ReNutriWater

HANDBOOK

on water reuse

Interreg
Baltic Sea Region

Co-funded by
the European Union

SUSTAINABLE WATERS
ReNutriWater

This Handbook is an output of the ReNutriWater project. It is the result of a collective effort, developed from the knowledge gained throughout the project in close cooperation with the project partners. Direction and editing: Klara Ramm.

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SUSTAINABLE WATERS ReNutriWater

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1 Introduction

1.1 EN

ReNutriWater – Closing local water circuits by recirculation of nutrients and water and using them in nature

Goals and activities

The project helps public authorities and wastewater treatment plant operators develop action plans to recover water from wastewater and reuse it for cleaning, watering recreational areas, and plants. It is a Water-smart Societies – priority project funded by the EU's Interreg Baltic Sea Region Programme.

Due to climate change and increasing pollution of the environment, freshwater has become an increasingly valuable resource. Hot summers and drought make saving water resources in summertime crucial, also in the Baltic Sea Region. Drinking water should be recognized as a labor-intensive product, which, despite extensive initial treatment, is still often discharged after a single use in many countries. This practice wastes money, energy, and human labour, which could be reduced with water recovery from wastewater.

However, reclaiming water has its challenges, which are related to specific requirements for its quality. The goal of research into reclaimed water is to reduce the risk of its potentially harmful impact on the environment and human health. The key is to develop solutions for the recovery of safe water, free of pathogens and micropollutants, with the right amount of nutrients. Overcoming potential societal hesitation is also crucial. ReNutriWater researchers are well aware of people's perceptions of what constitutes clean and dirty water, which is why the project aims to start by researching primarily non-potable uses of reclaimed water.

In ReNutriWater we strive to preserve nutrients in the reclaimed water, to combat the eutrophication of the Baltic Sea and reduce the need for artificial fertilizers. In the process of reclaiming water, nutrients can be preserved. The amount of them can be adjusted, and the water can then be used for irrigation. This decreases the need for artificial fertilizers and creates beneficial usage of nutrients instead of having them aggregate in the residue of the water treatment process. This mitigates the eutrophication of the Baltic Sea, which is caused by an excess of nutrients. In the pilot cases in ReNutriWater, we tested how nutrient-rich reclaimed water could be produced and used, thus creating circular economy business models in the water sector.

Among the beneficiaries of reclaimed water use, we count both local authorities and private entities. Reclaimed water can be used by local authorities and private entities for various purposes, such as street cleaning, car washes, fountains, and pond recharge, irrigation of recreational areas, and plant breeding.

ReNutriWater centres around three pilots:

Pilot 1: Disinfection efficiency of reclaimed water

As part of the pilot, effective methods for disinfecting reclaimed water were developed.

Pilot 2: Composition adjustment of reclaimed water

Research was carried out into methods for selecting the composition of reclaimed water to adapt it to specific needs, e.g., plant irrigation.

Pilot 3: Breaking barriers for reclaimed water use

Tests were conducted to ensure the safe use of reclaimed water through cultivation in greenhouses.

ReNutriWater partners share the results of the pilot tests with their target groups. The developed solutions and tools help assess the feasibility of implementing selected water reuse technologies.

This project is intended to address diverse challenges to accelerate policymaking, facilitating the implementation of water reuse in the cities of Europe. The good practice of reclaiming water promotes a circular economy and addresses several UN Sustainable Development Goals.

Project Partnership

The Lead partner of the project is the Chamber of Economy "Polish Waterworks". The initiative has 14 project partners from five countries: Poland, Finland, Latvia, Lithuania, and Denmark. The full list of participants can be found at the end of the handbook.

Project Lifespan

January 2023 – December 2025

Project budget and financing source

The total budget of ReNutriWater is 3.85 million euros. The 80% financing source is the Interreg Baltic Sea Region Programme. More about the Interreg Programme and the project can be found on the project website: ReNutriWater - Interreg Baltic Sea Region (interreg-baltic.eu/project/renutriwater).

Handbook

This handbook is specifically designed to serve as a comprehensive resource, offering valuable insights gained through extensive consultations with a diverse range of stakeholders. It seeks to raise awareness about the critical importance and vast potential of water reuse in addressing global water challenges, highlighting its role in sustainable resource management and environmental protection. By presenting expertise and best practices derived from carefully conducted pilot projects, the handbook aims to empower target groups with practical knowledge and actionable strategies that can be applied in various contexts. Furthermore, it provides a platform for fostering collaboration and encouraging innovation in water reuse practices, ensuring that the lessons learned and solutions developed are accessible and adaptable to a wide audience.

1.2 PL

ReNutriWater – Zamykanie lokalnych obiegów wodnych poprzez recyrkulację składników odżywczych i wody

Cele i działania

Projekt pomaga władzom publicznym i operatorom oczyszczalni ścieków opracować plany działań w celu odzyskiwania wody ze ścieków i ponownego jej wykorzystania do czyszczenia, podlewania terenów rekreacyjnych i roślin. Jest to projekt priorytetowy Water-smart Societies finansowany przez Program UE Interreg dla Regionu Morza Bałtyckiego.

Ze względu na zmiany klimatu i rosnące zanieczyszczenie środowiska, słodka woda staje się coraz cenniejszym zasobem. Gorące lata i susze sprawiają, że oszczędzanie zasobów wodnych latem jest kluczowe, również w regionie Morza Bałtyckiego. Słodką wodę należy uznać za produkt pracochłonny, który pomimo zaawansowanego uzdatniania, w wielu krajach jest nadal często odprowadzany po jednorazowym użyciu. Ta praktyka prowadzi do marnotrawstwa pieniędzy, energii i pracy ludzkiej, co można by ograniczyć dzięki odzyskiwaniu wody ze ścieków.

Jednak odzyskiwanie wody wiąże się z wyzwaniami, które są związane ze szczególnymi wymaganiami dotyczącymi jej jakości. Celem badań nad odzyskaną wodą jest zmniejszenie ryzyka jej potencjalnie szkodliwego wpływu na środowisko i zdrowie ludzi. Kluczem jest opracowanie rozwiązań umożliwiających odzyskiwanie bezpiecznej wody, wolnej od patogenów i mikrozanieczyszczeń, z odpowiednią ilością składników odżywczych. Kluczowe jest również przezwyciężenie potencjalnych wahań społecznych. Badacze ReNutriWater doskonale zdają sobie sprawę z postrzegania przez ludzi tego, co stanowi czystą i brudną wodę, dlatego projekt ma na celu rozpoczęcie od badania przede wszystkim niespożywczych zastosowań odzyskanej wody.

W ReNutriWater dążymy do zachowania składników odżywczych w odzyskanej wodzie, aby zwalczać eutrofizację Morza Bałtyckiego i zmniejszać zapotrzebowanie na sztuczne nawozy. W procesie odzyskiwania wody składniki odżywcze mogą zostać zachowane. Ich ilość może zostać dostosowana, a następnie woda może zostać wykorzystana do nawadniania. Zmniejsza to zapotrzebowanie na sztuczne nawozy i tworzy korzystne wykorzystanie składników odżywczych zamiast ich agregacji w pozostałościach procesu uzdatniania wody. Łagodzi to eutrofizację Morza Bałtyckiego, która jest spowodowana nadmiarem składników odżywczych. W przypadkach pilotażowych w ReNutriWater testowaliśmy, w jaki sposób można produkować i wykorzystywać bogatą w składniki odżywcze odzyskaną wodę, tworząc w ten sposób modele biznesowe gospodarki o obiegu zamkniętym w sektorze wodnym.

Do beneficjentów wykorzystania odzyskanej wody zaliczamy zarówno władze lokalne, jak i podmioty prywatne. Odzyskana woda może być wykorzystywana przez władze lokalne i podmioty prywatne do różnych celów, takich jak czyszczenie ulic, myjnie samochodowe, fontanny i zasilanie stawów, nawadnianie terenów rekreacyjnych i hodowla roślin.

ReNutriWater koncentruje się wokół trzech pilotaży:

Pilot 1: Skuteczność dezynfekcji odzyskanej wody

W ramach pilotażu opracowano skuteczne metody dezynfekcji odzyskanej wody.

Pilot 2: Dostosowanie składu odzyskanej wody.

Przeprowadzono badania nad metodami doboru składu odzyskanej wody w celu dostosowania jej do konkretnych potrzeb, np. nawadniania roślin.

Pilot 3: Przełamywanie barier w zakresie wykorzystania odzyskanej wody.

Przeprowadzono testy w celu zapewnienia bezpiecznego wykorzystania odzyskanej wody w uprawach w szklarniach.

Partnerzy

ReNutriWater dzielą się wynikami testów pilotażowych ze swoimi grupami docelowymi. Opracowane rozwiązania i narzędzia pomagają ocenić wykonalność wdrożenia wybranych technologii ponownego wykorzystania wody.

Projekt ten ma na celu rozwiązanie różnych wyzwań w celu przyspieszenia tworzenia polityki, ułatwiając wdrażanie ponownego wykorzystania wody w miastach Europy. Dobra praktyka odzyskiwania wody promuje gospodarkę o obiegu zamkniętym i odnosi się do kilku Celów Zrównoważonego Rozwoju ONZ.

Partnerstwo w projekcie

Liderem projektu jest Izba Gospodarcza „Wodociągi Polskie". Inicjatywa ma 14 partnerów z pięciu krajów: Polski, Finlandii, Łotwy, Litwy i Danii. Pełną listę uczestników można znaleźć na końcu podręcznika.

Czas realizacji

Styczeń 2023 – Grudzień 2025

Budżet i źródło dofinansowania

Całkowity budżet ReNutriWater wynosi 3,85 mln euro. Źródłem finansowania jego 80% jest program Interreg Baltic Sea Region. Więcej informacji o programie Interreg i projekcie można znaleźć na stronie internetowej projektu: ReNutriWater - Interreg Baltic Sea Region (interreg-baltic.eu/project/renutriwater).

Podręcznik

Niniejszy podręcznik został specjalnie zaprojektowany, aby służyć jako kompleksowe źródło, oferujące cenne spostrzeżenia uzyskane dzięki szeroko zakrojonym konsultacjom z różnymi interesariuszami. Ma on na celu podniesienie świadomości na temat krytycznego znaczenia i ogromnego potencjału ponownego wykorzystania wody w rozwiązywaniu globalnych wyzwań związanych z wodą, podkreślając jego rolę w zrównoważonym zarządzaniu zasobami i ochronie środowiska. Poprzez prezentowanie wiedzy specjalistycznej i najlepszych praktyk pochodzących z starannie przeprowadzonych projektów pilotażowych, podręcznik ma na celu wzmocnienie grup docelowych praktyczną wiedzą i wykonalnymi strategiami, które można zastosować w różnych kontekstach. Ponadto stanowi platformę do wspierania współpracy i zachęcania do innowacji w praktykach ponownego wykorzystania wody, zapewniając, że wyciągnięte wnioski i opracowane rozwiązania są dostępne i dostosowane do szerokiego grona odbiorców.

1.3 FI

ReNutriWater – Paikallisten vesikiertojen sulkeminen kierrättämällä ravinteita ja vettä ja hyödyntämällä niitä luonnossa

Tavoitteet ja toiminta

ReNutriWater auttaa kunnallisen jätevedenkäsittelyn kanssa työskenteleviä kuntien, viranomaisten ja operaattoreiden edustajia laatimaan toimintasuunnitelmia kierrätysveden käytöstä, jotta niin vesi kuin sen sisältämät ravinteet saadaan hyödynnettyä virkistysalueiden ja kasvien kasteluun, katujen ja liikennevälineiden puhdistukseen jne. ReNutriWater on EU:n Interreg Baltic Sea Region -ohjelman rahoittama Water-smart Societies -prioriteettiin keskittyvä hanke.

Ilmastonmuutoksen ja lisääntyvän ympäristön saastumisen vuoksi makeasta vedestä on tullut yhä arvokkaampi luonnonvara. Kuumat kesät ja kuivuus tekevät vesivarojen säästämisestä kesäisin ratkaisevan tärkeää myös Itämeren alueella. Puhtaan veden tuotantoon kuluu paljon energiaa, mutta siitä huolimatta sitä käytetään edelleenkin monissa maissa vain kerran, jonka jälkeen se käsitellään jätevetenä, joka on poistettava systeemistä. Tämä käytäntö tuhlaa rahaa, energiaa ja ihmistyövoimaa, joita voitaisiin säästää kierrättämällä puhdistettu vesi uusiovetenä.

Veden talteenotossa on kuitenkin haasteita, jotka liittyvät sen laatua koskeviin erityisvaatimuksiin. Uusioveden tutkimuksen tavoitteena on vähentää sen mahdollisten haitallisten vaikutusten riskiä ympäristölle ja ihmisten terveydelle. Tärkeintä on kehittää ratkaisuja turvallisen, taudinaiheuttajista ja mikrosaasteista vapaan veden talteenottoon. Uusioveteen voidaan myös jättää käyttötarkoitukseen sopiva määrä ravinteita. Yhteiskunnallisen epäröinnin voittaminen on myös ratkaisevan tärkeää. Koska ihmisillä voi olla hyvin vahva tunne siitä, mikä on puhdasta ja mikä likaista vettä, hankkeessa on aloitettu tutkimalla ensisijaisesti kierrätetyn veden käyttötarkoituksia muihin kuin juomavesitarkoituksiin.

ReNutriWaterissa pyrimme säilyttämään uusioveden ravinteita, torjumaan Itämeren rehevöitymistä ja vähentämään keinolannoitteiden tarvetta. Veden talteenottoprosessissa ravinteet on mahdollista säilyttää. Niiden määrää voidaan säätää, minkä jälkeen vettä voidaan käyttää kasteluun. Tämä vähentää keinolannoitteiden tarvetta ja hyödyntää ravinteita sen sijaan, että ne kasautuisivat vedenkäsittelyprosessin lietteisiin. Tämä lieventää Itämeren ja muiden vesistöjen rehevöitymistä, joka johtuu ravinnevalumien aiheuttamasta ravinteiden liiallisesta määrästä vesistöissä. ReNutriWaterin pilottihankkeissa testasimme, kuinka ravinnerikasta kierrätysvettä voitaisiin tuottaa ja käyttää luoden näin kiertotalouden liiketoimintamalleja vesisektorille.

Uusioveden käytön edunsaajiin lasketaan sekä kunnat että yksityiset tahot. Kierrätettyä vettä voidaan käyttää eri tarkoituksiin kuten katujen ja liikennekaluston puhdistukseen, suihkulähteiden ja lampien täyttöön sekä golfkenttien, virkistysalueiden sekä kasvihuoneiden kasteluun.

ReNutriWater keskittyy kolmeen pilottiin:

Pilotti 1: Uusioveden desinfiointi

Osana pilottia kehitettiin tehokkaita menetelmiä uusioveden desinfiointiin.

Pilotti 2: Uusioveden koostumuksen säätö

Pilotissa tutkittiin menetelmiä, joilla kierrätetyn veden koostumus ja ravinnesisältö voidaan valita sen mukauttamiseksi erityistarpeisiin, esimerkiksi kasvien kasteluun.

Pilotti 3: Uusioveden käytön esteiden murtaminen

Pilottitesteillä testattiin turvallisen uusioveden käyttö kasvihuoneissa.

ReNutriWaterin hankekumppanit jakavat pilottitestien tulokset kohderyhmilleen. Kehitetyt ratkaisut ja työkalut auttavat arvioimaan valittujen veden uudelleenkäyttöteknologioiden toteutettavuutta.

Tämän hankkeen tarkoituksena on vastata erilaisiin haasteisiin päätöksenteon nopeuttamiseksi ja veden uudelleenkäytön toteuttamisen helpottamiseksi Euroopan kaupungeissa. Veden talteenoton hyvä käytäntö edistää kiertotaloutta ja vastaa useisiin YK:n kestävän kehityksen tavoitteisiin.

Hankekumppanuus

Hankkeen pääkumppani on Puolan vesilaitoksen talouskamari (The Chamber of Economy "Polish Waterworks"). Hankkeessa on yhteensä 14 hankekumppania viidestä maasta: Puolasta, Suomesta, Latviasta, Liettuasta ja Tanskasta. Osallistujaluettelo löytyy käsikirjan lopusta.

Projektin elinkaari

Tammikuu 2023 – joulukuu 2025

Hankkeen budjetti ja rahoituslähde

ReNutriWaterin kokonaisbudjetti on 3,85 miljoonaa euroa, josta 80 prosenttia on EU:n Interreg Baltic Sea Region -ohjelman rahoittamaa. Lisätietoja Interreg-ohjelmasta ja hankkeesta löytyy hankkeen verkkosivuilta: ReNutriWater - Interreg Baltic Sea Region (interreg-baltic.eu/project/renutriwater).

Käsikirja

Tämä käsikirja on suunniteltu erityisesti toimimaan kattavana ohjeistuksena, joka tarjoaa arvokasta tietoa, mikä pohjautuu laajaan kanssakäymiseen eri sidosryhmien kanssa. Käsikirjalla pyritään lisäämään tietoisuutta veden uudelleenkäytön kriittisestä merkityksestä ja valtavasta potentiaalista maailmanlaajuisiin vesihaasteisiin vastaamisessa ja korostamaan sen roolia kestävässä luonnonvarojen hallinnassa ja ympäristönsuojelussa. Esittelemällä huolellisesti toteutetuista pilottihankkeista saatua asiantuntemusta ja parhaita käytäntöjä käsikirjan tavoitteena on antaa kohderyhmille käytännön tietoa ja toteuttamiskelpoisia strategioita, joita voidaan soveltaa eri yhteyksissä. Lisäksi se tarjoaa alustan yhteistyön edistämiselle ja innovoinnin kannustamiselle veden uudelleenkäyttökäytännöissä varmistaen, että saadut kokemukset ja kehitetyt ratkaisut ovat laajan yleisön saatavilla ja mukautettavissa.

1.4 LV

ReNutriWater – Slēgtu ūdens aprites ciklu veidošana, veicot atkārtotu barības vielu un ūdens izmantošanu un to pielietošanu dabā

Mērķi un aktivitātes

Projekts un tā rezultāti palīdz valsts iestādēm un notekūdeņu attīrīšanas iekārtu operatoriem izstrādāt rīcības plānus ūdens atgūšanai no attīrītiem notekūdeņiem un tā atkārtotai izmantošanai, piemēram, ielu tīrīšanā, rekreācijas zonu laistīšanā un augu laistīšanai. Šis ir ES Interreg Baltijas jūras reģiona programmas finansēts projekts prioritātē "Ūdens viedas sabiedrības (Water-smart Societies)".

Sakarā ar klimata pārmaiņām un pieaugošo vides piesārņojumu, saldūdens kļūst par arvien vērtīgāku resursu. Karstas vasaras un sausuma periodi padara ūdens resursu saglabāšanu, saudzīgu izmantošanu īpaši svarīgu arī Baltijas jūras reģionā. Saldūdens būtu jāuztver kā darbietilpīgs produkts, kas, neskatoties uz plašu sākotnējo apstrādi un sagatavošanu, daudzās valstīs joprojām tiek izlietots tikai vienu reizi. Šāda prakse rada līdzekļu, enerģijas un cilvēkresursu izšķērdēšanu, ko iespējams mazināt, atgūstot ūdeni no notekūdeņiem.

Tomēr ūdens atgūšana rada izaicinājumus, kas saistīti ar noteiktām kvalitātes prasībām. Mūsu pētījumu mērķis ir samazināt iespējamos riskus videi un cilvēku veselībai atkārtota ūdens ieguvē un izmantošanā. Būtiski ir izstrādāt droša ūdens atgūšanas risinājumus – bez patogēniem un mikropiesārņotājiem, bet ar atbilstošu barības vielu daudzumu, ja tiek izmantots apzaļumošanā un augu audzēšanā. Nozīmīgi ir arī pārvarēt sabiedrības atturību, kas var būt visai noturīga. Arī projekta pētnieki ir apzinājušies sabiedrības uztveri pret šāda ūdens izmantošanu, kas var variēt plašā spektrā. Sabiedrības attieksme un raksturojums kas ir tīrs, kas netīrs ūdens, radīja nepieciešamību sākotnējo uzsvaru likt uz atgūtā ūdens netiešo (nedzeramo) pielietojumu.

