Dissertation Theses

ANALYSIS OF FACTORS INFLUENCING THE WATER QUALITY OF RIVER KÖSELY WITH SPECIFIC ATTENTION ON SALT FLOW

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1. INTRODUCTION AND GOALS OF THE DISSERTATION

In my dissertation I review the surface water quality issues on the catchment of river Kösely. In my review I put emphases on the salt-related quality issues and the dilution-conditions based on known salt loads and requirements set against salt concentration. The topic is evidently actual for several reasons. First of all water quality standards defined in the Water Frame Directive (WFD, 2006.) are not met and the tendency is not likely to improve due to the predicted impacts of climate change on Hungarian water regimes and the trend of current thermal water management practices.

The ecological condition - which refers to the state of the physical, chemical, and biological characteristics of the environment, and the processes and interactions that connect them - of river Kösely and that of its receiver, river Hortobágy is not good (National Water Management Plan). The goal of WFD is to achieve the good ecological quality of every water body in the EU until year 2015.

I complete the available data series of the national Surface Water Monitoring network with my own measurements, calculations and the results of hydrodynamic modelling as there is a real-time monitoring station only at one cross section on the bottom of the watershed**.** Based on these data I make conclusions and suggestions regarding water quality management issues on the river catchment. The investigated water bodies are practically canals receiving rainwater and treated sewage of settlements - among others Debrecen with 200000 inhabitants. At the same time it is an advantage that the hole catchment lays on the territory of Hungary which makes it less complicated to implement any measurement compared to cases of transboundary watersheds.

I not only take WFD water quality criteria into consideration – which are developed in relation to the functioning of aquatic ecosystems in general - but also those for irrigation water as salinity of irrigation water is a main contributor to yield reduction and secondary salinity of soil . This is important because irrigation will be even more inevitable in the future due to the predicted impacts of climate change. Vermes (VERMES et al. 2008) concludes the arguments for the development of irrigation systems in Hungary as follows: " the climate of Hungary is expected to change to the Mediterranean character with higher mean temperatures, less summertime rainfall and increasing extremes like floods and droughts. While water resources are decreasing, the need for irrigation water is increasing.

Though Hungary is at the moment in a favorable situation regarding water resources compared to western European countries, agriculture must be prepared to more frequent droughts and floods in the future.

Losses in the agricultural sector due to droughts are much higher than the costs of irrigation. Hungarian agriculture is undefended against drought. Irrigated area in Hungary has been decreasing in the latest decades. Further actuality of the topic is confirmed with the following facts

- There is no existing BAT for thermal baths so far so no elimination of salt effluents from thermal baths can be expected.
- The modification of law N.LVIII. on water management from year 1995 decides about possible permission of neglecting the reinjection of energetically used thermal waters on request in certain cases. Thus increase in the discharge of salty thermal waters into surface waters can be expected.

The long term sustainable practices of water usage should be applied, so I investigate the sustainability of thermal water usage for thermal baths. According to OECD (2000.) SMM is an approach to promote sustainable materials use, integrating actions targeted at reducing negative   environmental impacts and preserving natural capital throughout the life-cycle of materials, taking into account economic efficiency and social equity, so the criteria of sustainable material flow are as follows:

- quantity of materials flowing from the antroposphere into the environment must not exceed the local and global assimilative capacity
- quantity of materials flowing from the antroposphere into the environment must not exceed the natural flow rate
- material flow should be controlled in a way that we will not run out of *non-renewable* materials
- Material flow should be controlled in a way that materials harmful to humans or nature will not accumulate. Salts are not toxic but above a limit the balance of the effected ecological system will not be maintained and the water will not be adequate for human usage

THE GOAL OF THE DISSERTATION TO ANSWER THE FOLLOWING
QUESTIONS

- Does the quality of river Kösely and tributaries meet the different requirements regarding salt content?
- What rate of dilution is needed to reach the adequate water quality according to different requirements? Can we solve the necessary dilution by the given possibilities ?
- Due to lack of enough river flow data the possibility of calculating runoff from precipitation data arises. To achieve this I define lag times based on correlation between EC and rainfall data in the same cross section.
- How can the pollution transport be characterized along the river? That is, how does the hydromorfologic characteristics determine self cleansing capacity of the river?
- What are the quantifiable facts and activities that determine the salt related water quality of river Kösely and tributaries?
- How much is the affordable salt load of the river sections - connected to limit values ?
- What impacts have the two main salt effluents on the composition of the sediment of river Kösely?
- What is the relationship between the Electrical Conductivity of the water and the sediment in the same cross section?
- Does the current practice of thermal water usage meet the requirements of sustainable material flow, that is:
  - Does the salt loads exceed the assimilative capacity of the receiving water body?
  - Does the current practice overexploit the non renewable resources?
  - Does the current practice result in adverse accumulation in the environment?

