COST ESTIMATING RELATIONSHIPS 0N WASTEWATER TREATMENT PLANT PROJECTS

An analysis to increase accuracy on cost estimating for wastewater treatment plant projects

Job van Staveren
S1475673
July 2019

University of Twente
Construction Management and Engineering
Witteveen+Bos
Cost management and advise

Witteveen+Bos

UNIVERSITY OF TWENTE.

Abstract

In this report an analysis is carried out on wastewater treatment plant project costs. This research aims to discover possible cost estimating relationships in order to increase accuracy on cost estimating for wastewater treatment projects. In order to discover qualitative cost estimating relationships the first chapters provides a study in the wastewater treatment processes and cost divisions in order to determine the scope. The possible cost estimating relationships are then shown and tested. For a set of objects from the waterline a cost estimating relationship has been determined. No conclusive cost estimating relationship tool could be created due to a lack of datapoints gathered. Possible improvements for further research include uniform storing of data regarding the different disciplines involved in the project, a uniform cost breakdown structure throughout all projects regarding wastewater treatment plants and more research on underlying cost determining factors of the objects researched.

Table of Contents

1. Introduction

Witteveen+Bos uses parametric design and parametric cost estimating on various project types. A parametric design of sea quays has recently been developed. Parametric design and parametric cost estimating paints a fast and accurate picture for tenders of upcoming projects.

1.1. Problem statement

Witteveen+Bos is interested in a parametric cost estimating tool for water treatment plant projects. In the past an excel tool has been built to quantify civil engineering- and construction costs of water treatment plant objects per m^3 (Hendriksen, 2011). Witteveen+Bos however would like more insight in the parameters that drive the costs of water treatment plant projects and the cost estimating relationships.

1.2. Research question

The main objective of this study is to find qualitative cost estimating relationships for water treatment plant projects. This leads to the main research question:

What are significant correlations between costs of wastewater treatment plant projects and descriptive variables of water treatment plant projects?

Sub-questions for this research question are divided in three parts. The first set of sub-questions is answered in chapter 2.5 and chapter 3.4 as well as chapter 4.6.

- o *What descriptive variables do water treatment plants have in common?*
- o *How are variables to be tested for correlation with project costs determined?*
- o *How can the costs be divided or grouped to test for correlation with descriptive variables.*

The second set of sub-questions is answered in chapter 4.

- o *How is enough data for an accurate statistical calculation of correlation ensured?*
- o *How can the data from different project with different scopes be compared?*
- o *How is the data handled with regard to outliers and anomalies?*

The last set of sub-questions is addressed in chapter 6 and 7.

- o *What is a significant correlation to be taken into account by Witteveen+Bos for future cost estimating of water treatment plant projects?*
- o *How accurate should the final estimate be in order for Witteveen+Bos to be useful?*

1.3. Deliverables

At the start of the research the goal was to deliver a tool in the form of an Excel file. This tool was to be able to offer options for which objects are present in a wastewater treatment plant of which the costs are to be estimated. Then by giving a volume or size, the tool would calculate the expected costs with a certain confidence interval. However, due to time constraints and limited data on similar water treatment processes this has been changed during the research. The current goal is to deliver a report on cos estimating relationships and discuss what could be done in order to get a better insight in possible cost estimating relationships.

2. Water treatment plants

In this paragraph the process at different types of water treatment plants will be taken under a loop to examine possible variables for parametric cost estimation. A division is made into drinking water treatment plants, wastewater treatment plants and renovations to water treatment plants as different variables for cost estimation are estimated to have an impact on the costs. During this research the focus will be on wastewater treatment plants.

In order to carry out a qualitative research on the relationship of costs to descriptive variables of wastewater treatment plant projects insight in the costs, descriptive variables and cost division of such projects is needed. In this chapter descriptive variables are defined on which parametric cost estimating might prove useful. The methodology used for this part of the research on the processes and objects present at water treatment plants is a literature study. For this literature study earlier research on parametric cost estimating at wastewater treatment plants is used besides information gathered on the overall process of wastewater treatment.

2.1. Wastewater treatment plants and sewage water treatment plants

Wastewater is collected and transported to water treatment plants through the sewer. Wastewater treatment plants fulfil the function of cleaning the wastewater. This is done till a sufficient water quality is reached for the water to be discharged into a surface water. In literature a difference is made between wastewater treatment plants (wwtp) and sewage water treatment plants (swtp). The difference lies in the measure of contamination of the water. Sewage water treatment plant is the term used for water treatment plants which focus on domestic wastewater and rainwater collected by the storm drain. Wastewater treatment plant is a term used for water treatment plants which also focus on industrial wastewater. Other treatment steps could be applicable at the different types of water treatment plants according to the level of contamination. Wastewater treatment plant and sewage water treatment plant are terms used interchangeably throughout reports like the wastewater calculator (Padmos, 2012) and project descriptions at Witteveen+Bos. In this report the term wastewater treatment plant will be used for both types as no difference in objects available between the two is observed. A difference in the costs of these different kind of water treatment plants could to some extent be present in the size or performance of the objects. For different kinds of wastewater, different processes can be used for treatment. There are different types of wastewater treatment plants found in the dataset provided by Witteveen+Bos. These processes will be explained in chapter Project information .

2.2. Waterline and sludge line

In the process flow of wastewater treatment a difference is made between the waterline and the sludge line. The waterline focusses on the processes and objects regarding the effluent to the surface area. This starts with the influent pumping station up until the effluent pumping station to a surface area. The sludge line focusses on the recovery, treatment and recirculation of the activated sludge removed from the wastewater. Due to time constraints a focus on a part of the waterline has been chosen. This separation is difficult as some machines/ processes for the waterline process flow involve input and output towards the activated sludge process flow. Another difficulty is found in what object or process flow to ascribe the costs to. In this research only the waterline will be taken into account.

2.3. Wastewater treatment process

The wastewater treatment process can be divided in a set of smaller processes and sub-processes. Each of the main processes involved in wastewater treatment will be explained and the possible sub-processes present in this step of the treatment process will be described.

2.3.1. Primary treatment

The first main process consists of the primary treatment of the wastewater. During this phase sand and other coarse parts are filtered out. The first sub-process is filtering by means of rosters. This can be done by different kind of rosters varying from a step-wise grid or coarse rake grate to fine rake grate. These grids filter out bigger waste particles. The waste from these filters is disposed of. A second possible sub-process is the removal of oil and grease. A grease removal tank can be integrated in a sand filter or a in a preliminary sedimentation tank. From grease removal tanks no data has been found in the projects researched. After the grid filter the influent is transported to the primary sedimentation tank for further sedimentation of sedimentation of coarse particles.

2.3.2. Biological treatment

The second main process of a wastewater treatment plant process is the biological treatment. The biological treatment can be done in a lot of different ways. The treatment process most used is the activated sludge process. The activated sludge process uses micro-organisms to cleanse the wastewater. This process has many different configurations, each being a different treatment method. Each method for the activated sludge process has different types of tank and aeration system in place. Other treatment options are membrane bioreactors, oxidation ditches, small-scale wastewater treatment plants and individual water treatment systems like a septic tanks.

Each method has its own ratio between objects needed and piping needed. For a parametric model an ideal situation would have multiple data points per method. The end result would be to choose a method and to construct a calculation tool for this method. This calculation tool would calculate what objects and dimensions are needed on for instance a given amount of influent. However, enough data is needed per activated sludge process treatment method. The sub-processes needed for the activated sludge treatment by a modified University of Cape Town method are given below. These main subprocesses are recurring processes at the different treatment methods.
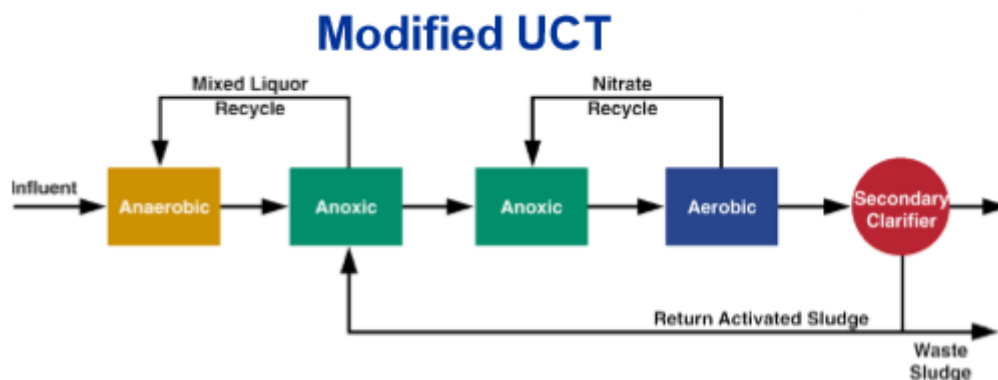
Figure 1 Modified University of Cape Town method (Georgine Grissop PE, 2010)

The sub-process found is the active sludge process or activated sludge tank are concurrent with the objects (tanks) needed for these processes. This tank houses processes like the anaerobic process, the anoxic selectors, pre-denitrification process and nitrification process. Circulation pumps, propellers and aeration machines are objects needed for these processes.

2.3.3. Secondary treatment

The last main process of wastewater treatment looked at is the secondary treatment process. This includes a settling tank where the activated sludge is removed with a skimmer and transported to the earlier phases in the activated sludge process or removed as waste sludge. Pumping stations and a

floating matter collector are bigger object present in this treatment phase. After this the effluent is discharged by an effluent pumping station into a surface water.

2.4.   Wastewater indicators

The main indicator for a parametric model of wastewater treatment plant projects should be the capacity, the influent is measured in population equivalent p.e. This value per p.e. is given in grams of biochemical- or total oxygen demand per day per person. This capacity together with the peak flow capacity and the yearly average flow rate of the wastewater determines the input and size of a wastewater treatment plant.

Volume and flow rate are the main indicators for the number and size of the objects. These indicators in combination with the above named general indicators determine the measurements for the size and thereby also for the costs involved. For the pumping station another factor however is the height difference between the two points which determines the costs. This could be looked at using a combination of flow rate and power of the pumping installation. To get an optimal idea of the costs and the parameters, a set of variables determining the dimensions and costs of these objects should be gathered and tested for their relationship to the costs of the object.

2.5.   Conclusion

To conclude this chapter it can be stated that in order to perform a parametric cost estimation for water treatment plants the scope of the processes and objects included should be properly defined. In this case the focus will be on the construction of new wastewater treatment plants. As there is no difference in objects present between a wastewater treatment plant and a sewage water treatment plant, the term wastewater treatment plant will be used to include both kinds. A wastewater treatment plant can be divided in the waterline and the sludge line. The waterline will be the focus of this study. Within the waterline there are multiple processes to treat the wastewater. The main division of process steps can be made by defining preliminary treatment, biological treatment and secondary treatment. Within these process steps multiple processes are carried out by their respective objects. The capacity of a wastewater treatment plant could be used for the finding cost estimating relationships. Objects found in all wastewater treatment plants are good division for finding cost estimating relationships for the separate processes and objects.

3. Cost divisions in wastewater treatment plant projects

In order to find and characterise the relation between certain descriptive variables and project costs, one could look at the total project costs and the correlation to certain cost driving parameters. However different costs of objects and processes in a wastewater treatment plant are dependent on different variables. A better insight in possible correlation between descriptive variables and costs could be gained by dividing the costs of different project processes or objects. However the type and scope of the costs should be uniform over the different projects looked at.

3.1. Direct costs, construction costs and investment costs

The costs found and used for analysis can only be compared if the same type of costs of the projects is used. The direct costs are costs for the materials used. The construction costs are the direct costs plus equipment needed for the construction and wages. Investment costs are the construction cost plus the costs for among others the costs of land purchase and ancillary costs. The direct costs are mostly found and easier to divide to objects and their cost driving parameters than wages, costs to cover the risks involved etc.

3.2. Cost estimate of different phases of wastewater treatment plant projects

The phase and type of cost estimation is important to consider when using the gathered data. In different phases of the project cost estimates are made which ideally should not be compared. For instance, a cost estimate of the preliminary design should not be compared with an assessment of the bid of a contractor. Ideally the real costs of the project should be used instead of the estimated costs. As primary data gives a better estimate for the future than secondary data. The primary data however is not available at the consultancy firm and is only known to the contractors. For Witteveen+Bos the estimated costs are part of the delivery product to a contractor or a client, so from the viewpoint of Witteveen+Bos cost estimates gathered at Witteveen+Bos from earlier projects can be regarded as primary data.

3.3. Cost breakdown structures

For the cost estimating methods used at Witteveen+Bos there are three breakdown structures. The costs can be presented in a cost breakdown structure (CBS). In such a division the costs are ranked according to the different cost categories like labour, plant and material. Sometimes the costs are further broken down into discipline like Civil engineering, Mechanical engineering and Electrical Engineering. In an object breakdown structure (OBS) structure the costs are divided according to a chosen accord like RAW, which is an arrangement for tender works, or NEN norms. In a work breakdown structure

Figure 2 OBS CBS WBS Cleopatra cube (Schulte, 2015)

(WBS) the cost division is variable according to a specific work, variant or other self-made structures. In Figure 2 OBS CBS WBS Cleopatra cube (Schulte, 2015) these breakdown structures are shown.

The cost breakdown structure of the available projects are done in different ways. This makes it harder to compare the data. In WBS or CBS structures the cost can include groundwork, demolition and foundation. In RAW structure of the OBS division this is a separate post. To divide these costs over the different objects requires a high level of expertise. It is recommendable to devise a structure where the cost of different structures can be reordered into other breakdown structures without the need for expert knowledge. Another option could be to set take the cost grouped at the RAW breakdown

structure as a leading point for the parametric cost estimation. Each of these ways could show insights in the costs per division, however for this thesis the division according to OBS with a subdivision in the style of a WBS is preferable. This gives a clear view of the type of costs included in the scope and the objects present in the project.

