PERSPECTIVES AND ASPECTS ON WHAT WE CALL SUSTAINABILITY, ESPECIALLY WITH RESPECT TO A DEMAND FOR A COMPACT WASTEWATER TREATMENT PLANT CONFIGURATION

PERSPEKTIV OCH SYNPUNKTER PÅ SÅ KALLAD HÅLLBARHET, SPEGLAD I STRÄVAN EFTER EN KOMPAKT KONFIGURATION FÖR AVLOPPSRENINGVERK

Stig Morling, Blindgatan 39A, 791 72 Falun,
stig.morling@kronskog.com

Abstract

The concept" Sustainability" has become an indeed demanding metaphor within society. However, without a deeper understanding and more accurate use of the word it may very well, by and by, become obsolete. In this paper the question is focused on the development of wastewater treatment. Some "curial" demands on a more specific approach to sustainability are presented in this paper: 1) The never- ending needs for improvement of the treatment needs with respect to, inter alia, occurring complex organic polluting agents. 2) The demands for efficient and compact treatment methods. 3) The needs for improved, relevant, and affordable analysis methods; 4) To occupy an accepted, limited area for the plant; 5) The social acceptance of the water environment protection. 6) An increased need for reuse of the used and treated water. At first a short historic perspective is enlightening these demands. In addition to this, a few other relevant points are discussed to demonstrate the urgent needs for the enhancement of the water environment protection in a longer perspective.

Keywords: Compact plant, complex compounds, historic perspective, nutrients

Sammanfattning på Svenska

Begreppet hållbarhet har under senaste årtiondet blivit en utmanande "metafor" för åtskilliga aspekter I vårt moderna samhälle. Men utan en djupare förståelse av vad som menas med begreppet, parad med en mer preciserad förståelse av vad som faktiskt menas riskerar ordet att mer eller mindre komma i "vanrykte". I denna uppsats begränsas diskussionen till att appliceras på utvecklingen av avloppsvattenrening. Några "kritiska" krav på vad som kan kallas hållbarhet i detta sammanhang diskuteras i sex olika perspektiv: 1) Ett aldrig avstannande krav på utveckling och förbättring av behandlingen av avloppsvatten, speglat av att komplexa organiska föroreningar identifieras, som kräver en ofta hög och säker reduktion. 2) Behovet av att anordna så kompakta och effektiva behandlingsmetoder som möjligt. 3) Detta åtföljs av ett uppenbart behov av förbättrade, säkra och kostnadseffektiva analysmetoder. 4) Att reningsanläggningens utrymmesbehov är i rimligt mått begränsat. 5) En väl så viktig aspekt är att avancerad avloppsrening är en socialt och politiskt accepterad verksamhet. 6) Ett ständigt ökat behov av återanvändning av behandlat avloppsvatten. Som tillägg diskuteras också några aspekter på mer angelägna behov av ett förbättrat vattenskydd – sett i ett längre perspektiv.

Background and Historic Perspectives on wastewater treatment

The wastewater treatment reality may be seen as a mirror, in a broad sense, of the modern society in several aspects. On the other hand, the old saying from the Old Testament (Eccl. 1:10), is very true: "Is there anything whereof it may be said, see this is new? It hath already of old time, which was before us." Now in this context we limit the perspective to around the latest 170 years. The disposal of untreated wastewater was totally based on the principle of dilution by discharge directly into rivers downstream of the city. Typical examples were London and Paris, see for instance Pinkney (1958). The especially illustrative example given by Pinkney is the rebuilding of Paris in the mid-19th century. The other adopted model for wastewater handling was the disposal of wastewater into a nearby sea.

An early "break-through" with respect to biological treatment was the insights found predominantly in Great Britain (Sidwick and Murray, 1976). They point out the importance of the break-through of the activated sludge concept, see also Arden and Lockett (1915). These findings could well be seen as a major step towards a "compact treatment model" for wastewater. The history of the activated sludge concept is since these findings a more than well-known and highly influential tool for wastewater purification. The model will be further commented in the following. With respect to the fundamental question of "sustainability" these early steps towards an improved sanitation may all be understood as exactly sustainable, based on the available and accepted knowledge at the time.

