Project and master thesis topics in water and wastewater engineering 2021/22

NTNU

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Introduction

The water and wastewater engineering group has introduced a procedure for the publication and distribution of project and master thesis topics last year. The new procedure aims at a **balanced** master student distribution among scientific staff in a **transparent** way and bridging the demand in ongoing research projects and student interests. One main priority of master student projects is the support of **ongoing activity and PhD students**.

A balanced distribution of students will increase the room for **adequate supervision** and support and increases the **spectrum of topics** covered by master thesis work. Even though there may be strong demand for specific topics, it should be noted that there is a need for diverse education, and that a master thesis is not a comprehensive specialisation, but a short term project work where students are supposed to learn how to tackle a specific research question within limited amount of time. Many topics are related to each other and more focus on shared topics may be a way to facilitate.

The procure was slightly modified based on last years' experience. The main adjustment is the significantly shortened amount of time between the submission of desired topics by the students and the final distribution of topics. The process will be finished at the begging of June.

The distribution procedure

1. Topic collection

Each professor suggests 3 to 4 topics, each Prof. II suggests 1 to 2. Submission deadline is the right **after Easter**. All submitted topics should be in a matured stage, including supervisors, partners, financing (travel of the student, lab work…) etc. The proposals should highlight the possibility for consecutive project and master topics, maybe already defining them in detail.

2. Internal review

After submission, topics will be reviewed internally. As many topics as we have students will be selected, maybe 10% more. Possibilities for coalescence and collaboration will be identified, projects with high relevance og needs prioritized etc.
As many topics as we have students will be made available, maybe 10% more, during the spring semester on a given platform, using a fixed template.

3. Publication

The topics will be compiled and made available for the students via the internal website and by email, no later than **25. April**. There will be a meeting with the students on **27. April at 9 o'clock**, where the projects will be presented.

4. Application phase

After the topics are published, students apply for their favourite topics. The topics are divided into three groups and students will need to pick two topics from each group. Each group will contain topics from two

permanent employees and one or two Prof. II. The six topics selected can be ranked freely, and the ranking will be submitted via an online form that will be available on the master topic page.
All students are encouraged to write half a page motivation letter (A4), their they explain their motivation and justify their ranking for the selected topics. This is optional. Deadline for the application of the ranking and the motivation letter is on **25. May**.

5. Additional topics

Students will have the possibility to deliver independent project proposals, i.e. with external partners, until the end of the application phase **25th of May.** These proposals will need to be as mature and well defined as possible. A template for the proposals will be provided on the webpage.

6. Internal review and topic assignment

The ranking and the motivation letters will be evaluated. Topics will be distributed based on that evaluation. In case of many applicants for certain topics and the delivery of several strong motivation letters, distribution will be done by drawing lots.

7. Publication of results

Results will be published right after the review is finished, on **11. June**.

Topic overview

Master projects in Group 1

Number	Title	Supervisor(s)	Partner(s)
1.1	Treatment of road runoffs using closed sedimentation	Tone Muthanna, Kamal Azrague	Klima 2050, SINTEF
1.2	Urban flood resilience and floodways role in stormwater management	Tone Muthanna, Thea Skrede	Klima 2050, SINTEF
1.3	Fremtidsrettet overvannshåndtering	Tone Muthanna	Bærum Kommune
1.4	Asset management and decision support for Nature Based Solutions	Tone Muthanna, Franz Tscheikner-Gratl	
1.5	Impact of detergents on the mobility of heavy metals and PAH in road tunnel wash water	Thomas Meyn, Hanne Vistnes, Wolfgang Uhl, Eilen Arctander Vik & Subhash S Rathnaweera	Aquateam COWI
1.6	Best treatment approaches for wash water from road tunnels	Thomas Meyn, Wolfgang Uhl, Hanne Vistnes	Aquateam COWI
1.7	Decision support for selection of future treatment technology for tunnel wash water	Thomas Meyn, Franz Tscheikner-Gratl, Kamal Azrague	
1.8	Pump selection for energy efficient fluid transport in Wastewater Treatment Plants	Sveinung Sægrov, Paul Thamsen	Bergen Vann

Master projects in Group 2

Number	Title	Supervisor(s)	Partner(s)
2.1	Digitalisation of water systems – Artificial Neural Networks to predict future Legionella outbreaks in buildings	Cynthia Hallé, David Steffelbauer, Michael Waak, Stian Bruaset Charuka Meegoda	
2.2	Hydraulic Residence Time and Water Quality in Drinking Water Distribution Networks	Cynthia Hallé, Michael Waak, Marius Møller Rokstad	
2.3	Quantitative Microbial Risk Assessment (QMRA) of Norwegian Drinking Water Systems and Water Reuse Systems (Wider Uptake)	Cynthia Hallé, Michael Waak, Charuka Meegoda, Kamal Arzague, Rizza Ardiyant	SINTEF
2.4	Ammonium removal by Anaerobic ammonium oxidation (ANAMMOX) under challenging conditions.	Stein W. Østerhus Blanca M. Gonzales Silva	
2.5	Understanding the Enhanced Biological Phosphorus Removal (EBPR) process	Stein W. Østerhus Blanca M. Gonzales Silva	
2.6	Optimization of the Enhanced Biological Phosphorus Removal (EBPR) process for typical Norwegian conditions	Stein W. Østerhus/ Blanca M. Gonzales Silva	
2.7	Optimization of treatment effectivity and energy efficiency for Swimming Pool Water treatment using granular activated carbon and UV	Wolfgang Uhl, (Stein, Cynthia, Thomas tbd.), Bjørn Aas	SIAT
2.8	Vann og avløp i utviklingsland	Tone Muthanna, Sveinung Sægrov	IUG

Master projects in Group 3

Number	Title	Supervisor(s)	Partner(s)
3.1	Decision support for water distribution system DMA/PMA creation	Marius Møller Rokstad, Franz Tscheikner-Gratl, David Steffelbauer, Sveinung Sægrov	
3.2	Leak Detection and Localization with the Dual Model	David Steffelbauer, Franz Tscheikner-Gratl, Marius Møller Rokstad	
3.3	Using AI in the battle against FOG: The FATracker project	Francois Clemens, Franz Tscheikner-Gratl, Marius Møller Rokstad, David Steffelbauer	
3.4	Using machine learning and artificial intelligence to reduce failures and leakages in drinking water pipes	Marius Møller Rokstad, Franz Tscheikner-Gratl, David Steffelbauer, Stian Bruaset	SINTEF
3.5	Model Based Risk Assessment for Risvollan, Trondheim	Marius Møller Rokstad, Franz Tscheikner-Gratl, David Steffelbauer, Robert Meier	
3.6	The Shape of Water Distribution Systems	David Steffelbauer, Franz Tscheikner-Gratl, Marius Rokstad	
3.7	Co-developing and testing a framework for smarter use of water resources – the case of Bodø.	Franz Tscheikner-Gratl, Marius Møller Rokstad, David Steffelbauer, Rita Ugarelli	SINTEF
3.8	Efficient uncertainty quantification in multi-model chains employed in early warning systems for seawater desalination operations	Christos Makropoulos, Franz Tscheikner-Gratl, Marius Møller Rokstad	

Detailed project descriptions: Group 1

Project Title	Treatment of road runoffs using closed sedimentation
Type	Project and Master thesis
Supervisors / Contacts	Tone Muthanna / Kamal Azrague
Location	Trondheim / FV 505 Sandnes

Project background

The SFI Centre Klima 2050 (www.klima2050.no) studies climate adaption within the build environment, including stormwater management. Klima 2050 has a strong focus on innovation and demonstration of novel solutions through pilot projects in close collaboration with the public and private partners within the centre.

Skjævelandsgruppen and Statens Vegvesen have established a pilot project in connection with the new Fv505 project at Sandnes and have installed a new sedimentation facility with post-treatment possibilities. Additionally, an open natural pond has been established in connection with the new Fv505 project at Sandnes.

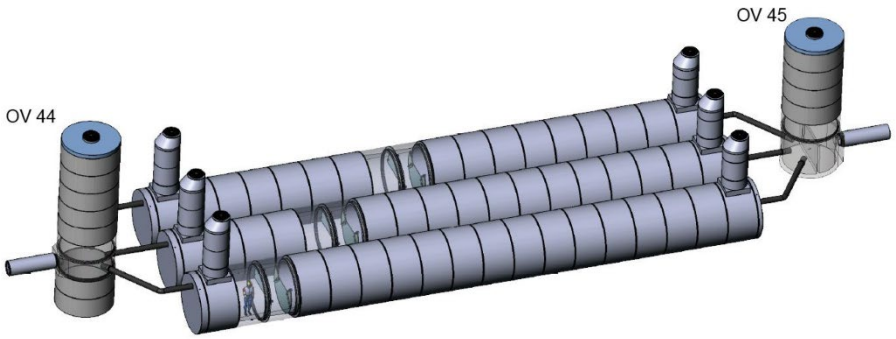


Figure 1. 3D scheme of the closed sedimentation system installed.

Aim of the project

The objective of the pilot project is to document the treatment efficiency, operation and maintenance of the solution for the treatment of road runoff. The outcomes of the studies will allow to compare the closed sedimentation with an open natural pond, in terms of removal efficiency, operation and maintenance requirements and costs (capex + opex). Based on the findings possible design optimisation will be proposed.

Specific work description

The work will include the following main tasks of; (1) Characterization of influent; (2)Characterisation of effluent; (3) Develop mass balances and models on contaminants removal; (4) Propose optimizations; (5)Evaluate the capital and operational costs. The system will be evaluated looking upon the efficiency in removing particles and other contaminants, mostly heavy metals and PAHs.

Samples will be collected manually or by an auto-sampler at the inlet and outlet of the systems and analysed for pH, conductivity, turbidity, TSS, TOC/DOC, heavy metals, PAH, according to Standard Methods and if adequate financial support is available. Online monitoring systems for turbidity, conductivity as well as TOC/DOC using S::can will be considered. Metal concentrations in water samples will be analysed using ICP-MS or other relevant methods. PAH will be analysed by commercial laboratories. Furthermore, particle size distribution will be also performed to characterise the size of particles at the inlet, settling inside the plant and remaining at the outlet.

In addition to water quality, it is desirable to measure the water flow in and out of the plants as accurately as possible.

Project Title	Urban flood resilience and floodways role in stormwater management
Type	Master thesis
Supervisors / Contacts	Thea Ingeborg Skrede NTNU/Norconsult
Location	Trondheim / Sandvika

Project background

Rapid urbanization and climate change impacts have resulted in frequent and severe urban flooding events in cities worldwide. In Norway, climate change is expected to increase both the intensity and frequency of precipitation. In urban areas, solutions must be established so that flooding from stormwater does not cause high monetary damages to both public and private properties, in addition to damages to infrastructure and public safety. It is not enough or even possible to prevent flooding; Solutions must also be established that reduce the extent of damage as much as possible during urban flooding.

In Norway, the three-step strategic approach (S3SA) introduced by Lindholm et al. (2008) is widely accepted as the industry standard and applied by municipalities to adapt stormwater management to climate change and urbanization impacts. The three-step strategy advises municipalities to (1) Catch and handle the first millimetre of the storm as infiltration; (2) Collect and detain the next millimetres; and (3) Convey what cannot be handled in the previous steps in open safe floodways. Little research has been done on floodway design or performance requirements, other than a design return period of 100 years. Today, we lack clear guidelines and regulations on what a safe floodway is, when a floodway is considered safe and what requirements to set for an exciting floodway. There is often little available space in urban areas that can be converted into floodways for safe stormwater transport. Hence there is a need to use existing and already occupied space for stormwater management. However, there are not all surfaces or urban areas that are suitable for stormwater transport. Significant research has been conducted both nationally and internationally on the first two steps of the strategy. However, they are often implemented on a property level and often as individual measures /components – not connected to the previous and the following step. A modified reversed version of the S3SA, introduced by Kristvik (2020), highlights the need for a system view of stormwater management and the importance of the floodway-system, when planning and implementing step 1 and 2.

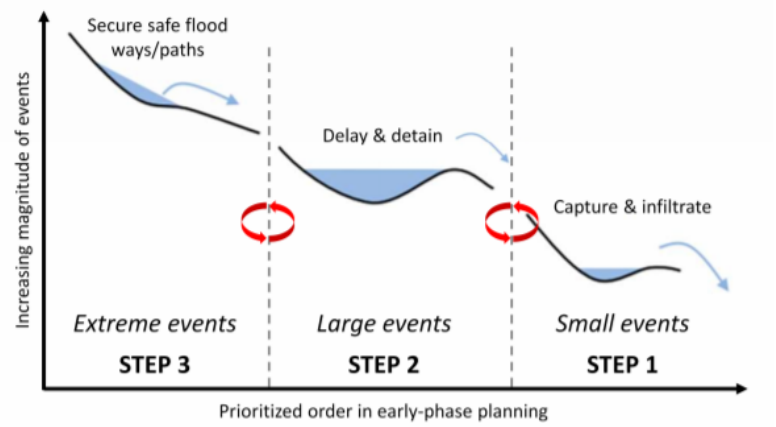


Figure 1 - Revised Three-step Approach for Stormwater Management, introduced by Kritsivik (2020)

Aim of the project.