ReNutriWater projekta ietvaros tiek strādāts pie barības vielu saglabāšanas atgūtajā ūdenī, lai samazinātu Baltijas jūras eitrofikāciju un nepieciešamību pēc mākslīgā mēslojuma. Atgūšanas procesā var saglabāt barības vielas, pielāgot to daudzumu un izmantot laistīšanai. Tas samazina nepieciešamību pēc mākslīgā mēslojuma un veicina barības vielu lietderīgu izmantošanu, nevis to uzkrāšanos notekūdeņu attīrīšanas atlikumos. Tas mazina ūdeņu eitrofikāciju, ko izraisa pārmērīgs barības vielu daudzums. Pilotprojektos tika testēts, kā sagatavot un izmantot ar barības vielām bagātu attīrīto ūdeni, veidojot aprites ekonomikas biznesa modeļus ūdenssaimniecībā.

Starp atgūtā ūdens lietotājiem var būt gan pašvaldības, gan privātais sektors, un šāda ūdens izmantošanas iespējas ir plašas, ietverot ielu tīrīšanu, automazgātavas, strūklakas, dīķu papildināšanu, parku un rekreācijas zonu laistīšanu, augu audzēšanu.

ReNutriWater ietvaros tiek īstenoti trīs pilotprojekti:

Pilotprojekts 1: Atgūtā ūdens dezinfekcijas efektivitāte

Tika izstrādātas efektīvas metodes atgūtā ūdens dezinfekcijai.

Pilotprojekts 2: Atgūtā ūdens sastāva pielāgošana

Tika pētītas metodes, kā pielāgot ūdens sastāvu konkrētam mērķim, piemēram, augu laistīšanai.

Pilotprojekts 3: Barjeru pārvarēšana atgūtā ūdens izmantošanai

Tika veikti testi, lai nodrošinātu drošu atgūtā ūdens izmantošanu, veicot audzēšanu siltumnīcās.

ReNutriWater partneri dalās ar iegūtajiem pilotprojektu rezultātiem ar dažādām mērķa grupām. Izstrādātie risinājumi un rīki palīdz novērtēt iespējas ieviest konkrētas ūdens atkārtotas izmantošanas tehnoloģijas.

Šis projekts risina dažādas problēmas, lai paātrinātu politikas izstrādi, atvieglojot ūdens atkārtotas izmantošanas ieviešanu Eiropas pilsētās. Atgūtā ūdens labās prakses piemēri veicina aprites ekonomiku un atbalsta vairākus ANO ilgtspējīgas attīstības mērķus.

Projekta partnerība

Projekta vadošais partneris: "Polijas Ūdensapgādes uzņēmumu kamera" (Chamber of Economy "Polish Waterworks")

Iniciatīvā piedalās 14 partneri no 5 valstīm: Polijas, Somijas, Latvijas, Lietuvas un Dānijas. Pilns dalībnieku saraksts pieejams rokasgrāmatas beigās.

Projekta ilgums

2023. gada janvāris – 2025. gada decembris

Projekta budžets un finansējums

Kopējais projekta ReNutriWater budžets: 3,85 miljoni eiro.

Finansējuma avots: 80 % no Interreg Baltijas jūras reģiona programmas.

Vairāk informācijas par projektu atrodama mājaslapā: ReNutriWater - Interreg Baltic Sea Region (interreg-baltic.eu/project/renutriwater).

Rokasgrāmata

Šī rokasgrāmata kalpo kā visaptverošs informācijas resurss, kas balstīts uz plašām konsultācijām ar dažādām ieinteresētajām pusēm. Tā palīdz palielināt informētību par ūdens atkārtotas izmantošanas nozīmi, uzsverot tās lomu ilgtspējīgā resursu pārvaldībā un vides aizsardzībā. Rokasgrāmata apvieno ekspertīzi un labās prakses piemērus no pilotprojektiem, lai nodrošinātu praktiskas zināšanas un stratēģijas, kas pielāgojamas dažādos kontekstos. Tā kalpo arī kā platforma sadarbībai un inovācijām ūdens atkārtotas izmantošanas jomā, nodrošinot plašai auditorijai pieejamus risinājumus.

1.5 LT

ReNutriWater – Uždaros vietinės vandens sistemos, recirkuliuojant maistingąsias medžiagas ir vandenį bei panaudojant juos gamtoje

Projekto tikslai ir veiklos

Projektas padeda valdžios institucijoms ir nuotekų valymo įrenginių operatoriams vystyti veiksmų planus, kaip iš nuotekų išgauti vandenį ir pakartotinai jį naudoti valymui, poilsio zonų ir augalų laistymui. Tai Europos Sąjungos Interreg Baltijos jūros regiono programos finansuojamas prioritetinis projektas „Vandeniui pažangi visuomenė".

Dėl klimato kaitos ir didėjančios aplinkos taršos gėlas vanduo tampa vis vertingesniu ištekliumi. Karštos vasaros ir sausros lemia, kad vasarą vandens išteklių taupymas yra labai svarbus ir Baltijos jūros regione. Pripažinkim, kad gėlas vanduo yra daug darbo sąnaudų reikalaujantis produktas, kuris, nepaisant intensyvaus pirminio valymo, daugelyje šalių vis dar dažnai išleidžiamas po vienkartinio panaudojimo. Dėl tokios praktikos eikvojami pinigai, energija ir žmonių darbas, kurių kiekį būtų galima sumažinti iš nuotekų išgaunant vandenį.

Vis dėlto vandens regeneravimas susiduria su iššūkiais, susijusiais su specifiniais jo kokybės reikalavimais. Regeneruotame vandens tyrimų tikslas – sumažinti jo galimo žalingo poveikio aplinkai ir žmonių sveikatai riziką. Svarbiausia yra sukurti sprendimus, kaip išgauti saugų vandenį, kuriame nėra patogenų ir mikrodalelių, kuriame yra tinkamas maistinių medžiagų kiekis. Taip pat labai svarbu įveikti galimas visuomenės abejones. „ReNutriWater" tyrėjai žino kokia yra visuomenės samprata ir įsitikinimai dėl švaraus ir nešvaraus vandens, todėl projekte siekiama visų pirma ištirti negeriamojo regeneruoto vandens panaudojimą.

Projekto „ReNutriWater" veiklomis siekiame išsaugoti maistingąsias medžiagas regeneruotame vandenyje, kovoti su Baltijos jūros eutrofikacija ir sumažinti dirbtinių trąšų poreikį. Regeneruotame vandenyje galima išsaugoti maistines medžiagas, sureguliuoti jų kiekį ir vandenį panaudoti laistymui. Taip sumažinamas dirbtinių trąšų poreikis ir naudingai panaudojamos maistingosios medžiagos, užuot jas kaupus vandens valymo proceso liekanose; mažinama Baltijos jūros eutrofikacija, kurią sukelia būtent maistinių medžiagų perteklius. „ReNutriWater" bandomaisiais projektais išbandėme, kaip būtų galima gaminti ir naudoti maistinių medžiagų turtingą regeneruotą vandenį, sukuriant žiedinės ekonomikos verslo modelius vandens sektoriuje.

Tarp naudos iš regeneruoto vandens naudojimo gavėjų yra ir vietos valdžios institucijos, ir privatūs subjektai. Vietos valdžios institucijos ir privatūs subjektai regeneruotą vandenį gali naudoti įvairiems tikslams, pavyzdžiui, gatvėms valyti ir plauti, automobilių plovykloms, fontanams ir tvenkiniams papildyti, poilsio zonoms drėkinti ir augalams veisti.

ReNutriWater remiasi trimis bandomaisiais projektais:

1 bandomasis projektas: regeneruoto vandens dezinfekavimo efektyvumas

Vykdant bandomąjį projektą buvo sukurti efektyvūs regeneruoto vandens dezinfekavimo metodai.

2 bandomasis projektas: regeneruoto vandens sudėties koregavimas

Vykdant bandomąjį projektą atlikti regeneruoto vandens sudėties parinkimo metodų tyrimai, siekiant jį pritaikyti konkretiems poreikiams, pvz., augalų drėkinimui.

3 bandomasis projektas: kliūčių, trukdančių naudoti regeneruotą vandenį, pašalinimas

Vykdant bandomąjį projektą atlikti bandymai, siekiant užtikrinti saugų regeneruoto vandens naudojimą auginant augalus šiltnamiuose.

ReNutriWater partneriai dalijasi bandomųjų bandymų rezultatais su tikslinėmis grupėmis. Sukurti sprendimai ir priemonės padeda įvertinti pasirinktų pakartotinio vandens naudojimo technologijų įgyvendinimo galimybes.

Šiuo projektu siekiama spręsti įvairius iššūkius, kad būtų paspartintas politikos formavimas, palengvinant pakartotinio vandens naudojimo diegimą Europos miestuose. Geroji vandens pakartotinio naudojimo praktika skatina žiedinę ekonomiką ir padeda siekti kelių JT darnaus vystymosi tikslų.

Partnerystė

Pagrindinis projekto partneris – Lenkijos vandens ūkio rūmai. Iniciatyvoje dalyvauja 14 projekto partnerių iš penkių šalių: Lenkijos, Suomijos, Latvijos, Lietuvos ir Danijos. Visą dalyvių sąrašą rasite vadovo pabaigoje.

Projekto trukmė

2023 sausis – 2025 gruodis

Biudžetas ir finansavimo šaltinis

Bendras „ReNutriWater" biudžetas – 3,85 mln. eurų. 80 proc. finansavimo šaltinis – Interreg Baltijos jūros regiono programa. Daugiau informacijos apie Interreg programą ir projektą galima rasti projekto interneto svetainėje: ReNutriWater - Interreg Baltic Sea Region (interreg-baltic.eu/project/renutriwater).

Vadovas

Šis vadovas yra konkrečiai sukurtas kaip išsamus šaltinis, kuriame pateikiamos vertingos įžvalgos, gautos išsamiai konsultuojantis su įvairiomis suinteresuotosiomis šalimis. Juo siekiama didinti informuotumą apie ypatingą pakartotinio vandens naudojimo svarbą ir didžiulį potencialą sprendžiant pasaulines vandens problemas, pabrėžiant jo vaidmenį tvariai valdant išteklius ir saugant aplinką. Pateikiant patirtį ir geriausią praktiką, įgytą kruopščiai vykdant bandomuosius projektus, vadove siekiama suteikti tikslinėms grupėms praktinių žinių ir veiksmingų strategijų, kurias galima taikyti įvairiomis aplinkybėmis. Tai lyg platforma, padedanti plėtoti bendradarbiavimą ir skatinti inovacijas vandens pakartotinio naudojimo praktikoje, užtikrinant, kad įgyta patirtis ir parengti sprendimai būtų prieinami ir pritaikomi plačiajai auditorijai.

1.6 DK

ReNutriWater – Recirkulere lokale vandkredsløb gennem genanvendelse af næringsstoffer og vand

Mål og aktiviteter

Projektet hjælper offentlige myndigheder og operatører af rensningsanlæg med at udvikle handlingsplaner til at genvinde vand fra spildevand og genbruge det til rengøring, vanding af rekreative områder og planter. Det er et Water-smart Societies – prioritetsprojekt finansieret af EU's Interreg Baltic Sea Region Programme.

På grund af klimaforandringerne og stigende miljøforurening er ferskvand blevet en stadig mere værdifuld ressource. Varme somre og tørke gør det endnu vigtigere at spare på vandressourcerne om sommeren, også i Østersøregionen. Ferskvand bør anerkendes som et ressourcekrævende produkt, som trods en omfattende indledende behandlingsproces stadig ofte udledes efter engangsbrug i mange lande. Denne praksis spilder penge, energi og menneskelig arbejdskraft, som kunne reduceres med vandgenvinding fra spildevand.

Dog har genanvendelse af vand sine udfordringer relateret til specifikke krav til dets kvalitet. Målet med forskning i genanvendt vand er at reducere risikoen for dets potentielt skadelige indvirkning på miljøet og menneskers sundhed. Nøglen er at udvikle løsninger til genvinding af sikkert vand, fri for patogener og mikropollutanter, men med den rette mængde næringsstoffer. At overvinde potentiel samfundsmæssig tøven er også afgørende. ReNutriWater-forskere er godt klar over folks opfattelser af, hvad der udgør rent og beskidt vand, hvorfor projektet prioriterer at undersøge genanvendelse af renset spildevand til formål, hvor vandet ikke skal bruges som drikkevand.

I ReNutriWater stræber vi efter at bevare næringsstoffer i det genvundne vand for at bekæmpe eutrofiering af Østersøen samt reducere behovet for kunstgødning på land. I processen med at genvinde vand kan næringsstoffer bevares i vandet. Mængden af næringsstoffer kan justeres, hvorefter vandet kan bruges til vanding. Dette mindsker behovet for kunstgødning og muliggør gavnlig brug af næringsstoffer i stedet for at de ophobes på rensningsanlæggene. Dette mindsker udledning af næringsstoffer og dermed eutrofiering af Østersøen. I pilotprojekterne i ReNutriWater testede vi, hvordan næringsrigt genvundet vand kunne produceres og bruges, og dermed skabe cirkulære økonomiske forretningsmodeller i vand- og spildevandssektoren.

Blandt modtagerne af genanvendt vand finder vi både lokale myndigheder og private virksomheder, der kan bruge vandet til forskellige formål såsom gaderengøring, bilvask, springvand og bassiner, vanding af rekreative områder og til dyrkning af planter.

ReNutriWater omfatter tre pilotprojekter:

Pilot 1: Effektiv desinfektion af genvundet vand

Som en del af pilot 1 blev der udviklet effektive metoder til desinfektion af genanvendt vand.

Pilot 2: Justering af sammensætningen af genanvendt vand

Forskning i metoder til at justere sammensætningen af stoffer i det genvundet vand for at tilpasse det til specifikke behov som f.eks. plantevanding.

Pilot 3: Nedbrydning af barrierer for brug af genvundet vand

Det blev testet hvor sikker genanvendelsen af renset spildevand er ved vanding af planter i drivhuse.

ReNutriWater-partnere deler resultaterne af pilotprojekterne med deres målgrupper. De udviklede løsninger og værktøjer hjælper med at vurdere gennemførligheden af udvalgte teknologier til vandgenanvendelse. Dette projekt har til formål at adressere forskellige udfordringer for at fremskynde politiske beslutninger og lette implementeringen af vandgenbrug i Europas byer. Den gode praksis med at genanvende vand fremmer en cirkulær økonomi og adresserer flere af FN's Verdensmål.

Projektpartnerskab

Hovedpartneren i projektet er Chamber of Economy "Polish Waterworks". Initiativet har 14 projektpartnere fra fem lande: Polen, Finland, Letland, Litauen og Danmark. Den fulde liste over deltagere kan findes i slutningen af håndbogen.

Projektets levetid

Januar 2023 – december 2025

Projektbudget og finansieringskilde

Det samlede budget for ReNutriWater er 3,85 millioner euro. 80% af finansieringen kommer fra Interreg Baltic Sea Region Programme. Mere om Interreg-programmet og projektet kan findes på projektets hjemmeside: ReNutriWater - Interreg Baltic Sea Region (interreg-baltic.eu/project/renutriwater).

Håndbog

Denne håndbog er specifikt designet til at tjene som en brugbar samling af værdifulde indsigter opnået gennem omfattende samarbejde med en bred vifte af interessenter. Den søger at øge bevidstheden om det store og vigtige potentiale for vand-genanvendelse i håndteringen af globale vandudfordringer, og fremhæver dets rolle i bæredygtig ressourceforvaltning og miljøbeskyttelse. Ved at præsentere ekspertise og bedste praksis afledt af de gennemførte pilotprojekter, sigter håndbogen mod at bidrage med praktisk viden og handlingsrettede strategier, der kan anvendes i forskellige sammenhænge. Desuden udgør håndbogen en platform til fremme af samarbejde og opmuntring til innovation i vandgenbrugspraksis, og sikrer, at de lærte erfaringer og udviklede løsninger er tilgængelige for et bredt publikum.

2 Water reuse in the Baltic Sea Region

Why reuse?

The Baltic Sea region is rich in water resources: it has the sea, a dense network of rivers, many lakes, and wetlands. The implementation of the water reuse concept is essential for regions with a hot and dry climate, but it is of rapidly growing importance for the Baltic Sea region.

Water reuse is relevant and, in the future, will become unavoidable in the Baltic Sea Region for several reasons:

1. Environmental Protection: The Baltic Sea is one of the most polluted seas in the world. Inland water quality, receiving discharges of treated wastewater, could be better. Water reuse can reduce the discharge of pollutants into the sea, thereby helping to protect marine on inland water ecosystems. Recovery of nutrients is essential for improved water quality.
2. Water Scarcity: Some areas within the Baltic Sea Region face water scarcity issues, especially during dry seasons. The increase in urbanisation is another water resource stress factor. Reusing water can provide an alternative source, helping to meet the demands of agriculture, industry, municipalities, and recreation.
3. Sustainable Development: As countries in the region aim to meet sustainability goals, water reuse aligns with efforts to promote efficient resource use and reduce environmental impacts. Water reuse can be considered as the implementation of the circular economy concept in water resource management.
4. Climate Change Adaptation: With changing weather patterns, including increased rainfall variability, regular drought periods during spring, summer seasons, reusing water can enhance resilience against climate-induced water supply fluctuations.
5. Economic Factors: Implementing water reuse systems, nutrient recovery can lead to cost savings and enhance water supply security, which is important for economic development in the region.
6. Technological Advancements: Innovations in treatment technologies have made water reuse more viable and safer, encouraging its adoption across various sectors.
7. Policies of the European Union: EU legislative initiatives concerning water resource-saving and reuse regulate and enable water reuse implementation.
8. Awareness rising: It is necessary to popularize knowledge in society and among stakeholders about the need to save resources and implement the principles of the circular economy in water resources management.

» **These factors make water reuse a critical topic for discussion and action in the Baltic Sea Region.**

How to deal with water shortage?

On one hand, Baltic Sea Region is rich in water resources, rivers, lakes, and wetlands, but on the other hand, water resource abundance and their use spatially differ: water consumption is significantly higher in urbanised areas, intensive agricultural areas, than in less populated, natural regions. Water scarcity is evident in the Baltic Sea Region – we need to mitigate it.

Yes, reclaimed wastewater can play a significant role in addressing water scarcity issues in the Baltic Sea area to cover the needs of industrial and agricultural development. Here are several ways in which it can contribute to solving this problem:

1. Alternative Water Source: Reclaimed water provides a reliable alternative water source, especially during periods of drought or low precipitation. This can help meet the needs of agriculture, industry, and municipal water supplies.
2. Sustainable Agriculture: In agricultural regions, reclaimed water can be used for irrigation, which is particularly valuable in areas facing freshwater shortages. By using treated water, farmers can maintain crop production without depleting natural water resources.

3. Reduced Pressure on Freshwater Resources: By utilizing reclaimed water, communities can alleviate the demand on freshwater sources, helping to maintain ecological balances in rivers and lakes that might otherwise be over-extracted for water supply.
4. Cost-Effectiveness: While initial infrastructure investments may be required, reclaimed wastewater can ultimately be a cost-effective water solution, reducing the need for costly freshwater infrastructure and treatment.
5. Nutrient Recycling: Reclaimed wastewater often contains nutrients like nitrogen and phosphorus that can benefit agricultural soil. This recycling is especially useful in enhancing soil fertility while reducing reliance on synthetic fertilizers.
6. Enhanced Resilience: Implementing reclaimed wastewater systems enhances resilience against the impacts of climate change, such as increased variability in rainfall and temperature patterns, which can affect the availability of freshwater.
7. Community Engagement and Awareness: Establishing successful reclamation projects can foster community awareness and engagement in sustainable water practices, promoting a culture of conservation and responsible water use.
8. Innovation and Technology Development: The adoption of reclaimed wastewater systems can drive innovation in water treatment technologies, leading to improved processes that could benefit both reclaimed and potable water systems.

» **While there are challenges and risks associated with reclaimed wastewater use, such as ensuring water quality and overcoming public perception issues, strategic planning and investment can effectively integrate this resource into a sustainable water management framework in the Baltic Sea area.**

What about the water quality?

There is an urgent need to address surface and groundwater quality in the Baltic Sea area.

