On classification and regionalisation of Danish watercourses

Geografisk Tidsskrift, Bind si01 (1999)

On classification and regionalisation of Danish watercourses

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Abstract

The need for a characterisation, classification and regionalisation of Danish watercourses is described. Existing classifications are described and criteria for a characterization and classification are discussed. A first approximation to a classification system is presented.

Keywords

Danish watercourses, classification of streams.

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Geografisk Tidsskrift, Danish Journal of Geography Special Issue, 1: 81-87, 1999

Characterization, classification and regionalisation of landscape features and land use systems have been carried out by geographers for many years and knowledge about techniques for doing these is an important part of the curriculum for a graduate in geography.

Streams and rivers are important features in the landscape and they have always been important to man, basically for extraction of water for drinking and for irrigation. Drainage systems are often used for transport where the conditions for roadbuilding are difficult. In more developed countries rivers are utilized for power production, and in heavily populated and industrial areas rivers and streams are important as recipients for waste water, often leading to severe pollution and destruction of habitats and of natural beauty. In Denmark manipulation of the drainage systems and watercourses has been going on since the early Viking age, first for transportation and fishery, later for construction of water mills, Bøcher (1942). In the 18th century works were carried out to facilitate meadow irrigation, Rasmussen (1964). At the beginning of the 19th century the main issue was the draining of wetlands and fields. This has led to a realignment of about 97 % of the total length of streams in Denmark, Brookes(1984). Recently restoration, for example remeandering and re-establishing of wetlands, has been on the agenda. Thus there has been a long tradition for manipulating the drainage systems in Denmark, but also quite recently a consciousness of conserving the beauty of the landscape and of rare species and their habitats. The uncoordinated manipulation of watercourses could, at least partly, be explained by lack of knowledge about what types of watercourses are present.

In biology and archaeology for example, selected objects are protected by conservation laws according to their rarity or unique spatial occurrence. Nevertheless, a lack of similar criteria for rarity of landscape elements is found. At the moment it is therefore not possible before any manipulations are carried out to tell if a certain type of watercourse is the last of its kind. The demand for a measure of "rarity" could also be expressed as a need to know the representativity of a given watercourse. This is typically demanded when case studies are to be extrapolated. Another way to benefit from a classification system is to use it as a basis for selection of study objects for research purposes, for example streams threaten by pollution by iron oxide. To summarize: a characterization, classification and a regionalisation could answer questions of the following type:

- Is this watercourse so unique that it should be protected partly or conserved totally?
- In how many watercourses can the results from an investigation be applied?
- Where do certain bedforms appear or where do morphological processes to be studied take place?

Previous attempts to classify watercourses

According to Davis (1899 & 1902) rivers could be classified using assumed stage of the erosion cycle, as : young, mature or old. This classification is, however, rather vague and furthermore the same watercourse along its course could posses all three classes, young in the upper reaches, mature in the middle and old in the lowermost reaches. In previously glaciated areas, like Denmark this classification is not very meaningful or informative.

Pardé (1955) describes a classification of river regimes based on the origin of the water, either nival or pluvial. He combined the origin with thermal conditions and managed to explain the yearly distribution of runoff very well. His work has later been further developed by Beckinsale (1969) to show river regimes for different climatic zones as described according to Kõppen.

The International Hydrological Decade (IHD), 1965-74, initiated standardized monitoring of hydrological parameters all over the world. One important improvement was the initiation of concerted measurements in whole drainage basins. In Denmark measurements were initiated in two basins that were believed to be representative for the two main types of watercourses in Denmark, the "eastern" and the "western" type. At the start of the measuring programme, however, no rational method for the determining representativeness was available. In the aftermath of the IHD there was the wish to know how much of the Nordic countries actually could be represented by the already established "representative areas". This question was answered quite simply and elegantly by Tollan (1975). He combined hydrological characteristics, relief, soil and land use. Each factor was allotted a position in a four-digit classification. Both quantitative and qualitative measures could be used for classification. He managed to classify the Nordic countries and to demonstrate that the representative areas in most cases were well chosen. It must be mentioned that Swedish watercourses were classified earlier by Melin (1970). However, his classification is based on hydrology alone and therefore not suitable for a morphological classification.

