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Master Thesis

**Mapping the distribution of Austrian wastewater treatment plants smaller than 500 PEs**

Submitted by

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in the framework of the Master programme

Natural Resources Managament and Environmental Engineering

in partial fulfilment of the requirements for the academic degree

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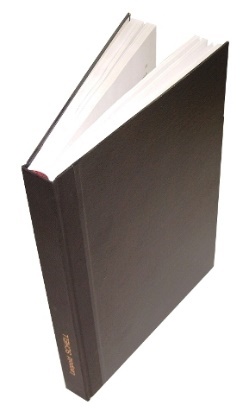
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*As for the future, the aim is not to predict it, but to enable it.*

Antoine de Saint-Exupéry, Citadelle, 1948

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This research was conducted with the generous support of the Austrian Federal Ministry of XYZ. Additional financial support for data analysis was provided by XYZ.

This research was financed by … and conducted at the Institute of …. over the period January 2021 to December 2024, in cooperation with ….

The research presented in this master thesis was conducted in the framework of the project “XYZ,” funded by XYZ (grant number: xxx)

This master thesis was funded by a fellowship of the XYZ and supported by the ACRONYM Project [Project number] from the Austrian Science Fund (FWF) and from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation program grant agreement No. xxxxx.

# Acknowledgements

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The acknowledgements thus usually cover three groups of people:

* your supervisor and colleagues who have provided scientific input in the design and implementation of your research and the interpretation of the results, especially through discussions;
* people who have helped you with the layout, wording, spelling, grammar, graphics of this master thesis;
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Table of Contents

[Introduction 2](#_Toc92367243)

[Goals 3](#_Toc92367244)

[Describe goals, approach and structure 3](#_Toc92367245)

[Fundamentals 4](#_Toc92367246)

[Methods 5](#_Toc92367247)

[Short overview of methodology 5](#_Toc92367248)

[Original dataset 5](#_Toc92367249)

[Data gathering 5](#_Toc92367250)

[Workflow of spatial referencing 5](#_Toc92367251)

[Workflow of data analysis 5](#_Toc92367252)

[Results and discussion 7](#_Toc92367253)

[Present and describe results. At the end short summary (few sentences) 7](#_Toc92367254)

[Unified dataset 7](#_Toc92367255)

[Spatial dataset 8](#_Toc92367256)

[Distribution of WWTPs 9](#_Toc92367257)

[Clusters of outdated WWTPS 14](#_Toc92367258)

[Interpretation 17](#_Toc92367259)

[Interpretation, explanation, comparison and contradiction with literature. Particularly new results and conclusions 17](#_Toc92367260)

[Data gathering and handling 17](#_Toc92367261)

[Distribution of WWTPs 17](#_Toc92367262)

[Outdated WWTPs 17](#_Toc92367263)

[Conclusion and outlook 18](#_Toc92367264)

[Evaluate goals at hand of discussion and interpretation. Result based outlook, further research 18](#_Toc92367265)

[Summary 19](#_Toc92367266)

[2 to 4 pages : 19](#_Toc92367267)

# Introduction

Rewrite

In Austria about 95% of the population is connected to major wastewater treatment plants. The remaining inhabitants rely on a high number of small systems designed for less than 50 PE. Although each WWTP has to be approved by the authorities, there is no central database.

During recent research by the [*Institute for Sanitary Engineering and Water Pollution Control*](https://forschung.boku.ac.at/fis/suchen.orgeinheit_uebersicht?sprache_in=en&menue_id_in=201&id_in=H811)*,* a significant gap between the estimated and the real number of small plants has been identified.

The gap originated from bureaucratic and federal political dynamics. In fact each federal state runs its own database. As follow-up research, the institute developed an Austrian-wide dataset, containing information on technology type, installation year and treated volume.

This newly retrieved information generated interesting questions on the distribution and role of small-scale wastewater systems in Austria. For example Lendl and Muller pointed out that 20% of the treatment plants are out of date, not satisfying the most recent Austrian regulations for wastewater quality.

Using the mentioned dataset to map the Austrian-wide distribution of small-scale wastewater system, this work aims at highlighting spatial information and represents the first spatial analysis on this subject. mention high resolution and make this better

More than 95% of the population are connected to municipal wastewater systems. Such is made of 15500 small wastewater plants and 1930 bigger than 50PE. 1

Small public wastewater systems are abou 15500 and have been built since 1993 by means of federal subvenstions. But very little PE.

Read :

* Kommunales Abwasser – österreichischer Bericht 2018, other collecting studies and Eu law.
* ÖWAV (2019): Branchenbild der österreichischen Abwasserwirtschaft 2020.
* Engstler

# Goals

## Describe goals, approach and structure

The first research goal of this work is to analyze the obtained dataset from a spatial perspective and describe the distribution of small-scale wastewater systems on a municipality level, the smallest administrative division in Austria.