SSK-2010

The Cost Engineering department of Witteveen+Bos uses a guideline as cost breakdown structure for civil engineering projects called standard methodology for cost estimating (SSK-2010). This guide is used by almost all parties in the civil engineering industry in the Netherlands. This guide provides a tool for uniform cost estimating throughout the entire field of civil engineering projects with respect to construction-, water management- and infrastructure projects. SSK is substantiated with a calculation tool and when used throughout the branch provides an unambiguous way of data exchange and comparison (CROW, pp. 7-8)**.** SSK-2010 is a method nowadays used by many governmental bodies, design- and construction companies. As SSK-2010 is used by many companies and provides a uniform way of presenting and comparing different projects this cost breakdown structure seems like a good choice for the cost division in the parametric cost estimation process.

SSK-2018

At the moment of writing SSK-2018 has been introduced as an updated version of SSK-2010. This update has not yet been implemented. Cost estimation should be easier to follow through time and better to compare to projects of the same kind with this version. The definition of some words has been changed in SSK-2018 with respect to SSK-2010 to broaden the scope of the phases included. This means the definition of the life cycle has changed between the two versions (Crow kennisplatform, 2019). However as the data available from former water treatment plant projects is provided in the format of SSK-2010, this division should be used for the cost division in the parametric cost estimation.

3.4. Conclusion

The scope of the costs known is an important factor to include in the research. From the information gathered the initial costs are the only costs gathered at Witteveen+Bos. The user phase and demolition phase are thus to be excluded from this research. This could change with the change in SSK norms and SSK scope. Another distinction should be made whether to use the direct costs, construction costs or investment costs. Another distinction in the cost estimate lies in the version of the design. A preliminary design cannot be compared to a final design in the ideal situation as this would affect the cost estimating relationship. For this research the construction costs are used with regard to the wastewater treatment plant as a whole and the direct costs are used for the cost estimating relationship with the separate objects looked at. If possible final designs are used, however if only preliminary designs where found, these were used.

Furthermore the costs of the different disciplines included in the project should be looked at for a consistent scope. This can include civil engineering-, mechanical engineering-, electrical engineering- and process automating objects and costs. Different departments are responsible for these different object calculations and in the past the cost estimations. This could lead to different cost breakdown structures being used. A uniform cost breakdown structure in which the different costs can be linked to the main processes and sub-processes or objects(tanks) would prove useful for a qualitative study in correlation between cost driving parameters and the costs. A work breakdown structure with an object as a sub-division would give the best insight in the project for further research in possible cost estimating relationships. Due to the different breakdown structures throughout the finished projects the current data is of a lesser quality for research in cost estimating relationships.

4. Parametric cost estimating method

The raw data gathered from literature and from Witteveen+Bos archives must be analyzed to make the data comparable and to establish cost estimating relationships. This chapter will address the type of data gathered and describe how the raw data is adjusted to compare the data for cost estimating relationships.

4.1. Data types and collection

To find possible cost estimating relationships in wastewater treatment plant projects historical data of the project costs is required. Furthermore, non-cost data about the projects is needed of variables which influence the project costs. It is important to order all information which is used transparently. This is done by leaving a clear audit trail of the data used and by recording the actions taken to make the raw data comparable.

For a parametric cost estimation on wastewater treatment plant projects credible and timely data is needed. Without this, the parametric cost estimation gets less reliable. If feasible primary information should be used, however a parametric cost estimation can be made using secondary data sources. Primary data sources are the most reliable and of the highest quality (International society of Parametric Analysts, 2008). These data sources about the cost, technical and scheduling information and their source type can be found in Table 1. For this research access is granted to the data regarding tenders from the consultancy firm Witteveen+Bos. This includes contracts, cost proposals and technical databases from the archives of Witteveen+Bos. Next to this historical database papers regarding the subject are studied and used for this research as other information systems. All data used is secondary information. A weakness of using secondary data sources is that knowledge of anomalies during the construction phase and the treatment of these anomalies may not be known by the consultancy firm. Another weakness is that only a select dataset is looked at as the data from other consultancy firms and executive companies is not available.

Sources of data

Source	Source type
Basic accounting records	Primary
Cost records	Either (Primary or secondary)
Historical databases	Either
Functional specialists	Either
Technical databases	Either
Other information systems	Either
Contracts	Secondary
Cost proposals	Secondary

Table 1 Sources of data (International society of Parametric Analysts, 2008, pp. 2-3)

4.2. Data normalization for inflation

The collected cost data of the wastewater treatment plant projects is not yet comparable. Non-cost factors need to be adjusted for first. This is done by a process called data normalization. Data normalization adjusts the costs of the projects to filter out price the fluctuation over the years due to the production rate, the improvement curve of technologies and due to inflation of materials, equipment and wages (International society of Parametric Analysts, 2008, pp. 1-20). This chapter will explain how data normalization is used in this research.

The normalization to adjust for inflation has no fixed method on how to be done. Inflation indices like the consumer- or producer price index are often used to forecast inflation or normalize data. Normalization, or price level correction can be done either top-down or bottom-up. Top-down uses

general indicators to establish price index of a sector or type of work or cost group. An advantage of this method is that it gives a general formula or dataset on correcting for inflation. This method is also time effective as one general price index level is used for the different components and costs. Bottom-up normalization for inflation is the opposite as the project data is used to look at the unit prices used in the cost estimates. By finding comparable materials/objects used and their unit prices the inflation rate of the materials and objects can be determined. This gives a very detailed price index and ensures high quality normalized data. The flipside of this method is that it is very time consuming and data hungry. For this reason, the more general top-down method is used.

The price index of the civil engineering sector from the central bureau of statistics (CBS) is used for this project. This price index however not only includes wastewater treatment plants, but all civil engineering projects in construction, infrastructure and waterway engineering. This is a weighted average of 7 different domains from which not all domains are present in wastewater treatment plant projects (CBS Statline, 2018). Using this price index creates a level of uncertainty for the results which should be considered at the data interpretation phase. Most of the costs of wastewater treatment plant projects are from the civil engineering discipline and a smaller portion of the costs are located at the mechanical engineering, electrical engineering and process automating disciplines. As one of the domains used for the civil engineering price index is electrical installations, this one is used for the mechanical engineering objects used for the CERs. This price index is used in the past for pumping stations by the municipality 'Stichtse Vecht' (Kennis van pompen, aug 2016).
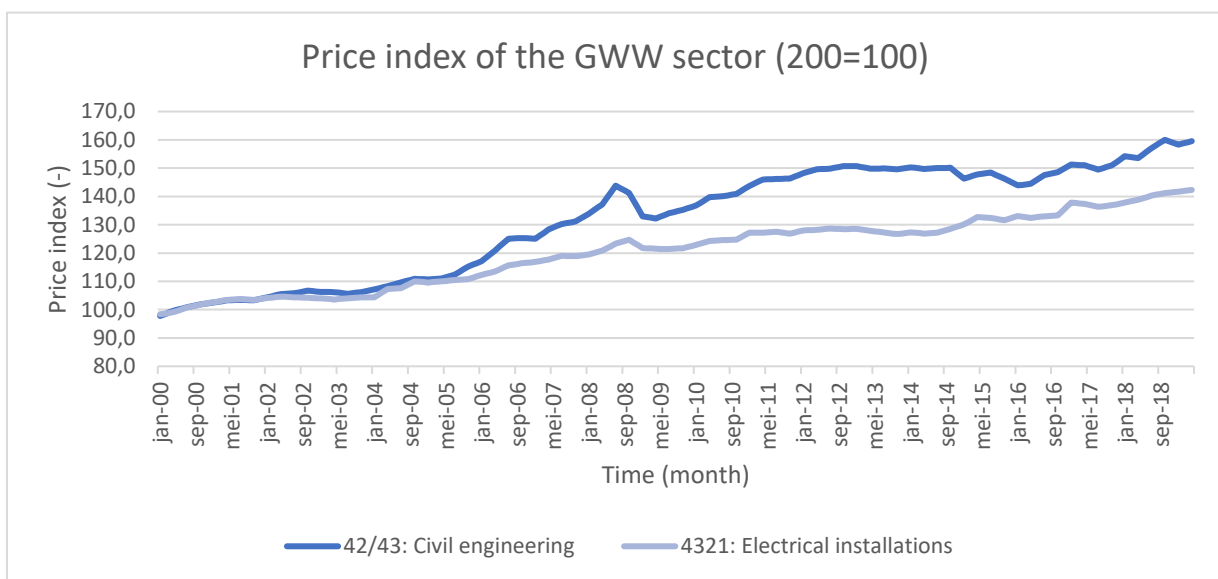
Figure 3 Price index for normalizing project costs (CBS Statline, 2018)

 In Figure 3 the price index of construction-, infrastructure- and waterway engineering from the central bureau of statistics (CBS) over almost the past twenty years is shown. This is a weighted average of the wages, materials and equipment from the 7 domains which are part of the civil engineering sector. Every three months calculates the price index of the sector. The values for the last year and a half are still under further notice.

There are different ways of interpreting and using the price index given by CBS on the gathered data. One option is calculating the trend line of the price index and using this trend line for normalizing the data from the different projects. This approximates a price index for future projects. Another way to use the price index data is backtracking the months the cost estimates of the projects were drawn up. By backtracking the price level used for projects and using the price index corresponding to this month to adjust the project costs an accurate dataset is prepared for finding CERs. This last option is chosen

as it given a better representation of the historical data used. To use the first option another level of uncertainty would be created for the resulting correlations.

Not all price level information off the projects coincides with month the CBS releases the national price index. In other cases, as the CBS releases the national price index every 3 months. Another inconvenience is when the specific month of the price level for a project is not given in the data gathered at Witteveen+Bos. In these cases, a price index forecast using the known datapoint before and after the relevant month is taken or the average price index over the year. For the data used from the wastewater calculator price corrections are not mentioned throughout the report. This could indicate that no price correction was done to account for the inflation, or it could be that this part was forgotten to elaborate upon in the report. It is assumed that price corrections still must be done.

Other types of data normalization include adjusting for production rate, the cost improvement curve and filtering recurrent from non-recurrent costs. The first of these normalization types is used as a CER on itself against the total project costs. In the hypothesis and results this will be further explained. However, the general idea behind this method is meant to adjust for high constant costs in the production line of mass production items, not these kinds of constructions. The last two types of data normalization filter out high startup costs when developing new technologies or designs. These costs don't have to be made in later projects of the same kind. This is again a type of normalization not applicable in this project as the technologies used are not in their developing phase. A case could be made to use this for the Nereda technology used at the wastewater treatment plant in project 5. However, not enough insight was gained on this project.

4.3.   Data normalization for scope and anomalies

Adjustments for a consistent scope must be made to compare the different projects. This is the most important part of the choosing of CERs with respect to object. For the different projects provided by Witteveen+Bos different cost breakdown structures are used. Due to this discrepancy it is not always clear which costs and sub-objects have been included in a project. To normalize the data all compared projects should include the same sub-objects or functions. In the chapter regarding the project information this should be explained in detail.

Adjustment for anomalies should be made in unusual events when costs are made due to factors which cannot be reasonably expected to arise in a new project. Anomalous data cannot simply be disregarded. An analysis should be done determining the reason of the anomaly with respect to the other data.

Due to the small number of projects available to Witteveen+Bos encompassing the full scope of wastewater treatment plant projects no statistical conclusions can be drawn from this data alone. In order to fix this problem, the data used in the wastewater calculator will be used as additional data. By doing the scope of this research is further limited to the constraints set in the wastewater calculator. Another downside of doing this is the fact that the results from the wastewater calculator cannot be used as a sample set to compare the results gathered from the data provided by Witteveen+Bos with.

4.4.   Curve fitting

For curve fitting of the CERs X-Y scatter plots are made to visually show possible CER X-Y relationships (International society of Parametric Analysts, 2008, pp. 3-13). By doing so hypothesis of correlation which turn out to be false can be dropped and new CERs for the object can be found before spending too much time on a possible CER. Outliers are spotted easily in a scatter plot, to see what data points need further investigation.

Using an ordinary least square (OLS) regression analysis a linear regression equation of the following form is calculated. $Y = a + bX$. In this formula Y represents the normalized costs of the wastewater treatment plant or the costs of an object or process at the wastewater treatment plant in euros. The values a and b are estimates of the linear correlation present between the costs and the cost driving variable X. The OLS method calculates a linear equation which minimizes the sum of the squared differences between the data points on the Y axis and the Y value of the line to be constructed at that give X value, also called sum of squares due to error (SSE) (International society of Parametric Analysts, 2008, pp. 3-15).

Using multiple regression, the formula given above can be expanded to encompass multiple cost driving variables. The formula $Y = a + b_1 X_1 + b_2 X_2 + \cdots + b_k X_k$ shows how this looks like for k cost driving variables. However, the more cost driving variables are introduced, the higher the number of observations which are needed for a significant correlation. In the chapter Testing CERs significance this will be further explained.

4.5. Testing CERs significance and quality

In Curve fitting the curve fitting method OLS is explained. The principles of this formula is explained by the sum of squares due to error. In this chapter several indicators are described to use statistical analysis to test a possible CER.

