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# Driving forces in the long range development of wastewater treatment plants

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**Abstract:** Wastewater treatment plants (WWTP) are planned and designed for a lifespan of 25 to 40 years. The catchment area, discharge requirements, available technology, institutional conditions, operational procedures etc. of these plants may change drastically over this long time period. In the private sector such dynamic development would possibly be considered in the planning and design phase based on a scenario analysis. However, conducting a scenario process requires knowledge about the driving forces of this dynamic, which at the moment is very limited in the field of urban drainage. In this paper we take a first step in closing this gap. In a case study we analyzed the development of a WWTP and its environment for a time period of over a decade. From this investigation we identified the driving forces responsible for the observed strong dynamic and their effect on the development of the WWTP. Based on the analysis of these forces, we deduce important aspects that will have to be considered in the future if scenario planning is to be applied routinely in the field of urban drainage.

**Keywords:** *Wastewater system; design; driving forces; long term dynamic; scenario planning*

## 1. INTRODUCTION

Wastewater treatment plants (WWTPs) are nowadays planned and designed based on forecasts encompassing a period of 25 to 40 years. However, the environment of a WWTP usually changes drastically and unpredictably during this extended life span. Unforeseen changes like new regulations, shifting economic conditions or improving technologies are not uncommon and may require costly adaptations in the operation of a plant. This future uncertainty can not be adequately characterized through the forecast-based approaches used nowadays in the field of wastewater treatment. There is therefore a need for methodologies which are capable of systematic identification of the relevant factors influencing the long term development of a WWTP, their interactions and possible future developments.

This future uncertainty could be considered during the planning and design of WWTPs through scenario planning [Schoemaker, 1995; Ringland, 2002], as proposed by Dominguez and Gujer [2006]. This approach acknowledges the uncertainty of the factors affecting the long term development of a system by developing a variety of futures based on possible states of these factors. However, applications of scenario planning in the wastewater sector are rare [Lienert, et al., 2006]. It is therefore still unclear how and to what degree

scenario planning is applicable to the field of wastewater treatment.

To close this gap, a methodology aiming at improving the long range planning of WWTPs by means of scenario analysis is currently being developed. A key element of the methodology will consist of a knowledge base containing factors expected to have an influence on the long range development of a WWTP. This knowledge base should guide the practitioner in the identification of the forces relevant to their particular system. To allow this identification, the knowledge base should include factors from a wide range of fields (e.g. social, economical and legal) and encourage the practitioner to think beyond his usual system boundaries.

In this paper, we present a first step in the creation of this knowledge base. We derive an initial set of influential factors from the historical analysis of the development of a WWTP and its environment for a period of over a decade. The aim of this initial set is to support the identification of additional influencing factors and expose aspects to be considered for further development of the knowledge base and the methodology.

For reasons of simplicity, the words “influencing factor” and “influencing force” will be used as synonyms in the following chapters.

## 2. CASE STUDY

### 2.1. Background

The plant analyzed in the case study was the WWTP Werdhölzli, located in Zurich, Switzerland. With an influent load corresponding to approximately 600'000 person equivalents (p.e.) it is the largest treatment plant in the country.

The planning and design phase of the plant started in 1972 and lasted until 1981. The plant was originally designed as a nitrifying two step plant (pre step and main step). Currently only the main step is in operation and a denitrification was added to the original processes.

The operational life of the plant started in 1985 and can be divided by six events listed in Table 1. These events were the culmination of a series of developments at the regional and national level affecting the operation of the plant. A detailed historical analysis of these developments and the mentioned events led to the identification of the factors influencing the development of the WWTP.