Lendl and Muller reported that 20% of WWTPS are outdated, because not designed for biological nitrification according to national law2. Building on this statement, the second research goal is to identify clusters of outdated infrastructure and the municipalities that mostly rely on them.

Furthermore, this works specifically aims at facilitating research on the topic. To do so the original datasets will be optimized for future research and updates. The entire source code will be published in order to ensure reproducibility.

In the order they will discussed later, the goals of this work are:

* To unify the existing datasets in a single database
* To describe the distribution of WWTPs at cadastral municipality level
* To identify clusters of non-nitrifying WWTPs and the municipalities that mostly rely on them

In fundamentals the theorical background is set, describing the legal framework and summarizing the state of knowledge on Austrian wastewater coverage. The methods part discusses the workflow from raw data to the desired dataset and its analysis. Results and rest not finished

Where to put Benefit of research

* + Goal 1:
    - solve mentioned issues,
    - facilitate research
  + Goal 2:
    - further insight in spatial dimension
    - understand where small WWTPS are important
  + Goal 3: identifying clusters with out-of-date and old systems permits to :
    - Point out at priority areas where ROS could be successfully implemented
    - This works is in the framework of the Verena research project and

# Fundamentals

## Legal Framework in Europe and Austria

In Europe general water management goals are set by the Water Framework Directive (WFD), a unified policy promulgated in 2000. Many implementations have been published since, including the Urban Wastewater Treatment Directive (UWWTD 91/271/EEC).

The UWWTD sets minimum wastewater requirements and has been translated into Austrian national law with a modification of the 1. Wastewater Emission Directive (WED)3. Together with the General Wastewater Emission Directive (GWED)4 this piece of law forms the essential pillar of national wastewater regulations. Their juridical background, as for any other Austrian water related law, is set in the Water Rights Act (WRA) issued in 1959. It regulates the use, protection and quality of water resources5.

In Austria WW is defined in the GDEW §1 as water that, after being used for human purposes (industry, cleaning, consumption) has been so affected that its reintroduction to natural water bodies would negatively affect them4. The goal of WWTPS is to ensure that all pollutants are removed according to WED. This piece of law defines general minimum treatment requirements according to plant size. The regulation has been updated in 1991, requiring nitrification through biological treatment.

Table 1 Austrian wastewater treatment requirements (WED)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **parameters** | **>50-<500 PE** | **>500-<5000 PE** | **>5000-<50000 PE** | **>50000 PE** |
| BOD | 25 | 20 | 20 | 15 |
| COD | 90 | 75 | 75 | 75 |
| TOC | 30 | 25 | 25 | 25 |
| NH4-N | 10 | 5 | 5 | 5 |
| Tot-P | - | 2 | 1 | 1 |

There is no standard for nitrogen and phosphorus removal. However discharge into sensitive water bodies may require special permits and additional treatment requirements6.

As stated in WED, minimum requirements for emission quality start at a design size of 50PE. Nonetheless authorities usually apply the same requirements for smaller WWTPs6,7. Note that not all WWTPS are subject to same requirements. For example, WTTPs in isolated areas, such as mountain shelters, are subject to less stringent requirements described in the 3. GWD8.

Design guidelines are describe in Ö-NORM B 2502-1 (2012) and ÖNORM EN 12566-3 (2016) for technical plants up to 50 PE and Ö-NORM B 2505 (2009) for treatment wetlands6.

Once the requirements have been respected and no damage is expected for the receiving water body, a discharge permission is issued by the authorities. The permission procedure is described in WRG § 32. Permissions are granted for specific periods , like 15 years in Upper-Austria9.

EmRegV-OW 2017 describes the national database for wastewater emissions, where WWTP bigger 2000 PE and industrial WWTPs according to 2010/75/EU and 91/271/EWG must be recorded10. This register is publicly available in the Water Information System Austria (WISA) database as promulgated by WRG § 59.

Furthermore all 9 federal states operate their own WIS, where all WWTPs on their territory should be listed.

The UWWTD 91/271/EEC sets out a timeline for the implementation of wastewater treatment in settlements of all sizes, where bigger settlements have priority. This sparked a run for sanitation and several countries invested in WWTP to fulfill the European goals according to timeline11,12. In case of non-compliance member states faced monetary sanctions like Spain and Italy12.

Member states have to report every 2 years to the European commission their progress in reaching the WFD goals in accordance with 91/271/EWG. In Austria the national WISA is one of the base datasets for the biennial report to European authorities. Information about WWTPs smaller than 200PE are issued from federal authorities to their national counterpart13. There is no national database for WWTPs smaller than 2000PE.

## Research on small WWTPs in Europe and Austria

According to 91/271/EEC Article 7 the sanitation of small settlement (<2000PE) had to be implemented by 200514. Aragon reports 2 school of thoughts in the national implementations of this Article. Some countries, like Spain, implemented that small agglomerations must comply with the same requirements valid for bigger ones. Other countries, like Austria, France and Finland established specific requirements15.