4.5.1. Error margins, confidence intervals and outliers

Determining the costs of objects or processes of a wastewater treatment plant with respect to certain cost driving variables is a simplification of the complex reality. To quantify the uncertainty of the costs two different types of error models are commonly used. The first one is the additive error model and the second one is the multiplicative error model (Tian, et al., 2013). In Figure 4 the difference
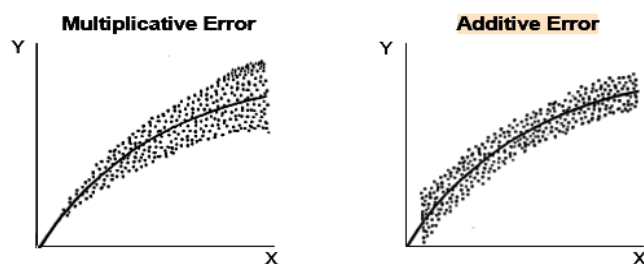

Figure 4 Multiplicative error and additive error (International society of Parametric Analysts, 2008)

between the additive- and the multiplicative error is shown. For cost estimating the multiplicative error model, or percentage error is best fitted to determine the accuracy of the CER. This is because the cost-estimator wants to be able to make a cost estimate with a standard error as a percentage of the expected project costs (International society of Parametric Analysts, 2008). After choosing an allowed error margin and fitting this in the X-Y scatter plot the outliers can be tracked and investigated further. This is a result driven approach to check if the OLS model predicts the situation well enough. A more data driven approach is to set up a confidence interval over the OLS model and the datapoints. A value is chosen of how high a percentage of the data should be correctly predicted by the model. This gives an error margin with which this can be forecast by the given data.

4.5.2. R^2 Coefficient of determination

The R^2 is a statistic about the goodness of fit of a model. The R^2 or coefficient of determination is the sum of squares due to regression divided by the sum of the squares due to error and regression. This is expressed as a percentage of the expected variation of the cost driving parameters given by the OLS curve fitting with respect to the total variation of the datapoints to the mean. A high R^2 is an indicator for a good CER, however this value can be misleading if for instance not enough datapoints are used and by chance the datapoints used seem to give a good correlation. On the other hand, a low R^2 with

OLS regression could be because a non-linear approach should have been taken or if the regression formula used doesn't fit the CER in another way. By visually showing the cost estimating relationship this can be considered in the discussion of the results (Mcclave, Statistiek, 2016).

4.5.3. Adjusted R^2

For a CER with one cost driving variable a minimum of three observations are needed to have one degree of freedom. With two observations every OLS will give a perfect OLS fit in this instance. The number of observations minus the number of cost driving parameters looked at minus one is the degrees of freedom (zedstatistics, 2013).

The adjusted R^2 is calculated with the formula $adj.R^2 = 1 - (1 - R^2)\frac{n-1}{DoF}$. Here n is the number of observations and DoF the degrees of freedom. This formula adjusts the R^2 value to consider the number of observations and the number of degrees of freedom. If more observations are added, the adjusted coefficient of determination approaches the standard coefficient of determination. If on the other hand the number of observations drops, the adjusted coefficient of determination reduces.

4.6. Existing cost estimating tools on water treatment plants

During the literature study a master thesis report was found on a parametric cost estimating tool for wastewater treatment plant projects. Thijs Padmos made a wastewater cost calculator for the university of Delft and Royal Haskoning DHV (Padmos, 2012). Another tool found during the study was a price index tool for wastewater treatment plant projects (Hendriksen, 2011). This paragraph will summarize the findings of the research and the implications of these researches for this bachelor thesis.

4.6.1. Wastewater calculator

In the wastewater calculator a tool is delivered to estimate construction- and exploitation costs of sewer water treatment plants. A division is made in the construction costs between the different disciplines involved. The disciplines consist of civil engineering costs, mechanical engineering costs, electrotechnical costs and process automating costs. Exploitation costs researched are capital costs, energy costs and maintenance costs of the aeration systems.

Goal and scope

The goal of this tool is to make cost estimating of wastewater treatment plants more effective for water boards. The tool is meant to provide reliable support in estimating investment – and exploitation costs with low time investments. It is also meant to provide water boards with a uniform framework for estimating investment – and exploitation costs.

The research done is based on conventional wastewater treatment plants. By separating the project into different processes, a set off components and structural objects is defined. These objects are divided per discipline. For this research cost estimations of realised projects are used. The data available shows a lack of electrotechnical costs and process automating costs, so these two are taken
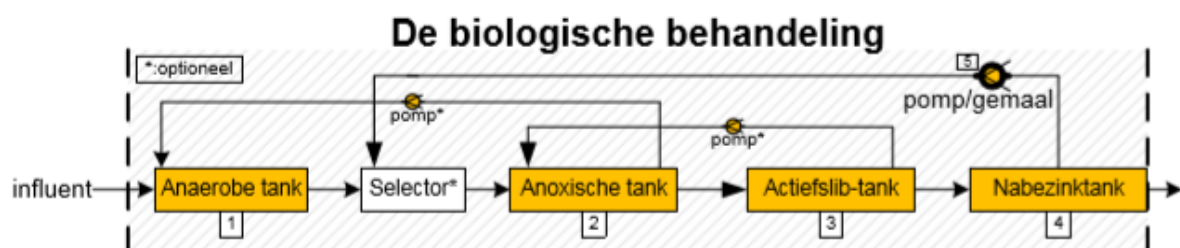

Figure 5 Schematic overview of researched objects in the wastewater calculator (Padmos, 2012)

as a percentage of the costs of the first two disciplines. The need for cost correction due to differences in projects and market forces is acknowledged.

The scope of the wastewater calculator encompasses the biological treatment process of the waterline divided into the different process parts. In Figure 5 the process parts taken into account for the wastewater calculator are shown. This process consists of the anaerobic tank, anoxic tank, aeration tank and secondary sedimentation tank and sludge return pumping station.

Objects, parameters and cost functions

Different construction cost functions are derived from the available data. These functions are based on the objects and components chosen in the scope. The cost functions are based upon cost driving parameters per object. Choosing the cost driving parameters has been done using common sense. The discipline the structural object or component is ascribed to is also given. Whereas the civil engineering (CE) costs and mechanical engineering (ME) costs are split up in the different components and elements needed, the electrotechnical-(E) and process automating (PA) costs could not be coupled to objects. These costs are taken as a percentage of the different process costs. This can be seen in Figure 6. The exploitation costs are based on the aeration costs. Kapital-, energy- and maintenance costs are taken from point- or bubble aeration systems.

For each of the objects, the costs taken into account are chosen by decomposing the object costs. In Figure 6 Decomposition of objects an example of this decomposition is given.
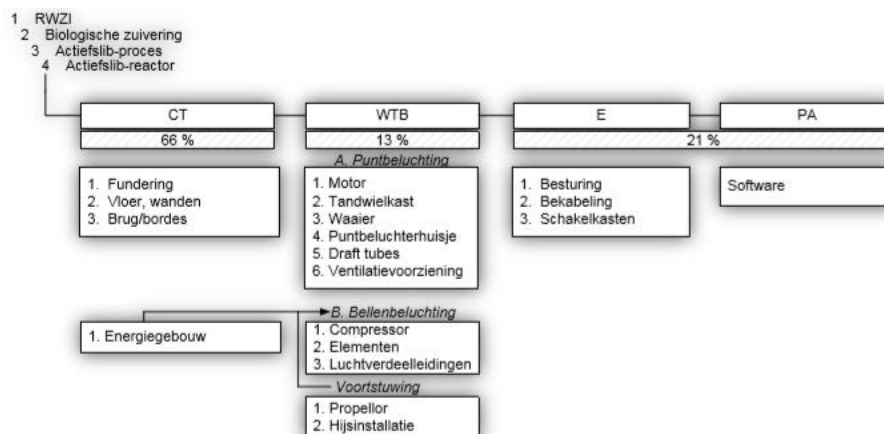
Figure 6 Decomposition of objects (Padmos, 2012)

The model consists of an excel file with multiple sheet types. To use the found correlation between objects parameters and the costs for the cost estimation of the construction of a wastewater treatment plant, a few more variables are needed. The first sheet is to fill in general information about the project and the starting parameters. The second sheet is used for every object chosen. In this sheet the parameters per object can be altered and checked against typical values for these parameters. A third sheet is used for the calculation of the estimated costs per object. This sheet uses a fourth sheet where key figures for the construction costs per object are given.

Basis of the model and usability

The wastewater calculator is based on a previously existing drinking water calculator from Royal Haskoning DHV. A few components are used in both calculators. In these cases the drinking water calculator shows a higher R^2 value. The data used for testing the wastewater calculator more than often exceeds the 20% fault margin of the regression line. In all cases where the drinking water

calculator has a higher R^2 value this cost function is used. In the appendix the objects/components used in the wastewater calculator are shown in Appendix 1. Usability of wastewater calculator.

The wastewater calculator is a good guideline for the steps to be taken in this report. In conversations Erik Schulte expressed the wish for a minimum R^2 value of 0,8. This means in most cases a lower fault margin is required.

4.6.2. CCC index numbers WWDW

The civil engineering and construction costs index file developed at Witteveen+Bos is a tool to look for a correlation between the costs per m^3 of a construction and the volume of a construction. To compare the different projects over time the price index of the civil engineering sector is used gathered from the CBS, the Bureau Documentatie Bouwwezen and Misset BouwKosten has been used for normalization (Hendriksen, 2011).

Goal and scope

The scope of this research encompasses the buildings present at wastewater treatment plants and drinking water treatment plants. The costs used are based on he construction costs. The inlet works, activated sludge installation and secondary sedimentation tank are taken as objects in this tool.

Objects, parameters and cost functions

The objects used for this research partly correspond with objects used for a parametric design. To use these cost estimating relationships for a parametric cost estimation of a wastewater treatment plant the relationship between the volume of surface area should be tested against the capacity of the wastewater treatment plants. By doing this a relation between the constructions needed for a wastewater treatment plant of a certain capacity could be calculated. This research however lacks enough datapoints to make grounded assumptions based on the data. The cost driving parameter of costs per m^3 is chosen to be taken as a logarithmic relationship. This is a logic assumption as the costs per m^3 tends to get bigger the smaller a construction is due to constant costs. As the constructions get bigger the constant costs are divided over a bigger volume.

Basis of the model and usability

The price index tool for wastewater treatment plants has less datapoints than the wastewater calculator and less information is given on what elements and objects are included in the costs and which are excluded. This makes the tool unreliable for this research thesis. This information should be included or accounted for by normalization. Another improvement to this model could be the data analysis. At the moment trendlines are only shown. By including tests on the reliability of the data like R^2 tests, adjusted R^2 tests and F-statistics or t-statistics, the information could be better interpreted.

4.7. Conclusion

This chapter has given a clear view of the steps to be taken in defining a cost estimating relationship. The two existing tools for calculating wastewater treatment plant costs give a clear view of what relationships have been researched. The data from the wastewater calculator can only be found in the rapport from Thijs Padmos (2012). This means that in order to use these datapoints the scope and costs used in this report should be the same as the ones used in the wastewater calculator. This limits this research greatly in possible cost driving parameters and objects to take under the loop as not enough datapoints are present from the projects found at Witteveen+Bos.

5. Project information Witteveen+Bos

This chapter will elaborate on the data gathered from projects where Witteveen+Bos took part in the tender process. Because of the data available the scope of the project will need to be limited to the investment costs. The available project information did not include maintenance costs of wastewater treatment plants. The costs relating to the civil engineering and construction sector are found with regard to direct costs, construction costs and investment costs. The mechanical engineering costs have been found with regard to the direct costs of objects. In some of the projects the demolition phase of an earlier wastewater treatment plant or construction is included in the scope. For this reason only the construction phase is looked at in this research.

5.1. Project 1

The first project looked at, dates to 2006. This is a wastewater treatment plant using a modified University of Cape Town (M-UCT) method for the biological treatment process. The civil engineering (CE) costs of this project are given in a cost assessment between the constructors cost estimate and the consultant's recommendation. The mechanical engineering (ME) costs are from the consultant's cost estimation as no detailed cost estimates could be found from the constructor. Tail costs are taken twice over the mechanical engineering. After a conversation with the head of the cost estimation and advice department of Witteveen+Bos it is suspected that this is a counting error due to lack of communication between the involved compartments in the past. The electrical engineering and process automating (EE and PA) costs are only found as the total sum of these costs, these costs will not be looked at in this research due to the scope of this research. The cost breakdown structure is done in the RAW style. Information about the project regarding the parameters for cost estimation are given in the final design of the civil engineering sector (Witteveen+Bos, 2006).

This project encompasses the construction of a new wastewater treatment plant. The data available is a cost estimate for the tender. The project was carried out for the water board. The duration of the project was from 2005 till 2009 and has a turnover value of EUR 680.000.