The concept described by Tollan has partly been adapted by the present author in a description and classification of watercourses in the Sisimiut community, Greenland, (Hasholt & Søgård 1978) and its use for all Greenland was later discussed by Hasholt (1997). The classification systems mentioned above are quite rude and result in few classes. Or, as is the case in Greenland, there is a lack of information about some of the parameters, which make a more detailed classification impossible. The typology of watercourses is dealt with in many textbooks e.g. Petts and Calow (1996), but most of the systems described are not well suited to Danish conditions.

Internationally Rosgen (1985 & 1994) has presented a classification system for natural rivers that encompass many of the factors relevant to a useful classification. He also points out the potential use of a classification system in river management and for prediction of river behaviour in the case of changes in the drainage system. His classification is mainly based on recognizable morphological features, but some hydrological characteristics are indirectly included in some of the seemingly morphological parameters. His paper discusses many of the important issues for setting up a classification system. Rosgen's system is examined critically by Miller & Ritter (1996). They critizise the lack of direct inclusion of hydrology and the use of undefined terms. They also state that Rosgen's stream types are not linked to the current equilibrium state of the channel and they question the applicability of the system for predicting the type or magnitude of geomorphic response to a given perturbation. In spite of the criticism Rosgen's classification attempt is a valuable contribution that demonstrates the need for a system although no final answers are at hand yet.

Types of watercourses in Denmark are described by Larsen (1969). His main characteristics are width, depth, temperature and related vegetation. For monitoring of pollution in Danish watercourses, a "pollution class" system, the saprobie system, was adopted, Landbrugsministeriet,The Ministry of Agriculture (1970). The system is based on a collection of macroinvertebrates in the different reaches of a drainage system. The occurrence of certain species is chosen as an indicator of the state of pollution. For example young aquatic stages of certain insects indicate weak pollution while tubifex indicates strong pollution. Instead of using a "pollution class" the quality of a watercourse could be expressed in terms of "fauna classes", using the Danish Fauna Index.

An administrative classification, the"quality objectives" was applied in 1978, and is based on politically or administratively reason what a given watercourse should be used for within a certain period. It is mainly based on biological criteria, with emphasis on angling, Danish Environmental Protection Agency (1995). Examples of classes are: Watercourse for a scientific purpose (A), salmonid (B2), eel and cyprinids (B3) and "reduced objectives", watercourses affected by waste water (D). The last classification mirrors the important use of Danish watercourses as recipients for sewage and the relative strength of the ecological movement and of the pressure group of sport fishermen.

Principles of classification

It is documented above that there is no generally accepted method for classifying of watercourses. Methods used in Denmark are mainly determined by biological objectives. It is therefore useful to try to set up a classification that also takes physiographic characteristics into account. Before going into a detailed attempt at classification, some of the more basic principles must be examined. The subject of classification is the watercourse, defined as a depression in the land surface caused by the geomorphic action of running water. With or without water this morphological feature is easily distinguishable and unique, even on Mars. Preliminarily the minimum unit of classification is suggested to be the reach. In the present context a reach is defined as the stretch of a watercourse of a certain order, for example according to Strahler, between the confluence

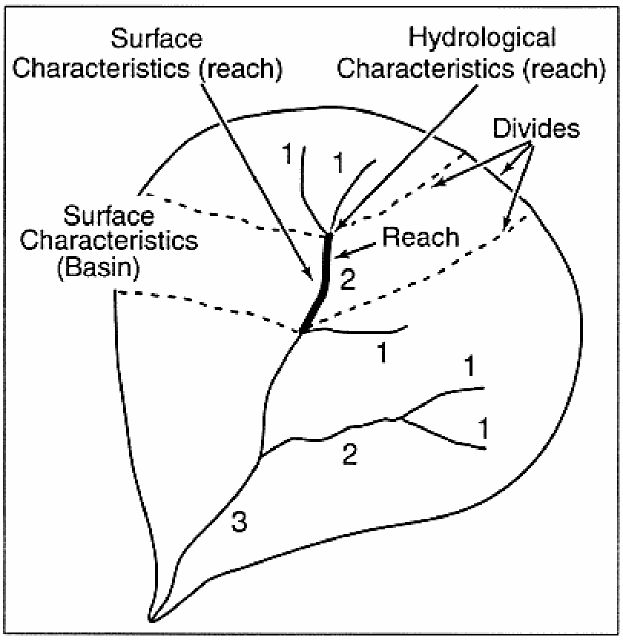

Figure 1: A reach defined as the stretch of a watercourse of a certain order, for example according to Strahler, between the confluence of tributaries of the same or different order.