In order for Norwegian cities to adapt for climate change and the effects of urbanization, better solutions for transport and storage of stormwater during extreme events is needed. The project will focus on the last step of the S3SA: (the transport of stormwater in safe *floodways* during heavy rainfall) as a system and the interaction between the other steps. The project aims to understand better how urban planning and decisions tools can be used to increase urban flood resilience.

Specific work description

During the project work, the student will get familiar with relevant literature and international theories that describe state of the art for. Relevant concepts within urban flood resilience and urban flooding will be combined with the S3SA to evaluate how the S3SA can be adapted to reduce to impact of urban flooding during extreme events. During the master project, the student will find a suitable analysis tool to evaluate urban floods and how different decisions models/framework can facilitate floodway design and management.

Project Title	Fremtidsrettet overvannshåndtering
Type	Project / Master thesis
Supervisors / Contacts	Tone M Muthanna og Bærum Kommune
Location	Vassbygget og evt. Bærum Kommune

Prosjektbakgrunn

Prosjektet er et innovasjonspartnerskap, fått 14 mill av Innovasjon Norge for å utvikle noe nytt som bidrar til fremtidsrettet overvannshåndtering. Prosjektet startet opp i 2020 med behovsavklaring. Markedsdialog med ulike bedriftskonsortier ble gjennomført i juni, og konkurransen ble kunngjort desember 2020. Prekvalifisering januar 2021, og tilbudsfrist 26/3. Syv tilbud har kommet inn, og vi skal nå i gang med evaluering, vurdering og forhandling, før kontrakt skal signeres 15. juni. Utviklingsperioden går ut 2022, og kommunen har opsjon til å anskaffe løsningen som utvikles uten ny konkurranse. Det samme gjelder for følgekommuner (i dette prosjektet Oslo, Bergen, Stavanger, Trondheim, Sandnes, Skien, Fredrikstad og Drammen).

Om behovet som skal dekkes/løses i utviklingsløpet

Bærum og Lørenskog kommune har behov for en løsning som skal bidra til helhetlig beslutningsunderlag for overvannshåndtering. Løsningen skal bidra til å ta de rette valgene knyttet til overvann, både når det gjelder planlagte byggeprosjekter, og for håndtering av spesielt utsatte områder i eksisterende bebyggelse. En fremtidsrettet overvannshåndtering må være mer helhetlig og systematisk enn i dag. Beslutninger som skal fattes i forbindelse med områdeutvikling, reguleringer og omreguleringer er flerfaglige, der overvannshåndtering er ett av flere hensyn. For å sikre at kommunen evner å ta de beste beslutningene ut fra ulike faglige hensyn er det behov for verktøy og prosesser som bidrar til å se større og helhetlig, gir nok detaljkunnskap og hjelper til å analysere behov og løsninger på tvers av reguleringsgrenser.

Mulig retning for oppgave:

Hypotesen vår er at løsningen som utvikles gjennom innovasjonspartnerskapet skal gi følgende effekter:

- Bedre beslutningsunderlag for valg av overvannstiltak
- Bedre håndtering i urbaniserende områder, herunder færre skader på grunn ved styrtregn
- Arbeidsprosesser som bidrar til bedre overvannshåndtering, og raskere behandling av byggesaker
- Mer effektiv implementering, drift og vedlikehold av overvannstiltak
- Mer fokus på overvann og generelt bedre klimatilpasning i kommunen innen 2030
- Høyere bruketilfredshet knyttet til kommunens overvannshåndtering (vi har baseline fra mai 2020)

- Betydelig markedspotensial for løsningen

Dette er utfordrende å måle, og flere av effektene kommer heller ikke før etter at løsningen er implementert.

Tenker det kan være interessant å se på dette fra et prosess-perspektiv;

- Mekanismer for hvordan et innovasjonspartnerskap kan fremme tverrfaglig samarbeid og nye arbeidsprosesser innenfor overvannshåndtering i kommunen.
- Se på hvordan innovasjonspartnerskapet kan legge til rette for markedsvekst for overvannsløsninger.

En annen vinkel mer knyttet til konkrete løsninger for overvann, siden løsningen må gi råd om hvordan ulike overvannstiltak vil kunne virke i nedbørsfeltet;

Project Title	Asset management and decision support for Nature Based Solutions
Type	Bachelor / Project / Master thesis
Supervisors / Contacts	Tone Muthanna (NTNU), Franz Tscheikner-Gratl (NTNU), Marius Møller Rokstad (NTNU), David Steffelbauer (NTNU)
Location	Trondheim

Project background

Background and Knowledge Needs:

Urban areas in developed countries typically rely on piped systems to convey wastewater (and stormwater) to, and potable water from, centralized treatment plants often located at the outskirts of cities. While this approach targeted 20th century priorities of improving sanitary conditions and reducing urban contaminant discharges, it does not meet 21st century challenges of urbanization and climate change. Research activities related to Nature Based Solutions (NBS) management have primarily focused on the design, demonstration, and incentives for NBS. This is associated with a strong push towards paradigm shift at the urban scale, aiming to reduce flooding, preserve the environment and enable a circular usage of stormwater. The transition from networks (pipes) to decentralized and hybrid solutions based on blue-green infrastructures will require the development of new strategies for assessing the performance of each individual asset, and the system. These infrastructures are also aging and often suffer from lack, if not neglect, of adequate maintenance and their long-term management must be considered if the performance of NBS are to be secured in the long run. Very few projects address NBS asset management, and there is thus a strong need to learn from existing asset management experiences in other urban water infrastructure, which has been extensively investigated over the last decades, while stormwater control facilities have only rarely received consideration for their operation and maintenance and their long-term performance. Asset management of NBS (in terms of economic and social value and the multiple benefits they can provide) and the influence of maintenance on the performance of NBS (and in consequence the technical lifetime) is therefore an underdeveloped field as there is a lack of quantitative decision support and modelling tools specifically tailored for NBS that inform the planning and design process on different decision levels.

Aim of the project

Due to the interconnected nature of the different parts of our urban drainage systems a performance assessment NBS and pipe system individually is not enough to assess the functionality of the system. On the other hand, the focus on system function alone, may lead to focusing on main parts and disregard of others.

Specific work description

Task 1 will therefore investigate methods available to measure and assess performance and condition in a hybrid solution context. The data availability in terms of NBS condition and performance over time is very limited. Task2 will therefore investigate possible data sources and gaps and propose solutions (e.g. by field tests) to fill them. From that data task 3 will try to develop models for the technical life expectancy of such solutions and assess the inherent uncertainties of such approaches. In task 4 the performance and the life expectancy will feed into a cost-benefit analysis of NBS in combination with multiple possible additional benefits that can be expected. This will be combined into an NBS decision support tool in Task 5.

Project Title	Impact of detergents on the mobility of heavy metals and PAH in road tunnel wash water
Type	Project & Master thesis
Supervisors / Contacts	Thomas Meyn (NTNU) / Wolfgang Uhl, Eilen Arctander Vik & Subhash S Rathnaweera (Aquateam COWI)
Location	Oslo /Trondheim

Project background

Norway has ~1150 road tunnels with a total length of ~800 km. In urban areas, where space is limited, and traffic load is high, road tunnels are often a preferred solution. For example, in the Oslo and Akershus region, there are 55 tunnels with a total length of 37 km. To maintain traffic safety and increase lifespans of the tunnels, tunnels are normally cleaned 1 to 12 times per year, using high pressure water jets and soap. Approximately 60-100 L water, mixed with 0.5-1% soap is used to clean one meter of tunnel. Wash water does contain a cocktail of pollutants consisting of e.g. heavy metals, different PAHs, soap, microplastic (e. g tire wear), road salt etc. The concentrations of the pollutants substantially exceeding that of normal road runoff and has caused acute toxicity of e.g. amphibians in nature-based treatment ponds. Many of the tunnels do not have a treatment for the wash water, and it is discharged directly to the closest recipient (creeks, rivers, fjords). Newer tunnels are built with a sedimentation basin for removal of particulate pollutants.

This project is related to two ongoing research projects, collaborating with Statens Vegvesen, Nye Veier AS, Aquateam COWI and Aalborg University. The thesis is the continuation of several finished and ongoing master thesis projects (i.e. Ågot Bjotveit, Sofie Eivik Karlsen). The student will work in a small research team together with the other students and a PhD and PostDoc.

Sampling from a sedimentation basin at Bjørnegårdtunnelen (Sandvika)

Washing of Grillstadtunellen (Trondheim), picture taken during sampling of wash water

Aim of the project

Little is known about the efficiency of installed treatment solutions. Detergents improve the cleaning effectivity of the washing. However, they contribute to the mobilization and remobilization of e. g. heavy metals, which have been shown to complex with the detergents, and treatment becomes more difficult. Though the natural degradation of soap is expected in sedimentation tanks, degradation of many soap types is slow and requires long residence time. Thus, the objective of this study is to understand the impact of detergents on the sedimentation rates of particles (including microplastics). Such information is crucial for decisions about future storm water treatment solutions.

Specific work description

During the **project work**, the student will get familiar with up-to-date knowledge regarding the state of the art regarding tunnel wash water quality and treatment. Basic methods of water quality analysis will be introduced, and sample analysis carried out in the lab (pH, turbidity, particle size distribution and density, organic carbon, sample preparation for advanced analysis such as heavy metals etc.). Results will be evaluated including accuracy, precision, and confidence intervals.

During the **master project**, the student will take part in several sampling campaigns in road tunnels in the Trondheim and Oslo region. The water will be transported to the lab, there a sedimentation pilot will be used for treatment and analysis. Sampling and analysis will be done like in the project work. A new method to determine particle density combining size distribution measurements with sedimentation rates will be applied, in addition to high performance particle counting and fluid image analyses. There may be the possibility that part of the experiments will be carried out in the Aquateam COWI laboratory.

The ideal candidate for this project

- A student that would like to combine the topics water and roads
- Students that look for a practical project with hands-on experience
- Eager to learn something new and willingness to work outside normal working hours, tunnel wash is normally happening during night-time
- Experience, with work at roads and tunnels (maybe from summer job?), maybe trained in arbeidsvarsling via Statens Vegvesen or similar
- Critical thinker
- Driver's license

What's in it for you?

- Get familiar with a pressing water management problem in Norway
- Practical experience related to real life challenge and ongoing projects
- (Co)-author and publish a scientific paper with your name on it
- SVV offers the possibility to apply for a student scholarship, corresponding to 15 000 NOK.

Fresh tunnel wash water in the sedimentation pilot

Project Title	Best treatment approaches for wash water from road tunnels
Type	Bachelor / Project and Master thesis
Supervisors / Contacts	Thomas Meyn (NTNU) & Wolfgang Uhl (Aquateam COWI)
Location	Trondheim / Oslo Region

Project background

Norway has ~1150 road tunnels with a total length of ~800 km. In urban areas, where space is limited, and traffic load is high, road tunnels are often a preferred solution. For example, in the Oslo and Akershus region, there are 55 tunnels with a total length of 37 km. To maintain traffic safety and increase lifespans of the tunnels, tunnels are normally cleaned 1 to 12 times per year, using high pressure water jets and soap. Approximately 60-100 L water, mixed with 0.5-1% soap is used to clean one meter of tunnel. Wash water does contain a cocktail of pollutants consisting of e.g. heavy metals, different PAHs, soap, microplastic (e. g tire wear), road salt etc. The concentrations of the pollutants substantially exceeding that of normal road runoff and has caused acute toxicity of e.g. amphibians in nature-based treatment ponds. Many of the tunnels do not have a treatment for the wash water, and it is discharged directly to the closest recipient (creeks, rivers, fjords). Newer tunnels are built with a sedimentation basin for removal of particulate pollutants.

This project is related to two ongoing research projects, collaborating with Statens Vegvesen, Nye Veier AS, Aquateam COWI and Aalborg University. The thesis is the continuation of several finished and ongoing master thesis projects (i.e. Ågot Bjotveit, Sofie Eivik Karlsen). The student will work in a small research team together with the other students and a PhD and PostDoc.

Sampling from a sedimentation basin at Bjørnegårdtunnelen (Sandvika)

Washing of Grillstadtunellen (Trondheim), picture taken during sampling of wash water

Aim of the project

Since sedimentation treatment only removes particulate pollutants, additional treatment is needed to further address dissolved pollutants such as heavy metals and organic micropollutants. Such a second treatment step has been requested for roads with higher amounts of traffic, such as the politically controversial upgrading of the E18 between Sandvika and Olso. However, it is unclear how such a treatment may look like at the moment. This project investigates if adsorption and membrane filtration are suitable alternatives.