The surface water quality in the Baltic Sea area is of significant concern due to various anthropogenic pressures, including agriculture, industrial activities, and urban development. Here are some key points regarding the water quality in this region:

1. Eutrophication: One of the primary issues affecting the Baltic Sea is eutrophication, primarily caused by nutrient runoff (nitrogen and phosphorus) from agricultural fields and wastewater. This leads to algal blooms, which can deplete oxygen levels and harm marine life.
2. Pollutants: The Baltic Sea is affected by the presence of various pollutants, including heavy metals (such as mercury and lead), persistent organic pollutants (POPs), and microplastics. Industrial discharge and non-point source pollution contribute to the accumulation of these substances in the water.
3. Salinity and Stratification: The unique brackish nature of the Baltic Sea, with lower salinity compared to oceanic waters, influences the distribution of species and the overall health of the ecosystem. Stratification, caused by differences in temperature and salinity, can lead to reduced oxygen levels in bottom waters.
4. Biodiversity Impact: Poor water quality can significantly affect fish populations, including commercially important species like herring and sprat. Moreover, increased nutrient levels and temperature changes can disrupt local ecosystems, affecting biodiversity.
5. Regulatory Measures: Several international entities, such as the Baltic Marine Environment Protection Commission (HELCOM), work to monitor and improve the water quality in the Baltic Sea. Initiatives include reducing nutrient inputs through better agricultural practices, improving wastewater treatment, and implementing marine conservation efforts.

» **Efforts to monitor and improve the water quality are ongoing, but challenges related to pollution, climate change, and habitat loss continue to pose risks to this delicate environment.**

And the quality of reclaimed water?

Sometimes, the quality of water in the river is worse than that of reclaimed water.

Indeed, there are scenarios where the quality of reclaimed water can be better than that of the water found in natural bodies like rivers. This phenomenon can occur due to several factors:

1. Pollution: Rivers can be affected by various forms of pollution from agricultural runoff, industrial discharges, and urban wastewater. This can result in poor water quality, with high levels of nutrients, heavy metals, pathogens, and organic contaminants.
2. Treatment Processes: Reclaimed water typically undergoes stringent treatment processes designed to eliminate contaminants and pathogens. These processes can lead to higher quality water compared to untreated or poorly managed river water.
3. Nutrient Levels: In some cases, reclaimed water may have a more balanced nutrient composition, which can be beneficial for agricultural uses, compared to river water that might have high levels of certain pollutants.
4. Consistent Quality: Reclaimed water is usually produced under controlled processes that can ensure consistent quality, whereas river water quality can vary significantly depending on upstream activities, seasonal changes, and weather conditions.
5. Use in Irrigation and Other Applications: Farmers and municipalities may prefer using reclaimed water for irrigation or other purposes when the quality assures safety and efficacy, despite nearby natural water bodies that are potentially polluted.

» **Recognizing these conditions is essential for effective water management strategies, particularly in regions facing water scarcity or pollution issues. It highlights the potential value of reclaimed water as a resource for sustainable development and environmental protection.**

Is recovering water from wastewater risky?

There are risks and challenges to achieving full-scale water reuse.

Reclaimed wastewater reuse in the Baltic Sea area presents several risks and challenges that need to be carefully managed:

1. Health Risks: One of the primary concerns with reclaimed wastewater is the potential presence of pathogens and harmful chemicals. Ensuring that the reclaimed water meets safety standards for its intended use is crucial to protect public health.
2. Environmental Impact: Improperly treated reclaimed water can lead to the introduction of pollutants, such as pharmaceuticals, endocrine disruptors, and heavy metals, into the environment. This can harm aquatic ecosystems and degrade water quality in the Baltic Sea.
3. Public Perception: There may be resistance or mistrust among the public regarding the use of reclaimed wastewater. Effective communication and community engagement are essential to address concerns and build acceptance for water reuse projects.
4. Regulatory Framework: The lack of clear and consistent regulations governing the quality and management of reclaimed water can present challenges. Establishing appropriate guidelines is necessary to ensure safe and effective practices.
5. Infrastructure Costs: Upgrading existing water treatment facilities and developing new infrastructure for reclaimed water systems can be expensive. Securing funding and investment can be a barrier, especially in economically constrained regions.
6. Technical Challenges: Reclaimed water must be treated to meet specific standards for different uses (e.g., irrigation, industrial processes). This requires advanced treatment technologies and expertise, which can vary by locality.
7. Climate Variability: Changes in weather patterns, including rainfall variability and temperature fluctuations due to climate change, can affect the availability and quality of reclaimed water, impacting its reliability as a resource.

8. Nutrient Imbalance: While reclaimed wastewater can contain beneficial nutrients for agricultural use, it may also lead to nutrient imbalances in soils or water bodies if not properly managed, potentially resulting in eutrophication.
9. Long-term Sustainability: Establishing robust systems for ongoing monitoring, evaluation, and maintenance of reclaimed water projects is essential to ensure their long-term viability and minimize risks.

» **Addressing these risks and challenges is vital for the successful implementation of reclaimed wastewater reuse in the Baltic Sea region, ensuring it contributes positively to water sustainability and environmental protection.**

What else can be done?

Recovery of elements and materials from wastewater is an emerging and vital area aimed at promoting sustainability, reducing environmental impacts, and creating valuable resources from waste.

Recovery can involve various technologies and methods, depending on the type of wastewater and the materials of interest:

1. Nutrients (Nitrogen and Phosphorus). Phosphorus can be recovered as Struvite (magnesium ammonium phosphate) by precipitation from wastewater rich in nutrients, particularly in anaerobic digestion effluents and sewage sludge. This struvite can then be used as a slow-release fertilizer. Advanced wastewater treatment processes can enhance the removal of nitrogen and phosphorus, which can then be reused as fertilizers.
2. Metals can be recovered from reclaimed wastewater using technologies such as adsorption, precipitation, and electrochemical methods.
3. Valorization of Sludge: Sludge generated during wastewater treatment can be processed to recover organic compounds, such as fatty acids and enzymes, which can be used in various applications.
4. Microplastics and Pollutants can be isolated: using technologies such as filtration, flotation, and chemical treatment can help remove microplastics and hazardous chemicals from wastewater, allowing for a potential recycling route for some plastics.
5. Carbon Recovery from wastewater can effectively help reduce greenhouse gas emissions and enhance carbon capture methods.

» **The recovery of elements and materials from wastewater and reused wastewater not only contributes to resource conservation but can also reduce the environmental burden of traditional wastewater disposal methods. However, challenges such as the economic viability of recovery processes, technological limitations, and regulatory frameworks need to be addressed to promote larger-scale implementation of these recovery techniques.**

Fit-for-purpose?

Fit-for-purpose water is the best solution (it is not overtreated, has the appropriate amount of nutrients, is safe, etc)

The concept of "fit-for-purpose" water reuse is indeed a promising solution, particularly in contexts where the quality of water can be tailored to specific uses. This approach has several advantages:

1. Resource Efficiency: By treating water to specific standards based on its intended use, less energy and chemicals are consumed compared to traditional treatment methods that aim for a higher level of purity than necessary.
2. Nutrient Management: In agricultural applications, for instance, using treated wastewater can provide essential nutrients (like nitrogen and phosphorus) that benefit crop growth, thus reducing the need for synthetic fertilizers.
3. Safety: Employing rigorous safety standards within the fit-for-purpose framework ensures that the water is treated adequately for its specific end use. This helps build public confidence in reused water.

4. Cost-Effectiveness: By adjusting treatment processes to fit the intended use, communities can save costs and resources that would otherwise be spent on over-treatment.
5. Sustainability: This approach promotes a circular economy by maximizing the utility of water resources, thereby conserving freshwater supplies and minimizing waste.
6. Flexibility: Tailoring the treatment to the specific needs allows for flexibility in water management strategies, adapting to varying demands in different sectors.

» **Overall, focusing on fit-for-purpose water reuse is an innovative strategy that addresses both environmental concerns and the practical needs of communities, particularly in water-scarce or ecologically sensitive regions like the Baltic Sea Area.**

Our approach to reclaiming and reusing water can be seen from the Figure 1.

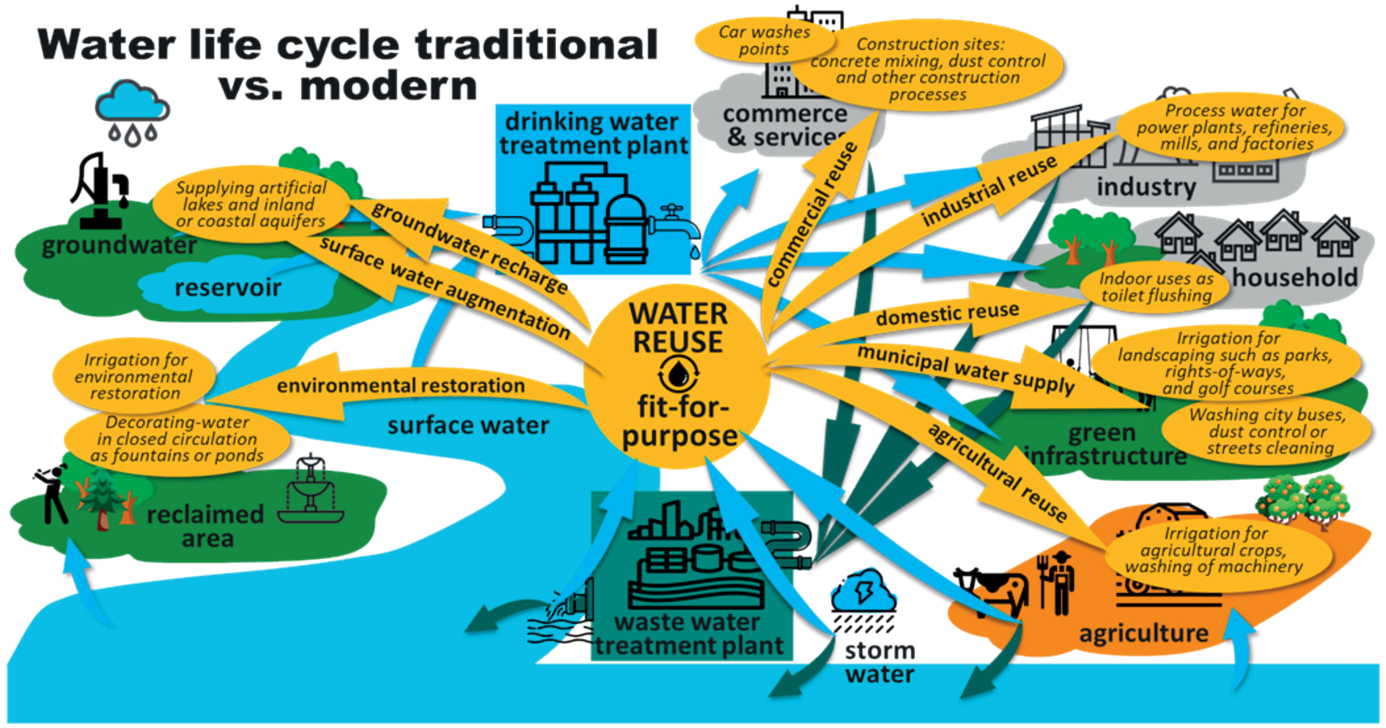


Figure 1. Fit-for-purpose water as a result of water reclamation

3 Legal aspects

The legal framework for water reuse plays a critical role in ensuring the safety, efficiency, and sustainability of water reclamation. This chapter outlines the key regulations and directives that govern water reuse and irrigation practices. These documents were used to establish both mandatory and optional measurement requirements for Project Partners and serve as guidelines for stakeholders to follow in meeting legal and environmental standards.

Key legal documents

LAW [Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse]

Water recovery from wastewater is partially addressed by Regulation 2020/741. It introduces basic parameters that must be monitored when recovering water from urban wastewater and using it in agriculture. It also introduces the obligation to assess the risk for each solution.

It divides reclaimed water into classes depending on the plants being irrigated and the irrigation method (Figure 2). The regulation defines four quality classes (A, B, C, D), with Class A being the strictest, intended for crops consumed raw.

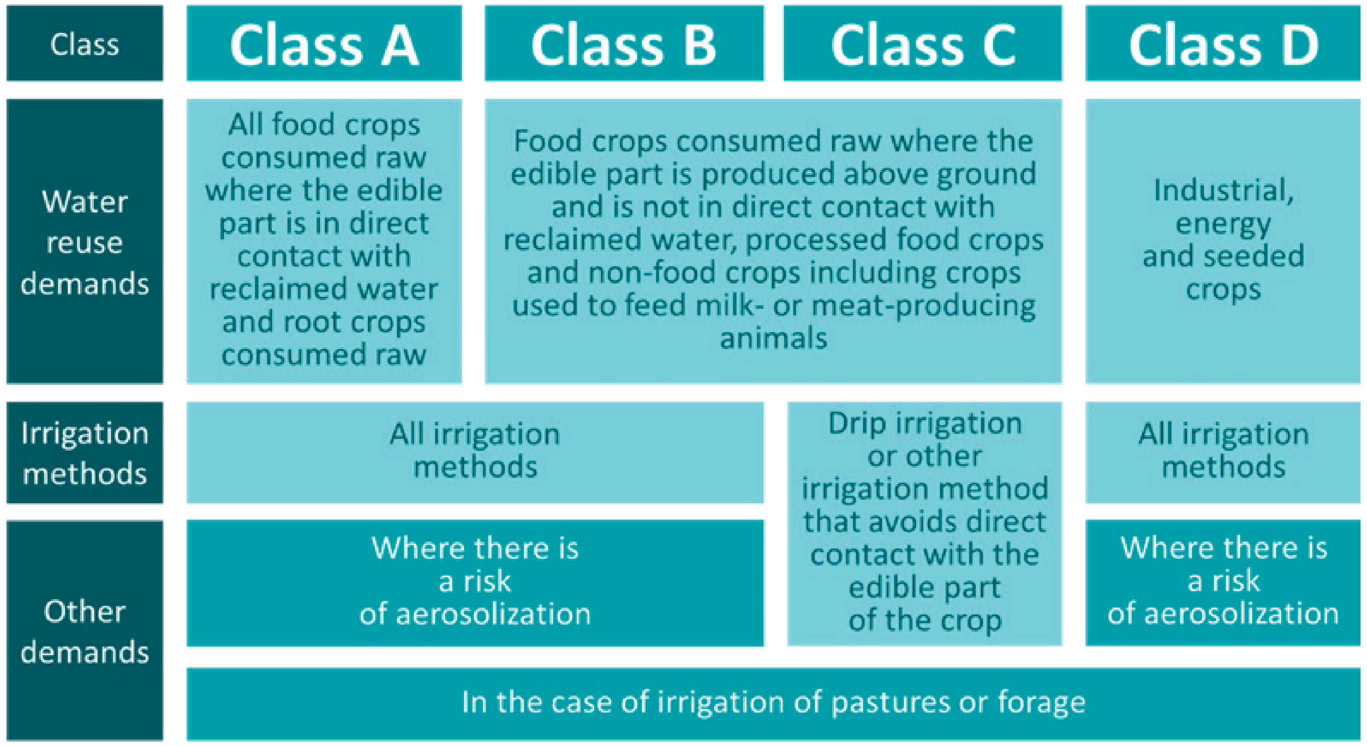


Figure 2. Reclaimed water classes according to Regulation 2020/741

Table 1. presents general requirements imposed by the regulation. Other parameters may be determined based on the risk assessment described in Annex II of this regulation. The minimum frequency of analyses is written in blue font.

- *2/w means twice a week*
- *2/m means twice a month*
- *BOD_5 - Biochemical Oxygen Demand*

Table 1. Requirements imposed by Regulation 2020/741

		Water quality				
Water class	**Indicative technology target**	E. coli (No/100 ml)	BOD5 (mg/l)	Total suspended solids (mg/l)	Turbidity (NTU)	Other
A	Secondary treatment, filtration, and disinfection	≤ 10 (1/w)	≤ 10 (1/w)	≤ 10 (1/w)	≤ 5 (continous)	Legionella spp.: < 1 000 cfu/l where there is a risk of aerosolisation Intestinal nematodes (helminth eggs): ≤ 1 egg/l for irrigation of pastures or forage (2/m or other)
B	Secondary treatment, and disinfection	≤ 100 (1/w)	In accordance with 91/271/ EEC, (Ann. I, Tab. 1) (Ann. I, sec. D)	In accordance with 91/271/ EEC, (Ann. I, Tab. 1) (Ann. I, sec. D)	-	
C		≤ 1000 (2/m)				
D		≤ 10 000 (2/m)				

You can check [here] if your country has already implemented Regulation 2020/741. There are, however, many Member States that have more detailed legal acts. These are mainly, of course, the southern countries, which are very affected by water shortages.

Additionally, on August 5th, 2022, the European Commission issued [Guidelines to Support the Application of Regulation 2020/741], providing guidance on permits, penalties, risk assessment, preventive measures, and emergency management to ensure smooth implementation of the regulation.

LAW [Council Directive of 21 May 1991 Concerning Urban Wastewater Treatment]

The Urban Wastewater Treatment Directive establishes requirements for the proper collection, treatment, and discharge of urban wastewater to protect public health and the environment. It specifies quality standards for treated wastewater discharged into surface waters. The directive mandates monitoring of key water quality indicators, including Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), total nitrogen, and total phosphorus levels, to minimize the risk of eutrophication in receiving water bodies. It also provides detailed requirements for concentration limits, minimum percentage reductions (relative to the influent), and the methods of measurement for each indicator to ensure consistent and effective compliance.

The directive has been updated by [Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 concerning urban wastewater treatment (recast)].

This directive establishes rules for the collection, treatment, and discharge of urban wastewater to protect both the environment and human health, following the One Health approach. It also introduces provisions for universal access to sanitation, improved transparency in the urban wastewater sector, regular public health surveillance through wastewater monitoring, and the enforcement of the polluter-pays principle.

The directive addresses modern challenges such as emerging contaminants, including microplastics and micropollutants, which can harm the environment even at very low concentrations. It emphasizes the importance of regularly monitoring these substances.

The directive classifies micropollutants into two categories:

- Easily Treatable Substances (e.g.: Amisulprid, Carbamazepine, Citalopram).
- Easily Disposable Substances (e.g.: Benzotriazole, Candesartan, Irbesartan).

To ensure environmental protection, the directive mandates an 80% removal efficiency for selected micropollutants in these categories.

LAW [Directive (EU) 2020/2184 on the Quality of Water Intended for Human Consumption]

This Directive establishes a legal framework aimed at protecting human health through appropriate monitoring and treatment of water intended for human consumption. It specifies microbiological and chemical quality indicators.

Although producing drinking water was not a goal of the ReNutriWater project, these indicators were included as optional measurements for Pilot 1 to enhance safety and align with best practices.

Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy

This directive establishes environmental quality standards (EQS) for substances that can pollute surface waters. Key pollutants covered under the directive include heavy metals (e.g., cadmium, mercury, and lead) and pesticides (e.g., atrazine and chlorpyrifos).

These standards are designed to ensure that treated wastewater complies with environmental safety benchmarks. The directive also provided a basis for incorporating a list of micropollutants into the analytical scope of the ReNutriWater project.

Commission Implementing Decision (EU) 2022/1307 of 22 July 2022 establishing a watch list of substances for Union-wide monitoring in the field of water policy pursuant to Directive 2008/105/EC

The 2022 watch list identifies emerging pollutants that pose a potential risk to aquatic environments and require monitoring due to insufficient existing data. These include substances like antibiotics, fungicides, and pharmaceuticals, which can harm ecosystems even at low concentrations.

Key additions to the 2022 watch list:

- Antibiotics: Clindamycin, Ofloxacin
- Other Pharmaceuticals: Metformin
- Pesticides and Fungicides: Azoxystrobin, Diflufenican, Fipronil

Monitoring these substances enhances irrigation water safety and aligns with EU environmental strategies, including the EU Strategic Approach to Pharmaceuticals in the Environment and the European One Health Action Plan against Antimicrobial Resistance (AMR). These initiatives aim to expand knowledge on the occurrence and spread of antimicrobials in the environment.

The watch list defines maximum concentrations for most micropollutants that have been studied. For those without established limits, these are expected to be added in future updates.

» FAO Paper No. 29: "Water Quality for Agriculture"

This document outlines proposed requirements for the concentrations of nutrients and heavy metals in reclaimed water used for irrigation. While nutrients promote plant growth, their levels must be carefully controlled to prevent biofilm formation and maintain an appropriate carbon-to-nitrogen-to-phosphorus (C:N:P) ratio for effective irrigation. The Food and Agriculture Organization (FAO) paper establishes maximum concentrations for heavy metals, such as cadmium (≤ 0.01 mg/l) and arsenic (≤ 0.10 mg/l), to ensure they do not inhibit plant growth. It also recommends maximum concentrations for trace elements, including iron (≤ 5 mg/l) and zinc (≤ 2 mg/l), which can enhance plant growth when maintained within safe limits. Additionally, the document specifies the usual ranges of nutrients in irrigation water, such as nitrate-nitrogen (≤ 10 mg/l), ammonium-nitrogen (≤ 5 mg/l), phosphate-phosphorus (≤ 2 mg/l), and potassium (≤ 2 mg/l), ensuring optimal conditions for agricultural use in line with the FAO's guidelines on water quality in agriculture.