of tributaries of the same or different order (cf. Figure 1). Depending on scale, however, the reach could be subdivided into minor units depending on, for example, changes in substrate or vegetation along the reach.

Scale is very important. For practical applications it is of interest that every visible reach could be classified. This could, however, lead to the partly correct conclusion that each unit is unique. Depending on scale a kind of hierarchy in the characteristics should be included in the classification so that a major common feature leads to a consistent common classification. A classification should satisfy the following demands:

1. It should be able to include all types of watercourses, i.e. be generally applicable.
2. It should be logically sound and the classes should be resilient, so that minor changes in one or a few parameters do not cause a major shift in class for a given reach.
3. The classification should be informative, in the sense that knowledge of a class should enable the user to recognize the physical appearance and, ideally, extract information that predicts the behaviour of the watercourse and its suitability for different uses.

This means that the classification should provide answers to the type of questions put forward in the introduction and to give guidelines for uses such as: 1. Habitat evaluation. - 2.Turism and recreation. - 3. Industry and agriculture. - 4. Recipient for waste water.

It could therefore be of interest to correlate the classification with existing systems for example the "fauna class" system.

Characteristics for classification

A watercourse and its environment could be characterized in many ways. Such characteristics, here called classification parameters, are selected in the following. Water is the geomorphic agent, and therefore it is logical to look at hydrological parameters first.The origin of the water, either pluvial or nival has been used earlier by Pardé. On a global scale this is sound, and informative for example about the water quality. In Denmark nearly all water is of pluvial origin.

The amount of water available is crucial, as the morphological impact is related to the discharge (m^3 / sec). To compare watercourses of different sizes, specific runoff (l/sec*km^2) is more informative. Care should, however, be taken when the topographic and the ground water divide for a given drainage basin is not the same. Basically, the amount of water cannot be separated from its distribution in space and time. Also the frequency of the discharge of a given magnitude is important. The bankfull discharge, which by many is considered determining the dimensions of a cross section, seems to occur with a return period of 1 to 2 years. A classification must therefore include some kind of parameter that takes distribution and/or frequency into account. In many places the amount of water is influenced heavily by man, either by abstraction for household and industry, or by controlled release from dams for navigation, irrigation or for power production. This should also be included in the classification. The water quality is very important for the potential use of the water. It is reasonable to distinguish between water quality determined by natural chemical compositions and quality more or less heavily influenced by human activities.

The next important set of parameters is related to the part of the land surface where the watercourse is developed. The type of landscape indirectly or directly mirrors many kinds of relevant information. Very different time scales are included in this information. Geological maps often give information with a time scale of millions of years, while geomorphological maps give information at time scales from recent to thousands of years. The trained professional observer can extract much information relevant to the watercourse from this type of maps.

The present watercourse is often the result of a long continuous history of geological development in the area. The processes taking place today are determined mainly by two parameters inherited from the long geological history. Slope, or more generally the relief, determines, together with the amount of water, the power available for geomorphic activity. A measure for this factor must therefore be included. The solid rocks or the sediments in the river bed and banks determine the roughness and the resistance to the power of the water. Bed material is therefore also an important parameter that influences the reaction of the stream to a given input of water, for example in producing sediment transport. The material in the stream bed and banks is very often strongly related to the geology and the soil in the immediate vicinity of the reach. Both geology and soil are also indirectly important because they determine the distribution between stormflow and baseflow and the erodibility of the basin that contributes sediment load to a stream.