Specific work description

During the **project work**, the student will get familiar with relevant literature and reports that describe the state of the art regarding tunnel wash water quality and treatment. The student will get familiar with the membrane pilot and learn how to operate it. Operational procedures will be developed, including filtration optimization, fouling minimization and cleaning strategies for the membrane. Basic methods of water quality analysis will be introduced, and sample analysis carried out in the lab. If time allows, adsorption experiments will be performed.

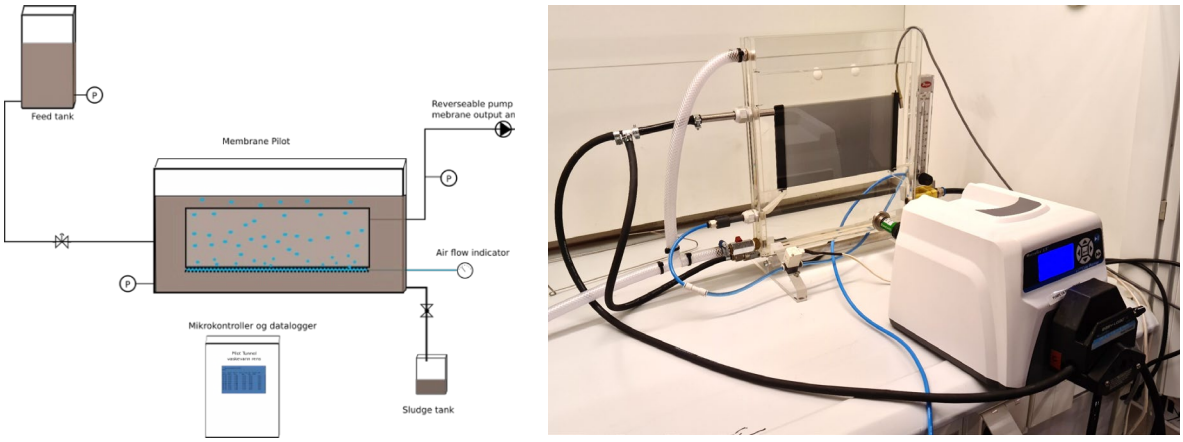
During the **master project**, the student will take part in several sampling campaigns in road tunnels in the Trondheim and Oslo region. The water will be transported to the lab, where it will be further treated and analysed. The student will carry out adsorption experiments and be responsible for operating the small membrane filtration pilot. Sampling and analysis will be done in a similar way as in the project work. Experience from the lab will be applied and verified at the full-scale treatment plant at Bjørnegårdtunellen in Sandvika.

The ideal candidate for this project

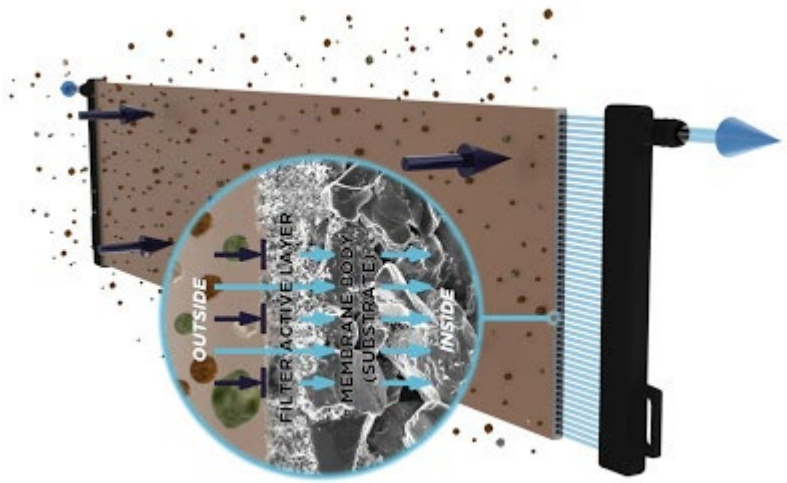
- A student that would like to combine the topics water and roads
- Students that look for a practical project with hands-on experience
- Eager to learn something new and willingness to work outside normal working hours, tunnel wash is normally happening during night-time
- Experience, with work at roads and tunnels (maybe from summer job?), maybe trained in arbeidsvarsling via Statens Vegvesen or similar
- Driving license

What's in it for you?

- Get familiar with a pressing water management problem in Norway
- Practical experience related to real life challenge and ongoing projects
- (Co)-author and publish a scientific paper with your name on it
- SVV offers the possibility to apply for a student scholarship, corresponding to 15 000 NOK.



Scematic and picture of the membrane filtration pilot

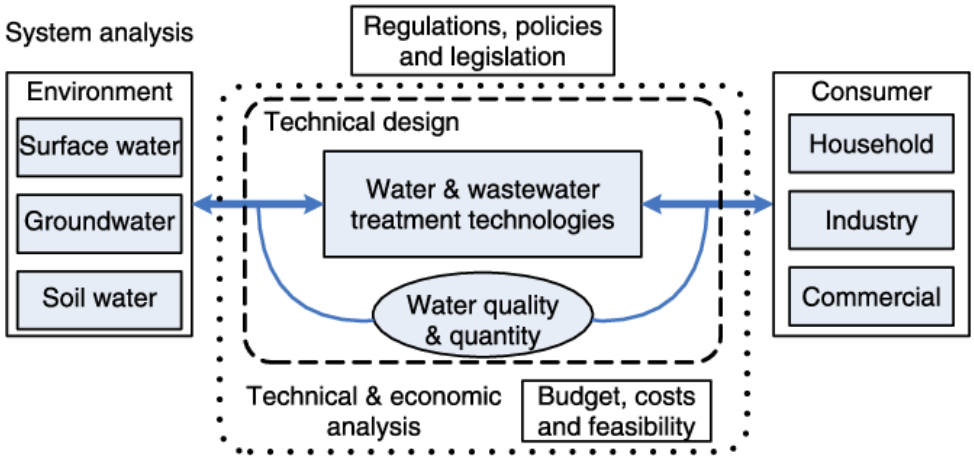


Scematic of a ceramic membrane sheet

Project Title	Decision support for selection of future treatment technology for tunnel wash water
Type	Bachelor / Project / Master thesis
Supervisors / Contacts	Thomas Meyn & Franz Tscheikner-Gratl (NTNU) / Kamal Azrague (SINTEF)
Location	Trondheim

Project background

Norway has around 1150 road tunnels with a total length of approximately 800 km. In urban areas, where space is limited, and traffic load is high, road tunnels are often a preferred solution. For example, in the Oslo and Akershus region, there are 55 tunnels with a total length of 37 km. To maintain traffic safety and increase lifespans of the tunnels, tunnels are normally cleaned 1 to 12 times per year, using high pressure water jets and soap. Approximately 60-100 L water, mixed with 0.5-1% soap is used to clean one meter of tunnel. Wash water does contain a cocktail of pollutants consisting of e.g. heavy metals, different PAHs, soap, microplastic (e. g tire wear), road salt etc. The concentrations of the pollutants substantially exceeding that of normal road runoff and has caused acute toxicity of e.g. amphibians in nature-based treatment ponds. While various projects evaluate possible treatment future solutions, a strategic framework for the selection of the "best technology" is missing right now. The problem at hand is complex and driven by multiple criteria, such as treatment efficiency, costs, maintenance needs, lifetime, environmental impact, policies, and legislation etc.



Approaches to water treatment problem analysis and their respective scopes (Hamouda et al. 2009)

This project is related to two ongoing research projects, collaborating with Statens Vegvesen, Nye Veier AS, Aquateam COWI and Aalborg University. It is directly related to the projects 1.5 and 1.6.

Aim of the project

The aim of the project is to develop a decision support system that allows the Norwegian Road Authorities and other relevant parties to assess and compare different treatment solutions for tunnel wash water, in dependence on their economic, social and environmental impact and other relevant criteria. The decision support system will be applied to the case study of Bjørnegårdtunellen in Sandvika, which is related to the politically controversial upgrade of the E18 highway between Sandvika and Oslo.

Specific work description

During the **project work**, the student will get familiar with relevant literature and reports that describe the state of the art regarding tunnel wash water quality and treatment. All relevant criteria for the decision support system will be identified, including approaches for how to quantify them. Various methods for decision support will be evaluated and a survey for weight and utility elicitation will be designed and carried out. As an option, the student will follow the course TEP4223 – Livssyklusanalyse, to get familiar with the Live Cycle Assessment methodology.

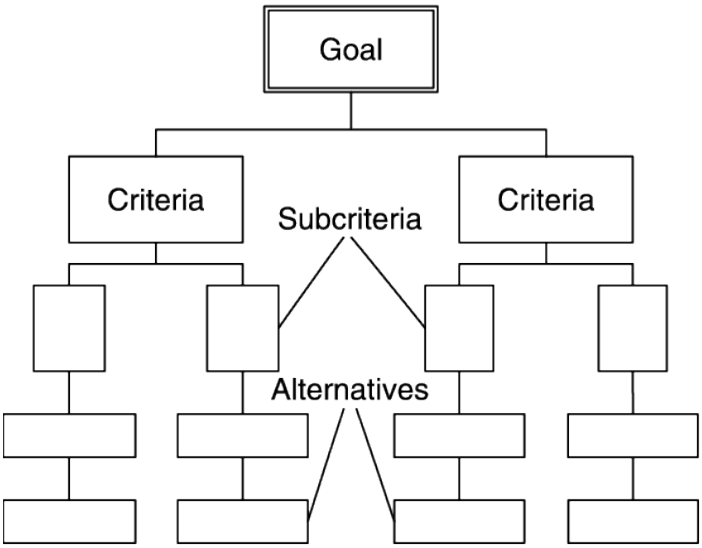
During the **master project**, the student will finalize the decision support system and use it for comparison of available treatment options for tunnel wash water. A Live Cycle Assessment and environmental impact analysis will be carried out for the different treatment options.

The ideal candidate for this project

- This project is perfectly suited for students that would like to combine the topics water and roads
- Experience with decision support, life cycle assessment and environmental impact analysis, i.e. from course TEP4223 – Livssyklusanalyse, which could be also followed in the autumn

What's in it for you?

- Get familiar with a pressing water management problem in Norway, and contribute to best solution section
- Project related to real life challenge
- (Co)-author and publish a scientific paper with your name on it



Typical hierarchical structure implemented in an AHP optimization technique. Source Bick & Oron (2005)

Project Title	Pump selection for energy efficient fluid transport in Wastewater Treatment Plants
Type	Bachelor / Project / Master thesis
Supervisors / Contacts	Paul Thamsen(NTNU) / Bergen or Trondheim Kummune
Location	Trondheim / Bergen

Project background

Wastewater Treatment (WWT) is known for a long time and successful processes are developed to clean the wastewater.

Typical lay-out of a wastewater treatment plant with an pump population of appr. 80 pumps.

However, the fluid transport inside a WWT is not spe cified clearly up to now and pumps are selected mainly based on the experience during planning and operation. In a lot of installation, wastewater pumps are in place, even the fluid passed already the grit and the sand collection tank. Every step like grit chamber, aeration tanks, settling tanks, sludge return, etc. needs a special solution for pumps gaining the most reliable and efficient transport. There is a high demand on a standardized specification for pumps inside a WWT, which is not available up to now. In the longer term, a new standard will be developed to be placed in EN ISO or similar organisations.

Aim of the project

Within this project, every pump (centrifugal, reciprocating) inside an existing WWT will be observed, documented and evaluated to provide an overview about the process and involved reliability and energy consumption. Thereafter, the pros and cons will be discussed during an expert workshop. Finally, recommended specifications will be developed for the different process steps and fluid flow machines. Overall, this project will provide a guideline to safe energy in WWT's by introducing the right fluid flow machines for the right application.

Specific work description

During the project work, the student will get familiar with relevant literature and reports that describe the state of the art regarding pump applications in wastewater with a special focus on WWT's. The student will collect field data about installed fluid flow machines from a WWT's in Bergen or Trondheim. During an expert workshop, the fluid machines for the defined process step will be evaluated in view of reliability and energy consumption. Finally, a guideline for selection and operation of pumps in WWT's will be developed.

Detailed project descriptions: Group 2

Project Title	Digitalisation of water systems – Artificial Neural Networks to predict future Legionella outbreaks in buildings
Type	Project and Master thesis
Supervisors / Contacts	Cynthia Hallé (NTNU), David Steffelbauer (NTNU), Michael Waak (SINTEF), Stian Bruaset (SINTEF) Charuka Meegoda (SINTEF/NTNU)
Location	NTNU Vassbygget, Trondheim

Project background

Drinking water is not sterile and may contain diverse microorganisms, including some that may cause disease. Opportunistic pathogens, such as *Legionella* bacteria, may cause severe or even deadly pneumonia, like Legionnaires' disease. Infection may occur after exposure to contaminated aerosols, such as by inhalation while showering.