**Table 1.** Key events in the operational life of the WWTP Werdhölzli

Event	Description	Date
Stop of pre-step	Stop of operation of aerated pre-step. Plant is now operated in single step mode	1989
Installation of anoxic zones	Gradual installation of anoxic zones in the existing activated sludge tanks (28 % of total volume) to achieve denitrification	1993-1997
Reduction of max. flow	Reduction of the maximum allowed storm water inflow from 9 to 6 m <sup>3</sup> /s. This allowed for an increase in activated sludge concentration from 3 to 4.5 kg TSS/m <sup>3</sup> (maximum possible concentration)	1996
Reorganization of processes and management	Plant is now managed as a private enterprise providing a service. Command structure is now flat and process oriented.	2000
Merging of catchment area	Stop of operation of the WWTP Glatt (approx. 100'000 p.e.) in Zurich's north. This wastewater is now treated by the WWTP Werdhölzli	2001
De-icing treatment	Treatment of the de-icing wastewater from the airport	2002

### 2.2. Influencing factors identification

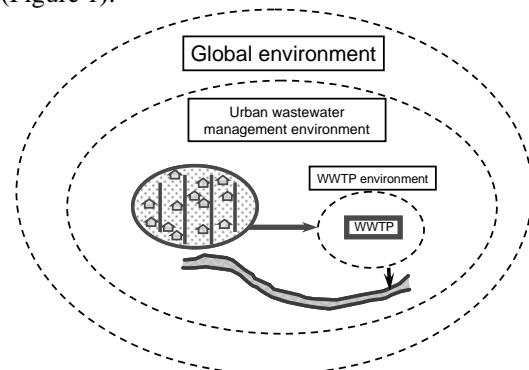
The influencing factors were identified by reconstructing the cause- and effect-chains leading to the changes in the plant. The events in Table 1 were thereby used as starting points. In a first step, the immediate factors leading to the occurrence of each of the events were identified. In the next step, the forces that had an influence on the development of the immediate factors were listed. This process was performed until the nature of the driving forces resembled that of national/regional descriptive variables. For example, the operation stop of the pre-step in 1989 was possible because the amount of sludge resulting from the chemical phosphorus precipitation had decreased strongly since the startup of the plant. This sludge decrease was the direct effect of a reduction in the incoming phosphorus load from the catchment. This load reduction, on the other hand, was the consequence of a national environmental regulation banning the use of phosphate in detergents (see Table 2).

This procedure led to the identification of the factors that had an influence on the development of the plant over the years and their mutual correlations (see Table 2). These influencing factors were thereafter grouped into categories (see below), as they represented influences from a variety of fields (or levels), reaching from technical measures in the plant to national environmental regulations.

Categorization fulfills several goals. First, it allows comparison of the influencing factors under each other and a better assessment as to their leverage, uncertainty and interference. Additionally, it leads to the recognition of fields to be included in the knowledge base, which is important for further investigation and abstraction.

### 2.3. Influencing factors categorization

The factors obtained from the historical cause- and effect-chain were categorized in three different areas: WWTP environment, urban wastewater management environment and global environment (Figure 1).



**Figure 1.** Areas to which the different factors influencing the development of a WWTP belong

This categorization reflects the diverse characteristics of the different influencing factors. Those in the WWTP environment are mainly technical or management-related. They describe the state of the plant and are usually the main concern of the operator. Influencing factors in the urban wastewater management environment describe on the other hand the state of the wastewater system, from which a WWTP is only a part. They are not only relevant for the plant, but also for the receiving water, the sewer and other wastewater related infrastructure. Finally, forces on the global environment include social, legal, economical, political and technological variables independent of the urban wastewater system but relevant to it. Sub categories were obtained within these areas by grouping the factors based on different aspects relevant to the respective environment (Table 2).

Once categorized, this initial set of influencing forces was further analyzed. Special emphasis was thereby given to the value of the set for the development of the knowledge base, the correlation of the factors and the scope they cover.

#### 2.4. Influencing factors analysis

The influencing factors and the different classes listed in Table 2 provide a basis for further development of the knowledge base. The different categories and sub-categories clearly indicate some areas where further influencing forces are to be searched and can therefore be included offhand in the knowledge base. The specific factors, on the other side, represent states only representative for this case study. Hence, they have to be generalized before they can be integrated into the knowledge base. This can be e.g. observed in the factor describing the recognition of the negative impact of phosphorus and nitrogen on water bodies (Table 2, factor G10). It stands exemplarily for the identification of negative environmental externalities related to known compounds. While in this case study the negative externality was caused by phosphorus and nitrogen, in other cases it could be caused by hormones or antibiotics.