To fulfill the goals and avoid sanctions, member states had to invest in the sanitation of small settlements. Furthermore, collecting reliable data on the topic became essential to report to the European commission and interest was sparked also in scientific circles. In fact, most of papers on the topic have been published in the last decade. It has to be mentioned that the compliance with Article 7 seems not to be a priority for the European Commission, as it is not mentioned in the 10th and most recent report on the implementation of the UWWTD16.

European research on the topic usually focuses on surveying the existing infrastructure17–20, the analysis of legal framework15,21,22 and monitoring of treatment and O&M quality17,19,23. No spatial analysis was found.

In 2013 Aragon found that less than 50% of small Spanish settlements (<2000 inhabitants) are properly sanitized. Furthermore the research highlighted that information about sanitation of small settlements was very limited15. Generally, the absence of a central database is evident and researchers often have to cope with sparse sources. Tsagarakis surveyed small (<10.000PE) WWTPs in Greece using data from “*information given by the personnel and management of plants, available design data, and on-the- spot investigations. Additional data were acquired by post or telephone contact.”* Nonetheless this work produced interesting results, stating that less than 50% of the built infrastructure was operational at the time and highlighted an overall poor O&M17.

In fact, maybe because it has remained unaddressed for long time, the topic of small WWTPs seems to deliver relevant pieces of information. A 2011 survey in Ireland found that 2 thirds of the population rely on decentralized WWTPs. Less than 1% of the households had no treatment facility but overall, the treatment was inadequate. In fact most of the on-site treatment systems consisted of a cesspool and a percolation structure19. Improper treatment has also been reported in Italy and Sweden18,22 .

Add reported effects of small WTTPs in environment – UNDER CONSTRUCTION

In Finland rural areas were reported to emit 50% more Phosphorus than urban ones. Linked to small WTPS21.Although reported to some extent19,22, the influence of such on a basin level is not more than a minor contribution to nutrient load19. Make two cits .On the other hand effects on surface waters are more likely, especially during low flow conditions19. Check source. Effect on water wells. Research impact of small WWTP on environment

Similarly to the European trend, Austrian popular topics for small wastewater research are treatment24 and O&M quality25,26. Only few published articles address the distribution of the infrastructure6,27 and no exhausting spatial analysis could be found either. Although relatively digitized, information on small WWTPS is not easy to collect because each federal state runs its own database.

The first Austrian work on the subject seems to be the 1971 paper by H. Donner where the “uncontrolled” status of small WWTPs and lack of data is strongly represented. The author reports that only 19% of the small WWTP in the federal state of Styria had a treatment and discharge permission. Furthermore the work suggests that an inappropriate treatment consisting of cesspool and inadequate percolation, thus similar to the Irish reports of above, was extremely frequent28.

In two recent articles Langergraber surveyed small WWTPS, reviewing the state of knowledge on the subject, including technology trends and missing information. The work is based on research accomplished by several bachelor and master studies6,27.

Dopplinger and Feigl accurately described the situation of small WWTPs in Austria and firstly identified a gap in the estimated and real number of those29,30. Gersthofer analyzed the situation in Upper-Austria focusing on P removal7. Although readily noted in previous works, Lendl and Muller were the first to valorize the information that about 20% of small WWTPs don’t comply with national law because unable to biologically nitrify2. Engstler reported on the treatment performance of small WWTPs in Upper-Austria9. Finally Sacken worked on sludge treatment in Upper-Austria and could collect recent data on local WWTPs31.

## Austrian wastewater landscape

Austria counts 8.9 million inhabitants distributed over 9 federal states. The total WWTP capacity is of 21.5 Mio. PE plus 10 Mio for industry and business1.

The connection rate, calculated as the houses relying on municipal wastewater-conveying channels is a typical measure used to describe the extent of wastewater services in a given area1. With 95%, Austria has one of the highest connection rates in Europe. According to EUROSTAT, the Netherlands are first with 99%, followed by Germany and Great Britain with 97%. In the last 40 years the Austrian connection rate almost doubled, following an average yearly increase of 1.2 %1. The remaining 5% of the population uses private small WWTPS or cesspools. In urban areas the connection rate is generally higher whereas rural areas show significantly lower values (Fig.1.)

Map

Description automatically generated

Figure 1 Connection rate to municipal infrastructure by district according to OWAV 2020

The Austrian wastewater review 2020 counts 17.500 WWTPs with direct discharge into water bodies. They are categorized into WWTPs under <50PE, WWTPs addressed by the WED categories and industrial WWTPS. The review cites Langergraber 2018, stating that there are 27.450 small WWTPs if exclusively mechanical WWTPs are also counted1.

Generally, the smaller the design size, the larger the number of plants and the smaller the contribution to total capacity. According to the 2020 Austrian Wastewater overview there were 15.554 WWTPs smaller than 50PE, accounting for less than 1% of the total PE capacity and 1040 WWTPs >50PE and <500PE accounting for 0.8% of total capacity.

