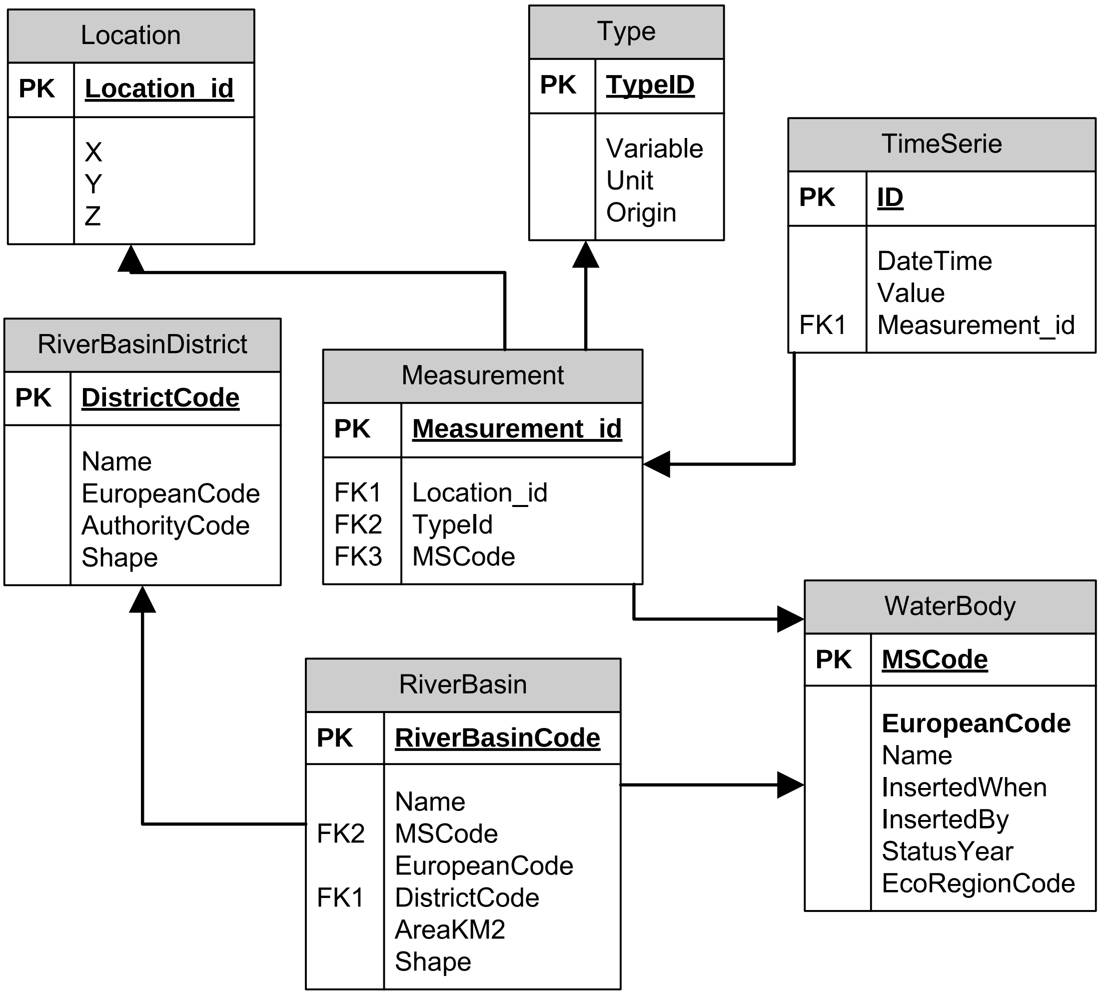


Figure 33: *Relational model for the runoff data*

6.1.2 Sediment Data

In the process of glacial erosion, rock is crushed and transported forward through the movement of the ice and transported by meltwater for long distances. Meltwater is the main agent for long-distance transport and creates new landscape away from the glacier as depositional form such as sandur (outwash plains), and canyon as erosion forms, especially in jökulhlaups. Among the factors involved, sediment transport can be measured, at least the suspended part of it. Systematic measurement of suspended sediment transport started in Iceland around 1963. There are about 40 sampling stations, visited fairly regularly, and many more where occasional sampling takes place. Different types of information may be obtained from each sample. The main goal is the calculation of a rating curve, which is the correlation between water discharge and sediment load. All the large glacier-fed rivers have formed sandur near the shore and a sandy coastline. The great sandy south coast regions of Iceland were formed where the sediment transport to the sea was and is greatest, either due to catastrophic events or not [33]. Many processes affect the sediment load in the glacier-fed rivers, including both human disturbances, such as land use and hydroelectric power construction, and natural instability caused by e.g., weather related flood events, glacier outburst floods (jökulhlaup) and glacier surges [34].