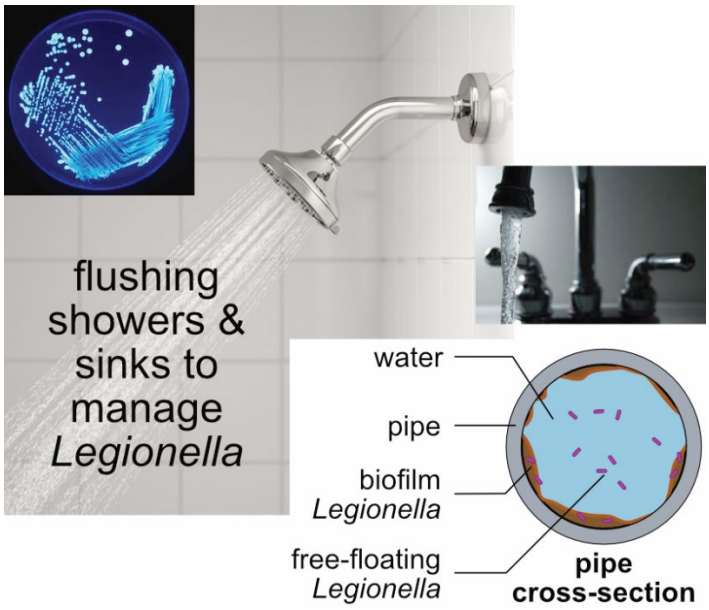
Legionella are commonly found in Norwegian drinking water at low concentrations. Building water systems—the pipes that bring hot and cold water to sinks, toilets, faucets, etc.—can be near-ideal environments for the proliferation of *Legionella*. This is especially true in large buildings, like hospitals and sports centers, because long, unused lengths of pipes may stagnate, favoring *Legionella* growth. Regular flushing of building water systems—running the water for extended periods—may effectively remove *Legionella* and prevent favorable conditions for growth. It is unclear, however, which flushing practices are best for *Legionella* control, because the underlying processes of how *Legionella* grow and spread in building water systems are highly complex and accurate mathematical models of these processes are not existing yet.

Aim of the project

The primary goal of the project is to overcome the lack of mathematical Legionella models by using Artificial Neural Networks (ANNs) to develop a data-based *Legionella* spreading model. This ANN *Legionella* model will aim use associate historical pathogene data of past events in the network (e.g., positive Coliform detection) and link it to exogeneous variable like weather, water quality, water treatment failures and network operation. Furthermore, the ANN *Legionella* model will serve as a surrogate to model and understand best flushing practices for *Legionella* control.

Specific work description

The student will work with predictive modeling to create warning or forecasting breakthrough events using ANNs. The model will be developed based on data produced in a pilot-scale system in the laboratories at Vassbygget. A comprehensive literature review will help the student develop competency in relevant areas, like drinking water, public health, infrastructure management, as well as artificial intelligence and machine learning. The student will be trained in cutting-edge Hydroinformatics techniques used in future smart water systems. Using experimental results and the literature review, the thesis will identify and assess best practices for management of drinking water systems. The results of this thesis are planned to be published in an international scientific journal (co-)authored by the student.


flushing showers & sinks to manage Legionella
water
pipe
biofilm Legionella
free-floating Legionella
pipe cross-section

Project Title	Hydraulic Residence Time and Water Quality in Drinking Water Distribution Networks
Type	Project and Master thesis
Supervisors / Contacts	Cynthia Hallé, Michael Waak, Marius Møller Rokstad
Location	NTNU Vassbygget, Trondheim

Project background

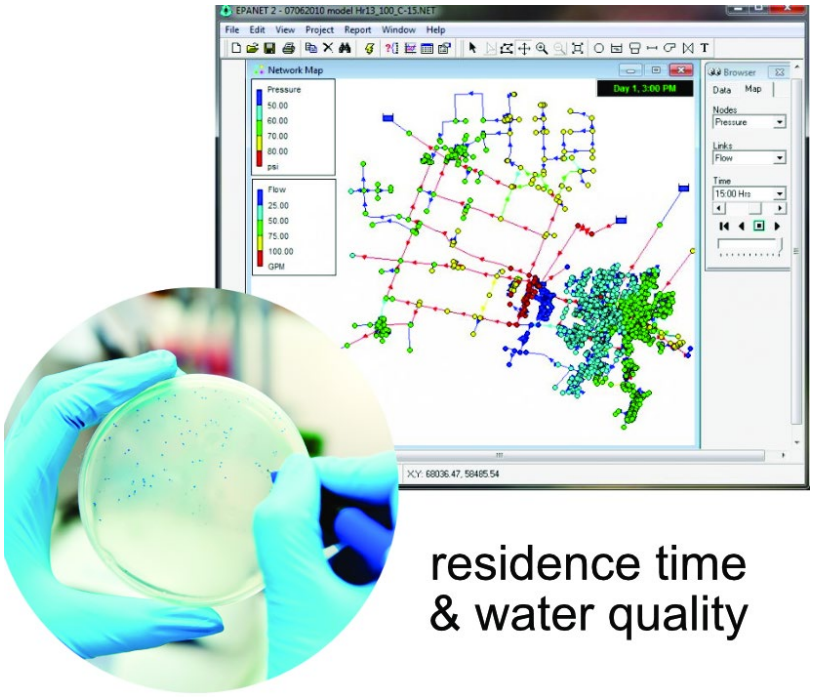
Despite treatment, drinking water may contain diverse microorganisms. After leaving the treatment plant, drinking water may spend hours, days, or even weeks in the municipal distribution network—traversing large storage basins and kilometers of water transmission mains. In contrast to many countries, Norwegian drinking water typically does not contain chlorine-based disinfectants during distribution, which may allow microbes to grow during distribution. Microbes may cause human disease but may also contribute to pipe corrosion as well as poor aesthetic qualities, like undesirable color, taste or odor. Additionally, hydraulic residence models of the distribution network are difficult to develop and calibrate. As a consequence, many municipalities in Norway have little knowledge about residence time ("water age") in their distribution networks.

Aim of the project

The goal of the project is twofold: First, there must be continued development of a hydraulic model for the Trondheim drinking water distribution network using EPANET (derived from MIKE URBAN). An accurate model is key to estimating water age and identifying problematic regions in the city's water network. Second, water age may influence multiple water quality parameters, but these parameters have not yet been measured or compared to water age in Trondheim. These parameters include indicators of microbiological activity as well as chemical parameters like organic carbon (total, dissolved, assimilable), temperature, dissolved oxygen, turbidity, and pH.

Specific work description

During the project, the student will become familiar with hydraulic modelling and water quality. The student will obtain valuable hands-on skills collecting samples, performing chemical tests, and analyzing data. The student will work in a collaborative, cross-discipline research team but will also be expected to take ownership of this specific topic through self-initiative, leadership and self-guided learning. A literature review will help the student develop competency in areas of drinking water, hydraulic modelling, public health, and infrastructure management. Most activities will take place at NTNU Vassbygget and around Trondheim. The thesis is expected to help Norwegian water utilities learn more about water quality—specifically as it relates to water age—and will also serve as a basis for future research activities at NTNU.


EPANET 2 - 07062010 model Hr13_100_C-15.NET
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XY: 68036.47, 58405.54
residence time
& water quality

Project Title	Quantitative Microbial Risk Assessment (QMRA) of Norwegian Drinking Water Systems and Water Reuse Systems (Wider Uptake)
Type	Project and Master thesis (2 students)
Supervisors / Contacts	Cynthia Hallé, Michael Waak, Charuka Meegoda, Kamal Arague, Rizza Ardiyant
Location	NTNU Vassbygget, Trondheim

Project background

Drinking water is not sterile and may contain diverse microorganisms. Opportunistic waterborne pathogens like *Legionella pneumophila* are commonly present in water and can cause a severe and often fatal pneumonia (Legionnaires' disease) when inhaled. *Legionella* proliferate in stagnant water within building cold and hot water systems and may be transmitted to humans through aerosols generated while showering, for example.

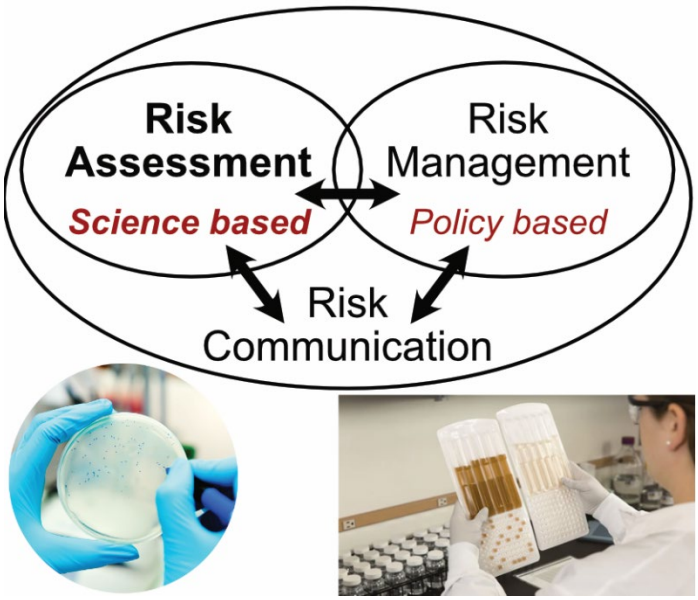
Previous research has indicated that *Legionella* are commonly present in Norwegian drinking water at low concentrations. There remains uncertainty, however, regarding the actual risk to water users. An important tool for quantifying this risk is quantitative microbial risk assessment (QMRA). QMRA utilizes mathematical models to convert various environmental factors into data, such that it becomes possible to compare the risks among different exposure scenarios. Identification of the most problematic scenarios is critical for developing effective mitigation strategies.

Aim of the project

The primary goal of the project is to develop a QMRA using existing datasets. Specifically, we wish to develop a QMRA for Norwegian drinking water systems so we can more effectively communicate environmental data (like *Legionella* concentrations in drinking water) to the relevant authorities (Norwegian municipalities, regulatory agencies like the Norwegian Institute of Public Health, and the scientific community at large). Part of the QMRA may be expansion of current datasets through ongoing environmental monitoring around Trondheim. This project will integrate with other projects, meaning there is a high potential for collaboration, teamwork, and research synthesis.

Specific work description

Using software tools like R or Matlab, the student will work on developing models/simulations to quantify microbial risk. Additionally, the student will perform a literature review to develop competency in various topics, such as QMRA, *Legionella*, drinking water, and public health/epidemiology. The student will work in a collaborative, cross-discipline research team but will also be expected to take ownership of this specific topic through self-initiative and self-guided learning. Through these collaborations, the student will have opportunities to either participate or directly lead environmental monitoring campaigns, such as testing for *Legionella* in drinking water around Trondheim and in the water supplies, Jonsvatnet and Benna. Other water quality parameters may also be tested, such as pH, temperature, and organic carbon. Thus, the student should expect some hands-on experience and training in the laboratories at Vassbygget as well as in the field. Overall, the thesis is expected to help the Norwegian water sector learn more about microbial risk in Norway and will also serve as a basis for future research activities at NTNU.


Risk
Assessment
Science based
Risk
Management
Policy based
Risk
Communication

Project Title	Ammonium removal by Anaerobic ammonium oxidation (ANAMMOX) under challenging conditions.
Type	Bachelor / Project / Master thesis
Supervisors / Contacts	Stein Wold Østerhus (NTNU) / Blanca M. Gonzalez Silva (NTNU)
Location	Trondheim

Project background

Anaerobic ammonium-oxidizing (anammox) bacteria are the last major addition to the nitrogen-cycle (N-cycle) and have the unique property of oxidizing ammonium in the absence of oxygen. During the anammox reaction, ammonium (NH_4^+) is oxidized to gaseous N_2 using nitrite (NO_2^-) as an electron acceptor, producing small amounts of nitrate (NO_3^-) (Eq. (1)) (Strous et al. 1998):

$$NH_4^+ + 1.32\ NO_2^- + 0.066\ CO_2 + 0.13\ H^+$$

$$\rightarrow 1.02\ N_2 + 0.26\ NO_3^- + 2.03\ H_2O + 0.066 CH_2O_{0.5} N_{0.15} \qquad (1)$$

Although a very interesting process for wastewater treatment, ANAMMOX is very demanding as the bacteria is very slow growing, and they prefer high ammonium concentration and temperature.

Aim of the project

In this research a partial nitrification-anammox (PNA) moving bed biofilm reactor (MBBR) (Figure 1), inoculated with ANITAMox carriers already colonized with ammonia-oxidizing bacteria (AOB) in the outer parts (aerobic zone) and anammox bacteria in the in the inner parts (Anoxic zones), will be used to explore different challenging conditions such as low ammonia concentrations and low temperatur

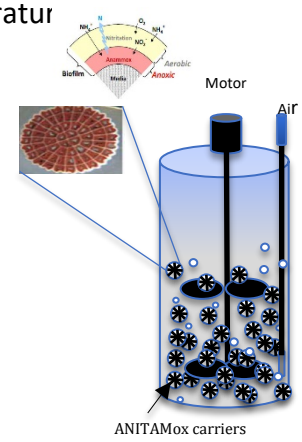


Figure 1. Partial nitrification Anammox (PNA) moving bed biofilm reactor (MBBR).