The wastewater treatment plant has a treatment capacity of 49.500 p.e. with a waste load of 54 g TOD/d (Total oxygen demand per day) per p.e. (Stichting Nederlandse Watersector, 2019). The wastewater treatment plant has an yearly average sewage water drain-capacity of 2.350 m^3/h. The waterline is based on a M-UCT configuration with biological P- and N- removal (modified University of Cape Town process). The process steps can be seen in Figure 7. The investment costs of this project are estimated to be 9 million euros (Witteveen+Bos, 2010).
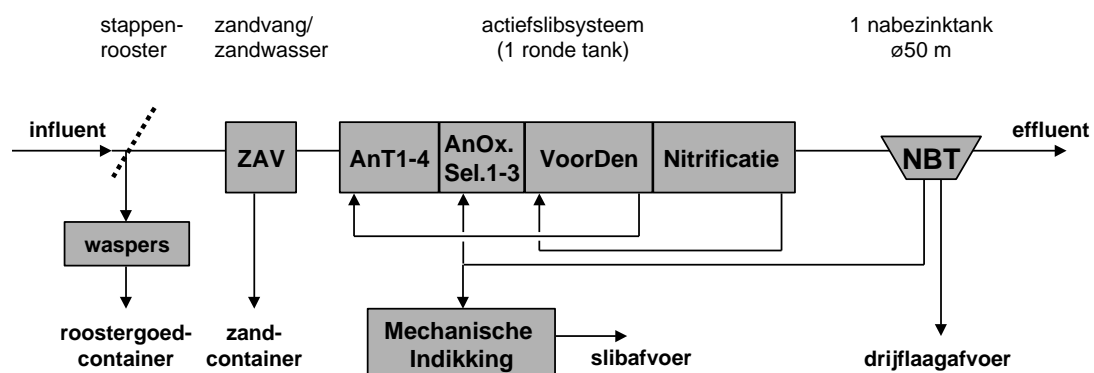

Figure 7 Process configuration wastewater treatment plant project 1 (Witteveen+Bos, 2006)

For the data of wastewater treatment plant project 1 different documents are used. For the Civil Engineering costs a price comparison between the consultant Witteveen+Bos and the contractor is

used. The prices used by the contractor are used for the data analysis. For the Mechanical engineering costs the cost estimate given by the consultant are used. The mechanical engineering cost estimate of the contractor were not found. There is a discrepancy of 84,9 thousand euros between the mechanical engineering cost estimate given by the contractor and the consultant. This is a difference of 5,8% with respect to the mechanical engineering cost estimate given by the contractor. Reasons for this discrepancy are not found.

For the costs of the activated sludge process, the civil engineering construction costs of the price comparison between the contractor and the consultant Witteveen+Bos have been used. (Witteveen+Bos, 13-09-2006). The costs given by the contractor are used for this research, as these costs are the tender which won the project. These costs are given in a RAW object breakdown structure. The fifth breakdown structure heading, constructions, lists the civil engineering objects needed for this research in a work breakdown structure.

5.1.1. Activated sludge process

The activated sludge process is done in one cylindrical tank. The tank contains different compartments where different processes are carried out. The wastewater flows through the first tank when it enters the biological treatment is the anaerobic tank. The anaerobic tank has 4 compartments and a total volume of 1.480 m^3. From the anaerobic tank the wastewater flows to the anoxic selectors. In 3 anoxic selectors with a volume of 810 m^3 the sludge from the secondary sedimentation tank is put in contact with the activated sludge stream (wastewater stream). From the 3th anoxic selector the wastewater stream flows to the pre-denitrification tank. The pre-denitrification tank is a ring around the anaerobic- and anoxic compartments. The pre-denitrification tank has a volume of 1.270 m^3. The outermost ring is the aerobic tank. In the aerobic tank has a volume of 8.030 m^3. The aerobic tank has 130 aeration plates with a total area of 260 m^2 and two blowers (Witteveen+Bos, 2006).

The costs for the activated sludge tank include the shuttering, reinforcements, concrete, piping and structural finishing. The wastewater calculator includes costs for the floor, walls, foundation, bridge, platform and cover if needed (Padmos, 2012). Discrepancies between the two lies in costs for the foundation and cover which are not included in the costs of wastewater treatment plant project 1. The direct costs of the activated sludge tank account for around 20% of the total construction costs. The construction cost of the foundation in total account for 3% of the total construction costs. This discrepancy should be considered when evaluating the results.

5.1.2. Sedimentation process

The aeration tank is connected to a secondary sedimentation tank. The sedimentation tank has a diameter of 50 meter and a surface area of approximately 1.900 m^2. The length of the skimmer installed on the sedimentation tank is 50 meters. The sedimentation tank has a floating layer scooper (Witteveen+Bos, 2006).

The direct civil engineering and construction costs of the secondary sedimentation tank amount to 10% of the total construction costs of the project. These costs include the same objects given at the activated sludge tank. The wastewater calculator uses the foundation, floor and walls. Just as with the activated sludge tank, the fact that the foundation construction costs are not included should be considered when interpreting the data. The direct mechanical engineering costs of the skimmer have been found in a price specification. The mechanical engineering costs of the floating matter pump have not been found (Witteveen+Bos, 2006).

5.1.3. Sludge return pumping station

The sludge from the secondary sedimentation tank is pumped to the anoxic selector by a sludge return pumping station. There are 2 return sludge agers with a total capacity of 950-1.640 m³/h (Witteveen+Bos, 2006).

The civil engineering costs of the sludge return pumping station are not known. These sludge return pumps are set up in the activated sludge construction (Witteveen+Bos, 2006). The direct mechanical engineering costs of the sludge return auger have been found in a price specification (Witteveen+Bos, 2006).

5.2. Project 2

Another project looked at is the 2008 wastewater treatment plant project 2. This is also a wastewater treatment plant using the M-UCT method for biological treatment. Just like the previous project, this financial information regarding this project contains the construction- and civil engineering costs from the cost comparison between the constructor and the consultant. The mechanical engineering costs are a cost estimate from the mechanical engineers of the water treatment compartment of the consultant. In this sheet multiple counting errors are found, and tail costs are done twice over the mechanical engineering costs. The cost division of the construction and civil engineering costs is in the RAW cost breakdown structure. Information about the parameters from this project is gathered from the final design from the civil engineering group of the water treatment compartment. This is given in a process description document.

This project includes the construction of a wastewater treatment plant for the water board. The scope of this project was the construction of a new water treatment plant on the location of the site of the existing water treatment plant. This project includes the demolition phase of the previous water treatment plant which is not considered part of the scope of this research. The wastewater treatment plant is designed for a treatment capacity of 110.000 p.e. with a waste load containing 136 g TOD/d per p.e.

For this project the cost comparison between the constructor and the consultant is used (Witteveen+Bos, 14-05-2008). The costs for this project are given in a RAW object breakdown structure just like at project 1. The cost division and subdivision of the objects however is done in a different way. Where the category constructions divided the costs per object in a work breakdown structure, The price comparison for the project 2 wastewater treatment plant between the constructor and Witteveen+Bos is split up in a cost breakdown structure with a work breakdown structure as a sublevel. This makes it harder to divide the costs per object. From this project the costs given by the constructor have been chosen for analysis as this is the tender offered to the client.

5.2.1. Activated sludge process

The activated sludge process is done in two identical cylindrical aeration tanks. Each tank contains a number of processes carried out. The objects for these processes are an anaerobic tank, an anoxic selector, a pre-denitrification- and a denitrification tank. In the innermost circle of the aeration tank an anaerobic tank consisting of 4 compartments is placed. Every compartment has a mixer. Each anaerobic tank has a volume of 1.310 m³. The anoxic selector is set up in a ring around anaerobic tank with a volume of 535 m³ per tank. From the anoxic selector the water passes on to the pre-denitrification tank is built as a ring around the anoxic selector. Each pre-denitrification tank has a volume of 1.105 m³. The outermost ring of the aeration tank is the nitrification tank. In the nitrification tank bubble aeration is used. The nitrification tanks have a volume of 4.915 m³ each (Witteveen+Bos, 2007).

The costs for the activated sludge tank include the foundation, shuttering, reinforcements, concrete, piping, structural finishing and cover. There are no discrepancies between the objects considered in the wastewater calculator and in this cost estimation division. The direct costs of the activated sludge tank account for around 11% of the total construction costs.

5.2.2. Sedimentation process
Each aeration tank is connected to a secondary sedimentation tank. These two sedimentation tanks have a skimmer installed with a length of two third the diameter of the sedimentation tank. The diameter of the sedimentation tanks is 47,2 meter. Each secondary sedimentation tank has a surface area of 1.750 m^2. To each of the sedimentation tanks a sludge return auger is connected (Witteveen+Bos, 2007).

The direct civil engineering costs of the secondary sedimentation tank amount to 7% of the total construction costs of the project. These costs include the foundation, floor, walls, cover and floating matter collector (Witteveen+Bos, 14-05-2008). The wastewater calculator uses the same objects. The mechanical engineering costs include the skimmer and floating matter pump in the wastewater calculator. From the data from this project however only direct costs of the skimmer are found (Keurhorst, 2008).

5.2.3. Sludge return pumping station
The sludge return auger returns the sludge from the secondary sedimentation tank to the anoxic selector in the aeration tank. The sludge return augers are placed in a sludge return pumping station in the blower room. Each secondary sedimentation tank has two sludge return augers. These augers are bilge pumps with a flowrate of 10 m^3/h (Witteveen+Bos, 2007).

The civil engineering costs of the sludge return pumping station account for less than 1% of the total construction costs (Witteveen+Bos, 14-05-2008). The mechanical engineering direct costs of the sludge return auger have been found in the same document as the skimmer.

5.3.   Project 3
This wastewater treatment plant focuses on cleaning wastewater, sludge- and biogas processing. A cost estimate is made according to December 2002 price levels. This project started its design phase in 2000 and was delivered in 2007. This project was conducted by Waternet and Witteveen+Bos for the waterboard (Waternet, 2017).

Construction costs are estimated at 99,5 million, euros consisting of 69 million euros in construction costs and civil engineering costs, 22 million euros in mechanical installations and 8.5 million euros for electronical installations and process automating costs. Construction fee are estimated around 11 million euros (Waternet, 2007).

This installations main treatment processes are: pre-treatment (fine screen grit- and sand removal and primary sedimentation); biological treatment; secondary sedimentation; sludge thickening; sludge digestion; biogas holder and sludge dewatering. The treatment capacity amounts to approximately 1.000.000 p.e. with a waste load of 136 g TOD/d per p.e. The wastewater treatment plant has a maximum peak flow capacity of 30.000 m^3/h and an average flow capacity of 200.000 m^3/d (Witteveen+Bos, 2007).
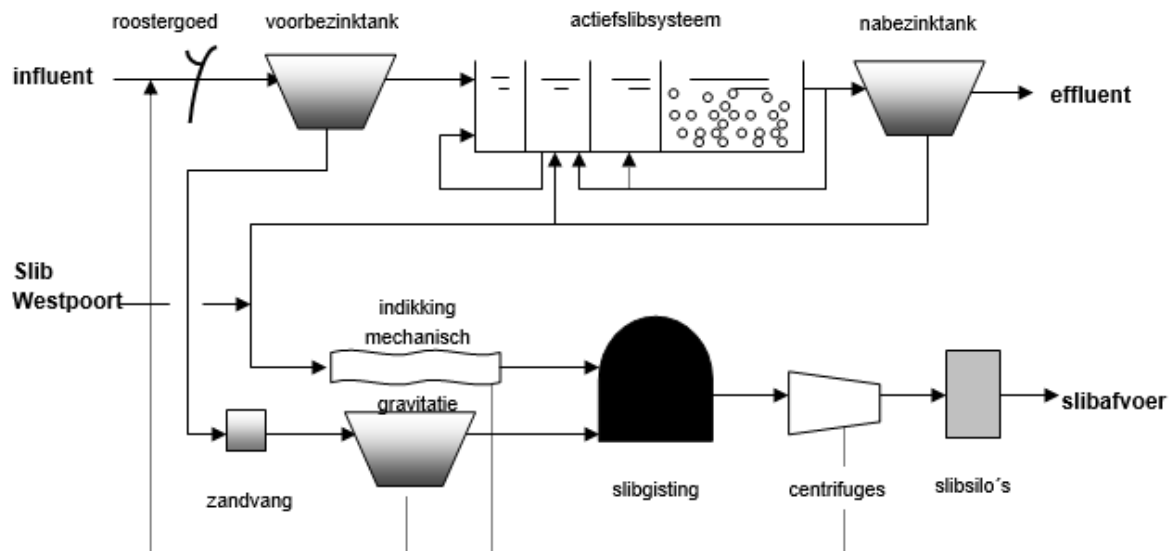

Figure 8 Process configuration wastewater treatment plant project 3 (Dienst waterbeheer en Riolering projectbureau A4, 2002)

From the process flow diagram shown above only the water line (upper part) is looked at in this research. From the water line the activated sludge process, secondary sedimentation process and sludge return process are investigated. Primary sedimentation tanks and secondary sedimentation tanks are of a similar built and comparable in cost set-up. This is the only wastewater treatment plant of the ones researched at Witteveen+Bos and will be used as an extra datapoint for sedimentation tank CERs. The tank itself will be described at the sedimentation tank sector of this paragraph (Dienst waterbeheer en Riolering projectbureau A4, 2002).

The cost data found from wastewater treatment plant project 3 consists of a cost estimation of the civil engineering sector for the wastewater treatment plant. This is given in a work breakdown structure per object (Witteveen+Bos, 2002). A gap of one year between the cost estimation and the preliminary design report available makes this data less reliable as changes to the design could have been made in the meantime. Another liability of this data is the fact that this is a preliminary design, whereas the other project data is gathered from final designs. This should be taken into account when interpreting the data. The data is however used in order to have enough data points.

5.3.1. Activated sludge process

The activated sludge process is conducted in 7 activated sludge tanks. Each activated sludge tank consists of an anaerobic tank, a denitrification tank, an intermittent aeration tank and a nitrification tank. Every activated sludge tank is connected to 2 secondary sedimentation tanks. Every anaerobic tank has volume of 2.590 m³ and a diameter of 20,3 meter. The activated sludge flows from the anaerobic tank to the denitrification tank. Each of the 7 denitrification tank has a volume of 4.350 m³, a surface area of 544 m² and a diameter of 33,6 meter. Around the denitrification ring an intermittent aeration tank is present with a volume of 4.350 m³, a surface area of 544 m² and a diameter of 43,1

meter. The intermittent aeration tank can be used for mixing or for aeration. The nitrification tank is the outermost ring of the aeration tank. The nitrification tank has a volume of 5.800 m^3 and a diameter of 53,2 meter (Dienst waterbeheer en Riolering projectbureau A4, 2002).