In accordance with Article 4(3), the Water Framework Directive allows Member States to identify surface water bodies which have been physically altered by human activity as “heavily modified” under specific circumstances [5]. The hydromorphological state of the river must be known, and if there is a disruption in river continuum and sediment transport, the water body is seen as heavily modified waterbody because of the impact on hydromorphology and biology [6].

Physical characterization of the hydromorphology can be carried out by using transparent and replicable indicators for the description of the water bodies. The following indicators have been proposed in the Synthesis Report on the identification and designation of Heavily Modified Water Bodies (HMWB): stream discharge, sediment discharge, riparian vegetation and valley gradient. These provide a brief physical description and a characterization of modification. The control variables are subject to disruption caused by environmental modifications. The assessment is based on expert opinion and must answer if the section has been significantly modified, and if yes, has it been done in a neither obviously nor an easily reversible way. The factors the question considers are mentioned above. If any of the factors have been modified and in a neither obviously nor an easily reversible way the section must be designated as a pre-candidate HMWB and an ecological analysis is then carried out [6].

Most of the largest rivers in Iceland are glacially derived and transport great amounts of sediment within their course from the glaciers towards the ocean. A thorough knowledge of sediment load is thus vital for environmental and engineering evaluation related to hydroelectric development of the rivers, and in addition gives a basis for the study of processes such as glacial surging and melting, as well as land erosion [34].

Sediment sampling in Icelandic rivers has been an integrated part of the river monitoring carried out by the Hydrological Service in Iceland since it was established in 1947. Figure 34 shows a UML model for the sediment data in the hydrological database. The measurement has date, time, location, owner and number.

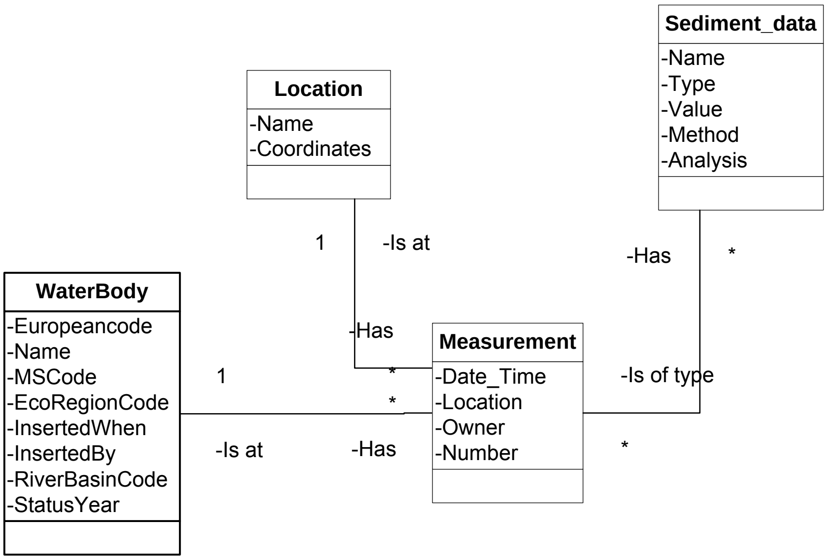


Figure 34: *UML model for the sediment data.*

The relational model for the sediment data is shown in figure 35.

