Dealing with Problems in Surface Water Quality Management in Upper Austria

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Abstract: Consideration of catchment condition is a new challenge in surface water quality management in Austria. On the one hand, it is now essential to identify potential pollution risk from non-point sources, on the other hand, it will be necessary to adapt existing survey systems to increase their accuracy in pollution source identification. In order to solve the task, the complexity of real systems needs to be reduced to manageable dimensions without time and cost-intensive investigations. The temporal and spatial scaling approach for Upper Austria is based on a conceptual model of environmental systems. With this conceptual model it is also possible to identify complex processes in environmental systems, which allows for an identification of relevant scale modifications in catchment systems caused by human activities. These attributes of the conceptual model are essential to overcome the problem, that a reference level of natural water quality can no longer be defined accurately. Differences in temporal scales are used for identification of particular non-point pollution sources in catchments in Upper Austria. Spatial scaling, concerning channel and catchment is used to identify survey site adjustments in monitoring non-point pollution sources. However, further optimisation of the survey system is necessary to improve the accuracy of the surface water quality survey system.

Keywords: Surface water quality management; Temporal and spatial scaling; Upper Austria; Conceptual modelling

1. INTRODUCTION

Management of surface water quality is a multi-disciplinary task, that needs to include an efficient application of scientific investigations and a continuous dialogue with stakeholders and policy-makers to prevent critical impacts. Regardless of disciplinary background, this task is rather typical for managing complex systems [Malik, 1992]. Restrictions in financial resources and time limits facing decision-makers are substantial constraints in applying survey methods. Efficiency in this context is an adaptive balance between information needs and the application of methods for generating sufficient information. In contrast to purely scientific research, greater focus is placed on applying harmonised methods under consideration of system characteristics than on the excellence of a particular method.

This paper describes scale based methods for the support of a regional surface water quality management system.

2. MANAGEMENT OF SURFACE WATER QUALITY IN AUSTRIA

2.1 Introduction

In the past the management of surface water quality in Austria was focused on quality surveys, based on chemical and biological indicators, and on the control of point pollution sources. Due to experiences in the field that highlighted shortcomings of the past, and in particular due to the introduction of the European water framework directive [EC, 2000], management has to be extended to catchment systems and to structural modifications of stream channels. Consequently, the management system has to be adapted in a cost efficient and successful way to the new framework conditions.

Due to the complexity of the task, solutions can only be found by coping with the temporal and spatial scaling problem. It comprises hydrological as well as land use or biological processes. Ideally a large-scale screening system should help identify critical conditions and deliver information for the application of specific methods on smaller scales in hot spot areas.

Traditionally, the complex task was reduced to the question of how far natural physical and chemical conditions in surface waters had been modified by direct human impacts. In practise, this was performed by measuring several chemical, physical, and biological parameters at certain time intervals on selected sites. Historically, site selection depended on the disciplines involved; with little co-ordination among them. As a result, hydraulic survey stations are located separately from chemical as well as from biological monitoring sites. The system was relatively efficient in measuring a reduction of impacts from large point sources, such as industrial plants or outlets from sewer systems. However, it is very inefficient in identifying impacts from small point sources and non-point sources.

2.2 Scaling in Surface Water Quality Management

Water quality management has to consider natural processes and in particular human activities in the catchment and channel systems. Both systems can be interpreted as emergent systems, based on the interaction of abiotic and biotic partial systems [Knoflacher, 1994]. Consequently the scaling problem can only be solved if scales of following partial systems are considered:

- Geospheric
- Hydrospheric
- Atmospheric
- Microbiological
- Botanical
- Zoological

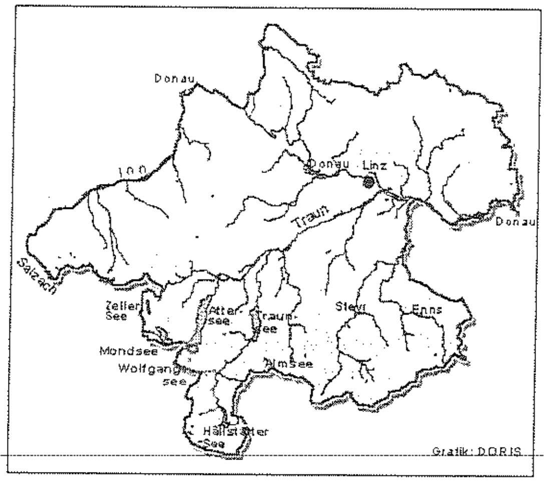
By this definition, humans are part of the zoological partial system; with respect to the relevance of human activities, a human subsystem is defined.