The growing concern with respect for the needs of an improved water environment may be found during the first decades of the 20th century and resulted in an analysis of the Stockholm sanitation scheme. The analysis presented in a good way how the sustainability criteria were used for the decision, see Stadskollegiets Utlåtanden och Memorial (1931). A use of treatment by disposal of the wastewater on arable land was rejected in favour of a location in the rock southeast of Stockholm. The plant was planned, designed, and built during the 1930s and taken into operation in 1941. The location in the rock concept has later been labelled: "The underground site added value". This solution satisfies the demand on not occupying valuable land. An interesting proof to this statement is that the facility the "Henriksdal WWTP" is now, more than 90 years after the initial decision, not only treating the wastewater from Stockholm, but also is facing a major upgrade, still in the same location. The upgrade may also underline another thesis commented further in this paper: By using the existing volumes in a partly new way it points out the practical possibilities to use "compact technologies" for quality upgrade. The forthcoming extension of the plant will increase the capacity to around 1 600,000 PE from 800,000 PE (person equivalents).

The concept of "The underground site added value" has further been implemented in some important plants in Sweden: The large regional plant for the greater northern Stockholm area, the "Käppala WWTP" that was taken into operation in the early 1970´s and is now facing major upgrades in a similar way as the Henriksdal WWTP. For a few midsized plants in Sweden the same concept has been used. Both the plant serving Uddevalla on the Swedish West coast, taken in operation in 1974, and the plant for Sundsvall called ("the Tivoli plant") were built in the 1960's. Both plants are still running. The Uddevalla plant is aimed for a prolongation of the formal operation permit, and the owner is aiming for a continued operation of the plant "in rock". The revised "permit capacity" has been chosen to 55,000 PE. The Sundsvall situation is somewhat different. They are for the time being evaluating three different options for the future wastewater management. Included in these options is still a localization of "in the rock".

As a summary: All these examples provide good arguments for a "sustainable" location as they do not "compete" with other activities. Furthermore, the chosen localizations along with the adopted configurations also may be defined as examples of: "A built-in upgrade capacity", see Rosén and Morling (1998). From the "sustainability" point of view the chosen localization may be seen as very acceptable.

The diversity of substances and the needs for a design þexibility

Often the book, "Silent Spring" by Rachel Carson (Carson, 1963), is seen as the eyeopener and an "eruption" of the modern environmental concern. One crucial point at the time was the discovery of DDT as a major threat to the environment and to a few harmful impacts on the biodiversity. The development of this chemical agent had in 1948 been awarded the Nobel Prize in Medicine. Thus, this situation may serve as an illustration of a situation we seem to meet repeatedly: With good intentions we are creating situations and chemicals that rather soon show to be more than a threat. A few such examples are presented in the following with special relevance to the wastewater treatment sustainability.

We may again recall the old wisdom from the Old Testament, Eccl 1:10, quote: "Is there anything whereof it may be said, See, this is new? It hath been already of old time, which was before us". An illustrate example is the development of the activated sludge from the early tests in Manchester, UK in the early 1910´s. The "main criteria" for a complete purification was the complete nitrification of the nitrogen content in the wastewater. Later, as the model with intermittent operation was abandoned this criterion was over-shadowed by other needs. When the Oxidation Ditch was developed by Dr Pasveer in the Netherlands during the 1950´s (Pasveer, 1959), a revitalized interest on nitrogen removal came about. In Sweden the technology was studied at the Chalmers Institute of Technology CIT, in Gothenburg, starting in the early 1960´s (Nilsson, 1965). These studies started an establishment of biological nitrogen removal in the Swedish market. However, this development was halted, due to the conviction that the main water environment problem was the eutrophication caused by phosphorous rather than by nitrogen, see inter alia Morling (2008).The Swedish environmental law put into power at the end of the 1960´s stipulated no restrictions on nitrogen, but for especially phosphorous stringent limitations were given, the normally stipulated discharge limit was < 0.5 ppm of total-P.

This focus on P-removal initiated an intense, around 15-year construction of municipal WWTP in Sweden. This period resulted in indoor plants with typical compact configurations. The plants were built with a typical layout as shown in Figure 1.