Table 2 Austrian treatment capacity by design size (OWAV)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **category** | **nr. of WWTPs** | **% of total** | **PE (Mio)** | **% of total PE** |
| <50 | 15554 | 88.98 | 0.16 | 0.74 |
| >50-<500 PE | 1040 | 5.95 | 0.18 | 0.83 |
| >500-<5000 PE | 505 | 2.89 | 1.13 | 5.22 |
| >5000-<50000 PE | 316 | 1.81 | 6.1 | 28.20 |
| >50000 PE | 66 | 0.38 | 14.06 | 65.00 |
| total | 17481 |  | 21.63 |  |

Fig 2 shows the geographic distribution of the small WWTPs counted by the Austrian wastewater overview. The comparison with Fig 1 clearly shows that their number is higher where the connection rate is lower.

Map

Description automatically generated

Figure 2 number of WWTPs <50PE per 1000 inhabitants by municipality

Furthermore, it is interesting to observe the projected population change for Austria (Fig.3). As usual the highest increase is foreseen in urban areas, meaning that especially centralized systems will have to cope with more users in the next years.

Map

Description automatically generated

Figure 3 Population chnage projection based on OROK data.

# Methods

## Short overview of methodology

The complete workflow, including plots and graphics has been executed using Python 3.8. The most used packages are pandas 1.3.3 and geopandas 0.9. For the sake of open science and ensure the reproducibility of this work, a code protocol including a complete list of packages and requirements was produced and is freely accessible online under https://github.com/anakarpow/small\_WWTPs\_MSC

The raw data was firstly rearranged to a unified format and compared with a control publication to check for differences in the key categories, such as amount of WWTPs, PEs and technology type. The obtained database was linked to governmental geodata to obtain the spatial dataset. During this process some data is expected to be lost because of insufficient spatial reference. To monitor data losses, the spatial dataset was compared with the control publication and the obtained dataset for the same key parameters as above. Insert validation in picture

Diagram

Description automatically generated

## Original dataset

The original dataset contained basic technical and geographical features of Austrian WWTPS up to 500 PEs. It consisted of several categories like treatment type, design size and some geographical reference. The dataset was arranged in 9 different excel files originated from different publications2,7,9,30,31. Each of the files covers a federal state and was created using data from its online water-infrastructure registry (WISA). The dataset was started in 2016 and updated last time in 2021, although not in uniform way. In fact, while last data on Upper-Austria has been collected in 2021, data on some federal states has never been updated since 2016.

|  |  |  |
| --- | --- | --- |
| **2016** | **2018** | **2021** |
| Vorarlberg | Carintia | Upper-Austria |
| Styria | Salzburg |  |
|  | Tyrol |  |
|  | Vienna |  |
|  | Burgenland |  |
|  | Lower-Austria |  |

## Workflow of data preparation and spatial referencing

The original files were not uniformly compiled and therefore individual processes had to be applied to perform the first three steps of the data preparation workflow: data wrangling, categorization and reformatting. In the first step, data types such as integers, floats and string had to be harmonized. Furthermore, misleading data entries, such as typos had to be disposed. This step ensures the correct functioning of further data processes. In the second step, categorization, the existing data categories were unified. For example, the technology type category has been harmonized according to ONORM standards. Furthermore, new data categories have been created. The reformatting step harmonizes tabular data in a single format ensuring that further data processes will work smoothly. To make sure no data was mistakenly altered or lost, the dataset obtained from these steps has been confronted with its original form. Furthermore, it was compared with a control publication that used the same data source.

Most of the original data did not contain spatial information in form of coordinates, but only as to which municipality it belonged to. Using the identifying number of the municipality as key, the data was merged with geodata provided by the Austrian government32. In this process the data that originally had no geographic reference was dropped. The resulting dataset contains only WWTPs that could be aggregated to at least their cadastral municipality. To monitor data losses in the spatial referencing process, the spatial dataset was compared to the control publication and to the obtained dataset.

The same procedure was followed to obtain the number of inhabitants by administrative unit. In this case, using the cadastral municipality as linking key led to unacceptable data losses, because some cadastral municipalities have been renamed and/or assimilated with others since the collection of the original data. For this reason, all maps containing population data are projected on a political municipality level which has not been renamed or modified and allowed to maintain the integrity of the data.

After merging with the cited supplementary datasets, the data has been aggregated by cadastral municipality and concatenated to a single national dataset.

## Workflow of data analysis

After gathering it in a single dataset, referencing it to spatial coordinates and checking any irregularities the data has been analyzed and interpreted. To study the distribution of Austrian infrastructure the dataset has been analyzed in all its dimensions : temporal, technical and spatial.

Outdated WWTPs have been identified according to the treatment type. In fact, exclusive mechanical treatment and filtration don’t comply with the actual regulation that requires a biological nitrification step. The most accurate way to measure which municipalities mostly rely on outdated system would be to relate them to a dataset including WWTPs of all sizes. Unfortunately it does not exist yet, as design size >500<5000 has not been surveyed yet. One could argue that it could be negligible because this design size only covers 5% of the total PE, but it probably covers more when considering only small settlements. For this reason the total population per administrative unit was used as proxy of PE, which is common in literature1,33.