Water quality management focuses on the deviation of quality parameters from natural conditions caused by human activities. For this reason, anthropogenic modifications of natural scales are essential in indicating relevant disturbances.

3. UPPER AUSTRIA

Upper Austria is situated in the north-west of Austria, bordering on Germany and the Czech Republic. Elevations range between 200 m and 2000 m above sea level with some summits close to 3000 m.

The area of 11,979 km² dominantly drains to the Danube catchment (Figure 1). Geologically, the area can be roughly divided into a northern part, dominated by crystalline bedrock, and a southern part, dominated by limestone bedrock. The central lowlands are filled with tertiary sediments. Annual precipitation varies between 2500 mm in the south, 700 mm in the central lowland, and 1200 mm in the north.



Grafik: DORIS

Figure 1: River network of Upper Austria.

Land use patterns follow the geological distribution. The cristalline north has a population density of 85 inhabitants per km²; 37 % of the area is covered by forest and 56 % by agricultural land. The population density of the central lowland is 177 inhabitants per km²; 23 % is covered by forest and 65 % by agricultural land. The mountainous south has a population density of 79 inhabitants per km² with 49 % being covered by forest and 31 % by agricultural land. Sewage treatment varies locally; on average 75 % is treated in waste water plants [Anonymous, 2000].

Problems with surface water quality are predominant in the central lowlands and in some parts of the north. Water quality problems are mainly caused by fecal coliforms, phosphorus, total carbon, nitrite and nitrate [Bachura and Müller, 1998].

4. SCALING IN CATCHMENT SYSTEM

4.1 Conceptual Background

In water quality laws and regulations [EC, 2000] the natural condition of a system is specified as a reference state for determining water quality. This political requirement of defining natural condition cannot be accomplished for several reasons.

Because of the long term and intensive human modification of the European landscape [Frenzel, 1994; Küster, 1999], it is unrealistic to find natural reference sites anywhere. Under a best case scenario it is only possible to find sites, which are currently less influenced by human activities than comparable sites.

The second point can be theoretically derived from the inherent dynamics and complexity of environmental systems [Haken and Wunderlin, 1991; White et al., 1992; Ebeling et al., 1998]. Environmental system would also have changed without human impacts, e.g due to natural climate variations [Folland et al., 1990]. Beyond the documented dynamics it has to be expected that breakdown of ecological systems can be caused by endogenous disturbances without human impacts or changes of abiotic conditions [Baken, 1996].

Under these conditions it is essential to look for evident modifications of the environmental systems caused through human activities. Although this approach seems simple at a first glance, it turns out to be a serious challenge if environmental system properties are considered. Environmental systems are not homogenous in any way. But they have some hierarchical properties, which can help solve the task.

Structures and processes within partial systems have common characteristics. With increasing interactions among partial systems, system complexity increases rapidly. Additionally, new system qualities will appear, not observable in isolated partial systems. Such emergent effects [Holland, 1998] are widely distributed in environmental systems. A typical emergent structure is soil. Its genesis is a result of interactions among all partial systems, with the consequence that soil variety is enormous [Fairbridge and Finkl, 1979]. Typical emergent processes are hydrological processes, also a result of interactions among all partial systems.

This concept helps to understand, why the success of deterministic methods in describing and predicting environmental processes is limited. Such methods are powerful when basic physical or chemical properties of singular partial systems or basic interactions among them have to be described. However, the uncertainty increases rapidly with an increase in interaction complexity.

Human activities are always producing emergent effects outside of laboratory conditions. It is therefore unavoidable to accept the challenge of emergent effects in applied environmental sciences. One potential solution is the use of system characteristics for identifying relevant interactions with a top down approach.

In this approach, the human induced modifications of scales are used for identifying impact risk and strategic development of survey systems .

4.2 Temporal Scaling in Catchment Systems

In Upper Austria, water quality management is performed in catchments of an area up to 4000 km². The actual temporal scale for observation is a maximum of 40 years, the temporal scale for implementation of measures lies at an average of 20 years.