5.3.2. Sedimentation process

The influent first passes a primary sedimentation tank before entering the activated sludge tank. There are 4 primary sedimentation tanks present at wastewater treatment plant project 3. Each of the sedimentation tanks has a surface area of 1.935 m^2 and a diameter of 49,6 meter. The preliminary sedimentation tanks have a skimmer with a length equivalent to the diameter.

There are 14 secondary sedimentation tanks. Each of these sedimentation tanks has a surface area of 2.200 m^2 and a diameter of 53,0 meter.

5.3.3. Sludge return pumping station

For each secondary sedimentation tank, 2 sludge return agers are installed. These augers have a flowrate of 300-900 m^3/h (Dienst waterbeheer en Riolering projectbureau A4, 2002).

5.4. Project 4

A fourth project is the 2008 wastewater treatment plant project 4. This project is different from the three projects given above as a different activated sludge process is used. Another reason this project is different from the ones named above is the scope of this project. The earlier named projects contained the entire construction of the wastewater treatment plants. This project however contains adjustments to existing installations and construction of new objects. The gathered (financial) information should be filtered on the objects constructed and filter out objects adjusted. The objects which are newly constructed are among others an aeration tank, a blower building, a secondary sedimentation tank and a sludge return pumping station. Because these objects fall in the scope of this research, the data from this project is usable (Waterschap Zuiderzeeland, 2008).

The financial information regarding this project is gathered from a civil engineering cost estimation with a work breakdown structure, in this cost estimation the direct costs are given (Schaper, 2008). The direct mechanical engineering costs have been gathered from a mechanical engineering cost estimation (Steijgerwalt, 2008).

5.4.1. Pre-development objects

Before the expansion the main objects which fall in the scope of this research are a preliminary sedimentation tank, 2 activated sludge tanks and 2 secondary sedimentation tanks. The primary sedimentation tank has a volume of 3.713 m^3, a surface area of 1.432 m^2 and a diameter of 42,7 meter. The activated sludge treatment has a volume of 2.550 m^3 per tank, a surface area of 636 m^2. The total denitrification volume of the two tanks is 930 m^3 and the total nitrification volume of the two tanks is 4.170 m^3. The two secondary sedimentation tanks each have a diameter of 46 meter, a surface area of 1.662 m^2 and a volume of 4.386 m^3 (Witteveen+Bos, 2008). The process flow diagram of the adjusted wastewater treatment plant is seen in Figure 9.

5.4.2. Activated sludge process

The newly constructed aeration tank consists of an anaerobic tank with three compartments, a selector with three compartments, a denitrification tank, 2 intermittent aeration tanks, 2 nitrification tanks, 2 distribution chambers and 2 floating matter collectors. The anaerobic tank has a volume of 1.946 m^3. The selector has a volume of 870 m^3. The denitrification tank has a volume of 5.464 m^3, the intermittent aeration tank has a volume of 6.557 m^3 and the nitrification tank has a volume of 9.835 m^3 (Waterschap Zuiderzeeland, 2008).
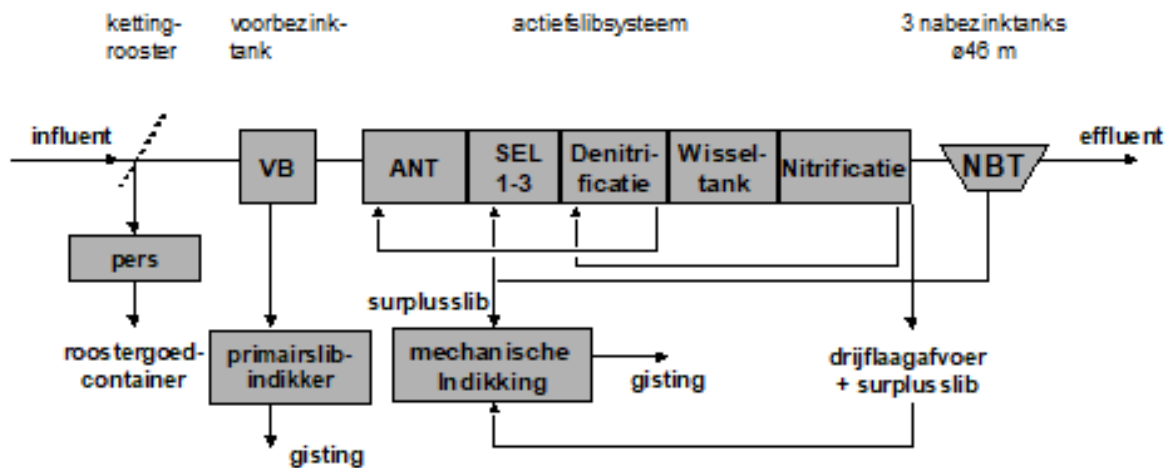
Figure 9 Process configuration wastewater treatment plant project 4 (Witteveen+Bos, 2008)

The direct civil engineering costs are 46% of the total civil engineering construction costs. This is because this wastewater treatment plant project is an expansion of a pre-existent wastewater treatment plant.

5.4.3. Sedimentation process and sludge return pumping station

The third secondary sedimentation tank newly constructed has a diameter of 46 meter and a skimmer with a length of two third the diameter of the tank. The secondary sedimentation tank has one sludge return pumping station with one sludge return auger. It is an auger with a diameter of 900 mm and a capacity of 285-700 m^3/h. The auger has a starting point of -4,9 meter NAP and a discharge point of -2,3 meter NAP. The auger is set up under an angle of 30⁰ (Waterschap Zuiderzeeland, 2008).

5.5. Other projects

From the wastewater treatment plants De Bilt, Soerendonk and Evertsekoog tertiary information has been found regarding the direct civil engineering costs. Information about the cost driving parameters of these projects and their costs have been found in the wastewater calculator (Padmos, 2012, pp. 96-97). The information regarding the activated sludge process, the secondary sedimentation process and the sludge return pumping process have been used for analysis. The scope regarding these processes and their objects have been used for analysis of these projects and the project information found at Witteveen+Bos.

5.6. Conclusion

With (cost) information of four projects regarding the direct- and construction costs gathered from cost estimates and (cost) information of several projects gathered from the wastewater calculator, the amount of data is not as good as was expected. The cost estimates can be regarded as primary information as this is the product Witteveen+Bos wants to deliver. The information gathered from the wastewater calculator however is secondary information and not all details of these projects and their scope is known.

6. Cost estimating relationships researched

In this chapter the data from Witteveen+Bos and the wastewater calculator is analyzed and possible cost estimating relationships are tested. First the overall project will be tested against the capacity of the wastewater treatment plant after which some objects present at wastewater treatment plants found in literature and in the data provided by Witteveen+Bos will be tested for cost estimating relationships.

6.1. Wastewater treatment plant total construction costs against capacity

From the projects Witteveen+Bos attributed to, some general information was gathered from the final designs. At project 4 this information was gathered from the preliminary design. The first correlation which is considered is the correlation of the project construction costs with the capacity of the treatment plants in person equivalent (p.e.) of total- or biochemical oxygen demand (tod/bod). Another correlation could be present between the average daily flow rate of the wastewater treatment plants and the construction costs. The interpretation of p.e. varies throughout the designs in mass of the oxygen demand needed per p.e. and in the scope (biochemical oxygen demand, chemical oxygen demand or total oxygen demand). The scope can also vary, as some values are given in gram per liter and some in kg per day. To make these amounts comparable the values from Table 3 in Appendix 3. Data analysis can be used to calculate a uniform p.e. value. The formulas used are $p.e.(54g\ bod) = Q * bod/54$ and $p.e.(136g\ tod) = Q * (cod + 4,57 * KjN)/136$. In these formulas bod and cod are given in grams of oxygen demand per m^3, Q is the average flow rate in m^3/d and KjN is the Kjedahl-nitrogen level in gram per m^3 (TU Delft, 2019)

Project	Price level	cod (g/m³)	bod (g/m³)	Flow rate (m³/d)	Kj-N (g N/m³)	p.e. TOD (136g per p.e.)	p.e. BOD (54g per p.e.)
Project 1	2006	590	232	11.500	56	71.628	49.444
Project 2	2008	536	203	19.500	51	110.105	73.333
Project 3	aug-08	554	226	24.193	57	144.991	101.111
Project 4	dec-02	486	220	200.000	45	1.014.003	814.815
Project 5	2016	730	287	64.400	61	476.640	342.593

Table 2 Capacity of wastewater treatment plants in p.e. and flow rate

Using these values of Figure 10 the relation between the wastewater treatment plant civil engineering construction costs and the capacity can be gathered as shown in the following figures.
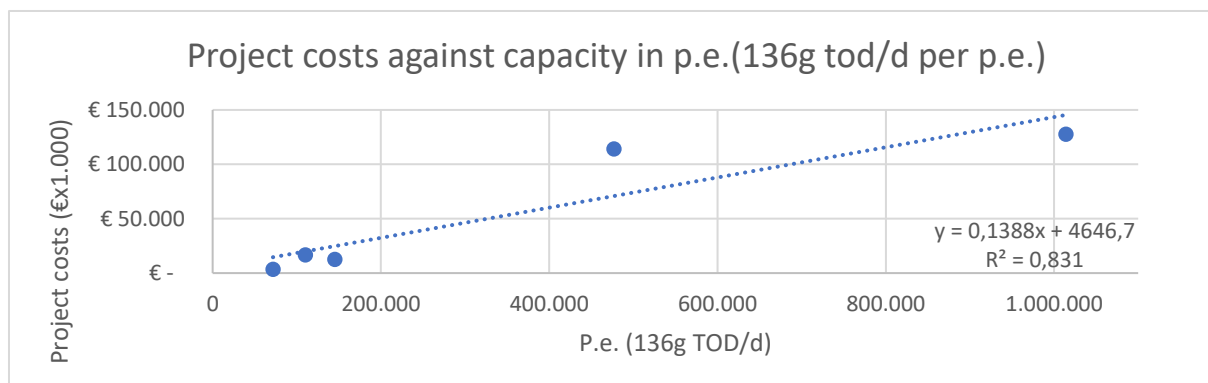

Figure 10 Wastewater treatment plants construction costs of the civil engineering secor against the capacity of the wastewater treatment plants in p.e. (136g tod/d per p.e.)

Figure 11 Wastewater treatment plants construction costs of the civil engineering secor against the capacity of the wastewater treatment plants in yearly average flow rate Q (m³/d)

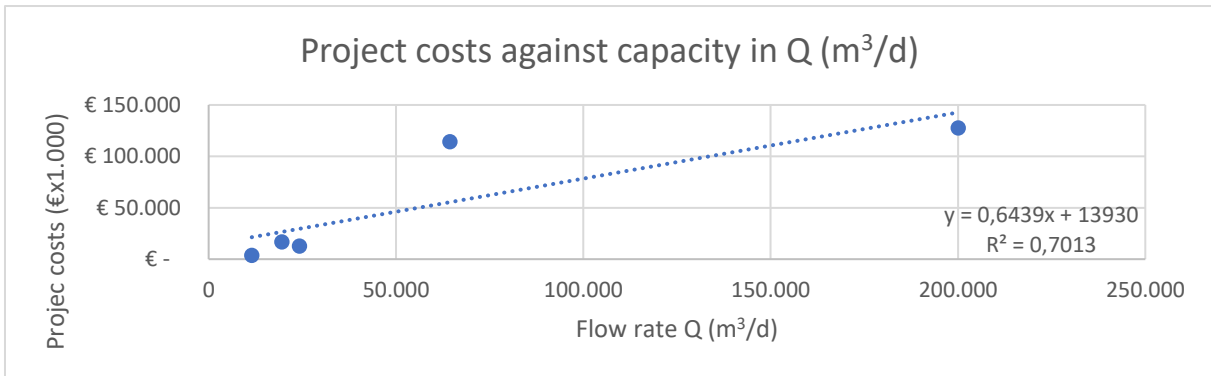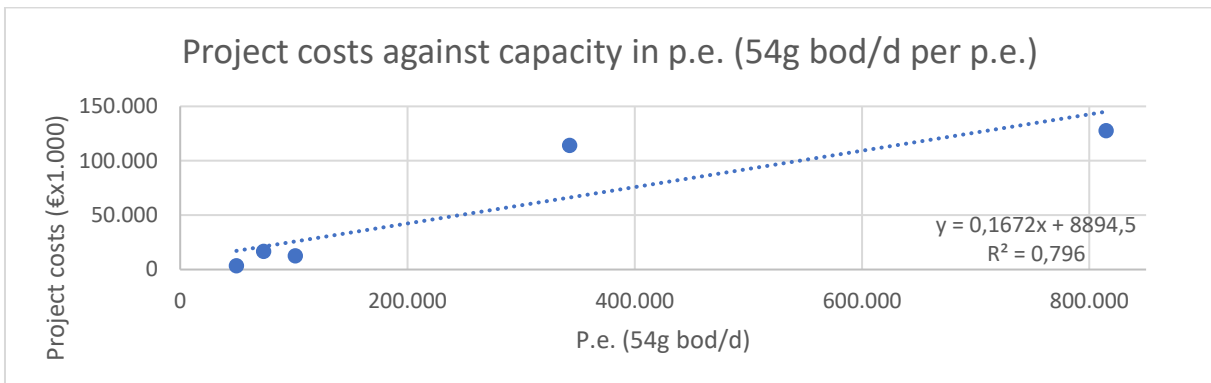*Figure 12 Wastewater treatment plants construction costs of the civil engineering secor against the capacity of the wastewater treatment plants in p.e. (54g tod/d per p.e.)*
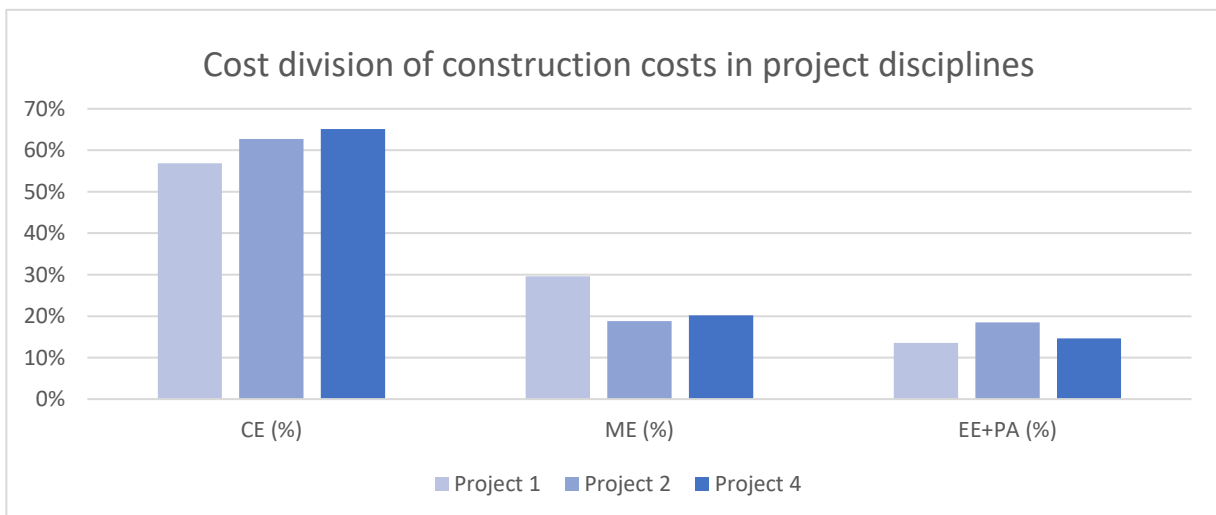
Figure 13 Cost division of the construction costs of wastewater treatment plant projects to the disciplines civil engineering (CE), Mechanical engineering (ME) and Electrical engineering and process automating (EE+PA)