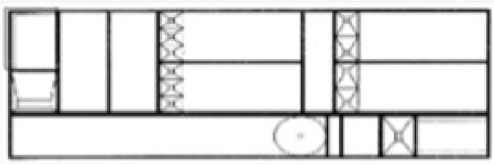

Figure 1. *Typical lay-out of a "compact plant" built at many sites in Sweden during the 1970's (a plant sized for about 6,000 inhabitants, for the Munkfors community in western Sweden).*

With respect to the formal demands, the removal of organics (expressed as BOD7 and total P) almost all municipal Swedish WWTPs performed extremely well (Morling, 2019). In Table 1 typical discharge levels for total P from seven diffe-

Table 1 *Summary of discharge values from some Swedish municipal plants with respect to P (annual mean values).*

Plant name and size	Control year	Discharge level, mg P/l
Klagshamn WWTP, Malmö 90 000 PE	2014	0.20
Duvbacken WWTP, Gävle 107 000 PE	2015	0.27
Torna Hällestad WWTP, Lund 800 PE	2014	0.10
Nynäshamn WWTP, 25 000 PE	2012	0.06
Käppala WWTP, Stockholm Suburban area 425 000 PE	2014	0.20
Solviken WWTP, Mora 18 000 PE	2015	0.14
Ellinge WWTP, Eslöv 330 000 PE	2014	0.19

rent plants of different sizes and locations within Sweden are presented. By-in large the discharge level has been substantially lower than the formally stipulated values, either < 0.3 or < 0.5 mg total P/l.

For the Scandinavian countries, except for the situation in Denmark, the focus on P-removal was the dominant task for many years. A model for quantification of the impact by relevant polluting agents on the receiving water bodies was suggested by Professor Halvard Oedegaard, Norwegian Technical University in Trondheim in the 1980s. The model quantifies the impact of municipal discharges into the water bodies. The following relation was suggested:

$$OCP = 1*BOD + 4*N + 14*N + 100*P, \text{ in } kgO_2/d$$

were

OCP = Oxygen Consumption Potential, defined as kg O_2/d,

1*BOD = Organic pollution, defined as kg O_2/d,

4*N = primary oxygen consumption due to oxidation of ammonia nitrogen into nitrate nitrogen, defined as kg O_2/d,

14*N = secondary oxygen consumption due to algae growth and decay driven by nitrogen, defined as kg O_2/d,

100*P = secondary oxygen consumption due to algae growth and decay driven by phosphorus, defined as kg O_2/d.

Several Nordic WWTPs have gone even further in efforts to minimize the phosphorus discharge, typically by adding different kinds of filter stages to the treatment chain. Some examples of full-scale experiences during the last few years have been presented by Morling and Feldthausen (2019).

Nevertheless, the problems with nitrogen discharges into the water bodies especially into the surrounding seas became apparent in the mid 1980´s when algae blossom occurred in the Baltic Sea and on the Swedish West coast. A comprehensive research and test program was initiated focusing on biological nitrogen removal.

A further focus on advanced phosphorus removal is still relevant, initiated not only by the obvious needs for further decrease of the phosphorus discharge, but also with respect to a growing need for phosphorus recovery from municipal sludge. In a Doctoral thesis, Hey (2016) focused on advanced removal of phosphorus compounds by use of the combination of chemical precipitation with advanced separation using Microsieving, Microfiltration and Forward Osmosis, thus reaching high levels of removal without a biological stage. A quotation from the thesis is worth presenting:

"Nevertheless, both concepts achieved high retentions, with ≥96 % for biochemical oxygen demand, ≥94% for chemical oxygen demand, and ≥99 % for total phosphorus. Furthermore, the evaluation of both concepts showed that the specific electricity demand was 30 % lower than the average specific electricity demand for 105 traditional Swedish wastewater treatment plants with population sizes of 1500 – 10,000".

This history from the Swedish perspective may illustrate the risks linked to a too shortsighted view of a problem. The further development of the nitrogen removal shows a needed "catch-up" of needed knowledge. This is a permanent risk in our comprehension of the needed technical solutions to a given problem. As we started to highlight the fate of DDT, we may again face similar risks for a too short-sighted apprehension of the possible polluting agents. In the next chapter a few such problems will be discussed.