Outside of these spatial scale dimension are the atmospheric and hydrospheric partial system; they will not be considered in discussion of temporal scales (Table 1).

Table 1. Estimated temporal scales (in years) of structural changes in relevant partial and emergent systems, based on data in Jenny [1941], Fletcher et al. [1987], Mason and Moore [1985], White et al. [1992].

Partial/emergent system	years
Geospheric ps.	$>10^6$
Microbiological ps.	10^{-3}
Botanical ps.	10^3
Zoological ps.	10^3
Soil.	10^3
Vegetation cover	10^3
Catchment draining system	10^4

Temporal scales of structural changes without human influences are far beyond the limits of the management systems (Table 1). On the contrary, most of human induced-structural changes are within the limits (Table 2).

Table 2. Estimated temporal scales (in years) of structural changes caused by human land use.

Structure	years
Landforms	10^1
Draining systems	10^1
Soil structure, grassland	10^1
Soil structure, field	10^{-1}
Vegetation cover, forest	10^2
Vegetation cover, grassland	10^1
Vegetation cover, field	10^{-1}
Built- up areas	10^1

By comparing analogous structures in Table 1 and Table 2 it can be derived, that human activity causes in general a reduction of temporal scale in catchment systems. Particularly important for calculating aqueous transport processes or erosion risk are the small temporal scales of soil structure and vegetation cover changes in fields.

The analysis of scales will remain incomplete, if other system properties are not considered. For structures of the abiotic partial system, and also for land cover structures with low human impact, it becomes increasingly evident that they have fractal properties [Mandelbrot, 1991; Forman, 1995]. However, in human influenced system structures fractal properties are rare. Predominant are geometric structures with clearly defined boundaries. Temporal patterns of human land use have two different characteristics. Activities on arable land have a discontinuous temporal pattern, determined by crop composition. Activities on grassland and other land use activities are randomly distributed on short-term temporal scales with some indication of seasonal dependencies on long-term temporal scales.

In comparing temporal scales it can be concluded, that in particular in arable areas the aqueous transport of nutrients or chemicals in the catchment cannot be sufficiently calculated without considering human land use practices. This conclusion is confirmed by parameter weights in the estimation formula of erosion risks in Dissmeyer and Foster [1984]. This conclusion is relevant for transport processes only.

4.3 Identification of land use units with different temporal scales

Actual land use in large areas can effectively be surveyed by use of remote sensing data. In the EU project "Applied Remote Sensing and GIS Integration for Model Parameterization" (ARSGISIP) the Innbach catchment with an area of 386 km² was used for application of catchment scaling [Flügel and Müschen, 1998]. Because built-up areas, infrastructure, and large point sources had already been digitised by water resource officials, the focus was placed on identifying agricultural pollution sources.

Multi-temporal land cover data from Landsat-5 TM were used to differentiate grassland and fields as well as crop types on fields. Soil types and data about drained areas were obtained from maps. Data on agricultural practices, related to individual crops were obtained through interviews with experts and from agricultural manuals.

Currently, the areas of high impact risk are identified in two steps. The temporal impact probability of different agricultural sources is identified by time series analyses [Lienert, 1978] of significant parameters, based on long term data sets. In the second step the impact relevance of the agricultural sources is being identified with the adapted erosion risk model [Schwertmann et al., 1990] on GIS. Further investigations on identified risk areas is dependent on the risk relevance in comparison with other sites in the catchment.

5. SPATIAL SCALING UNDER PARTICULAR CONSIDERATION OF THE CHANNEL SYSTEM

5.1 Background

From the viewpoint of systems research, channel systems are a part of the whole catchment system. Functionally a channel system is a dynamic integrator of hydrological processes in interaction with groundwater, and structurally, a fractal linear pattern in the catchment. The dimension of the channel system is consequently determined by dimensions of the catchment.

The continuity between catchment and channel system is changed by human activities in several ways. Far-reaching and widely distributed impacts occur through modifications of transient zones between channel and adjacent land such as floodplains, and through modifications of channel structure. The intensity of impacts increases with the construction of dams and weirs and reinforcement of banks and channel beds. Such changes are long-term changes in reference to Table 1, independently of the spatial scale of modification.