# Results and discussion

## Unified dataset

The unified dataset is derived from the original data and contains WWTPS up to 500 PEs. Categories, like technology type, have been unified and made comparable. Each data entry contains a unique identifier, all original categories (year, technology type, PE) and the most precise geographical reference available. Most of WWTPs are tracked to their political municipality at least, whereas for other there was no further information available than federal state. In graph, the obtained database is compared to a control publication34.

Chart, bar chart

Description automatically generated

Revise graph: add tot loss graphically. Add positive negative signs on bar top

The number of tops of each bar shows the percentual difference in the number of WWTPS, where 0.0 means no difference at all. In 5 out of 9 federal states the obtained dataset is identical to its source.

Only Salzburg shows a negative difference higher than 0.1%. For Upper-and Lower-Austria the percentual difference in the number of PEs is positive because data for this region has been updated after the control source. For this reason, the difference was expected and will be considered as explained. Burgenland and Vienna have such a small dataset that they are not visible at this scale. For 8 out of 9 federal states an accuracy of over 99.8% was achieved and the overall unexplained negative loss is of 0.02% of the total original data.

Because the control publication only offers a technology type overview for WWTPS < 50 PE, the comparison for this category refers exclusively to this design size. Here the number of WWTPs by technology is compared between the datasets and its percental difference is calculated as the divergence within each technology group. For example, the datasets report a 20% difference in the number of exclusively Primary WWTPs in Upper-Austria.

Calendar

Description automatically generated

In fact, the federal state of Upper-Austria shows significant divergences with the original dataset. As explained before this is due to its later update compared to the control source. Carintia, Salzburg and Tyrol show minor differences, especially in the primary treatment category. The ASP category in Vorarlberg shows relevant difference. It has to be mentioned that the dataset for this state is very small (n=23) and thus not very relevant for the whole analysis. Overall, the category Primary shows most differences.

## Spatial dataset

This dataset contains only WWTPS up to 500PEs that could have been linked to their cadastral municipality. This is the dataset that has been analyzed to answer the main goals of this work. All following thematic maps are based on this dataset.

Graph monitors the data losses due to spatial referencing, comparing the obtained dataset with the spatial data. About 95% of the WWTPs were tracked down to their cadastral municipality. Three federal states (Vienna, Vorarlberg and Burgenland) have been excluded because they completely lacked any spatial reference.

Chart, bar chart

Description automatically generated

Lower-Austria has the highest loss percentage. All lost entries belong to the district of Amstetten and had not further spatial reference. Generally, the data losses here are due to missing cadastral municipality reference in the original data.

## Distribution of WWTPs

### Distribution by federal state

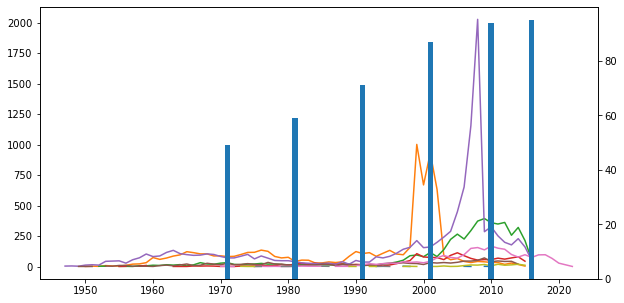
Most of WWTPS up to 500 PEs have been built between 1995 and 2015. In fact, in all states the construction of WWTPs of this size has peaked in this twenty-year period. Since 2010 a pronounced degrowth is evident. Comparing it with the development of the connection rate it is clear that with 2010 a plateau in building of small WWTPs was reached. In that year, the connection rate was 94%, almost at its maximum. Wait to finish graph!

It is interesting to note the differences in the temporal activity of the federal states. While small WWTPs in Lower-Austria were built between 2003 and 2015, Carintia has built them before 2003. All other states have a relative homogenous distribution.

Chart, histogram

Description automatically generatedgraph under development

Figure temporal distribution of WWTPs up to 500 PEs



Styria has the highest number of WWTPS, followed by Carintia and Lower-Austria. Nonetheless Lower-Austria leads with the number of PEs covered, before Carintia and Styria. As expected, the number of small WWTPs <50PE is overall higher than the number of WWTPs >50 PE. Styria is the only state where the coverage of WWTPs > 50PE is higher than their smaller counterpart.

Chart, bar chart

Description automatically generated

Figure 5 Distribution of WWTPs and PEs by design size

To obtain a clearer picture of the relation between state and technology, the PE were plotted against the total population. Carintia has by far the highest coverage with 17.5%. Overall in Austria 5% of the population relies on WWTPS up 500 PE, as confirmed by the national wastewater report1.