Next, we present the state of the law regulating water reclamation and reuse in selected EU countries: Estonia, France, Greece, Hungary, Italy, Portugal, Romania, Spain and Sweden.

Water reuse regulations in selected EU countries

ESTONIA

Estonia is the only Baltic country with legislation touching the subject of the recovery of water from wastewater. The relevant legal instrument is the Estonian *Water Act*, which introduces the topic of water reuse in §128. The act does not specify the permissible uses of treated wastewater. However, §128 provides that reclaimed water production refers to the treatment of wastewater, mine water, quarry water, cooling water, or aquaculture water, for the purpose of transferring it to a third party.

FRANCE

In France, the subject of reclaimed wastewater is addressed in the *Environmental Code*. Compared to EU legislation, French legislation is similar regarding the uses, classes, and monitoring requirements of reclaimed water.

GREECE

By virtue of the joint ministerial decision, measures, conditions, and procedures regarding the reuse of treated wastewater have been established. The aim of the document is to promote the reuse of such water and to conserve water resources, to counteract the effects of water shortages and drought in the Mediterranean region, as well as the negative impacts of climate change, overexploitation of water resources, and groundwater salinization.

According to Article 4, reuse is foreseen primarily for irrigation, which is classified into two types: restricted and unrestricted, depending on the use of reclaimed water, whether crops are consumed raw, and how they are irrigated. Article 6 regulates the potential use of reclaimed water in urban and suburban areas, including for the irrigation of green spaces, recreational areas, forests, cemeteries, roadside slopes, public parks, gardens, spaces around hotels, for firefighting, cleaning streets and sidewalks, decorative fountains, the creation and maintenance of lakes and wetlands, and for reinforcing surface water flows. Use for drinking, bathing, and domestic activities is explicitly excluded. Article 7 concerns the use of treated wastewater in industry.

HUNGARY

In Hungary, *Government Decree No. 50/2001 (IV.3.) as revised lays down the rules for the agricultural use and management of wastewater and sewage sludge*. Its purpose includes the implementation of *Regulation (EU) 2020/741 of the European Parliament and of the Council*, and among other objectives, the regulation of the use of certain types of wastewaters while avoiding harmful effects on the environment, human and animal health. The law permits the use of treated wastewater in agriculture, particularly for the irrigation of industrial crops, energy crops, and seed crops. §4 clarifies that such wastewater must not be used for crops intended for human consumption or as animal feed.

ITALY

In Italy, water reuse is governed by *the Regulation setting out technical standards for the reuse of wastewater for the implementation of Article 26(2) of Legislative Decree No. 152 of 11 May*. The Regulation establishes technical standards for the reuse of domestic, urban, and industrial wastewater. Permitted uses for reclaimed water include irrigation of crops, green areas, recreational and sport areas, as well as applications in industry and cities: street cleaning, heating systems, cooling systems, and toilet flushing, firefighting water, process water, cleaning water. Using water in contact with food, pharmaceuticals, and cosmetics is prohibited.

PORTUGAL

Portugal's *Water Resources Law* establishes the framework for the sustainable management of water resources. One of its manifestations is contained in Article 44(3), which stipulates that the abstraction of public water resources, especially for the irrigation of gardens, public spaces, and golf courses, should, whenever possible, be supplemented by alternative water sources, e.g., reclaimed water, storm water. To further promote water reuse, Article 60 establishes a general principle under which the granting of discharge licenses is subject to confirmation that no alternative disposal method is available, including recovery operations. This requirement is aimed at encouraging the reuse of water and minimizing unnecessary discharges into the environment.

ROMANIA

Pursuant to Article 5 of the updated *Decision No. 188 of 28 February 2002* on the approval of standards for the conditions of discharging wastewater into the aquatic environment, Romania—due to its geographic location within the Danube River Basin and on the Black Sea coast, as well as the need to protect these areas—declares its entire national territory a sensitive area. Article 6 provides that treated wastewater may be reused, subject to approval by the competent authorities, depending on its origin and intended field of application.

SPAIN

Spain has a rich experience in water reuse, mainly in agriculture. It responded to the need to establish a legal framework for water reuse and to implement Regulation (EU) 2020/741 by adopting *Royal Decree 1085/2024 of 22 October 2024*. This Decree amends various Royal Decrees governing water management. Its primary objectives are to ensure the safety of reclaimed water for its intended uses, protect human, animal, and environmental health, promote a circular economy and climate change adaptation, and ensure sustainable water management and the protection of water resources by addressing shortages and pressures on aquatic ecosystems. It goes far beyond agricultural applications but prohibits certain directions like direct human consumption, food industry, hospitals and medical facilities, aquaculture in the breeding of filter-feeding mollusks, recreational use in swimming pools.

SWEDEN

Swedish Regulation (2024:161) concerns the use of reclaimed water for agricultural irrigation. It complements EU Regulation 2020/741. Reclaimed water may be used for irrigating agricultural crops, and the end user is responsible for ensuring compliance with the required water quality standards. The Swedish Environmental Protection Agency may issue additional rules specifying the necessary safety measures for such use. Before doing so, the Agency must consult the Swedish National Food Agency and the Swedish Board of Agriculture.

4 ReNutriWater pilots

4.1 Introduction to piloting

Recovering water from wastewater is a very serious challenge, although at first glance it seems very easy. Urban wastewater is water in over 99% of its volume (Figure 3). It is enough to remove less than one percent of the pollutants from it. In reality, it is a serious challenge. We would like to recover water in which nutrients remain, but it will be free of other pollutants such as heavy metals, microplastics, pharmaceuticals and pathogenic microorganisms.

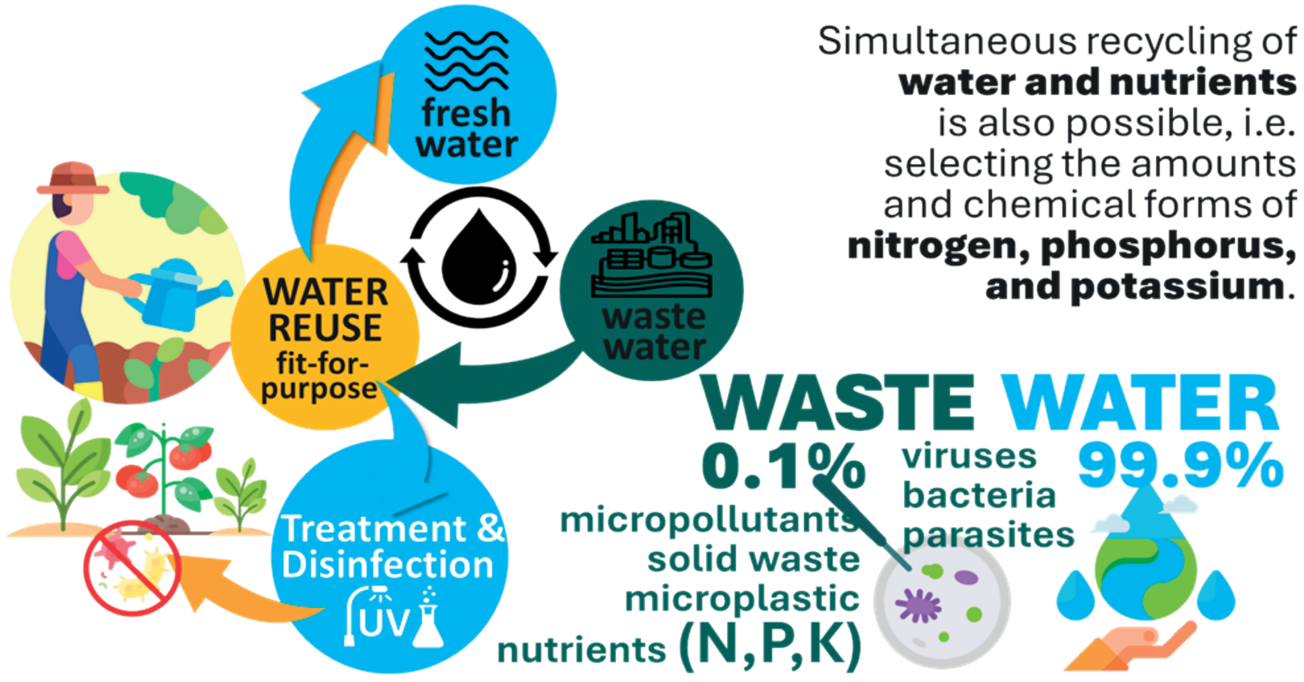


Figure 3. Challenges of water reclamation and reuse

In our project, we decided to introduce this issue to four target groups:

- Infrastructure and public service providers, mainly urban wastewater treatment plant operators
- Local public authorities (municipalities)
- Small and medium enterprises (SME) from tourism (hotel operators) and technology providers
- Interest groups, organizations interested in this challenge

We decided to focus on the basic issues that would bring the issue closer to our target groups. So we conducted three pilots and developed tools to support the development of decision-makers' knowledge.

The pilots covered three issues (Figure 4):

- disinfection of reclaimed water,
- irrigation of urban areas (lawns, flower beds),
- experimental greenhouse crops.

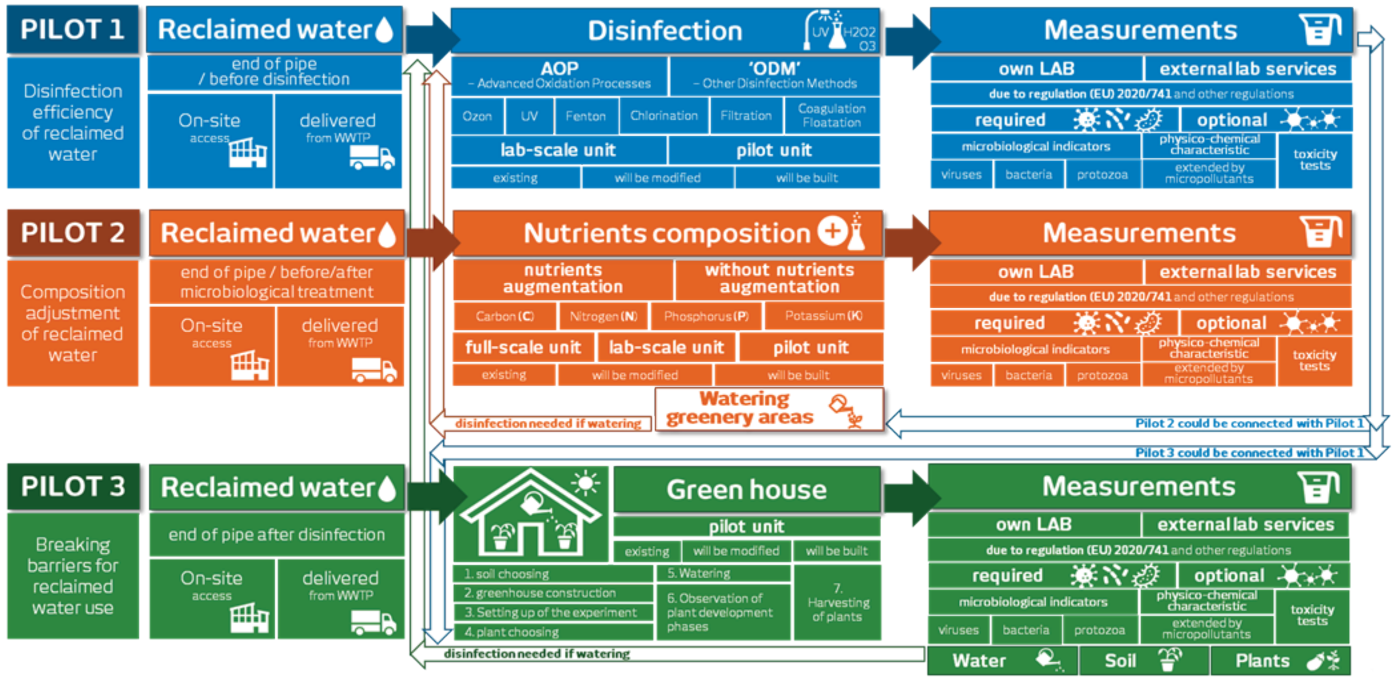


Figure 4. The pilots' scope

Pilot 1. "Disinfection efficiency of reclaimed water" focused on adapting and assessing the effectiveness of the disinfection stage in water reclamation. The primary objective was to develop science-based recommendations for optimizing disinfection processes after conventional wastewater treatment systems.

Pilot 1 main stations were located at:

- Savonia University of Applied Sciences, Kuopio, Finland,
- Wastewater Treatment Plant Warsaw Południe, Warsaw, Poland.

Disinfection methods were also tested in other pilots in Poland, Latvia, and Denmark. Pilot operators were supported by researchers from the Warsaw University of Technology and the University of Latvia.

Pilot 2. "Composition adjustment of reclaimed water" focused on optimizing the nutrient composition of reclaimed water, particularly nitrogen and phosphorus, to meet the requirements for its intended applications, such as irrigation or landscaping (e.g., parks and urban greenery).

Pilot 2 locations were the following:

- Wołkowyja (Poland) at a pilot plant operated by Schwander Polska Ltd, Poland
- Jūrmala Water Utility, Latvia

Moreover, the fertilizing properties of reclaimed water were analyzed at Savonia University of Applied Sciences in Kuopio and at Warsaw University of Technology.

Pilot 3. "Breaking barriers for reclaimed water use" aimed to develop practical applications to address barriers to the use of reclaimed water. The objective was to demonstrate that reclaimed water can be safely used for irrigation and as a nutrient source without requiring significant investments in existing wastewater treatment infrastructure.

The pilot included greenhouse trials for growing different crops with water reclaimed from wastewater. This approach is particularly relevant in regions where reclaimed water is not yet widely accepted or where external factors, such as water scarcity, are not major drivers for adopting sustainable water practices.

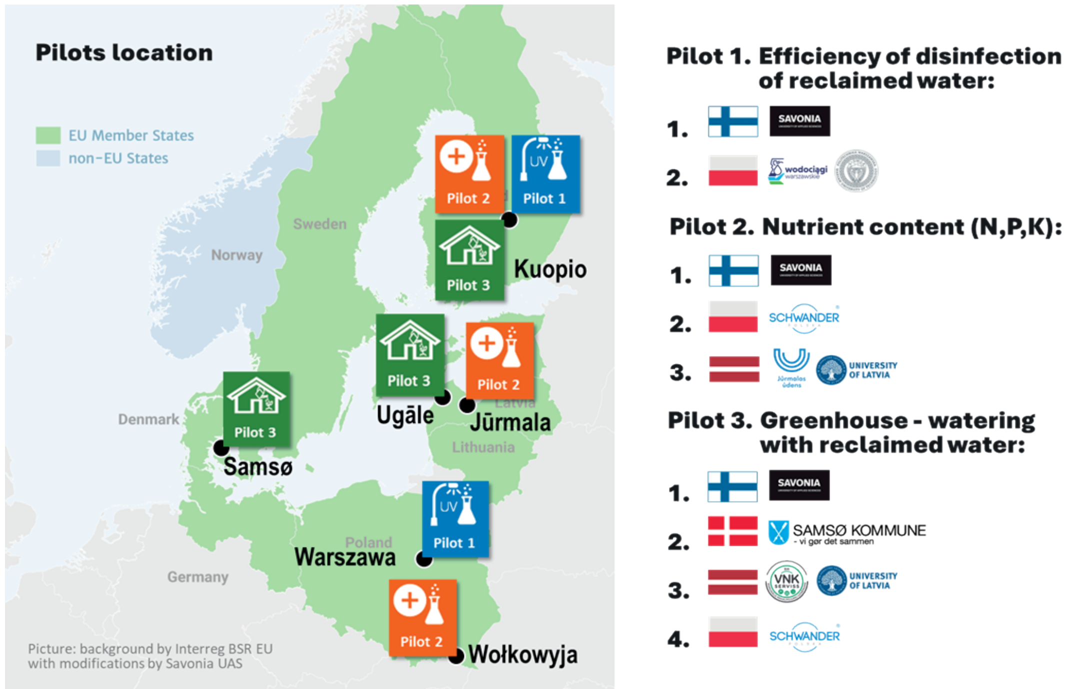


Figure 5. Overview of Pilot Locations

Greenhouses have been located at:

- Savonia University of Applied Sciences, Kuopio, Finland,
- Samsø WWTP, Denmark,
- Ugāle WWTP operated by VNK Serviss, Latvia,
- WWTP in Wołkowyja, Poland.

Therefore, treated wastewater from different treatment plants was used in the pilots (Table 2).

Table 2. Basic parameters of the wastewater treatment plants used in the project

WWTP name		Finland Kuopio	Finland Tahko	Poland Warsaw	Poland Wołkowyja	Latvia Jūrmala	Latvia Ugāle	Denmark Samsø
Parameter	**Units:**	**Pilot 1,2,3**	**Pilot 1,2**	**Pilot 1**	**Pilot 2,3**	**Pilot 2**	**Pilot 3**	**Pilot 3**
Population equivalent	[P.E.]	90,000	3,800	580 000	6,133	35,400	1,035	8,624
Treated wastewater volume								
Yearly	[m³/ year]	6,600,000	400,000	24 378 204	300000	2,700,000	99,623	426,942
Monthly	[m³/ mth]	550,000	33,333	2 031 517	25,000	225,000	9,057	35,579
Daily average flow	[m³/d]	18,333	1,111	66 607	1,000	7,500	317	1,170
Daily maximum flow	[m³/d]	40,000	2,500	94 034			940	1,645
Sources of treated wastewater:								
Domestic	[%]	70	70	80,4	100	80	30	65
Non-domestic	[%]	10	0	0	0	0	0	0
Rainwater	[%]	20	30	19,6	0	20	70	35

4.2 Water reclamation pilots

4.2.1 Kuopio

Tahko-Nilsiä wastewater treatment plant is located in central Finland, in the Northern Savonia region. It has a capacity of 3,800 PE, treating 400,000 m³ per year, with an average daily wastewater flow of 900 m₃ and a maximum of 2,500 m³/day. It treats 70% of domestic wastewater and 30% of surface runoff, but does not treat industrial wastewater. The area served by the WWTP is designated for tourism, where sports are practiced at any time of the year. The technology includes primary treatment on screens, sand removal with sedimentation, and then biological treatment (denitrification, alternating aeration, and nitrification), and sedimentation in a secondary settling tank. Before the treated wastewater is discharged into a lake, it is disinfected. Figure 7 presents the technology diagram.