On the other hand, it may be stated that the background formed by the society situation during the 1970´s, especially in Sweden, with very optimistic expectations on both the population growth and the specific water consumption figures resulted in oversized plants in comparison with the actual treatment needs. As pointed out above, this fact is important to keep in mind as the "built-in upgrade capacity" to be utilized for future needs. This matter will be further discussed in the following chapter.

Table 2 *presentation of sampling results from a few Swedish waterbodies with respect to the presence of diclofenac (Translated from the original version in Swedish), reference "VISS" and Finnson (2021).*

Watershed	Region	Year from	Last year	Nos of obs.	Recorded value	Consent value
					µg /l	µg /l
Långmyrbäcken	Jämtland	2018	2019	2	0.3267	0.1
Luossajoki	Norrbotten	2016	2019	2	0.25	0.1
Bergbäcken	Norrbotten	2016	2016	1	0.2	0.1
Kaavajoki	Norrbotten	2016	2019	2	0.2	0.1
Fyrisån	Uppsala	2010	2016	?	0.26	0.1
Rivö fjord south	West Götaland	2017	2018	5	0.4688	0.1
Rivö fjord north	West Götaland	2017	2018	5	0.4651	0.1
Friaån	West Götaland	2018	2018	1	0.218	0.1
Lidan	West Götaland	2018	2018	1	0.21	0.1
Viskan	West Götaland	2017	2018	2	0.19105	0.1
Ösan	West Götaland	2018	2018	1	0.139	0.1
Dofsan	West Götaland	2018	2018	1	0.135	0.1
Täljeån	Örebro	2016	2016	1	0.09	0.1
Roxen	Östergötland	2017	2018	2	92.56 (!)	0.1
Ljusterån	Dalarna	2018	2018	2	0.095	0.1
Kvarnbäcken	Jämtland	2018	2019	2	0.06805	0.1
Enköpingsån	Uppsala	2013	2013	?	0.059	0.1

VISS is a Swedish entity, understood as "Vatteninformationssystem, Sverige". The recorded value from Roxen of 92.56 mg /l seems to be extreme, in comparison with all other recorded values!

Demands and challenges for an improvement of measurements and analysis of complex substances

The three recent decades have demonstrated that the municipal wastewater contains far more complex substances than organic carbon and nutrients such as nitrogen and phosphorous. By and by unexpected problematic compounds found in the wastewater have been identified. As an example, some early findings were contraceptives identified even in the treated wastewater, and thus causing effects in the nearby water biotope. Successively, a growing concern was found, even more underlined some years later by complex substances such as PFAS (per- and polyfluoroalkyl substances), found in both cloths and in compounds for firefighting.

One of the more recent threats to the water environment has been identified as "diclofenac" found in several painkillers used without a formal prescription. The matter has been brought to attention the last few years, see Finnson (2021). In many respects the matter may illustrate a few crucial questions. The paper presents a summary of measurements in Swedish waterbodies on the presence of diclofenac and comparing the observed levels with the consent values for water bodies. In Table 2 is found a copy from the paper. In connection with this presentation some points of importance are given in the following.

As the report underlines the crucial impact of diclofenac, there are some necessary remarks to be given:

- A critical comment on the number of samples taken. As found in the summary for many water bodies, normally smaller water ways or rivers, or rivers only very few samples have been taken. As an example, only one single sample for six different locations and two samples at eight different sites are presented. Only at two presented sites, both labelled "Rivö fjord" found on the Swedish west coast are 5 samples presented during a two-year period. In view of the pointed importance with respect to the identified polluting agent there would be obvious needs for a more comprehensive sampling, analysis, and evaluation report.
- The accuracy of the analysis. As the concentration levels are very low it is more than desirable to present the accuracy of the analysis method at these levels.
- A report should also include the so called "detection level of the analysis method" for the diclofenac.

It is however of vital interest that the report enlightens the relevant question on what is often called "upstream work". In this situation it is interesting to discuss the efficiency removal efficiency inside the treatment plant with respect to different chemical agents of the different chemical agents. For the time being the efficiency is estimated at 10 % – in other words 90 % of the content is discharged into the water – ending up firstly in the wastewater.