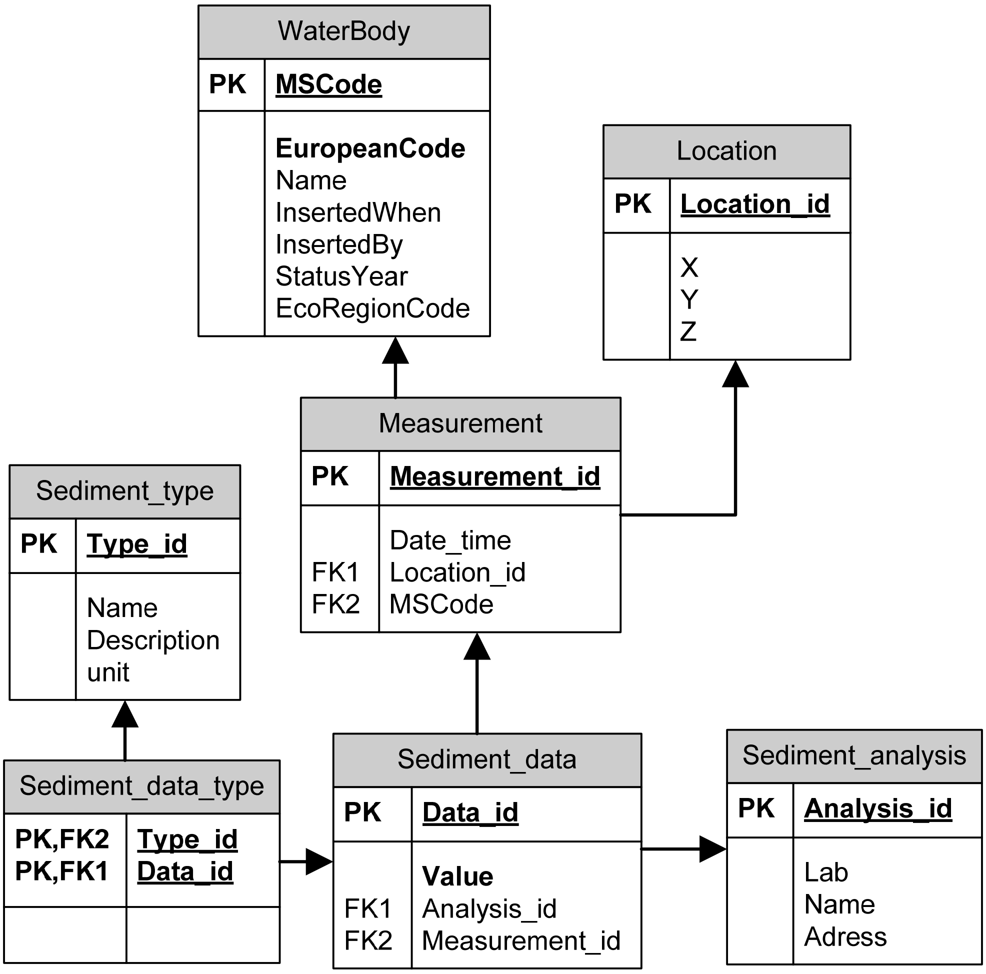


Figure 35: *Relational data model for the sediment data.*

6.1.3 Glacier Data

Glaciers are not mentioned in the Water Framework Directive [19]. In Iceland glaciers are a vital part of the hydromorphological system. The Hvítá catchment has two glaciers, Hofsjökull and Langjökull. Here glacier mass balance data from Hofsjökull will be used as an example of how glacier data can be linked to other hydrological data in the database.

Existing studies indicate that climate change will have a substantial effect on glaciers and runoff from glaciated areas in the Nordic countries in the future. Many glaciers and ice caps are expected to essentially disappear over the next 100-200 years and runoff from glaciated areas in the period 30-100 years from now has been projected to increase by 25-50% of the present runoff from these areas for typical glaciated watersheds in Iceland [35].

Mass balance data from glaciers and ice caps contain implicit information about the dependence of glacier mass balance on climate. The measured mass balance varies with elevation and from year to year, mainly as a consequence of variations in temperature and precipitation [35].

An UML model for the glacier mass balance data is shown in figure 36.