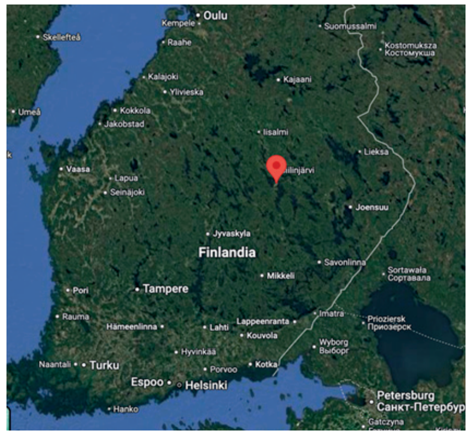
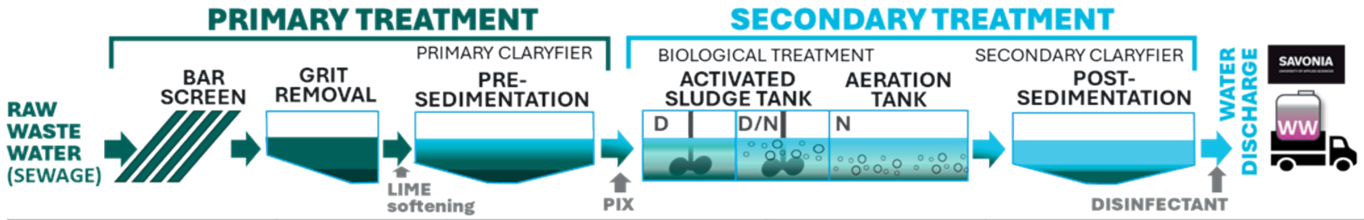


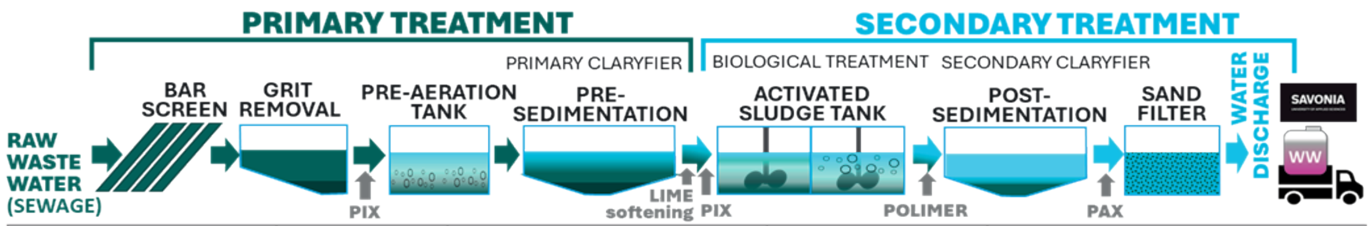
Figure 6. Location of Kuopio, Finland



Country	City	Object – the liquid stream only	Logo(s)	Pilots
Finland	Tahko	WWTP Tahko-Nilsiä	KUOPION VESI, SAVONIA	Pilot 1, Pilot 2

Figure 7. Tahko-Nilsiä Wastewater Treatment Plant technology

Kuopio-Lehtoniemi wastewater treatment plant is also located in central Finland, in the Northern Savonia region. It has a capacity of 90,000 PE. The amount of treated wastewater is 6.6 million m³/year, 550,000 m³/month, an average daily flow of 18,000 m³/d, and a maximum daily flow of 40,000 m³/d. Sources of treated wastewater are 70% domestic wastewater, 10% industrial wastewater, and 20% surface runoff. The area served by the plant is inhabited by over 120 thousand people. The city offers tourists and residents a combination of raw nature, lake waters, and active recreation, regardless of the weather. Treatment processes at WWTP include mechanical, biological, and chemical treatment, as well as sludge management. Biological microbial activity and appropriate chemical supplements remove organic matter, nitrogen, and phosphorus from the wastewater so that the water at the outlet of the discharge pipe is clean again and can be returned to the natural cycle. The treated wastewater is collected for several days at the treatment plant in one massive tank before it is discharged to the lake. Figure 8 presents the technology diagram.



Country	City	Object – the liquid stream only	Logo(s)	Pilots
Finland	Kuopio	WWTP Lehtoniemi	KUOPION VESI, SAVONIA	Pilot 1, Pilot 2, Pilot 3

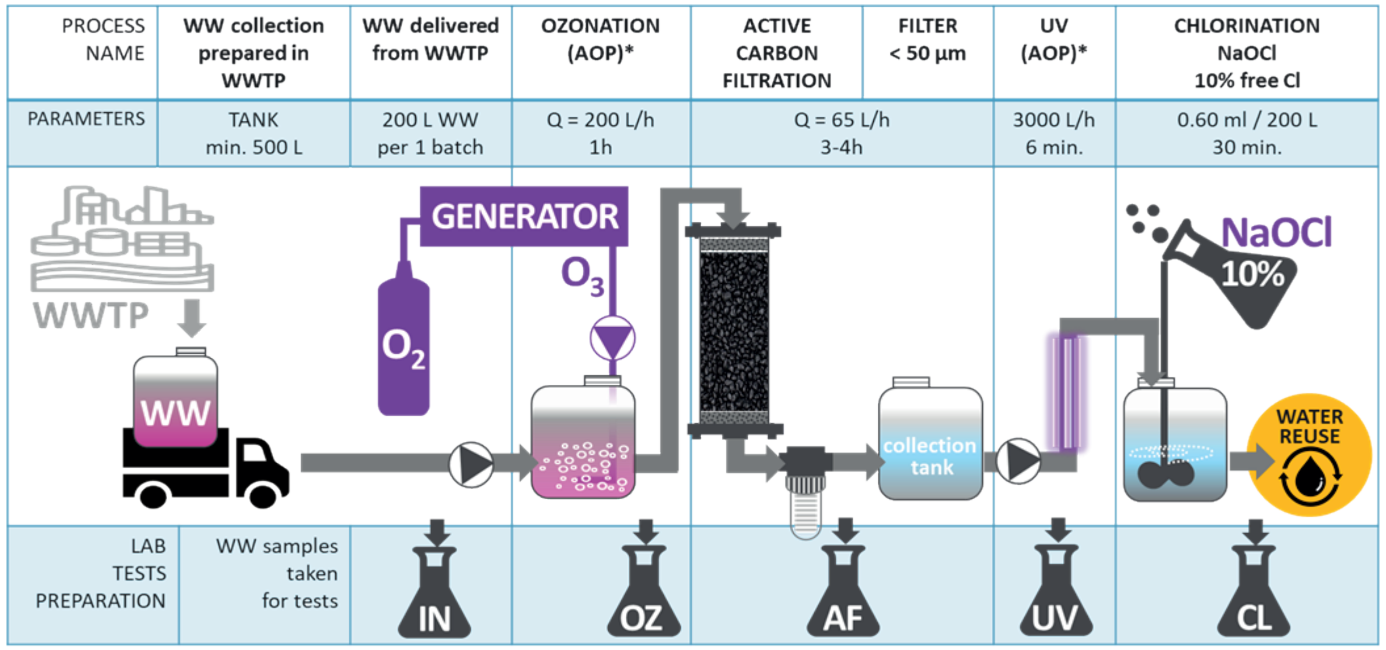
Figure 8. Kuopio-Lehtoniemi Wastewater Treatment Plant technology

Laboratory scale AOP pilot station is placed in Savonia University of Applied Sciences. Treated wastewater for piloting was transported from Kuopio-Lehtoniemi WWTP or Tahko-Nilsiä WWTP in an amount of about 500 L for making batches by passing it through the pilot station with Advanced Oxidation Processes (AOP). The pilot station used 200 L of wastewater in one batch. The pilot station is adapted only to perform treatment in batches on a lab scale; to use it at a wastewater treatment plant for continuous work would require scale-up and modifications.

Figure 9. presents the water reclamation process:

- IN - inlet. This is the point where the WWTP effluent is delivered without storage directly for testing.
- OZ – ozonation,
- AF – sorption on activated carbon + filtration on string filter (<50µm),
- UV – disinfection with a UV lamp,
- CL – chlorination with a dose of 10% NaOCl.

This pilot station demonstrates a comprehensive water treatment process integrating advanced oxidation, adsorption, UV irradiation, and chlorination. It operates within a controlled laboratory environment to optimize treatment parameters and evaluate the system's efficiency. Future modifications could adapt the system for continuous operation at full-scale wastewater treatment facilities.



Country	City	Object	Logo(s)	Pilots
Finland	Kuopio	Disinfection pilot station in lab scale	SAVONIA	Pilot 1, Pilot 2, Pilot 3

Figure 9. Laboratory scale AOP pilot station placed in Savonia University of Applied Sciences

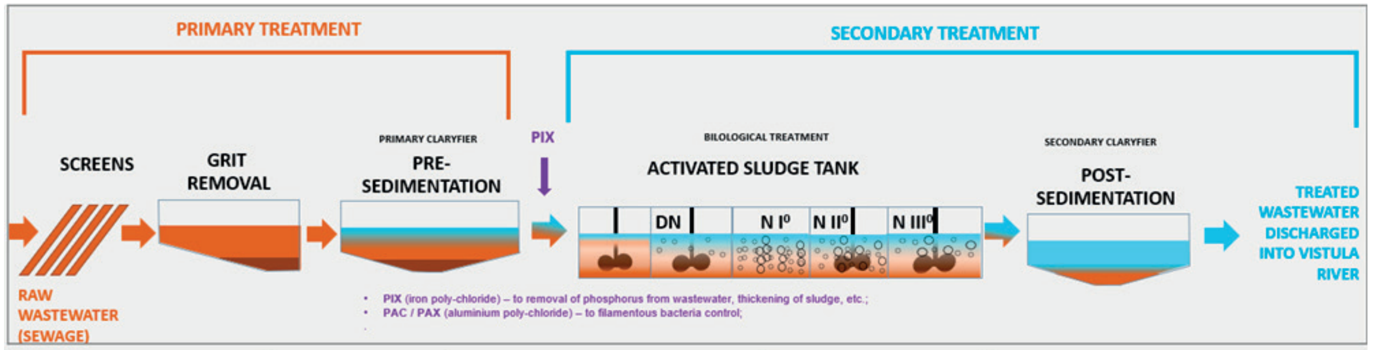
Water samples for testing were taken after every process step. Wastewater from Tahko-Nilsiä WWTP was treated in batches from the beginning of 2024 to May 2024 with a monthly frequency (weeks: 3, 7, 11, 12, 15, 20), and in fall-winter 2024 (week 44). Wastewater from Kuopio-Lehtoniemi WWTP was treated during the summer with a weekly frequency (weeks: 23-39), due to relating it with watering of greenhouse crops in pilot 3.

4.2.2 Warsaw

Południe WWTP is one of four WWTP operated by the Warsaw Municipal Water and Sewage Company SA. It is located in the southern part of Warsaw.

The WWTP Południe (Figure 10) was designed for a capacity of 580,000 PE. In 2024, over 24,000,000 m³ of sewage was treated there, with an average daily flow of 67,000 m³, a maximum of 94,000 m³/day. 81% of the inflow volume is domestic sewage, and approximately 19% is rainwater. The technological processes include mechanical and biological processes with increased removal of nutrients. The primary treatment is based on cleaning screens, grit removal, and sedimentation in primary settling tanks. Then, wastewater is directed to two biological lines. Each line consists of a radial reactor and two secondary settling tanks. The radial reactor is divided into five successive zones with different oxygen conditions. These are respectively an anaerobic zone, an anoxic zone, and three aerobic zones with different oxygen concentrations. After the reactor, the sewage is directed to secondary settling tanks where the sludge is separated from the active sewage sludge. Then, the treated sewage is discharged into the Vistula River. Figure. 11 shows the technology diagram.

Figure 10. Location of Południe WWTP in Warsaw, Poland



Country	City	Object – the liquid stream only	Logo(s)	Pilots
Poland	Warsaw	WWTP Warsaw Pł.	wodociągi warszawskie	Pilot 1

Figure 11. Południe Waste Water Treatment Plant technology

The semi-technical scale AOP pilot station is located on the WWTP Południe.
The station consists of two modules. The first module is designed to remove suspensions and other pollutants from sewage before directing them to the second module. The second module is an advanced oxidation process used for full disinfection of sewage and removal of micropollutants, including antibiotics, hormones, pesticides, etc. The ozonation process was tested at different retention times and variable ozone doses. The target pilot station with a capacity of 5 m³/h located on the WWTP Południe consists of successive ion exchange and disinfection processes through ozonation.

The research work carried out in the period from 2024-2025 was divided into two phases. The main goal of the first phase was to select an effective process for removing so-called remaining pollutants from wastewater, including total suspended solids. It was assumed that the sewage after module I would be characterized by turbidity below 1.00 NTU. Two technologies were accepted for testing (Figure 12). The first technology is based on the filtration process on fabric filters. The second technology is based on the ion exchange process. The first phase was completed in November 2024. The ion exchange process was selected as the most effective process, allowing the assumption results, i.e., turbidity below 1.0 NTU. The second phase of the research consisted of selecting the appropriate parameters of the reclaimed water ozonation process after the ion exchange process. Different retention times and equal ozone doses were tested. During the entire research period, the pilot installation operated with a continuous inflow of treated wastewater from the WWTP Południe.

Wastewater and water samples for testing were taken before and after every process point. During the first phase, average daily samples were collected at a frequency of once per week. During the second phase, the frequency of sampling for laboratory analysis was increased to twice per week.

This pilot plant demonstrates a comprehensive water treatment process integrating advanced oxidation and ion exchange. The pilot plant operates in real treatment plant conditions, with a continuous inflow of sewage with a capacity of 3 to 5 m³/h. The plant has a modular design, which allows for future modifications to test other processes used for water recovery from sewage, including sorption on activated carbon or disinfection with UV lamps or by dosing chemical reagents.

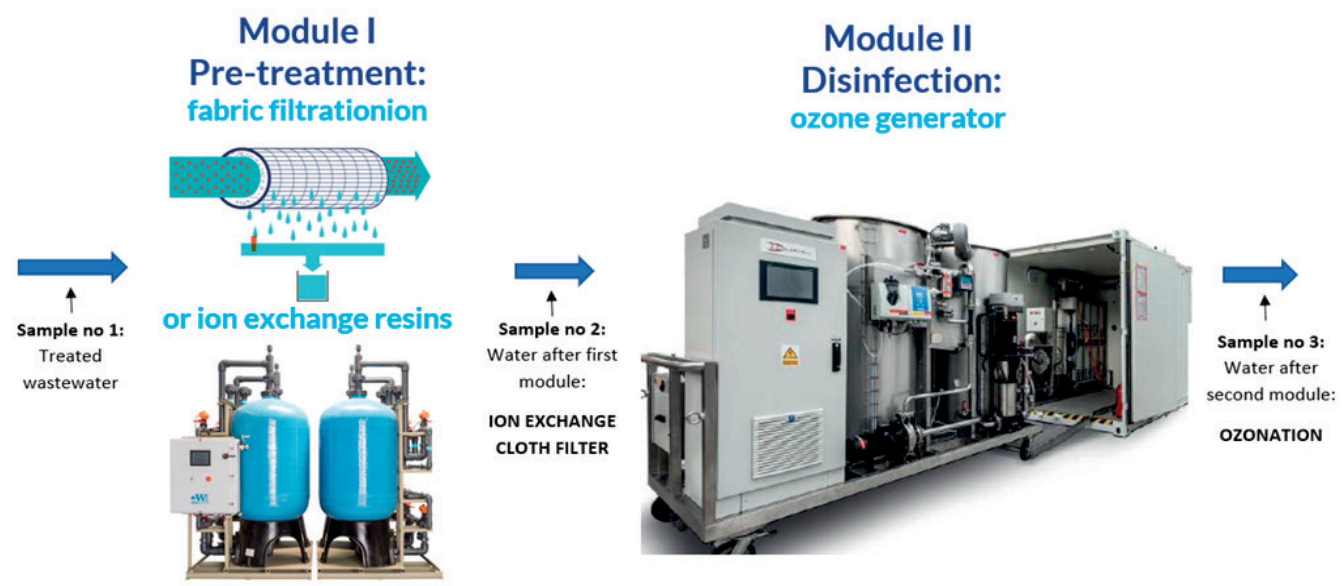


Figure 12. Semi-technical scale pilot station placed in WWTP Południe

4.2.3 Wołkowyja

Wastewater Treatment Plant in Wołkowyja is one of four urban WWTPs operating in the Solina municipality. Their capacities are as follows:

- Berezka WWTP – 1 800 m³/d (17 500 P.E.), construction year: 2020,
- Wołkowyja WWTP- 1000 m³/d 6133 P.E.), construction year: 2023,
- Solina below the Dam WWTP- 800 m³/d 6000 P.E.), construction year: 2016,
- Zawóz WWTP- 150m³/d (1000 P.E.), construction year: 2020.

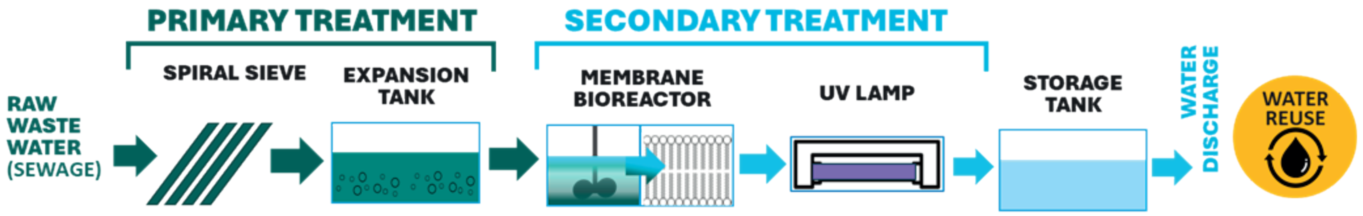
The modernization of two treatment plants is planned for the near future: in Solina below the Dam and in Zawóz. The design process for the modernization of the treatment plant in Solina has already been completed, while design work for the facility in Zawóz is in its final stage.

Figure 13. Location of Wołkowyja, Poland

The Solina municipality, located in south-eastern Poland (Figure 13), is currently inhabited by approximately 5,200 residents. Due to its touristic nature and the significant influx of visitors during the summer and peak tourist season, the local treatment plants must be prepared for much higher loads. During peak periods, the volume of wastewater can be as much as ten times higher than during standard use by residents, requiring adequate capacity and efficiency of the wastewater treatment system.

The provision of an efficient and effective sanitation infrastructure is crucial for the protection of the environment and of the comfort of both permanent residents and tourists visiting the municipality. The planned modernization and development of the water and sewage infrastructure aims to adapt the treatment plant to the dynamic changes associated with the development of tourism in the region.

The WWTPs in Berezka and Wołkowyja are based on MBR (Membrane Bioreactor) technology (Figure 14). The WWTPs in Solina below the Dam and Zawóz are also designed using this solution. The municipality of Solina chose MBR technology because of its high flexibility and efficiency in wastewater treatment, which is crucial in this municipality as the seasonal variability of the load on the sewer system is extremely high. Thanks to the use of membrane bioreactors and UV lamps, it is possible to achieve a high level of organic pollutant reduction and complete disinfection of the treated wastewater, which has a direct impact on the natural environment.



Country	City	Object – the liquid stream only	Logo(s)	Pilots
Poland	Wołkowyja	WWTP Wołkowyja	SCHWANDER POLSKA	Pilot 2, Pilot 3

Figure 14. Wołkowyja Waste Water Treatment Plant technology

Specifics and advantages of MBR technology

MBR technology is a combination of a gravity-flow MBR (Membrane Biological Reactor) system and UV lamp disinfection process, and is used to treat wastewater and recycle water from wastewater. Reclaimed water can be reused, among other things:

- for agricultural purposes for crop irrigation,
- for recreational applications such as snowmaking on ski slopes, irrigation of green spaces, and recreational facilities such as golf courses, sports stadiums, parks, ponds
- for use on farms as domestic water, for all purposes except drinking and personal hygiene,
- for urban applications for street and square cleaning, irrigation of green spaces, and ornamental plants

The quality of treated wastewater complies with the requirements of EU Regulation 2020/741 and Polish law. The applied MBR technology allows to obtain the quality of the treated effluent to comply with class 'A' of reclaimed water quality.

Thanks to proprietary technological solutions, MBR technology is characterized by high flexibility and resistance to seasonal load variations related to the volume of incoming sewage and sewage truck traffic, resulting, for example, from the tourist character of the region. Based on a proprietary process algorithm and a specific configuration of the process equipment, stable operation of the wastewater treatment plant in the range of 10% (off-season) to 100% load (tourist season) and a smooth transition between operating modes is ensured. With conventional solutions, this flexibility is difficult. Hermitization and thermal insulation of the reactors ensure their stable and trouble-free operation. The average annual temperature of the activated sludge in the process tanks is maintained in the range of 12-16°C, guaranteeing process stability. Figure 15. shows a technological scheme of the treatment plant with MBR technology. MBR technology consists of two independent process lines, each operating in three-phase mode. Each process line includes anaerobic, hypoxic, aerobic, and a separate filtration chamber. The anaerobic and hypoxia chambers are equipped with chamber mixers and overflow windows that allow the wastewater mixture to flow freely between the chambers. In addition, there is a denitrification reserve in the nitrification zone, which operates in the event of insufficient nitrogen reduction. In the hypoxia chamber, there are pumps for recirculating activated sludge to the anaerobic chamber.