Graphical user interface, application

Description automatically generated

Figure 6 Percentage of population covered by WWTPs up to 500 PEs

### Distribution by tech type

The 1991 update of the WED clearly marks a turning point in the development of technology types. Whereas before most of the infrastructure was built with exclusively primary treatment, afterwards the diversity of treatment has developed. Especially ASP, SBR and CW were built after 1991. The trend appears similar for both design sizes.

Chart, histogram

Description automatically generated

Clearly most WWTPS with exclusively primary treatment were built before the 1991 update of the WED that requires biological nitrification. Nonetheless some, even in the 50 to 500 PE category, were built afterwards.

Chart, histogram

Description automatically generated

The next graph shows how the percentual PE coverage by treatment technology. Note that the categories MBR and SFB had such a low percentage (smaller than 1) that they were avoided to maintain readability. The technology distribution follows a similar pattern in both design sizes. SBR, ASP and primary treatment are the major components with about 60%. Constructed wetlands are more frequent in smaller design sizes. As mentioned before, the category other (minor technologies like composting) is more developed in WWTPs from 50 to 500 PE. Rotating biological contractors are rare. On the other hand, WWTPs with only primary treatment are common and account for about 20% of the PEs in both design sizes.

Chart, treemap chart

Description automatically generated

Graph under development

### Spatial analysis

WWTPS up to 50 PEs are popular in Austria, as most municipalities contain at least one. The WWTPS are evenly distributed overall the country. Only north-east Upper-Austria is largely without. Those areas have high connection rates as showed by Fig. 1. Carintia has the municipalities with the largest number of WWTPS this size. About the three missing federal states no statement can be done yet.

A picture containing text

Description automatically generated

Because most of WWTPs in the dataset are smaller than 50PE, their distribution also defines the overall pattern. For this reason, here only medium sized WWTPs (50-500PE) are showed. Tyrol has the most WWTPs between 50 and 500 PE, followed by Carintia. Otherwise, this design size is sparsely distributed throughout the country.

A picture containing text

Description automatically generated

In the next plot the amount of PEs per municipality is projected.

Map

Description automatically generated

Add total population coverage as annotation or in text

In most of the municipalities less than 10% of the population relies on WWTPs up to 500 PEs. In Carintia a high population coverage is common and several municipalities even have a coverage higher than 90%. A similar pattern is observed in north-western Lower-Austria. These areas also contain municipalities where more than 100% of the population is covered by WWTPs of this size.

A map of the world

Description automatically generated with low confidence

## Distribution of outdated WWTPS

In all analyzed states at least 10% of the WWTPs up to 500 PEs are outdated because unable to nitrify. By far Tirol has the largest share of outdated infrastructure. Furthermore, all federal states still have medium size WWTPs with only primary treatment.

Chart

Description automatically generated with medium confidence

Graph development : Add national mean value

The next graph shows the occurrence of medium sized non-nitrifying by federal state. The highest number is in Carintia, where 60% of medium sized WWTPS are outdated. Tirol, Lower-Austria, and Styria follow with about 50 WWTPS. Salzburg and Upper-Austria have very few, with the latter having only one. About 35% of WWTPs up to 500 PE in Styria and Tyrol are outdated.

Chart

Description automatically generated

To see the amount of medium sized WWTPS with only primary treatment in relation to the whole dataset, the next graph shows the number of WWTPS and PE together. Obviously because small WWTPS are overall way more than medium sized we see that the distribution of non-nitrified WWTPS follows the same pattern.

On the other hand, the distribution of non-nitrified PEs shows interesting and diverging patterns. In Carintia non-nitrified PEs are equally distributed between small and medium sized WWTPS. In lower-Austria and Tirol most of them are discharged by medium sized infrastructure. The remaining states show the opposite pattern, where most of the non-nitrified PEs are discharged by WWTP up to 50PE.

Chart, bar chart

Description automatically generated

Because federal states have varied sizes and number of inhabitants, to understand the distribution of non-nitrified infrastructure the percentage of population covered by only primary treatment is shown in the next graph. 7% of Carintia’s population relies on non-nitrifying WWTPS, by far the largest share in Austria. In fact, all other analyzed states float around 1%.

Chart

Description automatically generated

Summarizing. Carintia has the highest number of exclusively primary treatment PEs and WWTPs, leading to 7% of the population relying on such systems and 40.000 insufficiently nitrified PEs being released daily. Furthermore about 170 (60%) of medium sized WWTPS are outdated because only primary.

A picture containing text, cake

Description automatically generated

The next plot identifies where most of non-nitrified PEs are released. We see non-nitrified PEs are more usual in Tyrol and Carintia. Tirol shows one municipality where more than 1000 PEs are daily released without proper nitrification. Carintia has a few very small municipalities where also about 1000 PE are daily released. These are the by far the highest national values. In fact, most of others affected municipalities only release about 200 PE.