The graphs of the capacity of the wastewater treatment plants versus their civil engineering construction costs show a correlation between the two. However due to a lack of datapoints nothing conclusive can be stated on this correlation. The R^2 value is quite high for all three tests, however as stated due to the lack of datapoints this gives no conclusive answers. The outliers to the left, being wastewater treatment plant project 5 and wastewater treatment plant project 3, impact the R^2 value greatly.

In Figure 13 the division of the costs of three projects is taken under the loop. From wastewater treatment plant project 3 and project 5 information about the mechanical engineering and electrical engineering and process automating costs has not been allocated, so these projects could not be used. There seems to be a connection between the cost discipline and the percentage of the total construction costs. To get a better idea of this relationship between the cost division and the percentage of the total construction costs further investigations and more data is needed.

6.2. Activated sludge process

The activated sludge process is done in several tanks or compartments of a tank. The aeration tank, the anoxic tank and the anaerobic tank are part of the activated sludge process. The cost information obtained from Witteveen+Bos is in given for the total activated sludge tanks containing these different objects. This is the level which thus can be used for analysis. The same goes for the possible cost driving parameter of tank volume. In an ideal situation these costs could be broken down per compartment of the activated sludge process. The data gathered from the wastewater calculator is given for the aeration tank, anoxic tank and anaerobic tank. Only cases where all three compartments in volume and their costs are given the data is usable for comparison with the data gathered from the projects Witteveen+Bos was involved with.

The results can be seen in Figure 14. In this graph the direct costs of the civil engineering costs of the activated sludge process are shown with a OLS curve fitted as expected CER. With the dashed line below and above, a 95% confidence interval has been fitted and the coloured area shows an error margin of 20%. Based on the datapoints gathered, his CER has a R^2 value of 0,89 and an adjusted R^2 value of 0,87. There are two outliers with respect to the 20% error margin. The first one is the activated sludge process costs of the wastewater treatment plant de Bilt with a volume of 5.875 m^3. It is not known why this value stands out. The second one is the activated sludge process of wastewater treatment plant project 1 with a volume of 11.590 m^3. Reasons for this outlier could partly lie in the absence of foundation costs. The absence of foundation costs however doesn't account entirely for this outlier. Further research is needed to see why this value is so low with respect to the expected value.
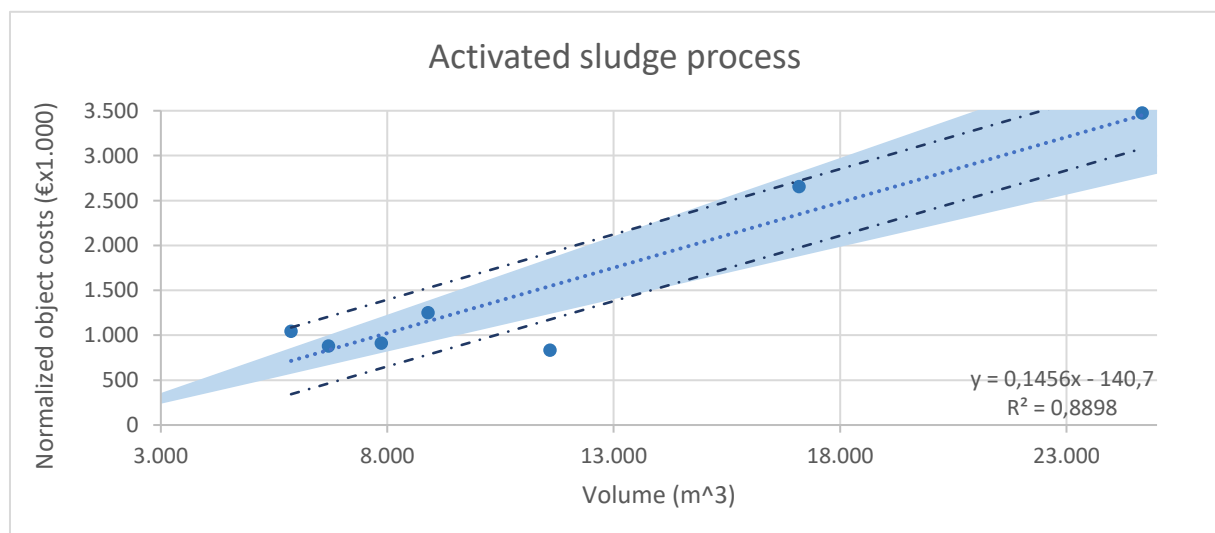

Figure 14 CER between tank volume of the activated sludge process and the direct civil engineering and construction costs.

5.5. Sedimentation process

At the sedimentation tanks the wastewater calculator uses tank diameter as cost driving parameter. In this research this will also be taken as the cost driving parameter to ensure enough datapoints.
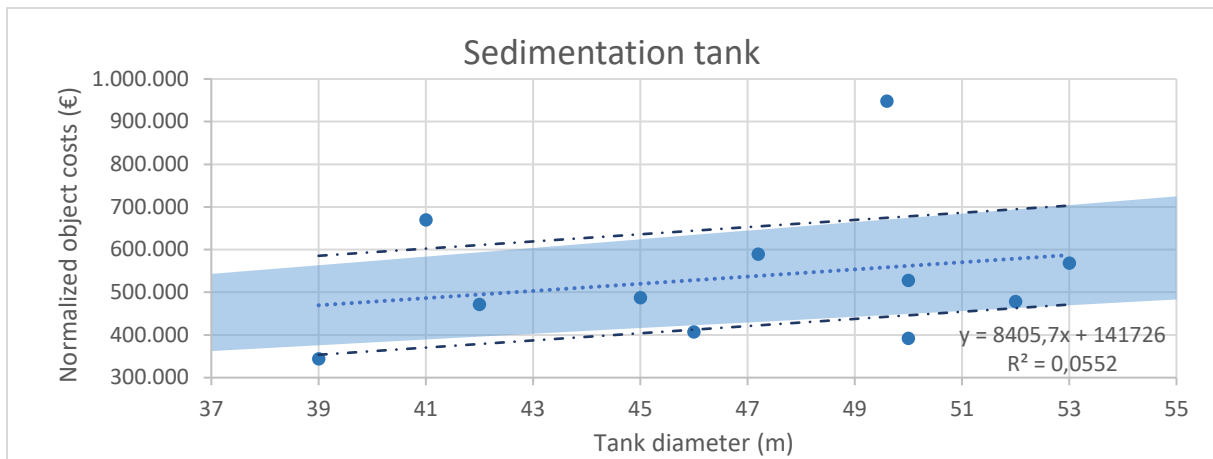
Figure 15 CER between tank diameter of the sedimentation tank and the direct civil engineering costs

In figure 18 the cost estimating relationship between the tank diameter and the direct civil engineering costs is shown. This is not a strong CER. Again there are few datapoints, the R^2 has a low value. The adjusted R^2 even has a negative value of -0,05. This again shows that the correlation is not as strong as is expected. More research on the relationship between the volume of the tanks could prove rewarding as the height is not taken into account in this research. The height of some wastewater treatment plant sedimentation tanks is tracked down from the Witteveen+Bos data. However not enough for statistical analysis of the height and volume versus the costs.

In the wastewater calculator the data on the surface skimmer used throughout the report of the wastewater calculator is questionable. A correlation between the mechanical engineering costs (skimmer and floating matter drainage pump) and the tank diameter is sought after. No clear correlation is found as the length of skimmers can be half the diameter, two third of the diameter or the entire diameter. The length of the skimmer is partly dependant on the diameter of the tank, but also on the quality of the water. The statement was made in the wastewater calculator that the length of the skimmer is half the diameter if the tank has a diameter of lower than 30 meters, two third the length of the diameter if the diameter is between 30 and 50 meters and just as long as the diameter if the diameter has a length above 50 meters. The data provided by Witteveen+Bos proves this statement to be false.
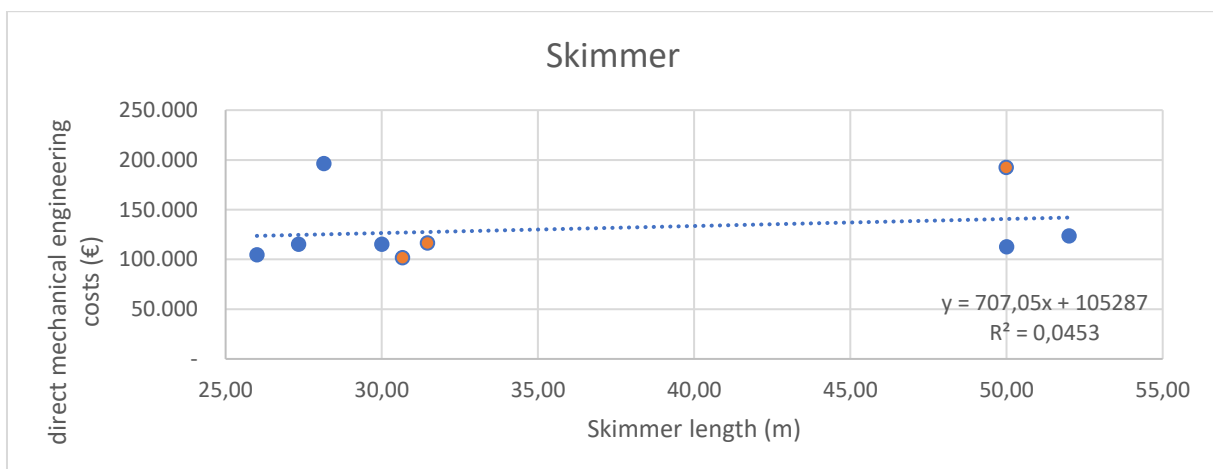

Figure 16 Skimmer costs of sedimentation tanks against skimmer length.

In Figure 16 the CER between the skimmer costs and the skimmer length is shown. The blue datapoints are datapoints gathered by Thijs Padmos, whereas the orange datapoints are gathered from data at

Witteveen+Bos. The graph shows a linear progression of the direct costs of the skimmer. With two outliers. The first outlier with a skimmer length of around 28 meters is from the project Dinther. No further information is known from this project to explain the outlier. The second outlier with a skimmer length of 50 meters is from project 1. In the mechanical engineering cost estimation no further explanation of the costs is given. By further research in conjunction with the mechanical engineering department the reason of this outlier could be found. Using all the datapoint an average of around €130.900 is gathered. Leaving out the outliers an average of €112.700 is gained. This is in both cases lower than the expected value used in the wastewater calculator. This could partly be due to the normalization. Another factor is the difference in cost driving parameter, from tank diameter to skimmer length.

6.3. Sludge return pumping station

The sludge return pumping process is divided in two parts in the wastewater calculator. The sludge return pumping station is taken under the loop for the civil engineering costs. The Sludge return auger is taken under the loop for the mechanical engineering costs. The sludge return pumping station consists of the foundation, floor, walls, roof, platform and the gutter. The sludge return auger encompasses the auger, engine and piping. According to Thijs Padmos these objects account for around 82% of the sludge return process. The remaining 18% are located at the electrical engineering costs and process automating costs.

There are three types of sludge return pumps: the sludge return auger, the positive displacement pump and the centrifugal pump. The first one is looked at in the research of Thijs Padmos. Centrifugal pumps are smaller and don't need a building for shelter. In Padmos' research centrifugal pumps and positive displacement pumps are not taken into the scope of the study.