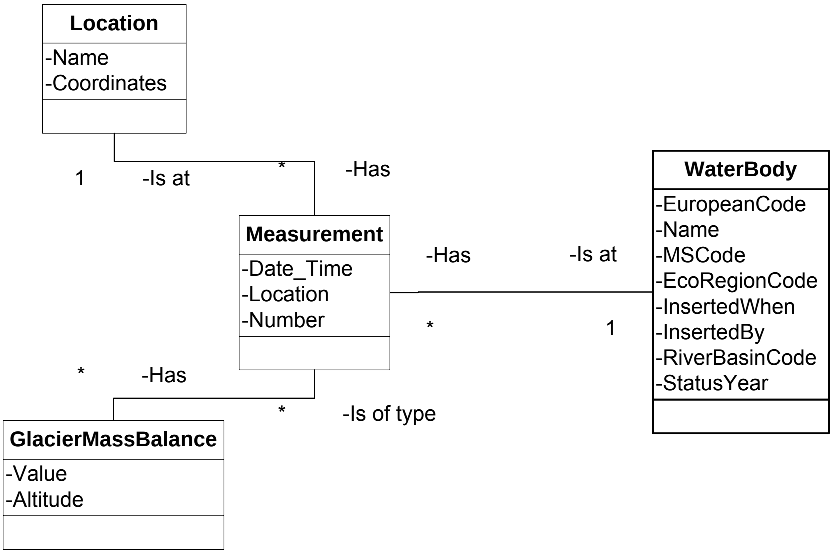


Figure 36: *UML model for glacier data.*

The relational model for the glacier data is shown in figure 37.