Specific work description

During the project work, the student will get familiar with relevant literature and reports that describe the state of the art regarding partial nitrification-anammox (PNA). Operation of a ANAMMOX reactor and monitoring parameters such as ammonium, nitrate, nitrite will be done. In addition, different anammox batch test under low ammonia concentrations will be tested.

Final delivery:
Project report from the lab work activities, including theoretical background and methods.

Project Title	Understanding the Enhanced Biological Phosphorus Removal (EBPR) process
Type	Bachelor / Project / Master thesis
Supervisors / Contacts	Stein W. Østerhus (NTNU) / Blanca M. Gonzalez Silva (NTNU)
Location	Trondheim

Project background

Enhanced biological phosphorus removal (EBPR) process is an interesting alternative to chemical phosphorus precipitation. Successful operation of EBPR depends, among other factors, on the presence of high content of readily biodegradable chemical oxygen demand (rbCOD), such as volatile fatty acids (VFA), glucose, etc, in the influent wastewater. In Norway biological removal of phosphorus from wastewaters can be challenging because the wastewaters can be very diluted, caused by infiltration and inflow of stormwater after periods of rain and snowmelt, and because it has a low readily biodegradable organic carbon content (such as volatile fatty acids, VFA).

Aim of the project

The aim of this project is to improve the process understanding by investigating the effect of some design and operational parameters on the performance of the EBPR process using a lab scale set-up (Figure 1).

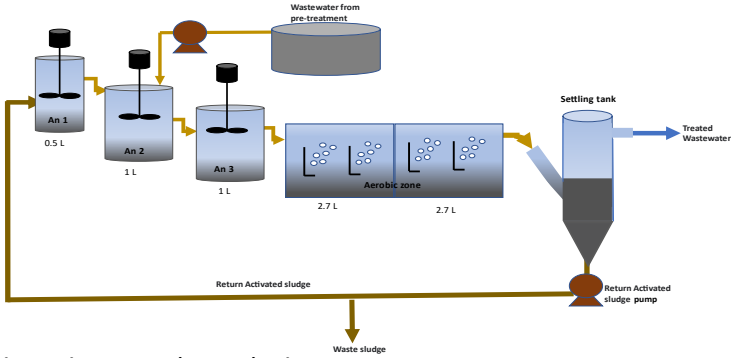


Figure 1. Lab scale Bio-P (EBPR) plant.

Specific work description

During the project work the student will get familiar with relevant literature and reports that describe the state of the art of activated sludge process for EBPR, and the lab work activities will involve investigations of different operational parameters, such as (using the lab scale Bio-P plant):

- Mixed liquor suspended solids (MLSS) in the reactors, in An1, and in the Return Activated Sludge (RAS).
- Waste activated sludge (WAS) flow rate
- Solids Retention Time (SRT)
- Hydraulic Residence time (HRT)

Final delivery:
Project report from the lab work activities, including theoretical background and methods.

Project Title	Optimization of the Enhanced Biological Phosphorus Removal (EBPR) process for typical Norwegian conditions
Type	Bachelor / Project / Master thesis
Supervisors / Contacts	Stein W. Østerhus (NTNU) / Blanca M. Gonzalez Silva (NTNU)
Location	Trondheim

Project background

Enhanced biological phosphorus removal (EBPR) process is an interesting alternative to chemical phosphorus precipitation. Successful operation of EBPR depends, among other factors, on the presence of high content of readily biodegradable chemical oxygen demand (rbCOD), such as volatile fatty acids (VFA), glucose, etc, in the influent wastewater. In Norway biological removal of phosphorus from wastewaters can be challenging because the wastewaters can be very diluted, caused by infiltration and inflow of stormwater after periods of rain and snowmelt, and because it has a low readily biodegradable organic carbon content (such as volatile fatty acids, VFA).

Aim of the project

The aim of this project is related to the optimization of a lab scale biological phosphorus removal (Bio-P or EBPR) plant (Figure 1), which is a semi replicate of the SNJ WWTP at IVAR, simulating the wastewater characteristics and operational conditions at SNJ-IVAR wastewater treatment plant, Stavanger.

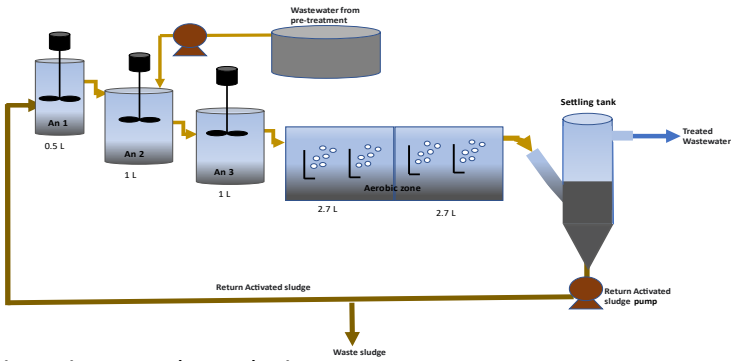


Figure 1. Lab scale Bio-P (EBPR) plant.

Specific work description

During the project work the student will get familiar with relevant literature and reports that describe the state of the art of activated sludge process for EBPR, and lab work activities will involve the following investigations:

- To investigate the potential of EBPR.
- Comparison of the sludge characteristics from Lab versus SNJ-IVAR WWTP.
- To investigate the potential of secondary P release.
- To investigate the quality of the sludge (mg P/mg TS ratio).

Final delivery:
Project report from the lab work activities, including theoretical background and methods.

Project Title	Optimization of treatment effectivity and energy efficiency for Swimming Pool Water treatment using granular activated carbon and UV
Type	Master thesis
Supervisors / Contacts	Wolfgang Uhl (Aquateam COWI & NTNU-IBM) / Someone from VA-group, Bjørn Aas (NTNU-SIAT)
Location	Bærum / Oslo / Trondheim

Project background

Pollutants in indoor swimming pools, such as particles, bacteria, dissolved organic and inorganic matter, mainly originate from bathers. Bacteria, parasites and viruses may act pathogenic and have to be inactivated by an efficient disinfection or to be removed by sufficient water treatment. The reaction of free chlorine with organic matter in pool water may result in the formation of disinfection by-products (DBP). In the treatment process a defined volumetric flow is drawn off the pool and treated by different processes such as coagulation, filtration, adsorption, membrane, and UV processes processes. After disinfection the treated water is re-circulated into the pool (see principle below).

Due to the discontinuous usage of pools, i. e. varying number of bathers, such as peaks while school classes use the pool, and zero-usage periods during the nights, water quality varies considerably. It is therefore difficult to judge the effectivity of different water treatment processes.

Bærum Kommune has built a new indoor swimming facility (see photograph below) with advanced treatment processes, which is going to be taken into operation during spring 2021. This opens for excellent opportunities to investigate the treatment facilities effectivity in the removal of contaminants and to develop pool operation procedures for saving of energy and costs.

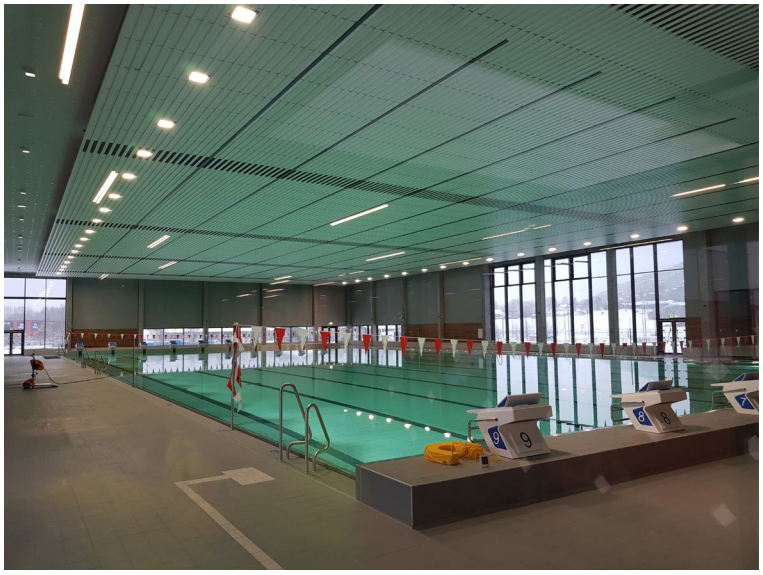
Aim of the project

The objectives of the project are to develop recommendations and procedures for optimization of swimming pool water treatment with respect to pool water quality and energy efficiency. The knowledge gained during the course of the project shall be used to derive recommendations for optimal operation of the treatment processes, taking into account the bather-load in the pool, contaminants in the water including volatile substances transferred to the indoor-air, and energy consumption. Especially, data from a drowning detections system which also counts bathers in the pool, which is installed at Bærum, shall be used to relate water quality to the bather load and to derive recommendations for control of the treatment system.

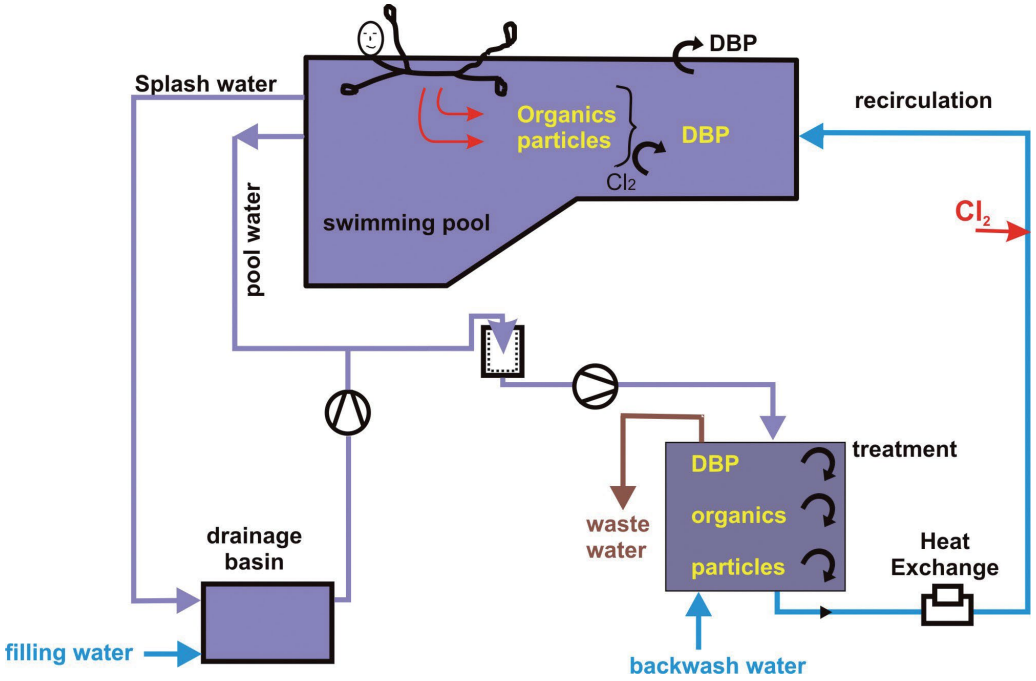
Specific work description

To become familiar with swimming pool water treatment, several publications authored by the supervisor will be used, including references therein. As for example: *Skibinski, B.; Uhlig, S; Müller, P.; Slavik, I.; Uhl, W.: Impact of Different Combinations of Water Treatment Processes on the Concentration of Disinfection Byproducts and Their Precursors in Swimming Pool Water. Env. Sci. Technol. 53(14), 8115-8126 (2019).* https://doi.org/10.1021/acs.est.9b00491

In close cooperation with Bærum Kommune and the suppliers of the treatment system, the pool and treatment systems, including current operation procedures, will be documented.
The supervisors have ensured advanced measuring techniques which can be used for online measurement of the pool water quality. This includes online particle-counters and automatic bather access documentation. Considering the goals of the project, an appropriate plan for instrumentation and measuring plan shall be set up.
The student will be made familiar with the instruments and special care that must be taken in its use.
Analysis of data gathered, considering the varying usage of the pool.
Computer simulations to find optimal treatment operation procedures.
Ideally, the project will yield results that can be presented at the next International Pool & Spa conference and be published in a journal.



The new pool at Bærum Kommune



Pool Water Treatment

Project Title	Vann og avløp i utviklingsland
Type	Project / Master thesis
Supervisors / Contacts	Tone M Muthanna og Sveinung Sægrov
Location	Vassbygget, feltarbeid i utviklingsland

Prosjektbakgrunn

Studenter med hovedretning vann og avløp har de senere årene gjennomført en rekke prosjekt- og masteroppgaver i Afrika og Sør Amerika, blant annet i samarbeid med Kirkens Nødhjelp og Ingeniører Uten Grenser. Prosjektene har i hovedsak handlet om vannforsyning til landsbygda og bruk av vannressursene (Tanzania) og rensemetoder for drikkevann (Brasil). Vi ønsker å tilby nye prosjekt og masteroppgaver i samarbeid med lokale organisasjoner og universiteter. Vi har et bredt nettverk av univesiteter i Øst-Afrika.