In the study of Thijs Padmos a coefficient of determination (R^2) of 0,64 is found. In Figure 17 the datapoints from several projects provided by Witteveen+Bos are added. The added datapoints are represented by the orange dots. The added datapoints are from left to right respectively from the projects 1, 2 and 3. From project 2 the capacity of the sludge return pumping station, the number of sludge return pumps and the capacity of the sludge return pumps are taken from the final design. (Witteveen+Bos, 2008). The costs are taken from the second version of the civil engineering cost estimate. (Witteveen+Bos, 2008). As the sludge return pumping station of only one of the sludge return augers is newly built, the capacity of only one sludge return auger is taken instead of the total capacity
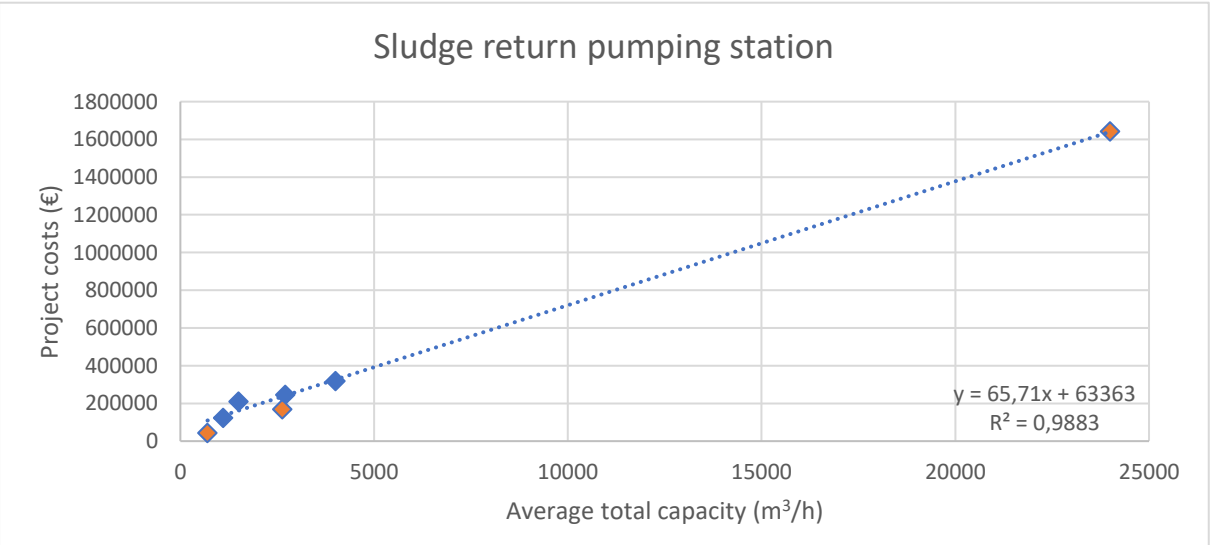

Figure 17 CER of sludge return pumping station with respect to capacity

of the wastewater treatment plant. For the wastewater treatment plant project 2 the costs are gathered from a RAW cost breakdown structure. All costs which can be directly linked to the sludge return pumping station are taken into account. Soil removal is not taken into account, as it is not clear how much of these costs are to be attributed to the sludge return pumping station. The information about the sludge return pumping station are gathered from the final design (Witteveen+Bos, 2007). The costs are gathered from the cost estimate comparison between the contractor and the consultant. The cost estimate of the contractor is used. The upper right dot is from wastewater treatment plant project 3. The costs are taken from the cost estimate of the civil engineering costs and the information about the pumping station is taken from the preliminary design as the final design could not be found.

This increases the number of datapoints and it increases the correlation. The number of datapoints is still too low for qualitative statistical conclusions. More datapoints with an average capacity between the current datapoints would be needed to confirm the correlation shown by the trendline. The increased correlation with respect to Padmos' research is supportive of a linear correlation between the CE costs of a sludge return pumping station and the yearly average cumulative capacity of the sludge return pumping station.

For the sludge return pump with regard to the mechanical engineering costs Thijs Padmos found no clear correlation between the capacity of a pump and its costs. In the recommendations it is advised to research the correlation between the costs of sludge return pumps and the auger length or pumping height. These parameters are more telling about the dimensions of the object. From project 4 this information has been gathered, however no such data is found among other projects to come to reasonable conclusions about possible correlation.

7. Conclusion and discussion

This chapter will conclude the findings of the research done. Possible options for further research on this subject will be discussed as well.

7.1. Conclusion

During the research on the relation between costs of water treatment plants and descriptive variables the scope had to be narrowed down to just the waterline of wastewater treatment plants. This was needed in order to find descriptive variables and to be able to interpret the financial data provided in the right way. This however leaves open many areas for further research. The cost estimating relationship of the sludge line or of several object breakdown structure given in the SSK-2010 and SSK-2018 remain uninvestigated.

Because the construction of new wastewater treatment plants is not as common as housing projects not enough data is available for a full statistical qualitative analysis. Many projects on wastewater treatment plants include renovation of tanks for example and new construction of objects from the waterline or sludge line. These projects could be used for single datapoints if these objects and constructions fall within the scope and same cost class as these objects and constructions at a new wastewater treatment plant project. Foreign projects should be carefully normalized to be usable for comparison, the objects however do not differ.

The scope of the costs known is an important factor to include in the research. The user phase and demolition phase are currently not available or researched. With the introduction of SSK-2018 this could be done in the future. The direct costs should be taken as a starting point for a cost estimating relationship. By bottom-up research more and more processes and their respective objects can be researched and added to an overall wastewater treatment plant cost estimation based on gathered data. If the objects included contribute to most of the direct costs the construction costs and investment costs could be added later on. For this research the construction costs are used with regard to the wastewater treatment plant as a whole in terms of capacity and the direct costs are used for the cost estimating relationship with some separate objects looked at. Due to the lack of primary information (cost estimates gathered from Witteveen+Bos) and the different breakdown structures being used no definitive answer can be given on the cost estimating relationships present in wastewater treatment plants. A work breakdown structure with an object as a sub-division would give the best insight in the project for further research in possible cost estimating relationships. Due to the different breakdown structures throughout the finished projects the current data is of a lesser quality for research in cost estimating relationships.

With (cost) information of four projects regarding the direct- and construction costs gathered from cost estimates and (cost) information of several projects gathered from the wastewater calculator, the amount of data is not sufficient. The cost estimates can be regarded as primary information as this is the product Witteveen+Bos wants to deliver. The information gathered from the wastewater calculator however is secondary information and not all details of these projects and their scopes are known.

7.2. Deliverables

The desired result was set to consist of an Excel program where the correlation of certain variables is shown. The calculation tool meant to give an accurate estimation of the costs of water treatment plant projects is however scrapped. Because not all aspects and costs of a wastewater treatment plant are addressed, this doesn't seem to be a cost accurate inclusion. More research should be done on the processes and objects left out of this study. With the resulting correlations and additional datapoints

a model could be made. This tool could combine these findings into a calculation format for cost estimating of future wastewater treatment plant projects.

7.3. Discussion

Due to the low amount of data points cost estimating relationships have not been researched with regard to multiple cost driving parameters per object or process. This is because of the amount of degrees of freedom. With one parameter there would be at least three datapoints needed for one degree of freedom. For two cost driving parameters of an object 4 datapoints are needed for one degree of freedom and so on. If more datapoints would be gathered a more accurate cost estimating relationship containing different parameters could be set up.

Another problem in comparing the available data was found in the different treatment methods used in different wastewater treatment plants. Different methods require different processes, objects and costs. To be able to compare different objects of cost groups from projects with one another they should regard the same treatment method and be of the same project phase. Another inconvenience lies in the different ways the costs are given. In some projects the costs are given per object, in others per cost group. Making these costs comparable is time consuming, because of the division of some cost groups to objects which requires more research on the subject.

It can be stated that the cost estimating for wastewater treatment plants at Witteveen+Bos from projects over the years are inconsistent. If a uniform way of storing information and a uniform cost breakdown structure would be implemented, this would improve insight in the costs and possible cost estimating relationships.

7.4. Recommendations

For future research into the costs of wastewater treatment plant projects to succeed a few guidelines could be laid out. In order to make data gathering easier the final cost estimation and the final design belonging to this cost estimation should be archived in a uniform way. The main cost driving parameters of the objects and their values should be written down in the final design reports of the projects. From the mechanical engineering, electrical engineering and process automating expertise is needed for good cost estimating variables. For civil engineering projects a combination of volume, capacity and surface area should be further investigated for the cost estimating relationships present between the objects and the costs.

Another improvement could lie in the cost breakdown structure used. The wastewater treatment plant projects researched are done in different cost breakdown structure. If a uniform cost breakdown structure would be used where most of the costs could be coupled to a structure, subprocess (for instance: aeration process, anaerobic process, aerobic process, sedimentation process) or object data from different phases (direct-, construction- or investment costs) could be better interpreted.

8. References

CBS Statline. (2018, 06 24). *Grond-, weg- en waterbouw inputprijsindex*. Opgehaald van www.cbs.nl: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/81139ned/table?ts=1561039057195

Crow kennisplatform. (2019, 6 3). *kostenramen met ssk*. Opgehaald van crow: https://www.crow.nl/over-crow/nieuws/2018/september/kostenramen-met-ssk-anno-2018

CROW. (sd). *Standaard Systemathiek voor Kostenraming SSK-2010.* CROW.

Dienst waterbeheer en Riolering projectbureau A4. (2002). *voorontwerp rwzi Project 3.* Deventer: Witteveen+Bos.

Duurzaam thuis. (2019, 6 3). *subsidie regenwater*. Opgehaald van duurzaam thuis: https://www.duurzaamthuis.nl/financieel/subsidies/subsidie-regenwater

Georgine Grissop PE. (2010, 12 1). *acswater.* Opgehaald van https://acsawater.com/sites/default/files/websitefiles/SVWWTPN/BNR%20Processes.pdf

Hendriksen, N. (2011). *CBK kengetallen AWDW.* Deventer: Witteveen+Bos.

International society of Parametric Analysts. (2008). *Parametric estimating handbook.* Vienna: ISPA.

International Society of Parametric Analysts. (2008). *Parametric Estimating Handbook, Fourth Edition.* Vienna: ISPA/SCEA Joint Office.

Kennis van pompen. (aug 2016). *Programma van eisen preventief en correctief onderhoud mini- en rioolgemaal.* Gemeente Stichtse Vecht.

Keurhorst, T. (2008). *Bouwkostenraming werktuigbouwkunde projectcode RAW 0034-00124.* Deventer: Witteveen+Bos.

Mcclave, J. (2016). *Statistiek.* Pearson Benelux B.V.

Padmos, T. (2012). *Stappen in de afvalwatercalculator; Kostenraming van afvalwaterzuiveringen.* Delft: TU Delft.

PWN. (1997, 5 27). *tevredenheidsverklaring.* Opgehaald van fena.wibo.nl: https://fena.witbo.nl/resy/bestanden/840TQO3R46I7PZ10MI22/verklaring/3%20pshk%20heemskerk.pdf

PWN. (2008, 12 10). *Letter of appreciation.* Opgehaald van fena.wibo.nl: https://fena.witbo.nl/resy/bestanden/NVMTBTHUVABBXBQUYXME/verklaring/E83%20-%20HEEM19-x%20Letter%20of%20Appreciation.pdf

Schaper, B. (2008). *Civiele besteksraming versie 2 Uitbreiding awzi Project 4.* Deventer: Witteveen+Bos.

Schulte, E. (2015, 10 21). OBS WBS CBS powerpoint. Deventer.

Steijgerwalt, W. (2008). *raming bouwkosten w: uitbreiding awzi Project 4 bestek.* Deventer: Witteveen+Bos.

Stichting Nederlandse Watersector. (2019, 5 7). *rwzi*. Opgehaald van watersector.nl: https://www.watersector.nl/rwzi/153/rwzi

Tian, Y., Huffman, G. J., Adler, R. F., Tang, L., Sapiano, M., Maggioni, V., & Wu, H. (2013). *Modeling errors in daily precipitation measurements: Additive or multiplicative?* GEOPHYSICAL RESEARCH LETTERS.

TU Delft. (2019, 07 12). *CT3011 Inleiding watermanagement*. Opgehaald van www.ocw.tudelft.nl: https://ocw.tudelft.nl/wp-content/uploads/CT3011_Afvalwaterbehandeling.pdf

Waternet. (2007, 2 6). *State of satisfaction, to whom it may concern.* Opgehaald van fena.wibo.nl: https://fena.witbo.nl/resy/bestanden/XTQYNGTKLJBXVVXJPOXV/verklaring/E62%20ASD491-X%20Waternet%20Amsterdam%20West%20-%20ENG.pdf

Waternet. (2017, 10 24). *State of operational performance WWTP Project 3.* Opgehaald van fena.wtbo.nl: https://fena.witbo.nl/resy/bestanden/XTQYNGTKLJBXVVXJPOXV/verklaring/E285%20-%20ASD491-X_Amsterdam%20WWTP%20_%20Statement%20of%20operational%20Performance_24-10-2017.pdf

Waterschap Zuiderzeeland. (2008). *Definitief ontwerp uitbreiding awzi Project 4.* Deventer: Witteveen+Bos.

Witteveen+Bos. (13-09-2006). *FH1-2 prijsvegelijking nieuwbouw RWZI Project 1.* Deventer: Witteveen+Bos.

Witteveen+Bos. (14-05-2008). *LEDN112-204 - Inschrijfstaat.* Deventer: Witteveen+Bos.

Witteveen+Bos. (2002). *Begroting civiel rwzi Project 3.* Deventer: Witteveen+Bos.