The second vital point to focus on – may the actual substance be replaced by other, less harmful to the environment? This is a classical model to solve an identified problem. This puts a demand to the industry, as the case was some 30 years ago for the paper industry, when the chlorine bleaching of paper was found to be a crucial environmental issue. In this case the paper industry made a swift response to the market and changed the bleaching method. Once the legal demands were in power many of the paper industries had already changed the bleaching method.

A third point to be addressed is to what extent the pollutant is handled in a wastewater treatment plant. Principally there are two fundamental functions to consider with respect to water purification technology: A transformation of the agent into less hazardous substances, and secondly a separation/ concentration from the liquid phase (water) into the sludge phase. This in turn raises further questions on the available technologies and the potentials to either refine these technologies or to replace them.

A fourth point is again linked to the points above regarding the scheme of sampling/analysis and evaluation. This problem has been addressed in discussions on the needs for an improved and more rapid sampling – analysis – evaluation -and finally adjustments of the process operation, see Morling (2014).

Some conclusive comments: The obvious results from the development in the modern society are that far more complex compounds are used in our daily life. The remains of which are often discharged by the wastewater, and thus also found in the environment. A growing demand are that these (new) substances must be as safe as possible in relation to the surrounding biotope and with respect to sanitation.

Consequently, this calls for a far more efficient on-line measurement system to be included in the treatment plant process. Furthermore, it would also call for onsite laboratories that are capable to analyse some of the pollutants with influence on the plant efficiency and performance.

Further to this point it is a strong demand to focus more critically to the systematics with respect to the sampling, analysis, and evaluation for accurate conclusions on various variables found in the wastewater. In this context it may be used the following "metaphors": WHY – WHEN – WHERE – HOW. The issue has been highlighted several times and in various perspectives. A short summary of the problem may be given as follows.

First, a short reflection on the issue "WHY?" This question may be answered by addressing two different purposes for sampling and analysis: On one side the formal, or legally demanded control of influent and effluent water to a treatment facility that is stipulated in the given permit. On the other side an equally important internal sampling and analysis control of the process. Both these control actions are as important, in some respects the internal process control is the basis for a successful formal report on the acceptable discharge qualities. Thus, in the following comments the "internal" perspective and use of sampling, analysis and evaluation are in focus.

Secondly is the question on "WHEN?" as important. The issue on this question is to be raised in a well-prepared manner. The first issue is what is the purpose (WHY)? There may be needs to go deep into a specific part of the plant, such as the main biological step, and to create a detailed picture of some specific parameters that are crucial for the performance of the treatment step. This could be the supply of oxygen related to time. Often the load at a municipal plant is varying substantially throughout the day. This in turn may result in an "over-aeration" during the night-hours, and subsequently an excess of energy use. Some studies performed on an intermittent aeration has even pointed out that for a normally or high loaded activated sludge plant even an improved sludge quality may be the result of an intermittent aeration. In addition to the online measurement of oxygen, other process parameters would accordingly be measured online, such as the suspended solids, the water temperature and sometimes even nitrogen compounds. However, even other compounds, not easily controlled by continuous online meters, may be vital to control either by 24- hour samples, or by short-time samples taken during a defined control period. The matter would be well suited for further in-depth studies, regarding the possibilities for not only the obvious energy savings, but also for an in-depth study on further process enhancements.

For the two other questions "WHERE?" and "HOW?" an illustrating story told some years ago may provide an illustration of the matter. The example is taken from a large WWTP in Scandinavia and gives us an illustration of an internal authoritarian attitude. An operator that was especially entrusted the operation and control of all online instruments observed that there was a consistent difference between the online recording of the suspended solids concentration in the aerated reactors and the results that were presented from the quality accredited laboratory. The difference was consistently more than 20 %, and the laboratory results were always the lower values – around 2,300 mg SS/l versus an average for all the online meters of around 2,900 mg SS/l. In the first place the operator´s observations were neglected. However, thanks to a combination of curiosity and stubborn attitude from the operator, he took out his own samples and handled them in the same manner as the ones sent to laboratory. He found that the same results in both samples occurred, both in his own samples and the ones sent to the laboratory. The probable hypothesis that would explain the results could be the following: A SS sample from an aeration basin is in fact a "living material". The organics will continue to work and thus change the sample as time goes by due to microbiological activity. The matter would have been possible to reveal if also the VSS-part was analyzed directly at the sampling time and after the "normal" handling time has passed – from sampling until the actual analysis is performed at the laboratory.