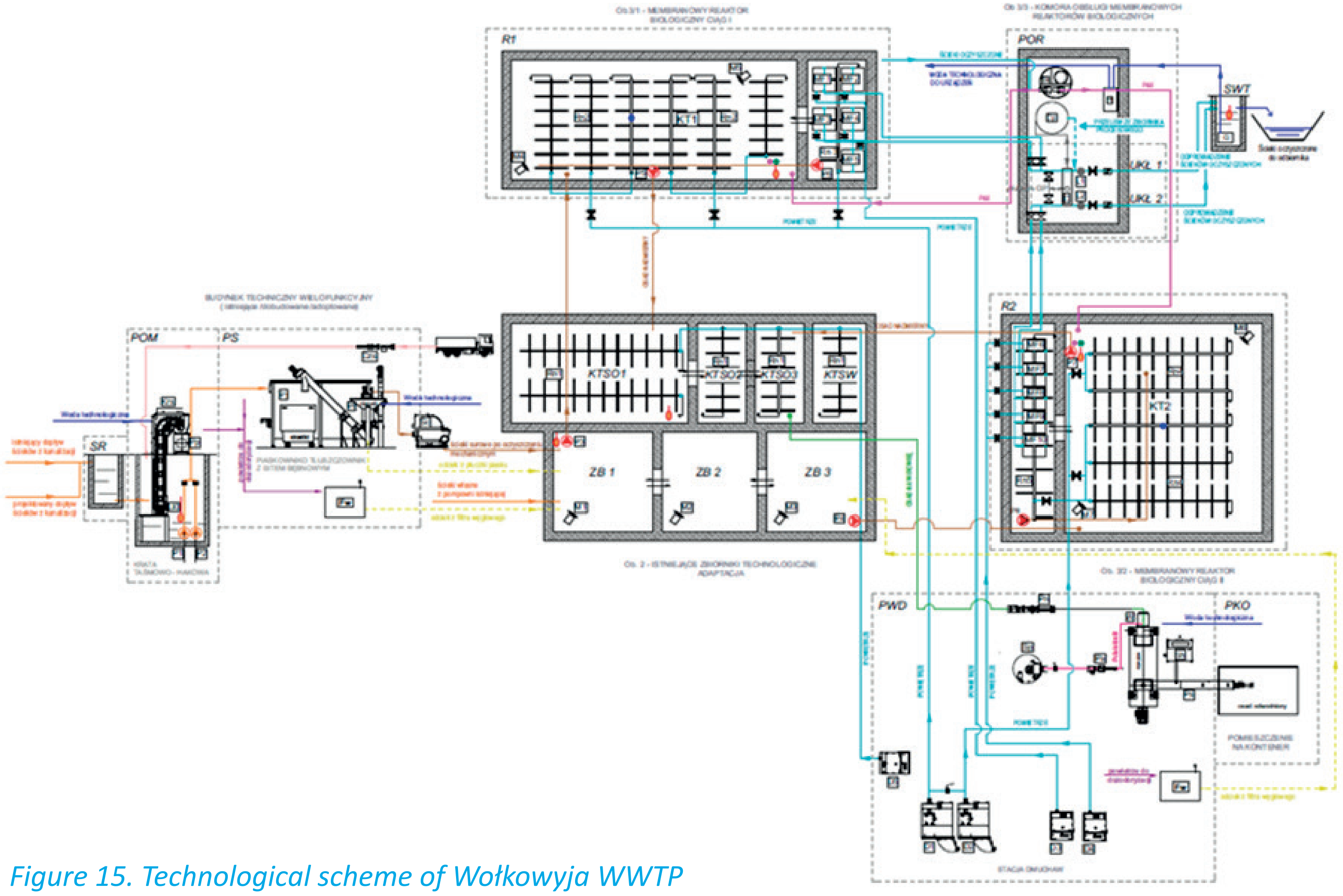


Figure 15. Technological scheme of Wołkowyja WWTP

In the anaerobic chambers, fine bubble membrane diffusers and 2 agitators in each one of them are installed across the chamber bottom to ensure mixing of the chamber contents. Internal recirculation from the filtration chambers to the hypoxia chamber is also used.

Filtration chamber

The final element of the process line is the filtration chamber, where water is separated from activated sludge by means of membrane microfiltration. Excess sludge is continuously discharged to the excess sludge chamber, depending on the indications of the density probe, and treated wastewater is directed to the UV lamp disinfection. The treated effluent is discharged to the receiver via a process water well. Gravity microfiltration modules from Alfa Laval were installed in the filtration chambers, with a total filter area of 3860 m². The flow of the effluent and activated sludge mixture from the aerobic chambers to the filtration chambers is by means of an overflow. The separation of the treated effluent from the activated sludge is carried out by gravity microfiltration membranes as a result of an overpressure of about 40 mbar, with the tank filling 1m above the module. Table 3. shows the parameters of the membrane filtration process.

Table 3. MBR membrane filtration process parameters

Specification	Unit	Value
Filtration cycle	min	12
Filtration time	min	9
Relaxation	min	3
Filtration time	min/h	45
Total filter area (10 modules)	m²	3860

Cleaning membranes

Two methods of cleaning membranes are used. The first method is to inject air between the membrane sheets, and the second consist of periodic chemical flushing (every 4 months for 1 hour, using 15% sodium hypochlorite (NaOCl) at a rate of 0.03 kg per square metre of membrane surface). In addition, the module is equipped with an S-Aerator™ aeration system. With traditional multi-tube diffusers, the problem is the need to remove blockages. Cleaning and restarting diffusers is a labour-intensive and time-consuming process.

The S-Aerator™ diffuser has a single-line design that prevents clogs from forming. These are removed automatically as the air pressure in the system increases. The system described above is a development and an in-house product of Schwander Polska®.

Automation of plant operation

All operations of wastewater treatment plant are automated and do not require constant maintenance. To optimise nitrification and denitrification processes and phosphorus precipitation in real time, a superior proprietary NSS control system is used (Schwander Polska® is the owner of the copyright to the software and the entity entitled to licence and supply the aforementioned software on the basis of many years of experience). The control system provides process control and operation in terms of process influence, visualisation, recording, reporting, archiving and data processing. A microprocessor-based PLC facility control system is used in the wastewater treatment plant. Signalling from the autonomous plants is made available on the panel and in the SCADA system. The power and control cabinet houses the drive control and protection systems, as well as the PLC controllers with the necessary input/output cards and an Ethernet switch. A 10"colour touchscreen operator panel for local control and input of operating parameters is built into the façade of the cabinet. The dispatching computer station is located in the control room and is connected to the PLC located in the supply and control cabinet. The connection is made via the Ethernet bus.

The NSS control system allows optimisation of nitrification and denitrification processes and phosphorus precipitation in real time. The current operating conditions of the reactor, the length of the aeration time and the mixing time of the aeration chamber of the biological reactor are monitored and adjusted. Optimisation and determination of the durations of these two phases is based on measurements of ammonium and nitrate nitrogen concentrations in the aeration chamber., whereby not only the absolute value of this concentration is taken into account, but also the trend and rate of its change. The nitrification and denitrification optimisation module also has the option of selecting the optimum dissolved oxygen concentration value required for each process line for the duration of aeration. It is also possible for the Operator to set a fixed dissolved oxygen concentration value. If, for some reason, the measurement values necessary for the operation of the optimisation module are not available or the validation of the measurement signals required for its operation is too low, the optimisation module automatically switches to standby operation based only on the ammonium or nitrate nitrogen concentration values and, as a last resort, on the time settings. The phosphorus chemical precipitation optimisation module operates on the basis of measuring the orthophosphate load in the closed-loop biological reactor effluent (measurement of orthophosphate concentration after the precipitating agent dosing point + measurement of the effluent flow supplied to the individual activated sludge chambers). Dosing of the precipitating agent (stepless control of the dosing pump capacity) is optimised in real time so that the required quantity is dosed, while at the same time ensuring that the target value for phosphorus concentration in the plant effluent is achieved. In addition, it is possible to enter a minimum and maximum precipitant dose value into the system (tank). The MBR technology enables simultaneous nitrification and denitrification processes of biological wastewater treatment with increased nutrient removal in one chamber.

The hermetic and thermal insulation of the biological reactors (minimum 15 cm thick polystyrene) ensures stable and trouble-free operation of the reactors. With conventional solutions, there is a high impact of ambient temperature in winter, which is particularly unfavourable for nitrification and denitrification processes.

The inflow of incidental water in MBR wastewater treatment technology has little effect on the treatment process due to the use of a proprietary process algorithm. This is particularly important in two cases that are very common in sewer agglomerations. The first concerns the illegal infiltration of rainwater (illegal connections of roof gutters into the storm water drainage system, etc.) and the second concerns the infiltration of groundwater through leaks in the sewer system. This is particularly important where high groundwater levels are observed. Both cases can occur simultaneously in a given sewer agglomeration, which exacerbates the problem of wastewater treatment. By controlling the equipment with a proprietary process algorithm, this problem can be significantly mitigated, and operational measures can be taken in real time (both day and night). Thanks to such measures, the risk of deterioration in the parameters of the treated wastewater is reduced and the recipient of the wastewater is not exposed to excessively high values of pollution indicators in the treated wastewater.

Intended use of the technology

Matrix: Municipal wastewater with the following parameters:

- Temperature: 8-22°C,
- BOD_5: 300-1000 mg/l,
- COD: 500-1500 mg/l,
- Total suspended solids: 200-800 mg/l,
- Total nitrogen: 20-150 mg/l,
- Total phosphorus: 5-30 mg/l,
- pH: 5-10.

Technology objectives

The aim of MBR technology is to treat municipal wastewater to a level that allows it to be reused in the economy. The effluent quality meets the requirements for Class A reclaimed water according to Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for the reuse of water.

Technical conditions

Membrane modules

MBR technology uses membrane modules with the following technical parameters:

- pH range: 1-11,
- membrane size: 0.2 µm,
- maximum temperature: 50°C
- recommended transmembrane pressure: 10 - 40 mbar,
- typical flow range: 10 - 30 l/m² filter area/h,
- filter area of 1 module: 386 m²,
- frame construction: AISI 316,
- PVDF membrane,
- gravity drainage of permeate,
- manufacturer: Alfa Laval Polska Sp. z o.o.,
- type: MFM 260

Wastewater disinfection

- UV lamps with the following parameters are used for disinfection of treated wastewater:
- UV transmittance min. 98 T 1 cm [%],
- UV dose: 400J/m²,
- Manufacturer: Xylem Water Solutions Polska Sp. z o.o.,
- Type: UV system Spektron 30e,
- Power: 0.38 kW.

MBR technology enables:

1. Treatment of municipal wastewater to the following pollutant levels:

- COD: ≤ 25 mgO_2/l
- BOD_5: ≤ 5 mg O_2/l
- Total suspended solids: ≤ 2 mg /l
- Total phosphorus ≤ 0.5 mg/l
- Total nitrogen ≤ 5 mg/l2
- Turbidity ≤ 2 NTU
- E. coli ≤ 10 NTU/100ml
- Helminth eggs < 1 egg/l
- Legionella spp. < 1 000 IU/l

2. Remove at least 90% of the following micropollutants from wastewater (e.g., Diclofenac, Ibuprofen).

- Achieving the above wastewater treatment effects is possible with the following process parameter values:
- Effluent flow rate: 100-1000 m³/d
- Reactor load of organic pollutants: 0.10 kg BOD_5/ 1 kg SM
- Hydraulic Retention Time: 23 h
- Sludge concentration in bioreactor: 10-12 mg/l
- Dissolved oxygen concentration: 0.3 mg/l

MBR technology combines traditional biological wastewater treatment processes with advanced membrane filtration. Compared to classical activated sludge methods, it allows for:

- Increased efficiency in the removal of organic pollutants and nutrients (nitrogen and phosphorus),
- Eliminates the need for secondary settling tanks,
- High quality of the treated wastewater, allowing it to be reused, e.g. for the irrigation of green areas,
- Reduction of the area required for the operation of the treatment plant, which is important especially in mountainous and tourist areas.

As part of the research, three plots were established, shown with the same plant (grass), differing in the method of irrigation:

- Plot I – irrigation with treated effluent (permeate) from the wastewater treatment plant, coming from the biological sequence in which the process of increased nutrient removal (nitrogen and phosphorus) was carried out.
- Plot II – irrigation with tap water from a local dug well.
- Plot III – irrigation with treated effluent (permeate) from the second process line, in which the technological process was carried out with only carbon removal without nutrient removal.

The research aims to assess the impact of different irrigation methods on plant growth and development, which can contribute to optimising the use of treated effluent in agriculture and the reclamation of green spaces as required.

A part of the pilot was also conducted in Stadła (Podegrodzie municipality).

4.2.4 Jūrmala

The Jūrmala Water Utility WWTP, situated in the Sloka region (Figure 16), treats approximately 70% of wastewater (PE 35,400), and the rest is pumped to the Daugavgriva WWTP in Riga. In addition, approximately 90% of the septic tank sludge collected in Jūrmala is transported to the Sloka WWTP.

The plant has conventional primary treatment (Figure 17) without primary sedimentation, activated sludge process for enhanced biological phosphorus and nitrogen removal, and sludge treatment by mechanical thickening and dewatering.

Influent wastewater flow varied from 5 300 m³/d to 13 500 m³/d. The yearly average was 7 450 m³/d.

The main input consists of wastewater from communal use, while industrial use accounts for less than 10% of the input water, which consists of wastewater from medical and food services.

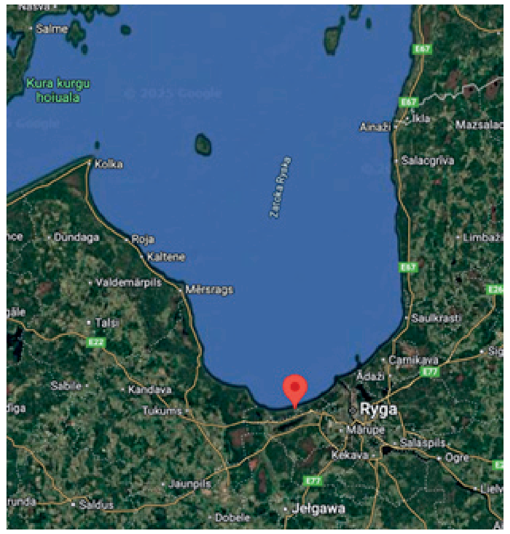
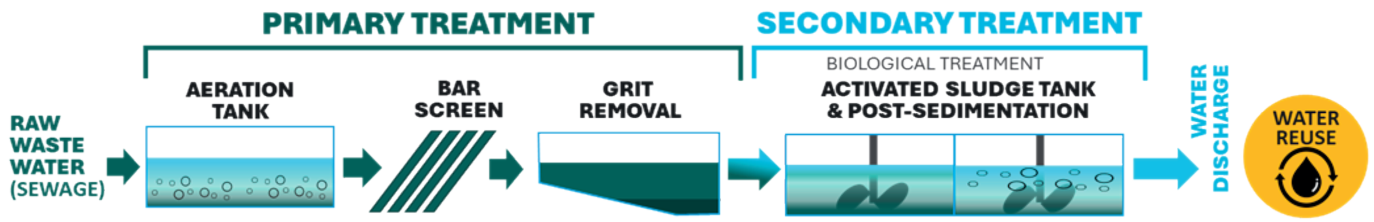


Figure 16. Location of Jūrmala, Latvia



Country		City	Object – the liquid stream only	Logo(s)	Pilots
	Latvia	**Jurmala**	**WWTP Sloka**	Jūrmalas ūdens; UNIVERSITY OF LATVIA	Pilot 2

Figure 17. Technological scheme of Jūrmala WWTP

To evaluate the efficiency of reclaimed water use, 1 m² grass plots within the wastewater treatment plant (WWTP) area were established. During the summer season (April to September), the plots were watered using three different sources: untreated wastewater, chlorine-treated wastewater, and clean drinking water (Figure 18). The grass was cut twice a month, and after being air-dried to a constant weight, its biomass was recorded. Height gain was calculated by subtracting the initial height (7 cm) from the height before cutting. After drying the grass, its dry weight was determined.

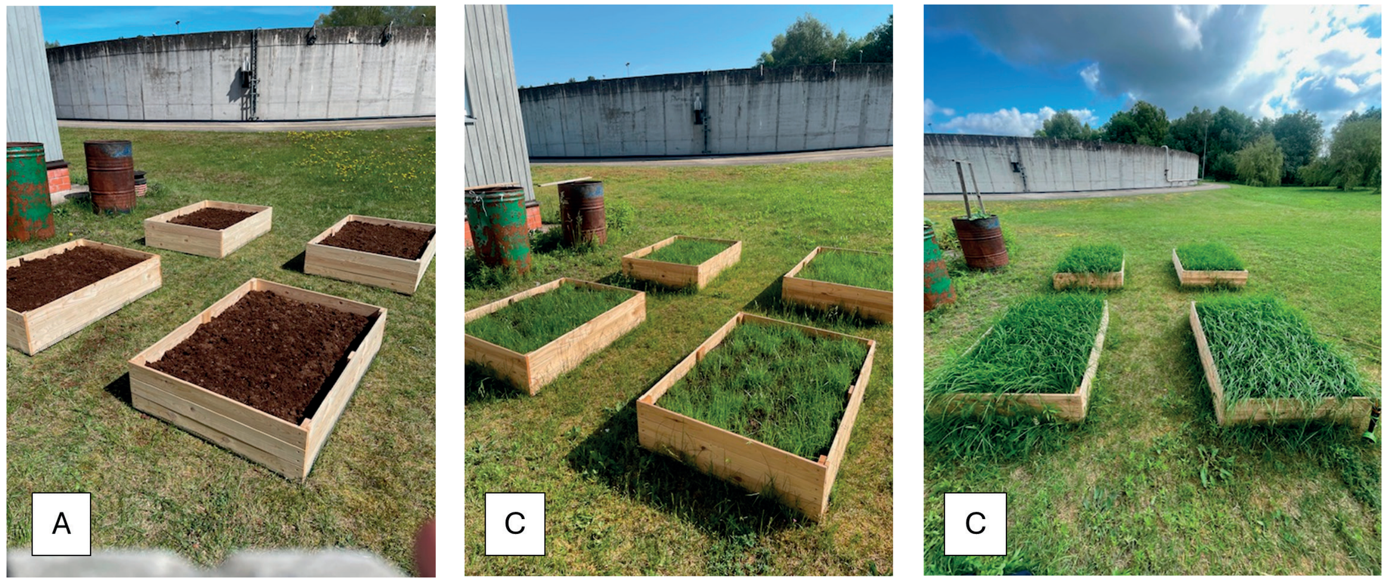


Figure 18. Experimental plots with grass

4.2.5 Ugāle

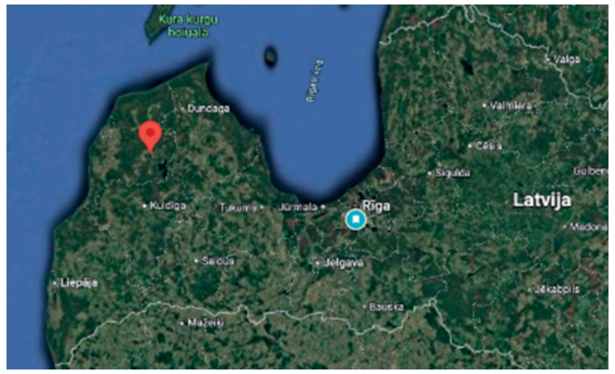


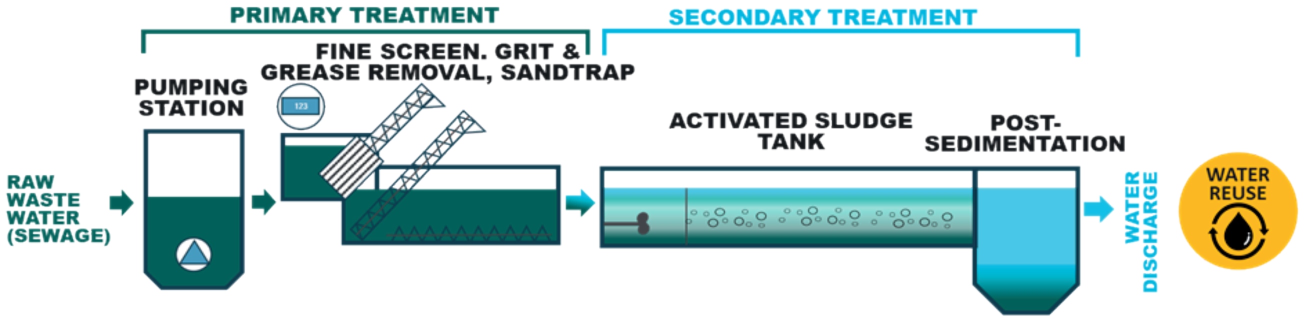
Figure 19. Location of Ugāle, Latvia

Ugale village WWTP is one of the 16 wastewater treatment plants VNK serviss operates in Venstpils region, Latvia. Ugale WWTP is located 39 km from Ventspils, the centre of the region, and 150 km from Riga, capital of of Latvia (Figure 19).