A picture containing text

Description automatically generated

A picture containing text

Description automatically generatedOverall, in Austria the percentage of population relying on non-nitrifying infrastructure is low. Styria and Tirol show some cluster-like pattern of municipalities where between 10% and 30% of the population relies on outdated WWTPS. Carintia definitely shows another pattern, where the municipalities with at least 10% are evenly distributed, 30% to 60% values are not uncommon and one municipality even exceeds 100%. Another municipality where more than 100% of the population relies on non-nitrifying WWTPs is in in Salzburg.

The next plot shows the distribution of medium sized WWTP with only primary treatment. A clear cluster is visible in Tirol. This municipality in Tyrol has 10 medium-sized WWTPS and all of them are outdated. Other municipalities with inadequate treatment are sparsely distributed.

Map

Description automatically generated

# Interpretation

## Interpretation, explanation, comparison and contradiction with literature. Particularly new results and conclusions

### Data gathering and handling

For 8 out of 9 federal states an accuracy of over 99% was achieved, practically meaning a perfect match. Deviations may be due to errors in the present or in the control workflow but are anyway not statistically relevant. For Upper-Austria, the nineth federal state, the 5% difference is assumed to be caused by the more recent version of data used in this work. In fact, the control publication has been published in 2018 whereas the Upper-Austria dataset was created in 2021. Overall, the database is considered valid and identical with the original data. The first goal is thus achieved.

After the spatial referencing about 5.5% of the original data was lost. Unfortunately, there is no way to further minimize this loss because of data incompleteness. The three excluded states: Burgenland, Vienna and Vorarlberg have a very small number of WWTPs (0.007% of the total) and their absence did not affect the results.

### Distribution of WWTPs

There are at least 25.868 small WWTPs in Austria. Considering the infrastructure that may have been built since the update of the dataset and interpreting Fig.4 for an approximate growth rate, the real number of small WWTPs is at about 27.000. Small WWTPs are evenly distributed over the country and most municipalities have at least one. Some clusters with higher concentrations are visible in Carintia, Styria and Lower-Austria.

The dataset reports 1471 medium sized WWTPs. Considering the growth trend, the real number is at about 1550. They are sparsely distributed and mostly in Lower-Austria, Tyrol and Carintia.

The reported WWTPs cover 419.651 PE, corresponding to about 5% of the Austrian population. Similar numbers shave been recently reported by Engstler, 2020 and the Austrian wastewater report 20201,9.

WWTPs up to 500PEs are essential for WW coverage in Austria because of the geomorphological barriers that do not allow a uniform centralized coverage. In fact, of the 2095 Austrian municipalities, about 5% (105) have at least 50% of their population covered by these design sizes. Such municipalities account for 107.330 PE and most of them are in Lower-Austria (55.000) and Carintia (36.000).

Observing the temporal development of WWTPs up to 500 PE, the UWWTD seems to have had a remarkable impact on it. In fact, most of the infrastructure has been built in the last 20 years. Styria has the most WWTPs of this design size (about 10.000), followed by Carintia with 7.000 WWTPs. Although Lower-Austria has about 4.000 WWTPs, they cover about 120.000 PE because many of them are medium sized. In fact, Lower-Austria is first by PE coverage, followed by Carintia (100.000) and Styria (90.000) (Fig.).

Nonetheless, when it comes to population coverage in percentage, as to say how much of the state’s population is covered by such infrastructure, Carintia is by far first with 17.5%. Lower-Austria and Styria follow with about 7%. The remaining states and the national average is at about 5% (Fig. 6).

* See Engstler, nice 3.3.1 spatial analysis
* Compare with OWAV geforderte Anlagen

### Outdated WWTPs

If the UWWTD signed a pivotal point for the development of small wastewater infrastructure, the 1991 update of the WED did so for the development of treatment technologies. The update requires all infrastructure to be able to nitrify biologically. In the early phase of Austrian small WWTPs the most common treatment was exclusive primary treatment. Staring with the early 90s this technology dropped nearly completely and SBR, ASP and CW started to be very popular. Today about 50% of the WWTPs use one of these three technologies.

Although not respecting the legal requirements for biological nitrification, some WWTPs with exclusively primary treatment continued to be built anyway. The last reported implementation was in 2014. For some of them the above cited exception for extreme places may have applied. Can it apply to medium sized too?

According to this dataset about 20% of WWTPs up to 500 PEs still have only primary treatment. Considering that not all states in the dataset are fully updated (Fig. ) and that some of these plants may have been renovated in the last years, the real number is probably slightly lower.

Interestingly, most of them rely on non-nitrifying infrastructure. which would point at the fact that it maybe are extreme places.

In every analyzed state at least 10% of the WWTPS up to 500 PE are outdated. Tyrol has the highest percentage (60%), followed by Carintia (33%) and Styria (20%). When it comes to discharge, Carintia leads with about 40.000 of non-properly nitrified PE. More than half of them are released by medium sized WWTPs. Carintia is also the state in where the percentage of population relying on outdated infrastructure is highest (7%), whereas all the others are at about 1%.