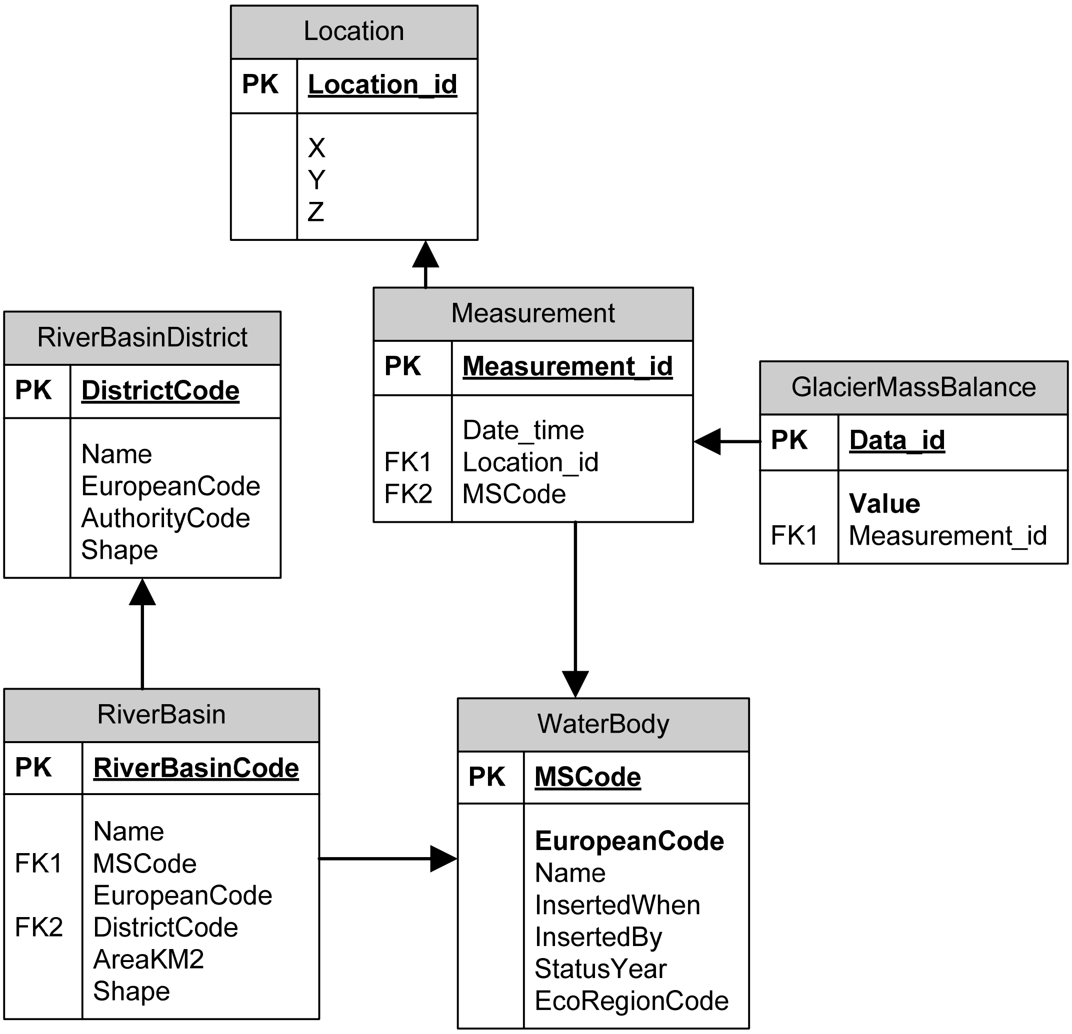


Figure 37: *Relational data model for the glacier data*

6.2 Physico-Chemical quality elements

The main purpose of the Water Framework Directive is to bring the member states to assess the ecological and chemical status of the waters. Groundwater will be tested on both quantitative status and chemical status. The member states should achieve good ecological potential and good surface water chemical status at the latest 15 years from the date of entry. The chemical status of groundwaters should be monitored and reported, as well as the chemical status of the surface waters [2]. A map for each river basin district illustrating chemical status for each body of surface water has to be reported [4].

Here not only the map will be the requirement, but also the chemical data itself, the information about the data will also be considered. The next step would be to include knowledge about the data, but in order to do so, the data and the information about the data must be kept in the database, and made accessible. Capturing the knowledge is a long term project, and the central part of this project is the database, since access to the data and information about the data is essential to map the knowledge about the data. Figure 38 shows a UML model of the data and the relationship between the data.

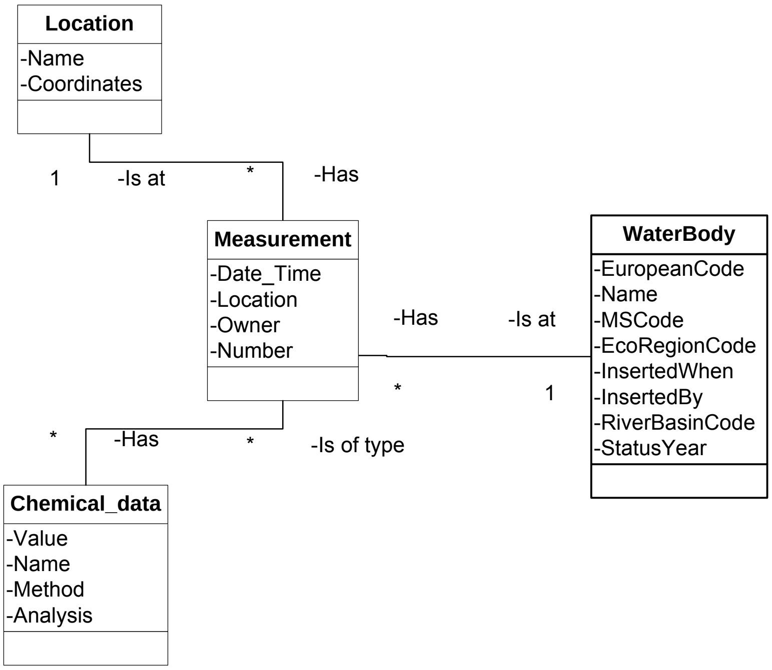


Figure 38: *UML model for the chemical data.*

It is important that the measurement is linked to a location, and the location must be linked to the river basin. It must be possible to select all chemical data from each river basin, and for each river. The measurement must be linked to the report, but the report contains the actual and full information about the data. Information about chemical data is very complex, there are many ways to take the samples and there are many details to consider about the methods and the equipments. There is also a lot of knowledge about the methods and the equipments, which will not be discussed here. There is always an owner, who pays for the data, this owner must be linked to the data. The relational model for chemical data is shown in figure 39.