## 2.	METHODOLOGY OF THE RESEARCH

In this chapter I describe the hydrometeorologyc characteristics   and the hydromorfological features of the study area which is the Kösely catchment. The qualification of the water bodies in the catchment - based on data series of the regional environmental regulatory agency TIKÖFE deriving from ten years anticipating the year of my own measurements - is presented. This evaluation serves on the one hand as a base for comparison with my findings and on the other hand as baseline-concentration of salts. Baseline-concentrations are necessary for determining permitted loads.

The study area with the eleven sampling sites is also introduced along with the results of EC-measurements of water samples on 28 occasions in the one year-long sampling period. This chapter also introduces the aim of sediment measurements, the preparation and analytical measurement process of 16 sediment samples collected on twelve sites.

Salt mass balance is also estimated in this chapter the results being quantified ratios of different loads on the catchment both in [tons/year] and in [mass/sec].

## 2.1	COLLECTION OF HYDROMETEOROLOGICAL-, WATER HOUSEHOLD- AND SALT LOAD DATA

As salt is a conservative pollution, rainfall- and river discharge data have a main role as they provide dilution water enhancing self cleansing process in the water body. The goal of collecting rainfall- and river discharge data is to determine the limiting – most critical - condition on the river catchment regarding salt content.

On the investigated river catchment most of the rainfall will evaporate and the remaining portion will infiltrate or run-off, increasing river discharge. Existing official river discharge data for the lowest river section at Nádudvar are valid only for a few hundred meters because inlets and outlets are influencing river flow rates on the upper river reaches.

In this contribution I determined the critical river discharge with two methods.

As for the first method I took the river discharge value out of the ten-year data series below which the return possibility of values is below 10 %.

As for the second method I took the river discharge value of the day on which the measured EC data was the biggest assuming that dilution is the lowest due to small river flow. These limiting discharge-data are then divided among 6 sub-catchments in the ratio of three factors which are the areas of the sub-catchments, the rainfall data of the

sampling year 2008 and the average monthly rainfall data of ten years. The river flow value was then divided further among on the 7 reaches of the 61 kms long river Kösely in the ratio of the factors above and the planned excess-water discharge values of the specific reaches determined by the Water Management Regulatory agency TIKÖVIZIG. Salt material flow data was collected in order to use the method of material flow management as a water quality control method which is very useful in case of conservative pollutions like salt and much simpler than comparing real-time concentration data with limit values.

2.2. COLLECTION OF WATER QUALITY DATA IN ODER TO QUALIFY THE WATER BODY

The goal of qualifying the water body is on the one hand to determine the reaches of the river and the time periods of water quality meeting the requirements. On the other hand the water quality above the known effluent discharges let us determine the background concentrations which is not yet known and have not been taken into consideration in the process of water quality control. Also detection of changes - trends - in quality is assessed.

According to already existing data series of the regulating agency water quality is not sufficient but we do not have enough data regarding sampling sites and frequency of sampling. I have processed the data series in order to determine background pollution and make comparisons with data from my own one year long measurements. The result of the data process is longitudinal sections of the Kösely River showing water quality (EC) from the headwaters of the Tócó River to the Kösely River Mouth.

2.3. ONE YEAR LONG SAMPLING AND EC-MEASUREMENT

Little information is available on the extent of surface water pollution with regard to salinity so in order to provide a proper qualification of river Kösely and tributaries a one year sampling plan was formulated. Here I introduce the study area with the eleven sampling sites along with the results of EC-measurements of water samples on 28 occasions in the one year-long sampling period. As a result I have evaluated the measured EC-data for the one year period and for the irrigation period as well to see whether quality standards are met in these periods and to see which reaches of river Kösely are suitable for irrigation. I present, which reaches of river Kösely and its

tributaries - with the currently given possibilities for irrigation water inlet - are appropriate for irrigation in different hydrologic situations. The results of the processed data are longitudinal sections of the Kösely River showing water quality (EC) from the headwaters of the Tócó River to the Kösely Orange River Mouth as well as changes in water quality with time during the sampling period at sampling sites on the Kösely River. By the help of the processed data I can present the differences between the annual and seasonal patterns of quality through general statistical characteristics. Also I present comparisons with the data series of longer periods of the regulating agency. It provides more information than expected because the sampling period happened to be a rainier year than usual.

As a result I could not exhibit significant seasonal fluctuations.

A complete description of the method used for the measurement and the statistical data process is given in the sections of chapter 3.