The WWTP in Ugāle village serves 1138 inhabitants connected to the centralised sewerage system. The WWTP in Ugale also accepts the contents of individual wastewater systems from 299 residents who are not connected to the centralised sewerage system. According to the latest data, the calculated PE of the Ugāle WWTP is 1035.

The WWTP of Ugāle village accepts basically a mixture of domestic and precipitation water per year with an average ratio of 30:70. There are no industrial polluters in Ugāle village. The hydraulic design capacity is 300 m³/day. Wastewater volumes vary from season to season and peak at 940 m³/day in raining period of year 2024. In 2024, the Ugāle WWTP treated 317 m³ of wastewater on average per day, which represents 9056 m³ of wastewater per month. In 2024, the Ugāle WWTP treated 99 623 m³ of wastewater.

The WWTP has conventional mechanical treatment without primary sedimentation and activated sludge process for enhanced biological nitrogen removal and partial phosphorus removal (Figure 20). Sludge treatment is carried out in sludge drying beds by natural evaporation.



Country	City	Object – the liquid stream only	Logo(s)	Pilots
Latvia	Ugāle	WWTP Ugāle	VNK SERVISS; UNIVERSITY OF LATVIA	Pilot 3

Figure 20. Wastewater Treatment Plant technology

For pilot studies in Ugāle WWTP was used treated wastewater which was filled into plastic container, where was added disinfectant to prepare reclaimed water for watering plants in greenhouse. As disinfection method were chosen peracetic acid because it is not only organic acid, but also very quickly biodegrades not leaving remains in water which could affect plant developments. Unfortunately peracetic acid for disinfection purposes in the market is combined with hydrogen peroxide which allows oxidising more compounds in the water, but is more stable than peracetic acid. Without longer storage period water with presence of hydrogen peroxide can negatively affect plants. To solve this issue to water after disinfectant made majority of reactions were added potassium permanganate to help degrade hydrogen peroxide remains. Since for disinfection was used dose 100 ppm it destroyed all pathogens in the water, but reduced water pH value till 5.6. After adding potassium permanganate pH value again reached optimal level and most of the suspended particles and other matter precipitated in sediments in the bottom of plastic container.

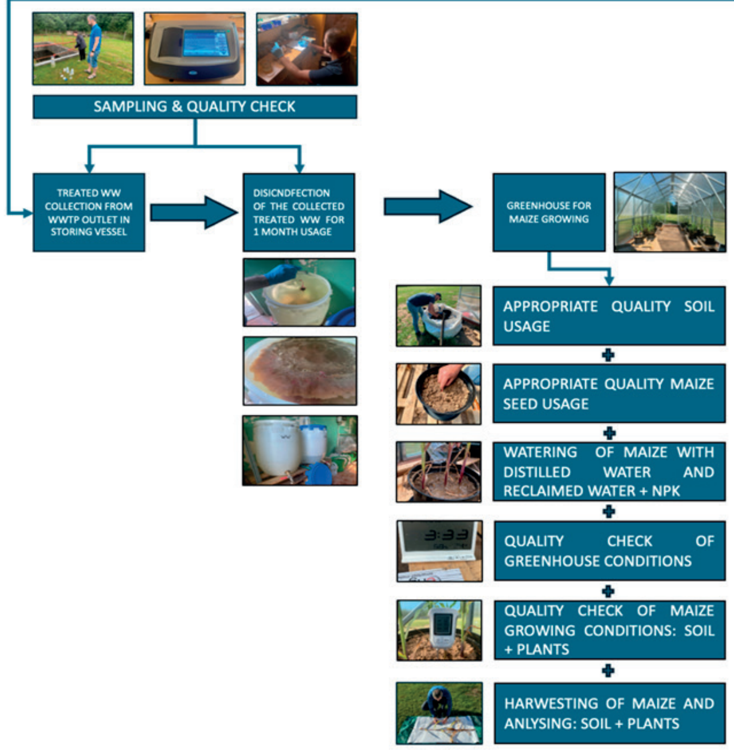


Figure 21. Activities carried out during the pilot

Noteworthy findings from Ugāle:

1) to reach A class quality reclaimed water can be used smaller doses of disinfectant;

2) Higher doses of applied materials for some time period increases BOD5 of water (storage with good ventilation is necessary before watering plants);

3) Higher doses of disinfectant and therefore also amount of applied potassium permanganate in water increased concentration of potassium and manganese. Therefore finding optimal dosage for defined purpose of reclaimed water can limit mentioned issues or can get rid of them completely.

In summary, applications of reclaimed water demonstrated positive impact of maize development and indicating nutrient recovery from wastewater. But series of plants where was used reclaimed water with NPK additives showed signs of oversaturation of nutrients, and important role for such outcome was increased potassium concentration. For maize are applied various optimal N:P:K ratios which depend on soil parameters, plant development stage and other aspects, and among these ratios as recommended appear 1:1:1.7 and 1:1.6:3.3, but our reclaimed water reached 3:1:34. Optimised water disinfection dosage will improve this ratio and using Renutriwater developed Water reuse calculator can precisely estimate amount of nutrient concentrations which should be used.

4.2.6 Samsø

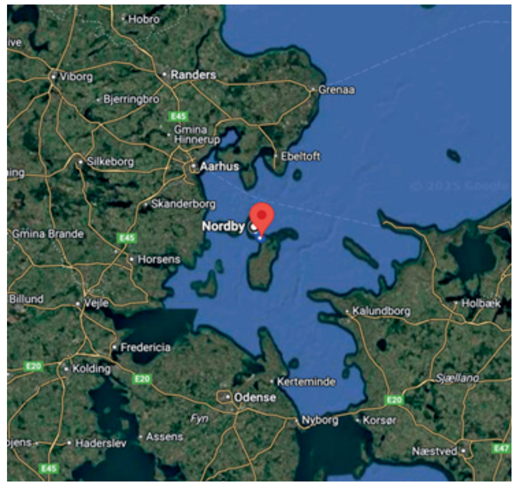
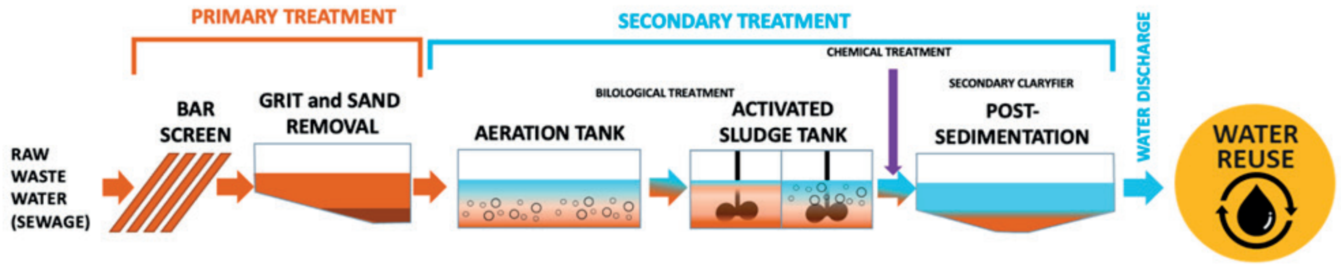


Figure 22. Location of Samsø, Denmark

Samsø Wastewater Treatment Plant is located on Samsø island in Denmark (Figure 22). Samsø is a small island in the middle of Denmark with 3,700 inhabitants. However, the number of residents increases drastically in the summer months as tourism is huge on the island. The estimated number of yearly visitors to Samsø exceeds 300,000 people. The wastewater utility, therefore, treats a seasonally variable amount of domestic wastewater.

The reclaimed water used for the Samsø pilot came from the WWTP of Samsø Spildevand A/S that is located at the southern part of the island. This WWTP has a capacity of 8,600 PE, treating 427,000 m³ per year, with an average daily wastewater flow of 1170 m³ and a maximum of 1645 m³/day. The sources of the wastewater are 65% domestic wastewater and 35% surface runoff, with no industrial wastewater.

The WWTP technology includes various processes such as bar screens, sand, grit and fat removal, biological and chemical treatment and settling. Organic matter, nitrogen, and phosphorus are hereby removed from the wastewater enabling the water to be returned to the natural cycle. Figure 23 presents the technology diagram.



Country	City	Object – the liquid stream only	Logo(s)	Pilots
Denmark	Samsø	WWTP Samsø	SAMSØ KOMMUNE - vi gør det sammen; SAMSØ Spildevand	Pilot 3

Figure 23. Wastewater Treatment Plant technology

The reclaimed water used in this pilot was furthermore disinfected with chlorine-free disinfection tabs before being used for irrigation of the maize plants in the two greenhouses located on site at the WWTP. In Pilot 3, we selected the soil, prepared the pots, and planted the corn. We cared for the plants throughout the growing season and conducted research.

5 Research results

5.1 Reclaimed water characteristics

This chapter presents the key results from the pilots. In Table 4, we collected results of the reclaimed water quality. As part of the quality control, we have established additional assumptions for class A resulting from Regulation 2020/741. This regulation imposes parametric values for E. coli, BOD_5, TSS, and Turbidity. We have added requirements resulting from the (current 91/271/EEC) urban wastewater treatment directive and the new directive, applicable from 2027 (2024/3019), the drinking water directive (2020/2184), and the FAO guidelines. It should be emphasized that the requirements we have set are not equivalent to the requirements for individual WWTPs. That is, the quality of reclaimed water may exceed the requirements we have set for water, but it meets the water permits issued to individual treatment plants.

Table 4. Average reclaimed water quality test results

Characteristics of treated wastewater		Finland	Finland	Poland	Poland	Latvia	Latvia	Denmark
		Kuopio	Tahko	Warsaw	Wołkowyja	Ugāle	Jūrmala	Samsø
Parameters:	ReNutriWater requirement for Class A water:	Pilot 1,2,3	Pilot 1,2	Pilot 1	Pilot 2,3	Pilot 2	Pilot 3	Pilot 3
Population equivalent	**[P.E.]**	**90,000**	**3,800**	**580 000**	**6,133**	**1,035**	**35,400**	**8,624**
Physicochemical quality of treated wastewater								
COD	125 [mg/l] (2)	9.66	0.50	12	16.00	48.00	11.30	22.30
BOD_5	10 [mg/l] (1)	0.00	0.00	2,5	0.25	39.5	4.60	0.50
Total Susp. Solids (TSS)	10 [mg/l] (1)	0.40	0.70	< 2	< 2.00	< 1	2.00	2.00
Total Nitrogen (TN)	10 [mg/l] (3)	4.43	2.20	7	3.50	7.1	1.78	3.50
Total Phosphorus (TP)	0.7 [mg/l] (3)	0.07	0.06	0.5	0.70	2.44	3.22	0.74
Total Org. Carbon (TOC)	37 [mg/l] (3)	5.77	4.04	10	4.00	4.7	n/a	33.00
Turbidity	5 [NTU] (1)	0.28	0.76	< 1	-	0.87	0.60	0.45
pH	8.4 [pH] (4)	6.80	6.55	7	6.50	7.34	7.11	6.96
Electrical Cond. (EC)	3.000 [mS/cm] (4)	0.592	0.466	1.3	n/a	1.115	0.356	0.110
Microbiological quality								
E. coli	10 [cfu/100ml] (1)	0	0	0	0	0	1,200	190
Legionella spp.	1,000 [cfu/l] (1)	0	0	n/a	0	0	0	10
Helminth eggs	1 [eggs/l] (4)	0	0	n/a	n/a	0	0	n/a
Macronutrients								
Ammonia ($N\text{-}NH_4$)	5 [mg/l] (4)	0.15	0	0.5	3.0	0.015	0.01	0.18
Nitrites (NO_2^-)	0.5 [mg/l] (5)	0.10	0.10	0.16	0.43	0.002	0	0.01
Nitrates (NO_3^-)	10 [mg/l] (4)	3.61	0.60	5.3	-	6.22	4.49	0.44
Phosphates (PO_4^{3-})	2 [mg/l] (4)	0.57	0.10	0.4	0.70	2.39	-	0.18
Potassium (K^+)	2 [mg/l] (4)	9.10	10.75	27	21.60	82.9	15.70	21.00
Metals								
Copper (Cu)	0.2 [mg/l] (4)	0.03	0.01	n/a	0.022	0.0197	0.002	0
Zinc (Zn)	2 [mg/l] (4)	0.01	0.02	n/a	0.025	0.057	0.010	0.003
Nickel (Ni)	0.2 [mg/l] (4)	0.01	0.01	n/a	0.005	0.0023	0.001	0.003
Cadmium (Cd)	0.01 [mg/l] (4)	0.01	0.01	n/a	0.003	0.0012	0.0001	0.05
Chromium (Cr)	0.1 [mg/l] (4)	0.01	0.01	n/a	0.002	0.0044	0.0010	0.02
Mercury (Hg)	0.0005 [mg/l] (5)	0.03	0.03	n/a	0.0005	0.00002	0.00002	0
Lead (Pb)	5 [mg/l] (4)	0.01	0.01	n/a	0.005	0.013	0.001	0.14
Reference no.: (1) – according to 2020/741, (2) – according to 91/271/EEC, (3) – according to 2024/3019, (4) – according to FAO, (5) – according to 2020/2184.								

Regarding the Warsaw wastewater treatment plant, several solutions were tested (ion exchange, fabric filter, active carbon, ozonation, etc.), so a comparison is not possible. The table 4. includes the results after ion exchange and disinfection with ozone. Because this WWTP has a capacity above 150,000 PE, the requirements for total nitrogen and total phosphorus are more stringent. Nutrient removal applies to tertiary treatment.

5.2 Disinfection efficiency of reclaimed water

5.2.1 Pretreatment methods prior to disinfection methods

Effective water reuse depends on the proper preparation of wastewater before disinfection. Pre-treatment methods play a crucial role in improving the efficiency of disinfection processes by removing contaminants that can interfere with pathogen inactivation. Preliminary treatment is also crucial for the removal of disinfection by-product precursors from wastewater subjected to reclamation. Among the most common disinfection by-products are trihalomethanes (THMs), including chloroform, bromoform, bromodichloromethane, and chlorodibromomethane, as well as haloacetic acids (HAAs) (Wang P. et al., 2021). The presence of these compounds is highly undesirable due to their adverse effects on human health and potential carcinogenicity. Therefore, the implementation of pre-treatment methods aimed at reducing the natural organic matter content – a known precursor to the formation of these harmful disinfection by-products – can be beneficial (Evlampidou, I. et al., 2020; Kumari, M. et al., 2022). These processes target suspended particles, organic matter, and other soluble compounds that may compromise water quality and hinder subsequent disinfection efficacy.

The effectiveness of disinfection is influenced by several water quality parameters, including turbidity and UV absorbance. Suspended particles in wastewater can shield microorganisms from disinfectants and serve as a growth medium for bacteria. To maximize disinfection success, turbidity levels should be kept below 1 NTU (Léziart et al., 2019). Implementing appropriate pretreatment methods ensures that these conditions are met, thereby enhancing the reliability of water reuse systems.

A range of physical and chemical pretreatment methods can be applied depending on the characteristics of the wastewater being treated. Common methods include:

- **Coagulation:** Used to aggregate fine particles and allow their removal through sedimentation and filtration. Coagulants such as aluminum sulfate or pre-hydrolyzed aluminum compounds are commonly applied, with dosages varying based on initial wastewater quality.
- **Filtration:** Various filtration techniques, such as sand filtration, remove suspended solids and reduce turbidity. Filtration rates typically range from 3 to 15 m/h.
- **Activated Carbon Adsorption:** This method is effective for removing organic contaminants, ensuring lower UV absorbance in the treated wastewater. It is usually preceded by sand filtration to optimize performance.
- **Other Methods:** Additional processes such as fabric filters and ion exchange can also be employed depending on specific treatment needs.

The choice of pretreatment method and its operational parameters should be tailored to the initial wastewater quality and the desired treatment outcomes. A case-by-case evaluation, supported by experimental testing, is recommended to determine the most effective approach. By implementing appropriate pretreatment strategies, the efficiency and reliability of disinfection processes can be significantly improved, ultimately ensuring the safety and sustainability of reclaimed water use.

Discussion of results

Coagulation, sand filtration, and activated carbon adsorption

The study assessed the effectiveness of various pretreatment methods for wastewater reclamation, including coagulation, sand filtration, and activated carbon adsorption. The experiments were conducted under controlled lab-scale conditions using daily wastewater samples collected from the Wastewater Treatment Plant in Warsaw, Poland. The objective was to evaluate the efficiency of these methods in removing contaminants that could interfere with subsequent disinfection processes. Key wastewater quality indicators analyzed included color, turbidity, chemical oxygen demand (COD), and total organic carbon (TOC).

The tested coagulation methods included surface and volumetric coagulation, both using aluminum sulfate and inorganic polymers PAX-XL 19F and PAX-XL 1911. In volumetric coagulation, the same doses of alum, PAX-XL 19F, and PAX-XL 1911 were applied (1.0, 2.0, 4.0, and 8.0 mg Al/l). In surface coagulation, the coagulant doses of alum, PAX-XL 19F, and PAX-XL 1911 were 0.25, 0.5, 1.0, and 2.0 mg Al/l, with a filtration rate of 3 m/h. Sand filtration was performed at different filtration rates (3, 5, 10, and 15 m/h), while activated carbon adsorption was tested at 5, 10, and 15 m/h, corresponding to approximate contact times of 13, 7, and 4 minutes. The key results are summarized in Tables 4 and 5, providing insights into the efficiency of each method in reducing contaminants and improving overall water quality.

Coagulation

Both surface and volumetric coagulation demonstrated strong efficiency in removing contaminants. Surface coagulation with aluminum sulfate achieved color reductions of 28-49%, while PAX-XL 19F showed a similar range of 26-30%. Turbidity removal was also comparable, with PAX-XL 19F reducing turbidity by 64-75% and aluminum sulfate by 69-76%. COD reduction was slightly higher for aluminum sulfate (26-30%) compared to PAX-XL 19F (19-35%), while TOC reductions were consistent across both coagulants, ranging from 16-20% for aluminum sulfate and 18-23% for PAX-XL 19F (Table 5).

Table 5. Characteristics of reclaimed water and treatment efficiency (η) in surface coagulation tests (average ± standard deviation)

Indicators		Dose of $Al_2(SO_4)^3$ [mg Al/l]				Dose of PAX-XL 19F [mg Al/l]				Dose of PAX-XL 1911 [mg Al/l]			
		0.25	0.5	1	2	0.25	0.5	1	2	0.25	0.5	1	2
Color	[mg Pt/l]	40.67± 4.71	36.33± 5.19	35.67± 4.78	29.33± 4.92	42.67± 3.30	42.67± 3.30	42.67± 3.30	40.00± 1.63	47.00± 4.24	44.33± 3.30	43.00± 2.83	40.33± 2.05
	η [%]	**27.56± 3.63**	**36.97± 5.14**	**38.08± 4.56**	**49.15± 5.79**	**25.64± 0.91**	**25.64± 0.91**	**25.64± 0.91**	**30.09± 2.62**	**18.16± 2.12**	**22.69± 2.06**	**25.00± 0.00**	**29.53± 2.75**
Turbidity	NTU	0.69± 0.17	0.60± 0.1	0.55± 0.09	0.54± 0.08	0.79± 0.05	0.72± 0.03	0.60± 0.04	0.55± 0.03	0.75± 0.12	0.66± 0.07	0.52± 0.03	0.50± 0.04
	η [%]	**68.95± 6.30**	**72.77± 3.35**	**75.03± 3.21**	**75.61± 2.89**	**64.21± 1.76**	**67.36± 1.25**	**72.96± 1.70**	**75.09± 0.50**	**66.15± 4.01**	**70.00± 2.10**	**76.29± 0.92**	**77.50± 1.31**
COD	[mg O_2/l]	16.60± 1.36	16.30± 1.39	16.03± 1.59	15.60± 1.55	18.33± 2.90	17.07± 2.58	15.40± 2.69	14.57± 2.07	17.50± 2.03	16.47± 1.67	15.43± 1.55	15.13± 1.60
	η [%]	**25.74± 3.35**	**27.13± 2.78**	**28.40± 3.08**	**30.36± 1.99**	**18.51± 6.50**	**24.02± 6.44**	**31.57± 7.03**	**35.14± 4.55**	**21.99± 2.93**	**26.49± 2.01**	**31.10± 1.88**	**32.46± 2.48**
TOC	[mg/l]	6.94± 0.34	6.88± 0.34	6.76± 0.34	6.54± 0.34	6.77± 0.16	6.71± 0.16	6.57± 0.16	6.31± 0.17	6.63± 0.13	6.58± 0.13	6.49± 0.14	6.32± 0.16
	η [%]	**15.54± 7.55**	**16.22± 7.48**	**17.63± 7.40**	**20.34± 7.17**	**17.63± 4.70**	**18.44± 4.69**	**20.10± 4.67**	**23.27± 4.65**	**19.43± 4.10**	**19.96± 4.09**	**21.07± 4.09**	**23.17± 4.07**
UV_{254}	[cm^{-1}]	0.208± 0.020	0.203± 0.020	0.199± 0.023	0.194± 0.022	0.207± 0.024	0.202± 0.024	0.198± 0.022	0.194± 0.023	0.209± 0.022	0.204± 0.02	0.196± 0.022	0.194± 0.023
	η [%]	**6.07± 0.48**	**8.19± 1.08**	**10.28± 2.07**	**12.39± 2.23**	**6.85± 2.68**	**8.97± 2.58**	**10.55± 1.77**	**12.58± 2.55**	**5.84± 1.44**	**7.87± 1.28**	**11.48± 2.17**	**12.56± 2.43**

In volumetric coagulation tests, aluminum sulfate reduced color by 22-47%, while PAX-XL 19F achieved reductions of 15-44%. PAX-XL 19F also demonstrated the highest turbidity removal (76-82%), with aluminum sulfate slightly lower at 66-75%. COD reduction was observed at 18-33% for PAX-XL 19F and 12-34% for aluminum sulfate, while TOC removal ranged from 15-25% for aluminum sulfate and 13-22% for PAX-XL 19F (Table 6).