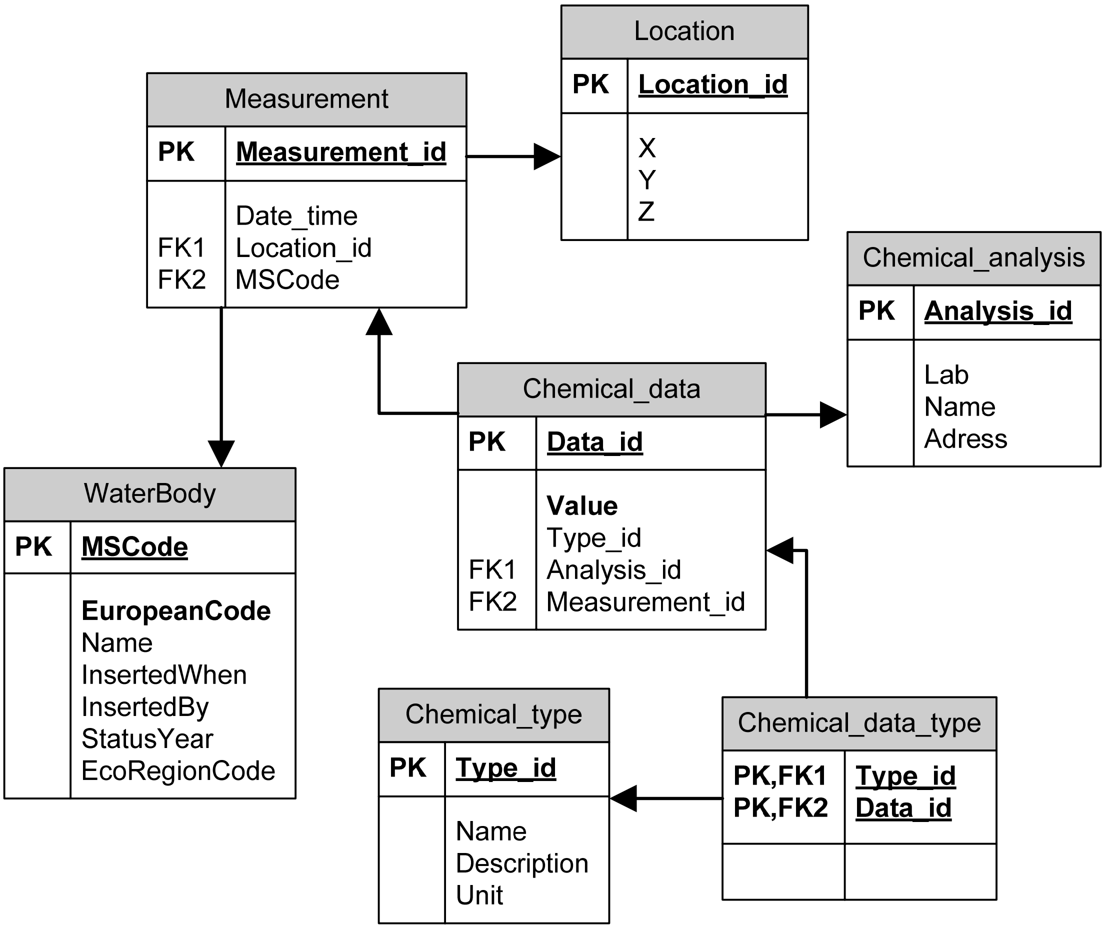


Figure 39: *Relational model of the chemical data*

7 SCIENTIFIC DATA

The access to scientific data is not enough for drawing conclusions, the intellectual capital in each field is both necessary and valuable in itself. Knowledge management is a new way to think about organizing and sharing intellectual and creative resources. It refers to the efforts to systematically find, organize, and make available the intellectual capital. Things that are already known can be stored and should be accessible to the people who work with the data. Although information technology plays an important role in knowledge management by enabling the storage and dissemination of data and information across the organization, information technology and databases are only one piece of a larger puzzle.

Knowledge is not the same thing as data or information, although it uses both. Data are simple, absolute facts and figures that, in and by themselves, may be of little use. If the data are to be useful for the organization, the data are processed into finished information by connecting them with another data and converted into a useful context for specific use. Knowledge goes a step further; it is a conclusion drawn from the information after it is linked to other information and compared to what is already known. Knowledge, as opposed to information and data, always has a human factor. The knowledge can be formal, systematic knowledge that can be codified, written down, and passed on to others in documents or general instructions. Knowledge can also be implicit, or tacit, it is based on personal experience, rules of thumb, intuition and judgment. It includes professional know-how and expertise, individual insight and experience, and creative solutions that are difficult to communicate and pass on to others [16].