Vegetation also plays an important role in the modification of the stream power input. Vegetation is a parameter which is not as permanent through time as the above. In-stream and bank vegetation have the most direct impact on the short-term changes in stream morphology, while vegetation strips along the watercourses and vegetation in the drainage basin are responsible for longer term modifications because of their influence on the sediment delivery to the watercourses.

The planform of a natural watercourse is at least partly a result of the interactions between the above parameters, but feedback mechanisms exist. In areas with human activities the planform is often more or less modified by man. The planform is an important parameter describing the impact of man and for example the possible use of the stream for fishing and other recreational purposes. It is therefore reasonable to include it in the characterization of a watercourse.

Classification in practice

In order to evaluate the use of the different parameters mentioned above, an attempt to develop a classification system for Danish watercourses is described below. The principles involved can be applied generally, but the possibilities of universal application depend on the available data. The author is familiar with the data available in Denmark and their quality, it is therefore natural to establish and evaluate the classification here.

Matters that should be dealt with can be coarsely grouped: Scale, hydrological parameters and parameters relating to the land surface.

Concerning scale, it is reasonable that the classification is based on recent maps, scale 1:25000. The scales 1:50000 and 1:100000 could be used, but minor reaches are omitted in some places. Hydrological information is available from DMU, the Danish Environmental Research Institute. Lyshede (1955) has clearly demonstrated the problems involved in using specific runoff in Denmark, because of the difference between the topografic divides, which are used in the determination of the yearly specific runoff, and the groundwater divides that determine the real contributing area. A theoretical map showing the "ideal runoff", defined as precipitation minus actual evapotranspiration is presented by Jensen (1969). The values for precipitation are not corrected for measuring errors and the actual evapotranspiration values used are biased too. A new and correct map of this type could, however, be used for this purpose. For classification, the specific runoff above is a reasonable parameter to apply as a measure for the amount of water. Areas with a large import of groundwater, because of the divide problem, will show high values and areas with artificial groundwater abstraction will show low values. The regime(distribution of runoff through time) of Danish watercourses could also be used for classification. There is, however, no obvious way how to do it, and furthermore it seems to be embedded in other parameters, as seen below, and thus not very selective. The differences in distribution can be described by use of a coefficient of variation, as used by Tollan (1975). This will separate watercourses with a large and stable contribution of groundwater from those with abstraction and in dryer areas. The probability of extreme values or other statistical measures can also be included, but will probably not lead to further identification of types of watercourses in Denmark.

Maps of Quarternary and of pre-Quarternary rocks and sediments are available at GEUS, the Geological Survey of Denmark and Greenland. Other information about the material in the drainage basins can be found on a map of sediments 1 m below the surface, Bornebush & Milthers (1935). Maps of soils and their qualities in relation to sediment transport are available in two forms. The standard ADK maps, Danish Land Data Survey, Landbrugsministeriet (1976) are mainly based on texture. The more thematic soil maps including soil genesis, Jacobsen (1984), Madsen et al. (1992) and Madsen & Hasholt (1986) include erosion risk.

Geomorphological maps have been produced by Schou (1949) and Smed (1978). These maps contain information primarily about the origin of the landscape elements, but there is often a very strong correlation between sediments, relief, and the type of landscape. For example sand and low relief are features typical of the outwash plains and meltwater valleys. Maps can be used to extract information on the different reaches : Stream order, slope and planform. The drainage area of a given reach can also be measured by use of the maps, which also contain information about manipulations and man-made structures such as canals and weirs.

An updated registration of vegetation and land use is not available at the moment, but satellite images can be utilised in the future. From ordinary maps, however, a separation between cultivated areas, meadows and wetlands and forest can be extracted.

Based on the above a tentative classification is shown in Table 1. See next page.

Each class is allotted a single figure in a nine digit characterization number. For example 133322311, refers to the reach of a watercourse with a specific runoff larger than 11 l/sec*km^2, low coefficient of variance, low slope and relief of watercourse and basin, sand substrate in both watercourse and basin, situated on an outwash plain, in a cultivated area and naturally meandering. Theoretically this classification results in 236196 individual classes, but in practice the number will be much lower, because several combinations do not occur.