Prosjektmål

Bidra til å oppfylle FNs bærekraftmål med hensyn til sammenhengen vann-energi-matproduksjon-fattigdomsbekjempelse

Studentoppgaver

Gjennomføre tekniske studier knyttet til sammenhengen mellom vann-energi- matproduksjon for å kartlegge muligheter og optimalisere anlegg.

Aktuelle oppgaver

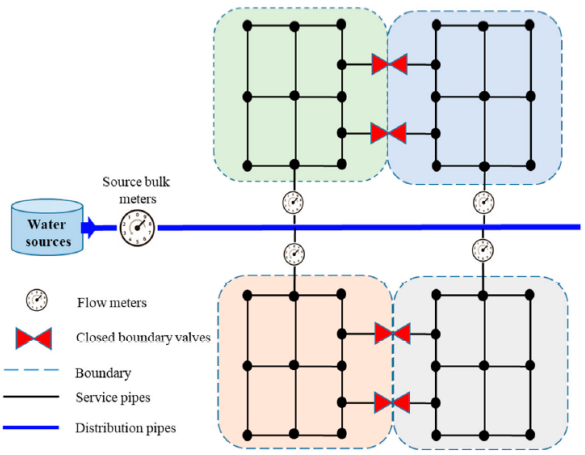
- Kartlegge muligheter for gjenoppretting av vannnforsyning i småbyen Rotifunk, Sierra Leone (etter borgerkrig, samarbeid med IUG og Lions Club)
- Overvannshåndtering og vannforsyning i skolelandsbyen Eco Moyo education centre, Mombasa, Kenya. Landsbyen er etablert av en norsk kvinne og utviklet i samarbeid med Arkitekter uten grenser og Ingeniører uten grenser. Den inkluderer barnehage og skole med kapasitet for 180 elever
- Forbedre vannprokusjon ved installering av batterier for energilagring (for vannpumping) i Haydom-distriktet, Tanzania (samarbeid med 4CCP, TU Berlin, IUG). Vi vil også utvikle samarbeid med University of Dar-Es Salaam (UDSM) og oppgaver vil bli gjennomført i samarbeid med dem.
- Deltakelse i WASH (Water, Sanitation, Hygiene) program i Sudan, (samarbeid med Kirkens Nødhjelp) Et prosjekt i Sudan (Darfur) er under utvikling ammen med WASH landkoordinator i Sudan og KNs hovedkontor i Oslo, blant annet knyttet til vann infrastruktur i flyktningeleire. Vi vil forsøke å få til et trekantsamarbeid med Unioversity of Science and Technology, Khartoum

Detailed project descriptions: Group 3

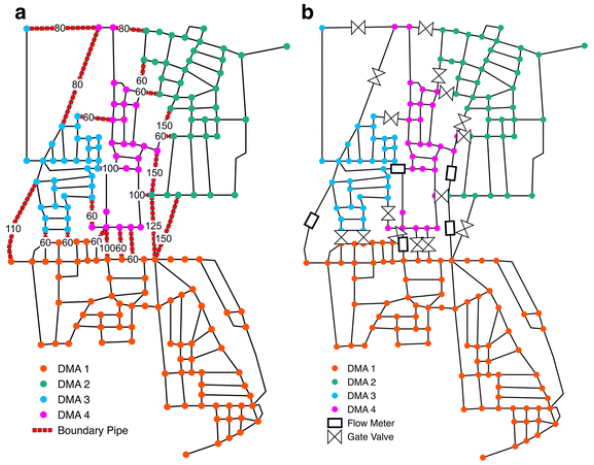
Project Title	Decision support for water distribution system DMA/PMA creation
Type	Project and Master thesis
Supervisors / Contacts	Marius Møller Rokstad (NTNU), Franz Tscheikner-Gratl (NTNU), David Steffelbauer (NTNU), Sveinung Sægrov (NTNU)
Location	Trondheim

Project background

Norwegian water distribution networks (WDNs) are prone to significant water loss, with an average of 30 % of the water being lost through leakages. Most of the larger municipalities in Norway have therefore included leakage reduction as a part of their strategies, and are currently trying various measures to reduce the leakage levels. One of the measures that can be applied to achieve leakage loss reduction, is to divide a network into smaller district metering areas (DMAs; also known as leakage zones) and pressure management areas (PMAs). By dividing a network into smaller DMAs, where the water flow is monitored, one is better equipped to detect and locate leakages quickly, allowing one the react effectively to reduce the losses. Likewise, by dividing a network into PMAs, one can reduce the pressure in sub-sections of the network, thereby reducing the pressure-dependent leakage loss from the system. The onset of smart water meters at household connections may facilitate the process of DMA creation and leakage control.



Principle sketch of WDN segmentation (from Bui et al., 2020; doi:10.3390/w12041002)



Example of network partitioning algorithm application (from di Nardo et al., 2017; doi: 10.1007/s41109-017-0033-4)

However, network segmentation comes at a price, as the realisation of new zones requires investments in new equipment (valves, flow/pressure gauges etc.). The creation of new zones in an existing network may also result in reduced hydraulic capacity, redundancy and flexibility, when isolation valves have to be closed off to create the DMA/PMA, thus risking that the system will be less reliable (consequence of failure will be higher) and that required fire-fighting capacities are not met. Change in topology and pressure in an already existing system may also affect water quality issues, due to increased potential for low pressures (and contaminant intrusion) and occurrence of areas with stagnant water (increased water age). In order to be able to make good decisions about how to divide existing water distribution networks into DMAs and PMAs, one needs to weigh the associated benefits (leakage reduction, improved control etc.) against the potential costs and risks (cost of investment, reduction in redundancy, risk of capacity loss etc.). This can best be done in a decision support system, in which factors that are relevant for Norwegian

utility managers are considered, thus enabling Norwegian utility managers in their quest to reduce water losses.

Aim of the project

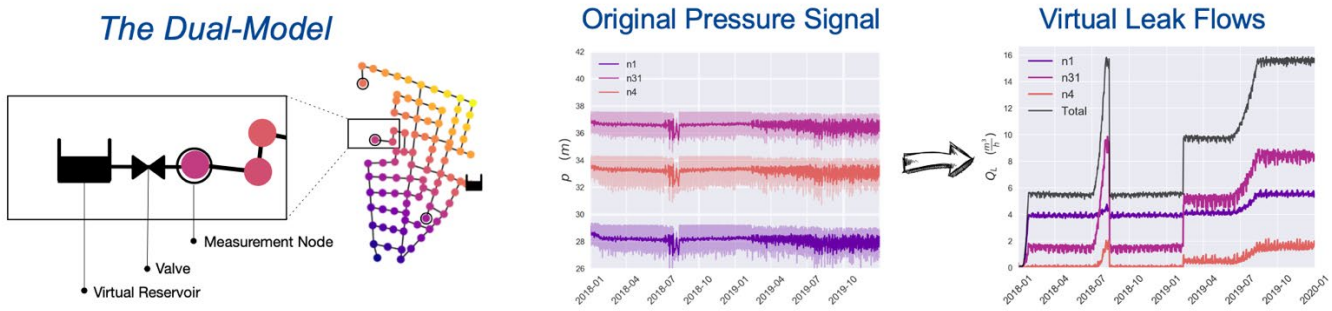
The aim of the project is to develop a decision support system that allows Norwegian utility managers to assess and choose different alternatives for network segmentation (DMA and PMA creation), in a cost-effective manner. The decision support system should cover all criteria considered relevant, and be tested in a real case study area.

Specific work description

The following tasks/actions are suggested:

- Description of status quo for water loss in Norwegian system, using different metrics for water loss (% leakage, ILI, non-revenue water, economic/sustainable level of water loss)
- Literature study on approaches to leakage management by means of DMA creation and pressure control
- Literature study and survey on which criteria are relevant for deciding how to segment a Norwegian WDN (costs of investment, hydraulic capacity, system redundancy, leakage reduction achieved, water age, contamination risks etc.)
- Literature study on existing methods for suggesting/deciding how a WDN should be segmented into DMAs/PMAs, e.g. by optimisation (assess pros/cons of methods, applicability and relevance for Norwegian conditions)
- Develop decision support system for network segmentation
- Test suggested decision support system using case study area

Project Title	Leak Detection and Localization with the Dual Model
Type	Project / Master thesis
Supervisors / Contacts	David Steffelbauer (NTNU), Franz Tscheikner-Gratl (NTNU), Marius Rokstad (NTNU)
Location	Trondheim



Project background

In Norway, an average of 30 % of treated water is lost before it reaches the customer. That is why one of the main challenges for water utilities is to detect and find leaks in aging water distribution networks. An early detection and management of leaks – in addition to reducing financial cost in non-revenue water – is critical to mitigate deterioration of pipes and surrounding infrastructure by preventing small leaks from turning into large pipe bursts.

Modern water utilities make use of model-based approaches to detect and locate leaks by analysing telemetry data from pressure and flow sensors and combining this information with hydraulic models to find leaks in near real-time. One of the main challenges for these model-based approaches is that the hydraulic models as well as the measurements are fraught with uncertainties; and these uncertainties can be magnitudes larger than the leak signals, making a fast detection and an accurate localisation almost impossible.

Recently, we developed a new duality-based approach to improve the sensitivity of the localisation process to smaller leaks through formulating a dual network model, where through a mathematical trick (by transforming the network model with pressure measurements to an equivalent model with additional virtual reservoirs and valves), we are able to translate pressure heads directly to virtual leakage outflows at the measurement locations. This approach magnifies the leak signal in pressure measurement and provides additionally a first estimate for the leak's size and location in the network. Theis dual model already proved to be superior to commonly used leak localization methods by winning the international "Battle of the Leak Detection and Isolation Methods" in 2020 (https://battledim.ucy.ac.cy) on a simulated benchmark water distribution system. However, the method has never been tested on real leaks in a real system.

Aim of the project

This project aims to investigate how the dual model performs on real measurement data taken from a case study in Graz, Austria. The measurement campaign consists of 12 pressure sensors that recorded data from ten different leaks in the system over a period of more than six months. This will be the first time

that the dual model is tested under real conditions. First experiments already showed very promising results. The aim of this thesis is to perform a thorough analysis of the dual model on the recorded leak scenarios. Furthermore, a scientific publication in an international journal is planned to advertise the results of this thesis within the scientific community.

Specific work description

- Literature study on leak detection and localisation methods in water distribution systems
- Data analysis of pressure and flow measurement data
- Transforming the hydraulic model of the case study area into a dual model
- Analysis of different recorded leak scenarios with the dual model
- Comparison of the performance of the dual model with commonly used model-based approaches

What's in for you

- Get the chance to play with Optimisation & Hydraulic Modelling tools on real water networks with real measurements
- Improve your Python and other software skills (e.g., EPANET)
- Get familiar with the latest developments in leak detection and localization and solve Norway's pressing leakage problem
- (Co)-author and publish a scientific paper with your name on it

Project Title	Using AI in the battle against FOG: The FATracker project
Type	Project / Master thesis
Supervisors / Contacts	Francois Clemens (NTNU), Franz Tscheikner-Gratl (NTNU), Marius Møller Rokstad (NTNU), David Steffelbauer (NTNU)
Location	Delft / Trondheim

Project background

The presence of FOG (Fat, Oil and Grease) is becoming a major concern for organisations managing wastewater systems, cleaning out is expensive and dirty, unhealthy work. The removal of these substances sometimes even draws the attention of the international press (for example, most recently, February 2021, Thames Water found a 'Bungalow sized fatberg' in the London sewer system). Numerous studies into the physical and chemical characteristics of FOG deposits have been published along with statistical properties of FOG accumulation in wastewater systems. However, these studies do not answer obvious questions like:

- How fast is the built up?
- There is a statistical relation between FOG built up and hydraulic properties, what are the fundamental mechanisms behind these relations?
- Which measures will work?

Aim of the project

Deltares (in Delft) started in co-operation with several parties in the Netherlands and France a project in which cheap remote cameras are installed in sewer pumping stations to obtain images once per 1-2 minutes. These images are used to:

- Measure water level
- Measure the ratio between FOG covered surface and total surface

Specific work description

This is done using an application of Artificial intelligence (i.e. a Sematic Segmentation CNN algorithm), which was trained on a limited data set (~ 100 images) and analysed > 100.00 images. Figure 1: shows some timeseries obtained in Rotterdam, the effect of rain events is clearly visible as is the effect of a change in pump regime starting on October 13th.Figure 1 shows an example of the output of the algorithm, given the input images. Figure 2 shows the successive steps the algorithm takes to arrive at results, Figure 3 shows the (DIY built equipment applied. If you like experimental work, like working with Arduino-like electronic concepts, you have a taste for hydraulics and some maths, you're welcome to join the team. Next challenges are manifold: can be detect vortices?, can be measure velocity fields at the surface using PIV or PTV technology (the answer is YES see figure 4, but we need some refinement here), how accurate can be measure water level using just a simple camera?