It is necessary to set up ways and means for knowledge management. This can be done by collecting and sharing knowledge through a sophisticated information technology system. An organization or a department focuses on collecting and codifying knowledge and storing it in databases where it can easily be accessed and reused by anyone in the organization. It is also necessary to connect people face-to-face or through interactive media, and information technology systems can be used for facilitating conversation and person-to-person sharing of experience, insight, and ideas. Organizations typically combine several methods and technologies to facilitate the sharing and transfering of both explicit and tacit knowledge [16]. Scientific databases must keep as much knowledge as possible. The first stage of scientific data is the raw field data that is collected over certain time and space. The second stage is derived information after the data has been resampled, processed, corrected or combined with other data. The final step is to capture the knowledge in the database. The knowledge is in the culture of the organization, people's minds and in documents.

In order to do good data processing, the scientist must know the data, how that data is collected, whether the quality of the data has been assessed and the scientific reasons behind the data processing. The database is an important part to understanding data, information and the knowledge as far as possible. Information about the data process can be logged in the database, and things that are already known should be connected to the actual data. All this can be achieved for example by linking reports to the data.

Here a general overview of the database will be presented. The data will be linked to the information about the data (figure 40).

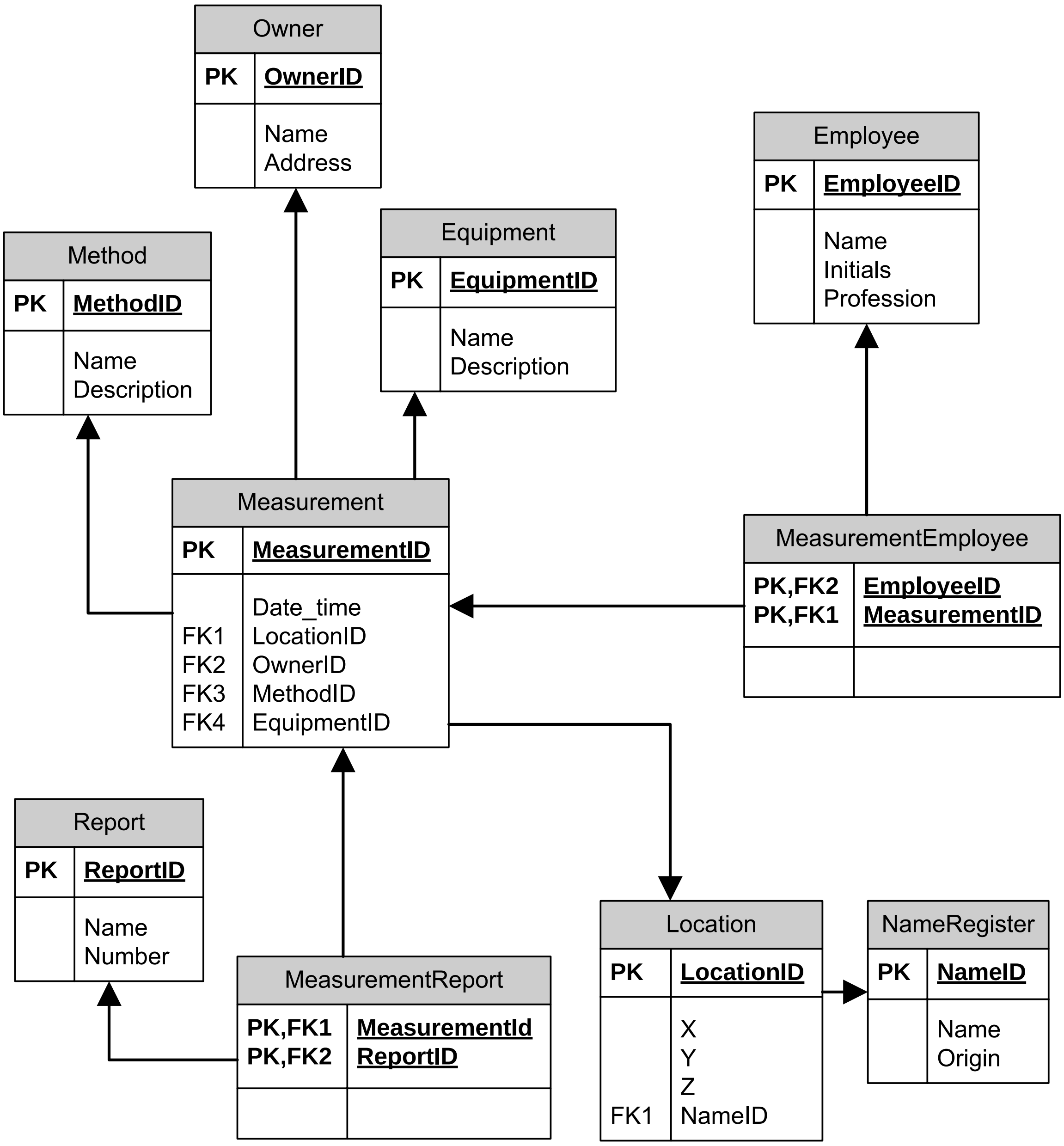


Figure 40: *General data model for scientific data.*

8 DISCUSSION AND RESULTS

The goal of this study was to design and implement a hydrological database for the Water Framework Directive. The database consists of data from and about a hydrological network as well as hydromorphological data. A connection between spatial and non-spatial data has been designed.
In order to understand the significant water management issues within each river basin and how they affect each individual water body, a geographical database with a hydrologic network is necessary.

In a case study the existing dataset for a river basin was compared to the requirements of the Water Framework Directive. As a spatial dataset, it suits the WFD well, however several attributes will have to be added. This river basin dataset is linked to the river network through the river basin code. The river network in the geographical database does not have the topographical attributes required for the Water Framework Directive. The lacking attributes are the direction of flow and continua through lakes, which are necessary for a conceptual understanding of the flow system within a water body as well as specific information system operations and for understanding the interaction between groundwater and surface ecosystems. Spatial attributes, like altitude and size can be found in the existing table.

In order to identify River Water Bodies, it will be necessary to complete the river network. The lines have to be connected through the appropriate nodes and the continua will have to be established through all the lakes. The identification of Lake Water Bodies can be performed using the existing spatial information. The existing attributes for the lakes are coherent with the requirements of the Water Framework Directive.