An interesting feature of the influencing forces identified in this case study is their degree of correlation. Those assigned to the global environment are to a high degree independent of each other. This is however not the case for the ones related to environmental issues. The factor "Involvement of Switzerland in international efforts to solve the nitrate problematic in Europe" (Table 2, factor G 6) led for example to environmental regulations on a national level addressing this problem. In turn, these international efforts were driven by the detection of the negative influence of nitrate on the North

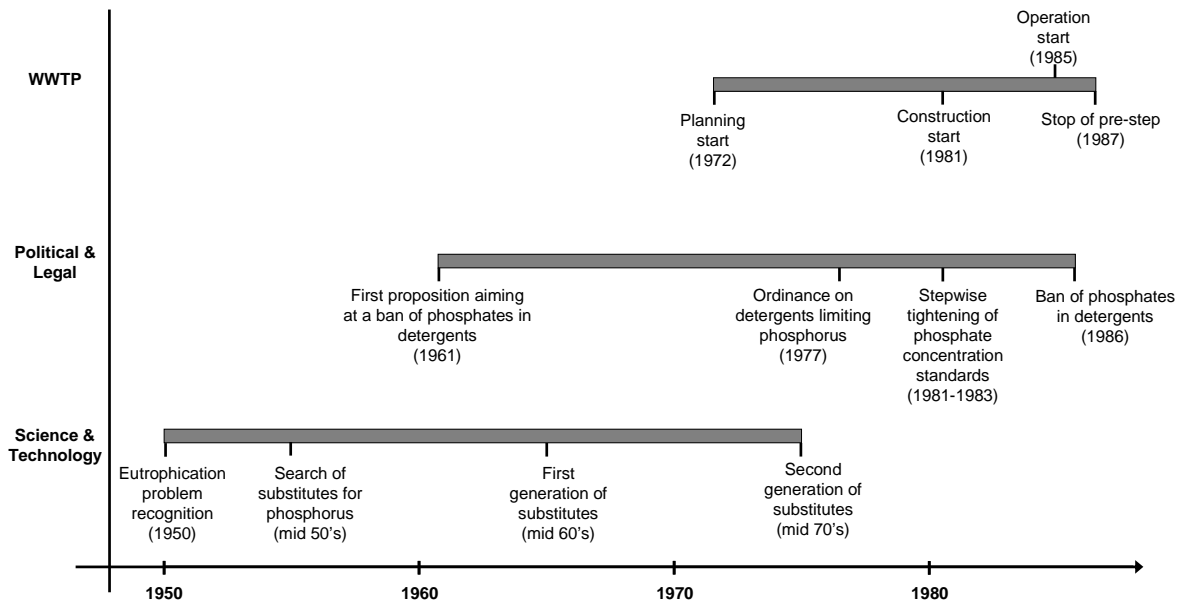
Sea (Table 2, factor G 10). By the same token, influencing factors in the lower environments are mostly driven by forces in superordinated environments (see Table 2). Exceptions like the application of long range planning (WWTP environment) represent actions or strategies actively taken by stakeholders involved in wastewater management. Other than the forces in the global environment, they are to some degree under the influence sphere of the plant operator. In this sense, the events (Table 1) used as starting points for the development of the cause-and-effect chains in section 2.1 represent also actions taken within the WWTP to react to developments mostly outside the reach of the operators.

The influencing factors and categories identified here go way beyond the usual system boundaries considered by today's practitioner. The potential advantages of this horizon expansion for the planning and design of a WWTP can be illustrated with the example of the phosphorus ban in detergents. In 1986 the Swiss government imposed a ban in the use of phosphorus in detergents to reduce the eutrophication of Swiss lakes by phosphorus. This drastically reduced the amount of phosphorus to be treated by WWTPs in Switzerland and consequently lead to a decrease in the sludge production of WWTPs where phosphorus was eliminated through chemical precipitation. In Werdhölzli this development made part of the treatment lane, the so called pre-step, obsolete. The pre-step was therefore taken out of operation in 1987.