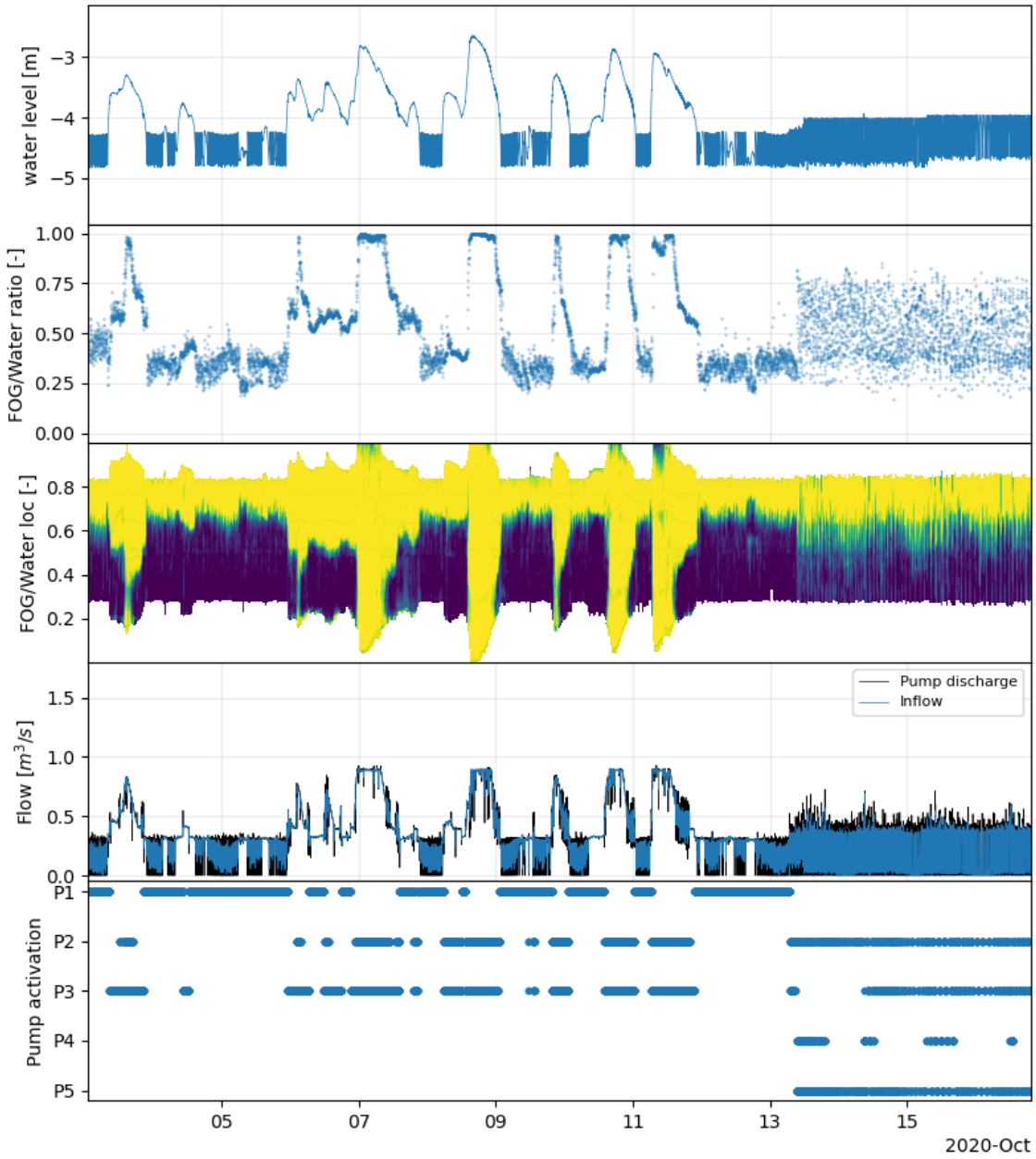


Figure 2: example of time series obtained in a pumping station in Rotterdam

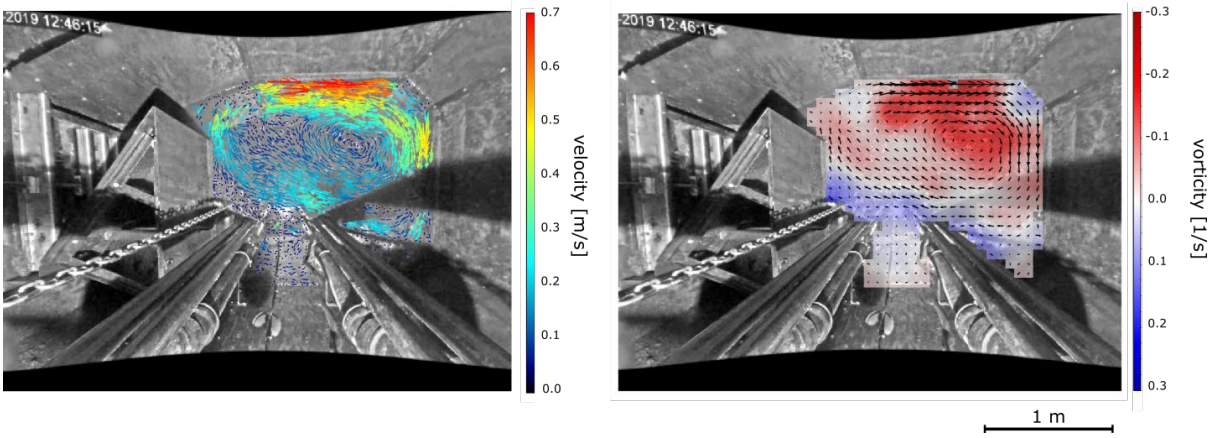


Figure 3: example of velocity and vorticity fields extracted from images using PIV.

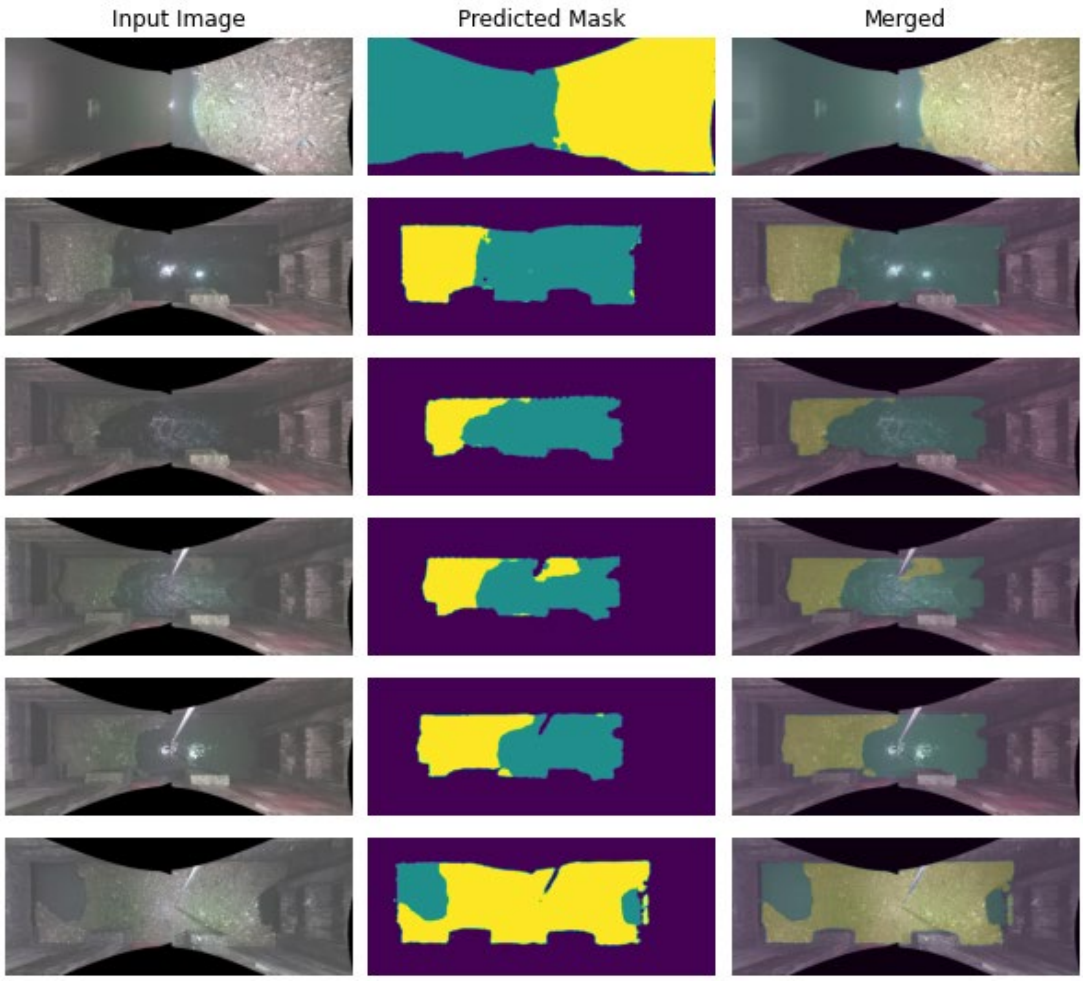


Figure 4: examples how the algorithm discriminates between FOG , water and construction

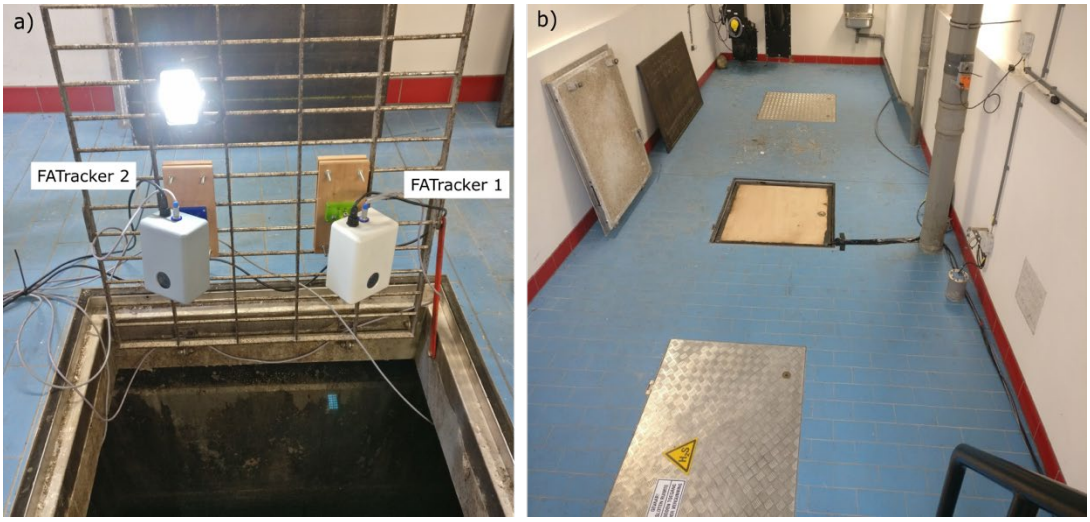


Figure 5: two DIY camera systems installed.

Project Title	Using machine learning and artificial intelligence to reduce failures and leakages in drinking water pipes
Type	Project / Master thesis
Supervisors / Contacts	Marius Møller Rokstad (NTNU), Franz Tscheikner-Gratl (NTNU), David Steffelbauer (NTNU), Stian Bruaset (SINTEF)
Location	Trondheim

Leakages from the Norwegian drinking water network is a known challenge in the water sector. Numbers from the national databank KOSTRA shows that there is an estimated average water loss of 30 % from Norwegian municipalities. The leakages are caused by structural failures in the pipes, corrosion and leaks in the gaskets. The leakage numbers from Denmark are less than 9 %, and Sweden around 20 %. The Norwegian topography and climate are more challenging than those in Denmark and Sweden, and are the causes for the increased leakage rates. However, the numbers also show that the Norwegian water sector need to improve the work to find and reduce leakages.

A new project with 20 partners from the public and private sector which is financed by the Norwegian water sector will look at new and innovative solutions, methods and technologies in order to find and reduce leakage rates. The project starts in April 2021 and lasts until 2025. Part of the project will use machine learning in order to understand why and when leaks occurs, and will also work to estimate and assess the probability of future failures and leaks in the pipes.

The master thesis will work closely with the researchers at SINTEF who work with machine learning and asset management of drinking water networks, and will be part of the research project. This includes participation in meetings with municipalities and other partners in the project.