Full spatial data about groundwater bodies do not exist in the database. In order to identify the groundwater bodies the spatial boundaries will have to be established. This can be done by using a layer of hydrogeology, information about the runoff, and plenty of insight from scientists. Spatial delineation on the transitional and coastal water bodies is not present, and has to be established in order to identify the transitional and coastal water bodies.

It is evident that there are severe gaps in the spatial data, which have to be filled during the process of drawing up the river basin management plan and the monitoring programme.

The starting point for an analysis of pressures and impact, is the data about the water bodies, and databases and GIS tools are needed for the identification of relevant water bodies and characterization of relevant pressures and ecological status.
For the grouping of water bodies on a scientific basis, information on the characteristics of the river basin and the hydrology must be accessible. The database for the supporting hydromorphological and physico-chemical elements has been designed and implemented. In order to handle the information about the data, a general data model has been presented. The connection between the spatial data and the hydromorphological and physico-chemical data has been designed. This is the foundation for a proper understanding of the significant water management issues within each river basin and how they affect each individual water body. A hydrological database should keep the relations between water bodies within a river basin, e.g. relations concerning pollution of downstream lakes and coastal waters or upstream river continuity issues. For the assessment of impacts on a water body, quantitative information to describe the state of the water body itself, and/or the pressures acting on it, are important.

Considerable amount of information in the form of maps will be required and presented in the relation to the WFD, and the best way to provide most of the requested information will be in the form of GIS layers. With a good GIS data management system, all relevant data can be stored with connection to the spatial data. It is very important that there is a core dataset that will be used to link all data together. Here this core dataset would be the river basin system and the water body system. The river and lake segments are a spatial dataset that can be developed further for a better spatial data later, but the tables for the lake and river water bodies keep the actual information about the river basin.

In the future it is very important for the implementation of the Water Framework Directive to establish the hydrological network, with flow and continua and with continuous rivers. This process should be performed on a spatial dataset. This is rather time consuming, and an expertise in both GIS and hydrology is needed.

The final step in the hydrological database would be to complete the database with missing information in the same way as presented here. Present and future non-spatial data would be linked to both a water body and, when possible to the river basin.

Biological data should also be implemented and linked to this hydrological database, saving a lot of time in the future and making ecological data analysis easier as well as giving better general access to the data.

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