Witteveen+Bos. (2006). *Prijsspecificatie W projectcode FH1.2.* Deventer: Witteveen+Bos.

Witteveen+Bos. (2006). *RWZI Project 1 Definitief ontwerp.* Deventer: Witteveen+Bos.

Witteveen+Bos. (2007). *Nieuwbouw AWZI Project 2 definitief ontwerp.* Deventer: Witteveen+Bos.

Witteveen+Bos. (2007). *Wastewater Treatment Plant Project 3: New, Large, High-Tech and Sustainable.* Vienna: IWA ProceedingDesign.

Witteveen+Bos. (2008). *Definitief ontwerp uitbreiding awzi Project 4.* Deventer: Witteveen+Bos.

Witteveen+Bos. (2008). *Tol2-21 Civiele bestesraming versie 2.* Deventer: Witteveen+Bos.

Witteveen+Bos. (2010, 12 15). *tevredenheidsverklaring rwzi Project 1.* Opgehaald van fena.wibo.nl: https://fena.witbo.nl/resy/bestanden/FRRPIBOPOISTQHLNPCJY/verklaring/E134%20-%20FH1-X%20_tevredenheidsverklaring%20rwzi%20Foxhol%2015-12-2010.pdf

zedstatistics. (2013, 8 11). *Regression II.* Opgehaald van www.youtube.com: https://www.youtube.com/watch?v=4otEcA3gjLk

Appendix 1. Usability of wastewater calculator

Component/ element	Data points	R^2 test	Direct Cost formula y(€)[4], x(cost driving parameter)	Domain
Anaerobic tank	4	0,96/1,00[1]	Y = 129x + 178.000	700 ≤ x ≤ 2800
Anoxic tank	4	0,64/1,00[2]	Y = 131x + 161.000	950 ≤ x ≤ 2000
Aeration tank	9	0,61/1,00[1]	Y = 64x+401000	3300 ≤ x ≤ 10800
Secondary sedimentation tank	6	0,05/1,00[1]	Y = 15.000x – 123.000	39 ≤ x ≤ 52
Pumping station (return sludge)	5	0,75/0,96[1]	Y = 17,5x + 168.000	485 ≤ x ≤ 4000
Point aerator	4	1,00	Y = 205x +38.000	45 ≤ x ≤ 110
Ventilation facilities	Some	-	Y = 7078x	X ≥ 1
Point aerator room	Some	-	Y = 18605x	X ≥ 1
Draft tubes	1	-	Y = 25629x	X ≥ 1
Adjustable tilt spillway	Some	-	Y = 27219x	X ≥ 1
Steel bridge	1	-	Y = 53619x	X ≥ 1
Bubble aerator				
• Compressors	4	0,86	Y = 7x + 34000	1600 ≤ x ≤ 6400
• Air ducts	3	0,17	Y = 27x + 79000	1600 ≤ x ≤ 6400
• Aeration elements	5	0,75	Y = 39x + 172000	1600 ≤ x ≤ 6400
Mechanical lifting installation	2	-	Y = 20700x	X ≥ 1
Energy building	2	-	Y = 33000x	X ≥ 1
Skimmer	8	0,37	Y = 3300x	39 ≤ x < 50
			Y = 3300x + 20000	X ≥ 50
Return sludge auger	12	0,21	Y = 29436,37ln(x) - 160222,48	485 ≤ x ≤ 4000
Propellers	3	-[3]	Y = 25000x	X ≥ 1
Mixers	4	-[3]	Y = 15000x	X ≥ 1

[1] Second value is the R^2 value of the DHV drinking water calculator model and components. This cost formula is used in the wastewater calculator.
[2] Second value is the R^2 value of the DHV drinking water calculator model for the anaerobic tank component. This cost formula is used in the wastewater calculator.
[3] Costs seem to follow a straight line, costs are taken to be constant.
[4] Costs of the leading discipline of a component are used For each object a predetermined set of costs is looked at. An example of this is given in Figure 6 Decomposition of objects .

Table 2 Usability of wastewater calculator

Appendix 2. Usability of the CCC index numbers WWDW

A worksheet of the CCC index numbers WWDW spreadsheet. As can be seen there are few data and no clear conclusion regarding a CER can be deduced.

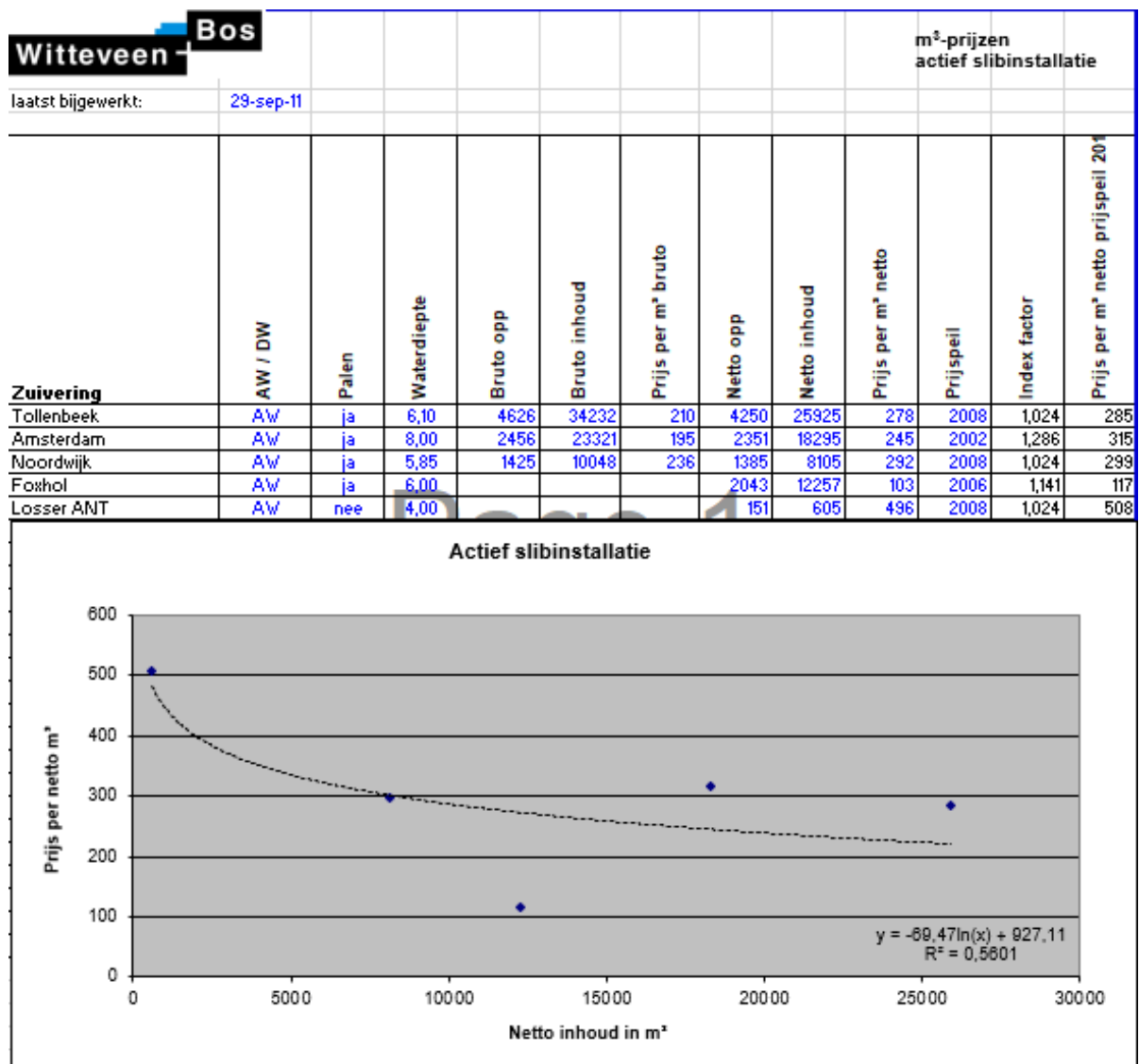| Zuivering	AW / DW	Palen	Waterdiepte	Bruto opp	Bruto inhoud	Prijs per m³ bruto	Netto opp	Netto inhoud	Prijs per m³ netto	Prijspeil	Index factor	Prijs per m³ netto prijspeil 201
Tollenbeek	AW	ja	6,10	4626	34232	210	4250	25925	278	2008	1,024	285
Amsterdam	AW	ja	8,00	2456	23321	195	2351	18295	245	2002	1,286	315
Noordwijk	AW	ja	5,85	1425	10048	236	1385	8105	292	2008	1,024	299
Foxhol	AW	ja	6,00				2043	12257	103	2006	1,141	117
Losser ANT	AW	nee	4,00				151	605	496	2008	1,024	508

Figure 18 Worksheet CCC index numbers activated sludge installation (Hendriksen, 2011)

Appendix 3. Data analysis

Table regarding general information of wastewater treatment plant projects gathered at Witteveen+Bos.

Project	Chemical oxygen demand (kg/d)	Biochemical oxygen demand (kg/d)	Yearly average flow rate (m³/d)	KjN (kg/d)
Project 1	6.780	2.670	11.500	648
Project 2	10.450	3.960	19.500	990
Project 4	13.403	5.460	24.193	1.382
Project 3	97.140	44.000	200.000	8.920
Project 5	47.000	18.500	64.400	3.900

Table 3 General information about the wastewater treatment plant projects gathered from the preliminary- and final designs

Table regarding all direct costs and cost driving parameters gathered of the civil engineering and construction costs sector. The Aeration tank (AT), Anaerobic tank (AnaT) and the Anoxic tank (AnoT) have been taken as separate objects in the activated sludge process. From the projects 1 to 4 the costs of the total installation have been given as the civil engineering costs AT.

RWZI	Price level AT	volume AT (m^3)	CE+CC costs AT (€)	Price level AnaT	volume AnaT (m^3)	CE+CC costs AnaT (€)	Price level AnoT	volume AnoT (m^3)	CE+CC costs AnoT (€)	Total volume	normalized CE+CC costs	Data gathered by
Unknown	2002	3.300	720.012							3.300	682	Thijs Padmos 2012
De Bilt	2009	3.800	778.793	2007	1.125	420.374	2007	950	172.210	5.875	1.043	Thijs Padmos 2012
Unknown	2002	4.300	791.352							4.300	750	Thijs Padmos 2012
Unknown	2002	4.375	948.482							4.375	898	Thijs Padmos 2012
Soerendonk	2010	5.000	667.829	2009	700	286.028	2009	1.000	249.844	6.700	880	Thijs Padmos 2012
Project 4	aug-08	21.856	4.966.454	aug-08	1.946		aug-08	870		24.672	3.475	Job van Staveren 2019
Project 2	2008	6.020	1.269.905	2008	1.310		2008	535		7.865	913	Job van Staveren 2019
Unknown	2002	6.125	1.199.097							6.125	1.136	Thijs Padmos 2012
Evert sekoog	2007	6.200	894.230	2010	1.300	629.313	2010	1.400	143.780	8.900	1.250	Thijs Padmos 2012
Unknown	2002	7.500	737.260							7.500	698	Thijs Padmos 2012
Project 1	2006	9.300	1.018.039	2006	1.480		2006	810		11.590	834	Job van Staveren 2019
Unknown	2002	10.800	1.632.970							10.800	1.547	Thijs Padmos 2012
Project 3	dec-02	14.500	2.827.179	dec-02	2.590					17.090	2.656	Job van Staveren 2019
Nieuwegein				2009	2.800	1.029.459	2009	2.000	493.742	4.800	1.140	Thijs Padmos 2012

Table 4 Information regarding price level, volume and direct costs of civil engineering objects of the activated sludge process.

In this table the civil engineering and mechanical engineering direct costs of the sedimentation tanks and skimmers are given.

Project	year	diameter (m)	Skimmer length (m)	CE+CC	CE+CC Norm.	ME	ME Norm.	Data gathered by
Soerend onk	2009	39	26,00	€ 459.817,00	€ 344.110,01	€ 127.127,00	€ 104.545,23	Thijs Padmos 2012
De Bilt	2007	41	27,33	€ 861.889,00	€ 669.688,42	€ 136.285,00	€ 115.373,54	Thijs Padmos 2012
Dinther	2002	42	28,14	€ 498.429,00	€ 472.108,93	€ 204.952,00	€ 196.455,31	Thijs Padmos 2012
Evertsek oog	2010	45	30,00	€ 679.873,00	€ 487.801,26	€ 142.920,00	€ 115.141,99	Thijs Padmos 2012
Foxhol	2007	50	50,00	€ 679.453,00	€ 527.935,51	€ 133.243,00	€ 112.798,31	Thijs Padmos 2012
Venray	2009	52	52,00	€ 639.319,00	€ 478.442,66	€ 150.122,00	€ 123.455,59	Thijs Padmos 2012
Project 1	2006	50	50,00	€ 479.455,50	€ 392.674,45	€ 220.000,00	€ 192.181,70	Job van Staveren 2019
Project 2	2008	47,2	31,47	€ 819.924,76	€ 589.767,85	€ 142.000,00	€ 116.298,12	Job van Staveren 2019
Project 4	2008	46	30,67	€ 566.000,00	€ 407.121,02	€ 124.000,00	€ 101.556,10	Job van Staveren 2019
Project 3	dec-02	53	35,51	€ 604.856,70	€ 568.296,30			Job van Staveren 2019
Project 3	dec-02	49,6	49,60	€ 1.009.276,42	€ 948.270,99			Job van Staveren 2019

Figure 19 Data gathered regarding civil engineering and mechanical engineering direct costs ad cost driving parameters of sedimentation tanks