The possibility of a reduction in the phosphorus load was not considered during the design of the WWTP, even though this development was not unthinkable at the time of planning. A number of developments in the scientific, technical, political and legal sector before and during the planning of the plant already hinted in this direction (Figure 2). The link between phosphorus and the eutrophication problematic was known to the scientific community since the beginning of the 1950's. Similarly, the detergent industry had been searching for substitutes for phosphorus since the mid 50's. The ban of phosphorus had been in the political agenda since the 60's and first regulatory steps were taken at the time the WWTP was planned. The ban can therefore hardly be regarded as an unpredictable development that could not have been considered in the planning of the plant. The ban on phosphorus was not considered as a possibility because the responsible engineers did not oversee the forces and developments that could affect their system on a long-term. This is especially critical if we consider that the development over time of the phosphorus problematic is by no means unique. The long time span elapsed between the recognition of a problem by the scientific community and the taking of

**Table 2.** Factors influencing the development of the WWTP Werdhölzli over time (1985-2003) and their categorization. The mechanism of action can be followed through the numbers in brackets (from left to right)

<u>Global environment</u>	<u>Urban wastewater management environment</u>	<u>WWTP environment</u>	<u>Event</u>
<p><b><u>Social</u></b>            G1. Increased civic pressure on public spending [U10, U11, U12]            G2. Decreasing urban population [U3, U5]</p> <p><b><u>Economical</u></b>            G3. Deindustrialization [U2, U4]            G4. Trend of organizing public enterprises as private [W7]</p> <p><b><u>Political</u></b>            G5. Decreased public investment in wastewater sector [U10, U11, U12]            G6. Involvement of Switzerland in international efforts to solve the nitrate problematic in Europe [G7]</p> <p><b><u>Legal</u></b>            G7. Coming into force of more holistic and tighter environmental regulations [U1, U6, U7, U8, W4]</p> <p><b><u>Technological</u></b>            G8. New technological developments in water savings [U4, U5]            G9. Development of acceptable substitutes for phosphorus in detergents [G7]</p> <p><b><u>Environmental</u></b>            G10. Identification of phosphorus and nitrogen as the limiting compounds in the eutrophication of Swiss lakes and the North Sea, respectively [G7, G6]</p>	<p><b><u>Material flows</u></b>            U1. Less phosphorus from catchment area [W3]            U2. Decreasing COD-load from industry [W1]            U3. Decreasing COD-load from household [W1]            U4. Decreasing water consumption from industry [W2]            U5. Declining water consumption in household [W2]            U6. Increased local infiltration of rain water, resulting in less water to be transported in sewers [W2]</p> <p><b><u>Infrastructure management</u></b>            U7. Restoration of sewer system, leading to a reduction of the extraneous water transported in the system [W2]            U8. Increased application of an integrated catchment area management [E5]            U9. Reinvestment requirements as infrastructure at a regional level reaches its planned lifetime [E5]            U10. Trend of merging the catchment area of WWTPs to save costs (economy of scales) [E5]</p> <p><b><u>Financing</u></b>            U11. Tight budget for WWTP operation [W5]            U12. Increased pressure to optimize regional wastewater treatment [E5]</p>	<p><b><u>Capacity</u></b>            W1. Increase of the load capacity reserves [E2, E5, E6]            W2. Increase of the hydraulic capacity reserves [E3]            W3. Decline in the sludge production (chemical phosphorus precipitation) [E1]</p> <p><b><u>Requirements</u></b>            W4. Requirement to eliminate N through wastewater treatment [E2]            W5. Increased pressure to reduce operational costs [E1]</p> <p><b><u>Management</u></b>            W6. Increased application of long range planning [E3]            W7. Management of the plant as a corporate entity in its own right [E4, E6]</p>	<p>E1. <b>Stop of pre-step</b></p> <p>E2. <b>Installation of anoxic zones</b> at the expenses of the load capacity reserves</p> <p>E3. <b>Reduction of max. flow</b> as part of a measure aiming at increasing the load capacity reserves for future eventualities</p> <p>E4. <b>Reorganization of processes and management</b></p> <p>E5. <b>Merging of catchment area</b>, increasing the load to be treated by the plant</p> <p>E6. Selling of load capacity reserves to the airport for the treatment of its <b>de-icing wastewater</b></p>