If each characterisation parameter keeps its position in the characterisation number, the system can be expanded without problems by adding new parameters, forming a matrice that is easily combined with EDP. The characterisation number can be transformed to maps by allotting each number a special colour. If information about one or more parameters is not available, the relevant characterisation digit could be left blank and a reduced classification compatible with the full one can be carried out.

Discussion, conclusion and perspectives

Unlike biological species having well defined genomes, landscape elements in reality are unique features. There is no doubt, however, that there are common features, enabling us to identify the elements and place them in groups. The very large number of possible parameters might end in a classification in which each reach end in a class of its own. This would render the system useless. Investigations in Danish watercourses, (Hasholt 1981 & 1983) have identified several common features. For example the characterisation number mentioned above is common to a lot of streams in West-Jutland. Furthermore, these streams are pointed out as examples of alluvial streams where the conditions for the application of sediment transport formulas are present. Similarily based on water quality, there is a rather clear distinction between watercourses in Western-Jutland and in the eastern part of Denmark, where young morainic deposits, rich in limestone, dominate. These facts support the hypothesis that it is possible to place single reaches into groups and regionalize parts of the drainage system.

In conclusion, a consistent classification system that enables a combination of abiotic and biotic features is pre-

Parameter	Object	Class	Definition
Hydrology			
1	*Amount of water*	*1* *2* *3*	*Specific runoff.:* $r \geq 11$ *l/sec*km²* *Specific runoff :* $11 > r \geq 7$ *Specific runoff :* $r < 7$
2	*Hydrological "Regime"*	*1* *2* *3*	*Coefficient of varience: high* *Coefficient of varience: medium* *Coefficient of varience: low*
Surface			
3	*Relief (reach)*	*1* *2* *3*	*Slope of reach: high* *Slope of reach: medium* *Slope of reach: low*
4	*Relief (basin)*	*1* *2* *3*	*Relative relief: high* *Relative relief: medium* *Relative relief: low*
5	*Substrate (reach)*	*1* *2* *3* *4* *5* *6* *7*	*Clay* *Sand* *Gravel/stones* *Clay till* *Sandy/gravelly till* *Organic* *Solid rock*
6	*Substrate (basin)*	*1* *2* *3* *4* *5* *6* *7*	*Clay* *Sand* *Gravel/stones* *Clay till* *Sandy/gravelly till* *Organic* *Solid rock*
7	*Geomorphology*	*1* *2* *3* *4* *5* *6* *7* *8* *9*	*Morainic, Weichselian* *Pre- Weichselian moraine* *Outwash plain* *Meltwater valley* *Tunnel valley* *Dunes* *Raised seabed, Yoldia* *Raised seabed, Littorina* *Salt Marsh*
8	*Vegetation*	*1* *2* *3*	*Cultivated* *Meadow/wetland* *Forest*
9	*Planform*	*1* *2* *3*	*Meandering* *Braided* *Regulated*
10	*Other parameters ?*		

Table 1: *Tentative classification of Danish watercourses*

liminarily outlined. Theoretically the system is capable of answering the kind of questions put forward in the introduction. The system also has much wider perspectives for studying the interaction between various parameters and other classification systems. Such interactions can easily be built in, for example a possible correlation between the saprobie system and physiographic characteristics. The system is flexible and might be expanded without changing parameters already included, and it is also well suited for the use of EDP.

So far, however, the system is only developed in theory and not tested thoroughly against reality. Some of the parameters used in characterisation might be strongly intercorrelated and therefore not suitable elements in the classification. A statistical analysis of the selection of the "best" parameters should be carried out. Before the system is applied in full, it is reasonable to test and further develop it in a minor pilot area that includes a large spectrum of different watercourses: for example a cross section of Jutland from Blåvands Huk to Vejle Fiord. Although his system has been debated, Rosgen (1994) claims that it has been used for water management and river restoration with good results. The present focus on watercourses and wetlands in Denmark makes for a strong case for a rational classification system both for identifying scientifically relevant types of watercourses, and as a sound background for management decisions.

Acknowledgement

Thanks to my teacher in regional geography, who actually discussed with the students. Also thanks to Conrad Aub Robinson and Jørgen Kisling-Møller for comments and useful suggestions.

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