Furthermore, the discharge of non-nitrified PE is particularly concentrated in Carintia, where 3 very small municipalities (Pörtschach am See,Hüttenberg,Reifnitz) discharge more than 800PE/day. Tyrol also has one high discharge municipality (1000 PE) but its area is way larger and the discharge distributed over several WWTPS. Because of the reltively high discharge and the very tiny area, these Carintia municipalities may be a good study area to research the effect non-nitrified discharge has on the environment.

As a matter of fact, all states still have some exclusive primary treatment, but way less. The situation is particularly good is Upper-Austria where only one WWTP is still exclusively primary. Interestingly most of non-nitrified PE in Tirol and Lower Austria are due to medium sized WWTPS. Renovating such systems, respectively 75 and 45 WWTPs would mean a quick and effective improvement and would get rid of the majority of the non-nitrified PEs in these states. This would mean a very effective transition towards complete compliance with the 1991 WED update. The federal state of Salzburg, having only 10 WWTPS between 50 and 500 PE that account for about 25% of non-nitrified PEs, would also easily find a way towards compliance.

More difficult and costly would be in the remaining states, where most of non nitrified PEs are due to small sized WWTPS. Especially Styria has about 2000 outdated small WWTPS, which makes it more difficult to improve quickly. Lower Austria has 500 outdated WWTPs. Most difficult would be in Carintia, where a high number of both small and medium sized WWTPS equally contribute to the total non nitrified PEs.

Tirol has overall a large amount of municipalities where most of the WWTPS up to 500 PE are inadequate for biological nitrification. Further clusters are in the north-eastern part of Lower-Austria, the south-central area of Carintia and two more areas in Styria. Upper-Austria has a very low percentage of outdated infrastructure.

All in all, these three states appear to have a tighter relationship and a more developed WWTPS landscape. Can we see a geomorphological reason?

# Conclusion and outlook

## Evaluate goals at hand of discussion and interpretation. Result based outlook, further research

In his 1971 seminal work on Austrian WTTPs, H. Donner states observes that “*As known in expert circles, a absolute representation [of the existing small WWTPs] is nearly impossible. On the one hand because the evaluation of single discharge permissions would mean a enormous bulk of work, on the other hand because of the high number of illegal(dunkelyiffer), and thus not registered, infrastructure.”*

Because of the relatively recent start in data collection, information on the topic is relatively difficult to gather and several European countries seems to suffer from it.

Remarkably the percentage of non-nitrifying infrastructure is relative high in Austria. Especially in Tirol and Carintia the potential for updating or building new WWTPS is considerable.

Although such high percentages, the population relying on those outdated WWTPS is comparably low. In fact 5 out of 6 analyzed states float around 1%. Carintia has by far the highest coverage by non-nitrifying WWTPs.

* Cite Lendl and Muller
* Put tot pop relying on this
* Environmental estimate ?
* Put plot with PEsum nonitri. To see for environmental impact

# Summary

## 2 to 4 pages :

This chapter should be two to four A4 pages at most and should answer the following questions in the context of the thesis: **Why? What? How? Where? When?**

In other words:

* The motivation driving your thesis, i.e. what topic did you choose? Why did you choose it? Why is this issue/problem relevant? For whom?
* The specific purpose of your research, i.e. what research question(s) you addressed (which is narrower than the overall topic)
* How you addressed it, i.e. what methods you used, what data you collected
* What your results are, i.e. the answers to the research questions
* The significance of your research, i.e. what new insights have you generated? What contribution does your thesis make to the literature? How as it advanced the state of knowledge?

The essential results of the thesis are to be summarised in clear sentences and if viable in one or two tables/figures.

The summary definitely gains clarity and clearness, if logically related results and the conclusions derived are structured in short sentences, which may be numbered continuously.

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# List of abbreviations

This section is optional. If relevant include a list of abbreviations and/or acronyms. This is mostly necessary if you are using many and/or uncommon abbreviations. If you only use a few abbreviations or only common abbreviations (e.g. EU for European Union), it is sufficient to spell them out the first time you use them in the Introductory summary.

# List of tables / figures

This section is optional. Lists of tables and figures can be included, if you feel these are helpful to the reader. For this you need to use the tool ‘add caption’ under references in MS Word to add figure captions (see section 2.4), this then allows MS Word to generate a list with the captions of all figures.

# Appendix

Larger graphical figures, construction plans, minutes, tables etc. can be added at the end of the thesis as an appendix or attachment. However, an attachment has to be numbered continuously. Furthermore, the number and content of the attachment has to be quoted on a separate sheet. In the text the attachment is shortly quoted by mentioning the attachment number (e.g. Attch. 1, appendix, etc.)

# Curriculum Vitae

As last part of the master thesis the curriculum vitae is to be included. Besides personal data (incl. picture) it should give information on the educational career in schools and universities, and possibly on the professional course of education including internships as well as exams taken.

The format of the curriculum vitae is optional (e.g. in table form).