**Figure 2.** Scientific, technological, political and regulatory milestones over time that led to a ban of phosphorus in detergents. The development over time of the WWTP Werdhölzli until the operation stop of the pre-step is depicted for comparative purposes

actions at a political level is typical for environmental problems [Kummert, et al., 1992]. A horizon expansion as obtained through Table 2 could therefore improve the long-range planning in the wastewater sector.

### 3. DISCUSSION

The historical analysis of the WWTP Werdhölzli gives a first impression of the driving forces and categories to be considered in a methodology aiming at improving the long range planning of WWTPs. Additionally, the obtained results exemplarily illustrate the importance of integrating the knowledge of different fields into the planning process. Especially this last point is regarded as one of the main strengths of scenario planning [Ringland, et al., 1999; Van der Heijden, 1997]. However, the exercise also points out several aspects that will have to be considered during further development of the methodology. First, it has to be considered whether the degree of abstraction of the factors still permits the use of the methodology by practitioners. The global factor “Involvement of Switzerland in international efforts to solve the nitrate problematic in Europe” is e.g. indirectly included in the environmental regulation factor, as it had an influence in its development. During the analysis we decided that despite their high correlation, both factors have to be included in the knowledge base. It is however unclear if the inclusion of higher ordered driving forces serves the practitioner at all.

It could as well confuse him. Deciding what degree of abstraction is adequate for today’s practitioner will require a high degree of interaction between the scientific and the engineering community.

An important lesson for the future development of the methodology is the necessity to clearly differentiate between influencing factors and courses of action. While the former describes forces influencing the development of a WWTP, the latter stands for actions that can be taken to deal with these forces. Both will shape the development of a plant, but only the influencing factors belong to a scenario process [Fink, et al., 2002]. Courses of action become relevant once the possible scenarios are known, as a mean to ensure flexibility in view of the envisaged futures. In doing so, it has to be considered that courses of action are time dependent: Some options are only open during the planning of a plant (e.g. overdesign), while others can only be implemented during its operation (e.g. management decisions). Because of this time dependence, the application of the methodology should be conceived as a continuous procedure requiring a constant repetition over time of the scenario process. This continuity is necessary to account for changes in the influencing variables that were either not foreseeable during the original scenario process or the consequence of actions taken afterward. The action options to be considered should be updated correspondingly.

#### 4. CONCLUSIONS

The development of a wastewater treatment plant over time is shaped by social, economical, political, legal and environmental factors beyond the influence sphere of the plant's operator. Possible changes in the characteristics of these driving forces can lead to unexpected and often costly adaptations in the operation of a plant. However, today's engineers lack the tools to identify these driving forces, which as a consequence can not be integrated in the planning and design of infrastructures.

In this paper, we take a first step in the development of a method to guide the practitioner through the identification of project specific driving forces. The driving forces and categories identified in this study can be further extended and lay therefore the basis for further research.

The analysis of the driving forces revealed several aspects that will have to be considered during the further development of the methodology. First, it is unclear if the degree of abstraction chosen is adequate for the practitioner working in the field of wastewater management. Future research will therefore require a stronger interaction between the scientific and the engineering community. Second, the analysis showed that many of the forces influencing the development of a WWTP were actually measures taken by stakeholders in the wastewater sector as a reaction to the driving forces they could not influence. Driving forces will have to be clearly separated in the future from courses of action, given that only the first are to be included in the methodology.

It also became clear that considering the driving forces and its uncertainty in the planning and design of wastewater infrastructure through scenario planning is only the first step in a planning strategy. A long range planning is a continuous process requiring a constant repetition of the scenario process to acknowledge future developments and new information. This will have to be considered in the future if scenario planning is to be applied routinely in the field of urban drainage

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