The example reflects a rather common problem in many organizations, where the management is more concerned with its own "prestige", rather than to take the time to carefully listen to the sub-ordinates. The operator was following both the demands of "WHERE to take the samples, as well as to follow the demands on "HOW".

Summary, conclusions, and further perspectives

To summarize the questions raised with respect to the development of an advanced wastewater treatment the following viewpoints are highlighted:

- The needs for a deeper political and social understanding of the water environment protection.
- The development of even more compact technical solutions.
- The development of further techniques to meet even more stringent effluent standards.
- To underline and exercise the importance of an efficient day-by-day process control.

At the end of the day, it is imperative to understand two major points:

- Operating a modern wastewater treatment plant is in some respects to be seen as an ongoing very large, full-scale scientific work.
- The needs for committed and skillful operators that are also driven by a crucial virtue: Curiosity.
- Further challenges may include a more active and implemented re-use of treated wastewater. In this respect some lessons learned may be picked up from the industry sector, where the re-use of process wastewater is developed in the steel industry, in pulp and paper mills and in the food industry.
- Accordingly, an improved work on separation of wastewater and storm water will become even more an urgent need, not at least in the light of occurred inundations in densely populated areas.

Acknowledgements

This paper has in a constructive way been scrutinized by some colleagues, Doctor Åsa Davidsson and Doctor Michael Cimbritz, both at Lund University, by Per Lennart Karlsson and Anders Ullman, both MSc, and all given valuable and fruitful comments to this paper. Mr Guy Taylor, MSc has taken his time to correct linguistic errors. A warm thank you all to you for your valuable contribution. Finally, a deep thanks to the J Gustaf Richerts Stiftelse (a Swedish private foundation that supports applied scientific development studies) that has supported the work on analysing ”How compact WWTP facilities may become”. This paper is a part of the major study, thank you again!

References

Arden, E. and Lockett, W. T. (1915) The oxidation of sewage without the aid of filters. Journal of the Society of Chemical Industry, 827 – 943.

Carson, Rachel (1962) Silent Spring. Houghton Mifflin.

Finnson, A. (2021) Diclofenac found in many Swedish water bodies – it is time for measures on many levels .VATTEN – Journal of Water Management and Research 77, 39 - 44

Hey, T. (2016) Municipal Wastewater Treatment by Microsieving, Microfiltration and Forward Osmosis: Concepts and Potentials. Water and Environmental Engineering, Department of Chemical Engineering, Faculty of Engineering, Lund University, Lund.

Morling, S. (2008) Why the Oxidation ditch disappeared in Sweden? VATTEN - Journal of Water Management and Research, 64: 209–214.

Morling, S. (2014) Problems in Water Environmental Control – Sense and Nonsense in Measurement of Water Protection Journal of Water Resource and. Protection, 6, 1381 – 1389.

Morling, S. (2019) Swedish experience and Excellence in Wastewater Treatment Demonstrated Especially in Phosphorus Removal. Journal of Water Resource and Protection, 11, 333 – 347.

Morling, S. and Feldthausen (2019) Advanced Phosphorus Removal and Needs for Recovery by Enhanced Filtration of Municipal Wastewater. Journal of Water Resource and Protection, 11, 626 – 637.

Nilsson, K. (1965) Investigations on oxidation ditches Publication from CIT, Serie B, No 66:2 (In Swedish, with a summary in English).

Pasveer, A. (1959) A Contribution to the Development in Activated Sludge Treatment. Journal of WPCF, 449–465.

Pinkney, D.H. (1958) Napoleon III and the Rebuilding of Paris. First Princeton Paperback Edition.

Rosén, B. and Morling, S. (1998) A systematic approach to optimal upgrading of water and waste water treatment plants Water Science and Technology, 37, 9 – 16.

Sidwick, J.M. and Murray, J.E. (1976) A Brief History of Sewage Treatment, Effluent and Water Treatment Journal 65 – 71.

Stadskollegiets Utlåtanden och Memorial (1931) Förslag till Anordningar för Rening av Avlosvattnet I Stockholm. Stadskollegiets Utlåtanden och Memorial Bihang 48 (in Swedish).