2.4. CALCULATING THE DILUTION OF CONDUCTIVITY

I have calculated dilution water for every reaches of river Kösely

Based on the lowest – limiting - river flow rate, the EC-values measured on the day of the limiting flow rate, the EC value of the available dilution water and the required EC value according to Hungarian Standard, WFD recommendation and the irrigation water requirements. In the calculations I have used the generalized mass balance equation assuming immediate mixing of dilution water and the river flow. The EC of the dilution water is that of the water sample taken from Eastern Main Channel in summer.

I have - theoretically - let in different quantities of dilution water in two cross-sections of river Kösely. One of these is the really existing Eastern Main Channel, the other is an optional – alternative – one at the ending section of the river, at the confluence of river Tócó and Kondoros. This latter case is considered in order to provide dilution for the upstream reaches as well, above the Eastern Main Channel. The bottle-neck turned out to be the hydraulic capacity of river Kösely which means that there is not enough flow capacity in the river bed for the needed quantity of dilution water. In non of the limiting cases could the needed quantity of dilution water be let in, due to insufficient area of the cross section so the quality of most reaches of the river Kösely remain only *tolerable*.

2.5. APPLICATION OF THE HEC-RAS HIDRODYNAMIC MODELL FOR SEVERAL TYPICAL HYDROLOGIC SITUATIONS IN ORDER TO CHARACTERISE TRANSPORT PROCESSES OF RIVER KÖSELY

Also in this chapter on methodology the preparatory calculations for using hydrodynamic model HEC-RAS is carried out. The 3D model of the river channel is readily adopted with 11 cross sections but the lowest - the least favorable - discharges in plant vegetation period and in the whole year - which is the relevant discharge regarding water quality - is calculated based on the data of the only one gauging station. These discharge-data are then divided among the 7 reaches of the river channel, in the ratio of three influencing factors which are the areas of the sub-catchments, the planned excess-water discharge on the reaches and the ten years-long series of rain data. Further cases are than determined by letting in different quantities of dilution water in two cross-sections. One of these is the existing Eastern Main Channel, the other is an optional – alternative – one at the ending section of the river, at the confluence of river Tóbó and Kondoros. This latter case is considered in order to provide dilution for the upstream reaches as well, above the Eastern Main Channel. HEC-RAS calculates several hydraulic variables for each cases which allows for calculating the longitudinal transport of the river, namely advection and longitudinal dispersion coefficient. I provide longitudinal dispersion coefficients for cross sections in every 500 m-s calculated with two experimental formulas of FISCHER and MC QUIVEY-KEEFER.

The results characterizing the transport processes in river Kösely are presented. I found on the one hand – as it is already published - that longitudinal dispersion coefficients must be determined through measurements, because formulas have proved to be appropriate only for estimation. On the other hand I emphasize those river sections where the maximum and minimum values of D_L are calculated. These may have importance in determining the optimal section for the inlet of dilution water. I also compare the calculated the range of values with those given in literature.

2.6. SIMULTANEOUS SEDIMENT AND WATER SAMPLING AND ANALYTICAL MEASUREMENTS

The chapter on methodology also introduces the aim of one series of sediment measurements, as well as the preparation and analytical measurement process of 16 sediment samples collected on twelve sites.

The three goals of the measurements

- to assess the impacts of the two main salt effluents on the composition or any other characteristic of the sediment of river Kösely
- to assess relationships between different characteristics of the sediments
- to assess whether there is any relationship between the Electrical Conductivity of the water and the sediment in the same cross section

I have made measurements on three kinds of solutions made of the sediment samples with the methods of

- flame photometry
- atom absorption spectroscopy and
- ultraviolet-visible spectroscopy

I also analyze the results from the laboratory measurements of the sediment samples with due regard to variables of high correlation coefficients, to changes in sediment quality below thermal water or sewage emission points. I also present changes in the quality of humus content in the sediments as an effect of effluent discharges. The whole correlation matrix is included showing which variables are in significant correlation (> 0,7) and which are not.

2.7. SALT FLOW CALCULATION IN ORDER TO DETERMIN AFFORDABLE LOADS OF SALT

Using the data records on monthly thermal water extraction in the river basin this chapter also includes the calculation of annual total mass of water and salt flowing down the river in order to determine the affordable annual and season al loadings of salt in g/s and in m^3 of thermal water/year on three reaches of the river Kösely. The notion of affordable loading and the methodology for its calculation I have adopted from the WFD-related literature. This method is very useful when data series are insufficient like in the investigated basin of river Kösely.

2.8. INVESTIGATING RELATIONSHIP BETWEEN EC AND RAINFALL DATA IN ORDER TO DETERMINE TIME LAG

For each sampling cross sections I have investigated in vain the relationship between the measured EC values and the total rainfall of 5 days and of one month above that certain section. The concept of the investigation – to determine the time lag - is still valid but it needs more EC-measurements and correlation-analysis of these values with total rainfalls of 1-100 days.