Specifically the master thesis includes the following tasks:

- Read up on tactical asset management in the water sector.
- Review different machine learning methods and how they may be suitable for use in water infrastructure.
- Use 1-2 machine learning methods on 2-3 Norwegian networks. Build different models and compare them in terms of how accurate they are in predicting failures/leakages.
- Estimate the cost savings a municipality can achieve by using machine learning in fighting leakages and failures.

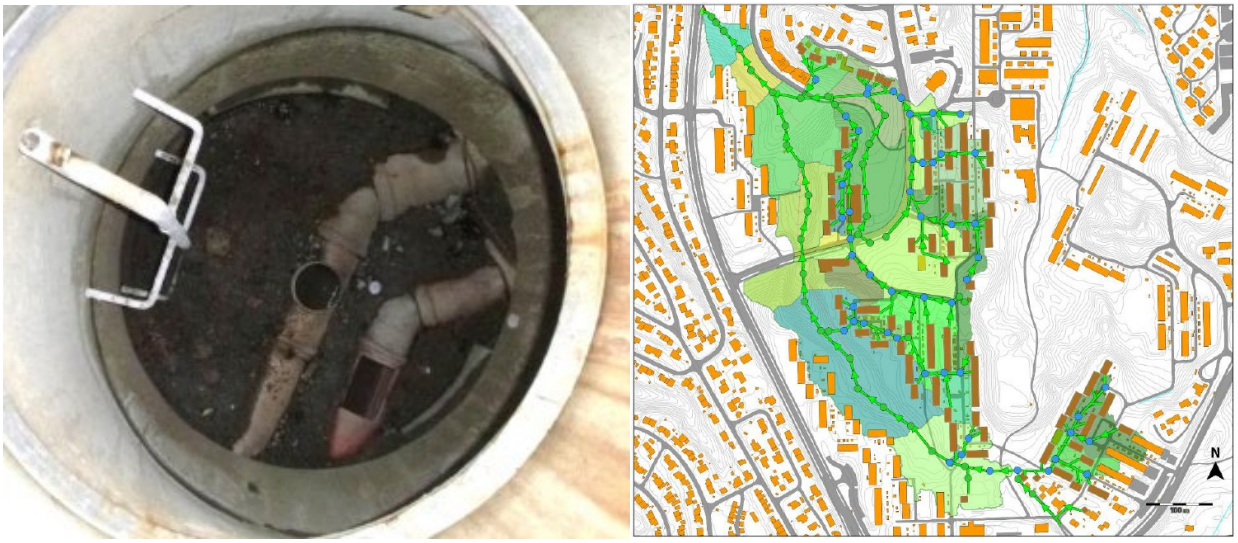
Project Title	Model Based Risk Assessment for Risvollan, Trondheim
Type	Master Thesis
Supervisors / Contacts	Marius Møller Rokstad (NTNU), Franz Tscheikner-Gratl (NTNU), David Steffelbauer (NTNU), Robert Meier (NTNU)
Location	Trondheim

Project Background

In recent decades there has been a strong movement to separate the urban wastewater flows by using separated sewer systems. Many systems are still hybrids where separated systems upstream connect to combined ones downstream. Even if the systems theoretically and ideally should be fully separated, they can still interact. This can occur when pipes are physically close to each other, or when elements of the systems are shared, such as sewer and stormwater pipes going through the same manholes.

The interaction in such multifunctional manholes may cause a whole host of problems. The foul sewer system can overload and cause backflow to buildings due to unintended inflow of stormwater. Even if that does not happen, the dilution of the sewage may increase the treatment need in the collecting wastewater treatment plant. Vice versa, seeping of sewage into the stormwater pipes may enable flows without treatment into the recipient or groundwater.

In Trondheim, one such system can be found in the Risvollan residential area. Interactions between the separated systems can be observed and seem to be connected to multifunctional manholes. To assess potential risks to the environment and inhabitants, different scenarios need to be evaluated using a hydrodynamic model of the area. Such a model has been created and tested, but due to lacking knowledge about the shared manholes, only inaccurate predictions are possible at the current stage.



Left: Shared manhole with open sewer- and stormwater-pipes in the same trench which might interact during high flows. Right: Visautlisation of the existing Risvollan SWMM model.

Aim of the Project

To improve the validity of the model predictions, more information related to these multifunctional manholes is needed. Field measurements should provide us with accurate information to update the

hydrodynamic model, which in turn should improve the prediction accuracy.
Using the improved model, different scenarios should be defined and evaluated to assess the hydraulic behaviour of the system, and the associated risk of environmental pollution in the area, as well as the risk of backflow to households. This work represents a novel approach to the management of sewer systems.

Specific Work Description

During the project work, the student will get the opportunity to improve and evaluate the model of a real-world residential area. This will include field measurements to more accurately represent multifunctional manholes and the observed interactions between the supposedly separated systems, as well as using real-world measurement to calibrate the model.
Once the model is more representative of the Risvollan residential area, the student will use it to assess potential risks, such as backflow into individual households, undetected blockages, or the dilution of sewage.

Project Title	The Shape of Water Distribution Systems
Type	Project / Master thesis
Supervisors / Contacts	David Steffelbauer (NTNU), Franz Tscheikner-Gratl (NTNU), Marius Rokstad (NTNU)
Location	Trondheim

Project background

The performance and resilience of a water distribution system (WDS) is connected to its underlying topologic structure (aka its shape). However, the field of Hydroinformatics is still lacking thorough investigations of the shape of water distribution systems. Literature mostly differentiates between two main shapes of networks – branched or looped networks. However, real networks do not consist only of branches nor loops; their shape is always somewhere in between. Furthermore, all WDS networks differ in their shape globally, but on a local scale (e.g., single neighbourhoods or boroughs in a city) they are highly similar all around the world.

WDS can be mathematically described via Graph Theory (simply as pipes connecting tanks and customers). Recent studies used highly efficient Graph Theory algorithms to investigate how network resilience and performance is connected to the shape of the network graphs. However, all of these studies were looking at global network parameters (average node degree, network diameter, …), none of them took the more important local structures into consideration.

This thesis enters the new terrain of local WDS investigations through **Graphlet analysis**. Graphlets are small connected subgraphs of a large network and have recently gathered much attention as a useful concept to uncover structural design principles of complex networks. Consequently, these novel analyses techniques can provide deep insights on how local WDS structures influence their overall performance.

Aim of the project

This project aims to investigate the influence of local network structures on the resilience of entire networks through Graphlet analysis. We will provide you with a collection of real hydraulic networks from all over the world, as well as all computer algorithms necessary to conduct Graphlet analysis on these networks. The aim of the thesis is (i) to compute Todini's index as a resilience measure of the networks,

and subsequently, (ii) to investigate how this resilience measure is related to their underlying local Graphlet structure. Since the research conducted within this project is of high novelty, a publication in an international scientific journal is planned to promote the results of this study to the scientific community.

Specific work description

- Literature study on Graph Theory applications in the field of Urban Water Management
- Obtaining the relevant background knowledge on Graphlet analysis based on selected lectures from an online series on Machine Learning with Graphs from Stanford University (CS224W– 3 videos each of 1.5 h length).
- Compute the Todini index for each member of network through the implementation of this calculation in the Python package WNTR.
- Use Python packages WNTR and NetworkX to extract network Graphs and analyse them with Graphlet analysis Python packages (e.g., OrbitalFeatures, LiftSRW).
- Investigate how the Graphlet structure of the network relates to Todini's index.

What's in for you

- Work with the latest Hydroinformatics techniques on a highly innovative research topic
- Hands on experience with a lot of diverse hydraulic models from all over the world
- Deep understanding of resilience of WDS and how to measure it
- Polishing of your Python skills for your later professional career
- Peak into the exciting field of Graph Machine Learning
- (Co)-authoring of a scientific paper plus academic publishing experience

Project Title	Co-developing and testing a framework for smarter use of water resources – the case of Bodø.
Type	Bachelor / Project / Master thesis
Supervisors / Contacts	Franz Tscheikner-Gratl (NTNU), Marius Møller Rokstad (NTNU), David Steffelbauer (NTNU), Rita Ugarelli (NTNU/SINTEF)
Location	Trondheim

Project background

The uncertainty that arises from climate and environmental crisis in the 21st century cities requires new integrated approaches towards an efficient and resilient management of the urban water cycle. This challenge needs to respond to the weaknesses that result from the combination of population growth and aged water infrastructures vulnerable to climate extremes, the shift in social priorities and public policies, a new demand on governance issues and the emerging technologies, namely, natural systems, information technology (IT), and small-scale modular units. The definition and implementation of new strategies and policy tools to the management of the urban water cycle needs to adapt to these dynamic settings, which implies an integrated perspective.

The United Nations World Water Development Report 2021 "Valuing Water" highlights that "*the different values of water need to be reconciled, and the trade-offs between them resolved and incorporated into systematic and inclusive planning and decision-making processes*".

Understanding and assessing the value of water and incorporating it into decision-making, are fundamental to achieving sustainable and equitable water resources management and the Sustainable Development Goals (SDGs) of the United Nations' 2030 Agenda for Sustainable Development.

One of the goals of the H202 project B-WaterSmart is to provide such decision making tool, called Water smartness assessment Framework. The framework measures 'water smartness gains" by analysing how well the user organization performs today and will perform in the future towards the achievement of set strategic objectives. By assessing defined challenges, the framework supports specific, concrete and applicable outcomes to and through experts and practitioners in the field. Through the definition of objectives and targets to be achieved, also under different scenarios, the user can monitor the progress towards a process of transformation (becoming water smarter).

The Framework is currently under development and a first prototype will be delivered in February 2022.

The framework will consist of structured libraries of strategic objectives, assessment criteria and metrics to be selected while applying the methodology which includes the following steps: setting the objectives, diagnosis, strategic plan development, monitoring loop.

Aim of the project

The aim of the project will be to contribute to the development of the framework through interaction with the B-WaterSmart project Living Lab of Bodø.

Specific work description

During the project work, the student will get familiar with relevant literature and reports that describe the Framework, the ambition of the Living lab of Bodø and the specific technologies there developed within the B-WaterSmart project. Based on the study, a list of assessment criteria and indicators customised for

the Bodø Living Lab will be produced and agreed with the project's contacts in Bodø.

During the master, the student will make a preliminary testing of the framework, run the required interviews with identified stakeholders and identify data already available and eventual gaps and finally provide a structured feedback on how to further improve the framework. The student will be supported in the project and in the master by NTNU personnel involved in the B-WaterSmart project.

Project Title	Efficient uncertainty quantification in multi-model chains employed in early warning systems for seawater desalination operations
Type	Master thesis
Supervisors / Contacts	Christos Makropoulos, Franz Tscheikner-Gratl (NTNU), Marius Møller Rokstad (NTNU)
Location	[…]

Project background

Seawater desalination has evolved rapidly along with increasing water demands. Yet, it is threatened by the emerging problem of coastal water pollution, which erodes the resource base on which desalination, and most of the blue economy, depends. Therefore, trustworthy and timely information of coastal water quality is valuable, as it enables proactive decision-making and, thereby, affords desalination operators both time and resources for adaptive planning against changes in water quality.

Existing modeling efforts – multi-model chains comprising wave, hydrodynamic, and water quality components – are powerful tools for simulating the hydrodynamic and water quality dynamics of coastal waters. However, their reliability depends on the overall uncertainty of their predictions, affected by diverse sources, e.g., uncertainty in field data, uncertainty resulting from the simplifications of the modelling process, uncertainty resulting from its parameterization. Considering such levels of uncertainty, single-point deterministic forecasts may be inadequate for operational early warning systems and, thus, a poor support for decision making. Consequently, there is a clear need to devise efficient ways to quantify the propagation of uncertainty in all the links of such a complex modeling chain.

Although uncertainty has been identified as a challenge, uncertainties in forecasts are typically underestimated. A rigorous and efficient approach for the quantification of uncertainties in the modelling chain is still lacking.

Aim of the project

This master project aspires to examine emerging concepts and technologies that could quantify uncertainty propagation in the wave-hydrodynamics-water quality modeling chain used to support decision making in desalination plants operationally.

The key ambition is two-fold. First, the project targets the reduction of complexity to the key features of the system by appropriately quantifying and processing all relevant heterogeneous uncertainties without losing important information. Second, the project will seek for an efficient quantification and processing of uncertainties to provide a probabilistic early warning system for proactive decision making in seawater desalination operations.

Specific work description

During the master project, the student will get familiar with (a) the concepts of aleatory and epistemic uncertainties in coastal water quality forecasting, and (b) diverse approaches to quantify them in a computationally efficient way using a validated coastal model.

The student will apply a sampling-based higher order global sensitivity analysis to reduce the complexity of the system and concentrate the analysis on key uncertainties. Subsequently, the reduced-order model will be further accelerated by a more flexible metamodel. A benchmarking analysis of candidate metamodels will be performed to indicate the most suitable approach for emulating the performance of the high-fidelity, complex coastal model.