The dynamics of channel systems are modified by flow regulation, hydroelectric power stations, water extraction or sewer systems. The dimension of such modifications depends on the dimensions of the specific impact.

From a simplified viewpoint, water quality is modified by human -induced chemical or physical impacts. Under consideration of the interactions in channel systems, water quality will also be influenced by changes in self-regulatory capacities. Such impacts can for example be caused by dams with a subsequent increase in local sedimentation rates, or also by a reduction of biocenosis turnover rates, caused by channel modifications.

Water quality control solely through the monitoring of certain chemical and biological parameters without consideration of scale relationships will not deliver sufficient information about the causes of a deterioration in water quality. For an integrated quality management system the scales of the channel system have to considered in combination with the catchment system.

A well developed method for consideration of channel system scales is the river habitat survey [Boon and Raven, 1998]. With the combination of map data and data from systematic ground survey on randomly selected 500 m sites, geo- and hydromorphological information of the channel at all relevant scales can be gathered. Additional data about channel vegetation and land use within a 50 m wide strip along both bank shoulders are also included in the survey. The data can be analysed for different purposes. One application is the characterisation of runoff conditions for system related sampling of water quality indicators. This method is still not applied in Upper Austria, but it is recommended to improve surface water quality management.

The author and colleagues were able to demonstrate the information strength of integrated methods, with a similar but much simpler survey procedure in mountain brooks [Knoflacher et al., 1990]. The investigations were conducted to assess the feasibility of constructing small hydropower plants at 24 mountain brooks in north west of Styria (Austria) in 1989. Without our previous knowledge, one brook had been investigated for more than three years by disciplinary scientific approaches. Despite the single integrated survey approach, the team independently achieved the same results at four randomly selected sites concerning the water quality status of the brook system (modified because of interrupted sediment transport) as in the scientific investigations.

5.2 Consideration of Catchment Scale in Water Quality Survey Site Selection

Consideration of catchment scales in survey site selection in the channel is confronted with the pattern of land uses at plot scale. A first reduction of the land use diversity can be achieved by adopting a rule based aggregation of land use patterns at plot scale and applying it to different land use categories (Figure 2).

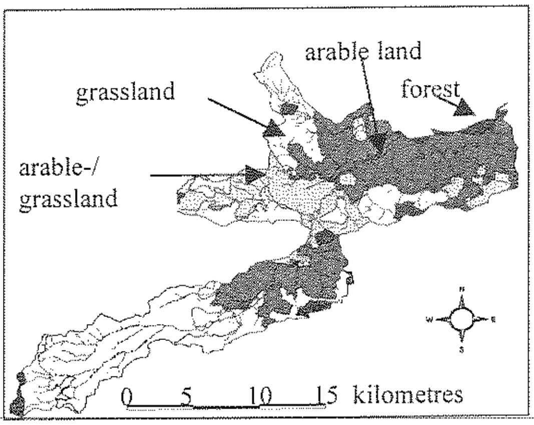


Figure 2. Pattern of aggregated land use categories, based on satellite remote sensing data (Innbach catchment, Upper Austria).

Land use clusters are needed for modelling agricultural land use activities, as for example crop rotation. However, despite of the homogeneity in land use activity, there is no regular relation to channel positions. The solution concept for this problem is based on mid-term intermediate flow time, under consideration of soil draining installations. The transformation of transport time into spatial dimensions will be made with the TOPMODEL approach (Beven, 1997).

Basic spatial control units will be derived by superimposing aggregated land use categories on calculated runoff isolines. The final determination of water quality survey sites depends on the optimisation between runoff conditions in the channel, river network structure, and basic spatial control units. In existing survey systems, this approach is used to check the accuracy of site data on non-point source impacts.

6. CONCLUSIONS

Scaling is often discussed solely from the viewpoint of physical and chemical processes. In this paper, it was demonstrated that human activities strongly influence scale conditions in catchment systems. Accurate and efficient surface water quality management is consequently strongly dependent on considering human-induced scale modifications and using a strategic approach to developing survey systems.

The essential power of scaling lies in reducing complexity in real systems to manageable dimensions. Scaling in combination with robust modelling are fundamentals for application of cost-efficient field surveys and dynamic modelling in applied sciences.

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