3. NOVEL SCIENTIFIC RESULTS

Thesis I

As a new method I have applied the cross section-averaged one-dimensional hydrodynamic model HEC-RAS for determining the movement and change in concentration of salts discharged into river Kösely. I have used the hydraulic variables - which are the results of the model-run - for calculating D_L (Longitudinal Dispersion Coefficient) in sections of every 500 meters using the experimental formulas of FISCHER and MC QUIVEY-KEEFER. The calculated coefficients are in the range of D_L values offered in referred papers. The goal of the analysis was to determine the ideal cross-section of Kösely for either effluent discharge or inlet of dilution water. By the application of this method I have got information of a significantly higher resolution compared to other methods used so far. By determining the minimum input-data requirement of the method I provide a tool for preparing the analysis of the transport processes of other catchments as well. As such this is a helping tool for decision-making in water quality control.

Sub-Thesis I

Based on my newly developed methodology I have demonstrated that the longitudinal dispersion coefficient values calculated with the experimental formula of McQuivey-Keefer belong to the stretch of the river in which the measured depth of sediment is the greatest - one hundred cms - on river Kösely.

Thesis II

I have analyzed visible light absorption of the Sodium hydroxide (NaOH)- and nitric acid (HNO_3) solution of the sediment samples. Being suitable for characterizing the quality of the humus content this is a newly developed method of mine. The results are demonstrating that the absorption of all samples above 600 nm are decreasing exponentially and that the humus is more stable below the discharges of thermal water effluent.

Thesis III

The results of my sediment analysis contribute to the demonstration of changes - increasing or decreasing - in the quantity of certain components between the samples from above and from below the effluent discharges. This result is suitable for demonstrating that - due to remnants of former effluents and uncontrollable movements of sediments in the riverbed - sediment analysis is adequate neither for monitoring the real effect of effluent discharges on water quality, nor for separating the effects of different effluents.

Thesis IV

It is a new result – not published in the literature yet – that there is very slight correlation between measured EC values of water and sediment in the same cross section of river Kösely which is apparently valid for other water bodies as well.

Thesis V

I have applied a novel method of material flow analysis for determining the seasonal rate of affordable loading of certain reaches of the river with specific water demands and during low runoff. This novel method helps to determine which section of the river would it be most effective to implement any measure of water quality-improvement. The usefulness of the method is underlined by the fact that the result does not depend on the frequency of water quality monitoring. I have determined the data-requirement of this method which helps to apply it on other river basins as well.

4. PRACTICAL APPLICATIONS OF THE RESULTS

1. In spite of high loadings of salt on river Kösely there are a few facts which queries the reasonability of applying polluter pays principle in this case, these are

    - the rates of background concentrations are already high,
    - thermal waters are used in their natural form and
    - there exist no BAT for this technology for this usage

    Considerable attention is needed both at policy and practical levels. That is, BAT must be developed and implemented by help of subsidies on river basins where high background concentrations, low river discharges and high salt content of thermal water makes it impossible to meet water quality requirements. This notion must be followed in order to achieve good irrigation water quality and the goals of the Water Frame Directive.

2. In the frame of a one year-long hydrologic monitoring program the time lag between the rainfall event and the river flow can be determined. Being in possession of the time lag the time of effluent discharging and dilution water inlet could be harmonized with the rain events resulting in optimal and effective dilution just by taking advantage of the natural dilution capacity. Effluents would be discharged in at time of higher river flow rates and dilution water would be et in when natural dilution is lacking.

3. When planning the implementation of certain water quality control measures in which the role of natural pollution transport plays a significant role, the longitudinal dispersion coefficient should rather be determined by experiment especially in the case of salt pollution where salt as a conservative material can be the tracer used for the experiment. This experiment is suggested to be executed simultaneously with the hydrologic monitoring program.

4. Applying the new novel method of material flow analysis the affordable loads on any river reaches can be easily determined independent of frequency of monitoring.

5. By the application of the cross section-averaged one-dimensional hydrodynamic model HEC-RAS calculation of D_L (Longitudinal Dispersion Coefficient) in sections of every 500 meters is possible which makes one capable for determining the ideal cross-section of a river for either effluent discharge or inlet of dilution water. This method provides information of a significantly higher resolution compared to other methods. By determining the minimum input-data requirement of the method I provide a tool for preparing the analysis of the transport processes of other catchments as well. As such this is a helping tool for decision-making in water quality control.

6. The novel method of material flow analysis can be applied for determining the seasonal rate of affordable loading of certain reaches of a river making it a useful tool for determining the section of the river where the implementation of any measure of water quality-improvement would be most effective. The usefulness of the method is underlined by the fact that the result does not depend on the frequency of water quality monitoring. I have determined the data-requirement of this method which helps to apply it on other river basins as well.

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