Table 6. Characteristics of reclaimed water and treatment efficiency (η) in volumetric coagulation tests (average ± standard deviation)

Indicators		Dose of $Al_2(SO_4)^3$ [mg Al/l]				Dose of PAX-XL 19F [mg Al/l]				Dose of PAX-XL 1911 [mg Al/l]			
		1	2	4	8	1	2	4	8	1	2	4	8
Color	[mg Pt/l]	40.67± 4.19	36.67± 4.99	33.67± 4.19	27.67± 1.7	48.67± 5.79	42.67± 5.25	36.00± 2.94	32.00± 2.45	42.33± 6.13	38.33± 5.31	34.33± 4.19	30.33± 3.30
	η [%]	**21.89± 6.76**	**29.74± 7.56**	**35.46± 6.24**	**46.77± 3.31**	**15.38± 5.31**	**25.64± 6.86**	**37.18± 3.43**	**44.19± 2.25**	**19.37± 2.27**	**26.94± 1.59**	**34.40± 1.51**	**41.87± 3.42**
Turbidity	NTU	0.62± 0.07	0.53± 0.06	0.52± 0.05	0.43± 0.07	0.53± 0.03	0.45± 0.06	0.41± 0.07	0.38± 0.11	0.64± 0.03	0.52± 0.05	0.44± 0.09	0.39± 0.09
	η [%]	**65.90± 3.65**	**70.43± 6.75**	**71.05± 7.05**	**75.05± 8.96**	**75.65± 2.58**	**79.25± 3.76**	**81.21± 4.22**	**82.40± 5.66**	**63.74± 10.03**	**70.47± 9.50**	**74.16± 11.58**	**77.04± 10.50**
COD	[mg O_2/l]	18.51± 2.02	16.13± 1.43	15.97± 1.42	13.83± 1.17	18.37± 1.13	16.20± 0.49	15.40± 0.96	14.87± 1.57	18.17± 2.01	16.30± 1.77	15.60± 1.57	13.95± 1.85
	η [%]	**12.39± 1.16**	**23.40± 4.30**	**24.17± 4.79**	**34.35± 2.43**	**17.50± 1.71**	**27.05± 3.68**	**30.83± 1.37**	**33.44± 2.63**	**14.01± 3.33**	**22.86± 1.10**	**26.09± 2.04**	**34.02± 4.50**
TOC	[mg/l]	6.96± 0.15	6.78± 0.12	6.53± 0.14	6.15± 0.13	7.17± 0.31	7.04± 0.34	6.83± 0.38	6.36± 0.48	7.10± 0.34	6.96± 0.34	6.68± 0.34	6.14± 0.31
	η [%]	**15.41± 3.10**	**17.61± 4.66**	**20.62± 4.99**	**25.20± 4.78**	**12.68± 7.18**	**14.25± 7.61**	**16.87± 7.89**	**22.44± 8.87**	**13.61± 7.42**	**15.27± 7.30**	**18.67± 7.13**	**25.22± 6.59**
UV_{254}	[cm^{-1}]	0.210± 0.02	0.197± 0.015	0.182± 0.013	0.173± 0.025	0.205± 0.013	0.191± 0.011	0.18± 0.013	0.173± 0.015	0.208± 0.015	0.195± 0.011	0.182± 0.013	0.171± 0.014
	η [%]	**5.41± 0.47**	**11.06± 1.98**	**17.86± 4.23**	**2.74± 4.52**	**7.20± 3.28**	**13.80± 3.34**	**18.89± 2.01**	**22.17± 1.33**	**6.08± 2.44**	**12.10± 3.67**	**17.91± 2.91**	**23.12± 1.77**

A significant finding was that surface coagulation achieved comparable treatment efficiency to volumetric coagulation but at lower coagulant doses, making it a more cost-effective option. Additionally, both coagulation methods successfully reduced turbidity below the recommended 1 NTU threshold, ensuring better conditions for effective disinfection.

Sand Filtration

Among the tested methods, sand filtration had the lowest overall contaminant removal efficiency and did not meet the recommended turbidity threshold of 1 NTU, making it an ineffective standalone pretreatment method. At lowest filtration rates the process reduced color by only 20%, turbidity by 40%, COD by 8%, and TOC by 20% (Table 7.).

Given these limitations, sand filtration alone is not a viable standalone pretreatment option, especially when dealing with wastewater requiring substantial organic matter reduction before disinfection. Its role may be limited to a supplementary step following coagulation or as part of a multi-stage treatment approach, but it should not be relied upon as a primary pretreatment method.

Activated Carbon Adsorption

Among all tested pretreatment methods, activated carbon adsorption was the most effective. At lowest filtration rates the process achieved 90% removal of color, 88% removal of COD, a 55% reduction in turbidity, and 87% TOC removal (Table 7). However, this method is relatively expensive.

While coagulation was effective in reducing turbidity below the recommended threshold and provided significant removals of organic pollutants, activated carbon adsorption demonstrated the best purification results, making it the preferred choice for pretreatment when high reclaimed water quality standards are required. Furthermore, activated carbon adsorption consistently reduced turbidity below the recommended 1 NTU threshold, reinforcing its effectiveness in improving water quality for subsequent disinfection.

Table 7. Reclaimed water characteristics and treatment efficiency (η) in the sand filtration and activated carbon adsorption tests (average ± standard deviation)

Indicators		Sand Filtration Rates [m/h]				Activated Carbon Filtration Rates [m/h]		
		3	5	10	15	5	10	15
Color	[mg Pt/l]	42.5± 7.5	42.5± 7.5	47.5± 7.5	50± 5.0	5.0± 0.0	5.0± 0.0	5.0± 0.0
	η [%]	**19.44± 2.78**	**19.44± 2.78**	**9.72± 1.39**	**4.17± 4.17**	**90.28± 1.39**	**90.28± 1.39**	**90.28± 1.39**
Turbidity	NTU	0.99± 0.04	1.13± 0.14	1.24± 0.19	1.42± 0.21	0.73± 0.02	0.81± 0.09	0.79± 0.06
	η [%]	**40.18± 10.55**	**33.03± 5.62**	**26.57± 4.35**	**16.18± 5.07**	**55.83± 8.42**	**49.28± 15.94**	**51.26± 13.48**
COD	[mg O_2/l]	17.8± 0.0	18.55± 0.55	18.65± 0.55	19.15± 0.95	2.19± 1.09	3.52± 2.17	4.08± 2.53
	η [%]	**8.05± 4.27**	**4.31± 1.6**	**3.79± 1.63**	**1.30± 0.32**	**88.43± 6.16**	**81.32± 12.03**	**78.34± 14.02**
TOC	[mg/l]	6.78± 0.0	6.78± 0.0	6.81± 0.0	6.92± 0.0	1.08± 0.29	1.23± 0.33	1.52± 0.37
	η [%]	**20.31± 1.98**	**17.87± 1.26**	**17.74± 1.46**	**16.51± 1.65**	**87.09± 3.88**	**85.23± 4.47**	**81.75± 5.02**
UV_{254}	[cm^{-1}]	0.23± 0.003	0.23± 0.004	0.23± 0.004	0.23± 0.003	0.07± 0.007	0.07± 0.009	0.07± 0.009
	η [%]	**3.14± 0.99**	**4.00± 0.55**	**4.00± 0.55**	**4.20± 0.76**	**69.88± 2.11**	**69.69± 3.16**	**69.06± 3.36**

Key Takeaways

- The findings indicate that surface coagulation was as effective as volumetric coagulation but required lower coagulant dosages, making it a more efficient option.
- Sand filtration showed the weakest performance, with low removal rates across all tested water quality indicators, confirming that it is best suited as a supplementary rather than a primary treatment method.
- Activated carbon adsorption emerged as the most effective process, achieving the highest reductions in color, COD, turbidity, and TOC, demonstrating its superior ability to remove organic contaminants and improve water quality before disinfection. However, from an economic perspective, it is also the most expensive method among those analyzed.
- All tested pretreatment methods except for sand filtration were able to reduce turbidity below the recommended 1 NTU threshold, ensuring improved conditions for effective pathogen inactivation.

These results emphasize the importance of selecting pretreatment methods based on wastewater characteristics and treatment goals, with activated carbon adsorption being the most effective standalone method, while coagulation offers a cost-efficient alternative with moderate contaminant removal efficiency.

5.2.2 Comparison of the efficiency of different disinfection methods

Disinfection is a vital step in the treatment of municipal wastewater, especially when the reclaimed water is intended for reuse in irrigation. Its main purpose is to safeguard public health and protect the environment by eliminating or deactivating harmful microorganisms. These include bacteria, viruses, protozoa, and parasitic worms that may be present due to fecal contamination or other sources. Effective disinfection reduces the risk of disease transmission and ensures that the reclaimed water meets quality standards for safe use.

A wide variety of disinfection methods are available, each using different mechanisms to achieve microbial inactivation. Common methods include:

- **Chlorination:** Chlorination remains one of the most commonly used chemical disinfection methods in municipal wastewater treatment due to its simplicity, affordability, and widespread availability. It is typically applied in the form of sodium hypochlorite, which offers ease of use and long-lasting disinfection (Collivignarelli et al., 2017). It acts by generating free chlorine species that oxidize microbial cells, disrupting membranes, enzymes, and DNA, and ultimately inactivating pathogens (de Oliveira Freitas et al., 2021). However, chlorination also produces disinfection by-products (DBPs) when chlorine reacts with organic substances in wastewater. These include trihalomethanes (THMs), haloacetic acids (HAAs), haloacetonitriles (HANs), and haloketones (HKs), which have been linked to potential health risks such as mutagenicity and carcinogenicity (Quartaroli et al., 2018; Yang et al., 2020). As a result, chlorination must be carefully managed in reuse settings to balance microbial safety with chemical risk. Typical chlorine doses in wastewater disinfection range from 5 to 20 mg/L (EPA's Wastewater Technology Fact Sheet Chlorine Disinfection, 1999).
- **UV radiation:** Ultraviolet (UV) radiation is a physical disinfection method increasingly used in wastewater treatment for its effectiveness and environmental safety. It works by damaging the DNA of microorganisms through UV light exposure, preventing them from reproducing. UV radiation effectively targets bacteria, viruses, protozoa, and helminths, particularly through the UV-C range (200–280 nm), with peak efficacy at 253.7 nm (González et al., 2023). A key advantage of UV treatment is its chemical-free operation, avoiding harmful by-products and preserving water quality. The process is fast and does not alter the taste or composition of the treated water. However, its performance is sensitive to water clarity, as suspended solids can block UV light and reduce efficiency. UV treatment also lacks residual disinfection, offering no ongoing microbial control once water leaves the treatment system. Recommended UV doses range from 50 to 200 mJ/cm², depending on influent quality and disinfection goals (Linden et al., 2002; EPA's Wastewater Technology Fact Sheet Ultraviolet Disinfection, 1999).
- **Ozonation:** Ozonation uses ozone gas (O_3), a powerful oxidant, to inactivate microorganisms in wastewater. Ozone reacts with microbial cells, damaging membranes and internal structures, and also helps purify water by breaking down complex organic pollutants into simpler, less harmful compounds. This makes ozonation valuable for both disinfection and overall water quality improvement. It is highly effective against a wide range of pathogens and does not leave chemical residues, as ozone naturally decomposes into oxygen. However, ozonation requires on-site ozone generation and precise control of treatment conditions, making it more complex and costly than other methods. Its efficiency depends heavily on the initial wastewater quality and process parameters. Recommended operational ranges include 3–20 mg/L ozone dose and 20–40 minutes hydraulic retention time (Lazarova et al., 2013; Levine et al., 2000; Hogard et al., 2021; Barry et al., 2014).

The selection of a disinfection method and its operational parameters should be guided by the specific characteristics of wastewater and the intended treatment objectives. A case-by-case assessment, supported by experimental testing, is recommended to identify the most effective approach. Implementing well-suited microbial inactivation strategies can greatly enhance the efficiency and reliability of the reclamation process, ultimately ensuring the safe and sustainable use of reclaimed water.

Discussion of results

Chlorination, ozonation, and UV radiation

The study evaluated the effectiveness of several disinfection methods for wastewater reclamation, including chlorination, ozonation, and ultraviolet (UV) radiation.

Disinfection experiments were conducted in two series: (i) using effluent from the "Południe" WWTP pre-treated via ion exchange (IEX), and (ii) using effluent from the "Czajka" WWTP pre-treated via sand filtration (SF). Both WWTPs were located in Warsaw, Poland. The objective of the experiments was to assess the disinfection efficiency of these methods based on the following microbial quality indicators: total coliform bacteria, *Escherichia coli*, fecal enterococci, *Clostridium perfringens*, the number of microorganisms at 22°C after 72 hours, and the number of microorganisms at 36°C after 48 hours. In addition to microbial parameters, selected physico-chemical indicators were also analyzed, including temperature, pH, conductivity, color, turbidity, chemical oxygen demand (COD), and 5-day biochemical oxygen demand (BOD_5).

The chemical disinfection methods tested included chlorination with sodium hypochlorite and ozonation with ozone gas. In series (i), chlorination was performed using chlorine doses of 0.5, 2.0, and 4.0 mg Cl_2/l, with contact times of 5, 15, and 20 minutes. In series (ii), the applied chlorine doses were 0.5, 1.0, 2.0, and 4.0 mg Cl_2/l, with contact times of 10 and 20 minutes. For ozonation, ozone doses were adjusted by varying both the ozone concentration (100% in series (i); 20%, 40%, 60%, and 100% in series (ii)) and the flow rates (3 l/min and 8 l/min in both series). In series (ii), this resulted in applied ozone doses of 16.67, 33.33, 50.00, and 83.33 mg O_3/l at 3 l/min, and 5.00, 50.00, 75.00, and 125.00 mg O_3/l at 8 l/min. In series (i), the applied ozone doses were 83.33 mg O_3/l at 3 l/min and 125.00 mg O_3/l at 8 l/min. UV disinfection was conducted in series (ii) using three different doses: 279, 312, and 484 mJ/cm².

Chlorination

A comparison of series (i) and series (ii) highlights notable differences in disinfection efficiency, likely influenced by the pre-treatment method. In series (i), where effluent was pre-treated via ion exchange, chlorination achieved complete inactivation of key microbial indicators (*E. coli*, fecal enterococci, and total coliforms) at 4.0 mg Cl_2/l within 15–30 minutes. In contrast, in series (ii), which used sand filtration as pre-treatment, E. coli and coliforms remained detectable across all tested chlorine doses and contact times – even at 4.0 mg Cl_2/l for 20 minutes, *E. coli* was only partially reduced. Moreover, while Clostridium perfringens was consistently absent in both series, the total microorganism counts at 22°C and 36°C were significantly higher in series (ii) and less responsive to chlorination. These findings suggest that ion exchange pre-treatment (series i) may enhance the efficacy of subsequent chemical disinfection compared to sand filtration (series ii), particularly in reducing resistant microbial populations and achieving full compliance with microbiological standards.

It is also important to note that the initial quality of the WWTP effluent prior to pre-treatment likely contributed to the observed differences. Effluent from the "Południe" WWTP (series i) exhibited lower microbial loads at baseline – e.g., *Clostridium perfringens* was already undetectable, and total microbial counts were below 300 CFU/ml – whereas the "Czajka" WWTP effluent (series ii) showed substantially higher initial counts, including >2400 CFU/ml at 36°C. These disparities in influent quality, in combination with the different pre-treatment methods, should be considered when evaluating disinfection outcomes.

Tables 8. and 9. present the results of microbial inactivation achieved through chlorination.

Table 8. Series (i) – microbial inactivation achieved through chlorination

Microbial Water Quality Indicator	Unit	"Południe" WWTP Effluent (IEX Pre-Treated)	Contact Time: 5 min			Contact Time: 15 min			Contact Time: 30 min		
			0,5 mg Cl_2/l	2,0 mg Cl_2/l	4,0 mg Cl_2/l	0,5 mg Cl_2/l	2,0 mg Cl_2/l	4,0 mg Cl_2/l	0,5 mg Cl_2/l	2,0 mg Cl_2/l	4,0 mg Cl_2/l
Legionella	CFU/100 ml	0	0	not tested		not tested			not tested		
Total Coliform Bacteria	CFU/100 ml	>80	>80	65	25	>80	33	0	>80	0	0
Escherichia coli Count	CFU/100 ml	>80	>80	0	0	>80	0	0	>80	0	0
Fecal Enterococci Count	CFU/100 ml	>80	>80	>80	0	>80	>80	0	>80	0	0
Clostridium Perfringens Count	CFU/100 ml	0	0	0	0	0	0	0	0	0	0
Total Microorganisms at 22°C / 72 h	CFU/1 ml	>300	>300	221	38	>300	179	18	>300	20	14
Total Microorganisms at 36°C / 48 h	CFU/1 ml	>300	>300	>300	28	>300	>300	23	52	12	16

Table 9. Series (ii) – microbial inactivation achieved through chlorination

Microbial Water Quality Indicator	Unit	"Czajka" WWTP Effluent (SF Pre-Treated)	Contact Time: 10 min				Contact Time: 20 min			
			0,5 mg Cl_2/l	1,0 mg Cl_2/l	2,0 mg Cl_2/l	4,0 mg Cl_2/l	0,5 mg Cl_2/l	1,0 mg Cl_2/l	2,0 mg Cl_2/l	4,0 mg Cl_2/l
Legionella	CFU/100 ml	not tested	not tested				not tested			
Total Coliform Bacteria	CFU/100 ml	>80	>80	>80	>80	>80	>80	>80	>80	>80
Escherichia coli Count	CFU/100 ml	>80	>80	>80	>80	>80	>80	>80	>80	16
Fecal Enterococci Count	CFU/100 ml	>80	>80	>80	>80	>80	>80	>80	>80	>80
Clostridium perfringens Count	CFU/100 ml	0	0	0	0	0	0	0	0	0
Total Microorganisms at 22°C / 72 h	CFU/1 ml	1370	1640	390	820	1070	830	710	1450	31
Total Microorganisms at 36°C / 48 h	CFU/1 ml	2430	2080	10600	1470	2020	12000	1220	1960	132

In terms of physico-chemical water quality, distinct differences were observed between series (i) and series (ii), which reflect not only the impact of disinfection but also differences in the initial effluent quality and pre-treatment method. Effluent in series (i) (IEX pre-treated) exhibited notably lower color, turbidity, and COD values across all chlorine doses and contact times, indicating better baseline quality and more effective removal of organic matter. In contrast, the effluent in series (ii) (SF pre-treated) showed significantly higher color (up to 93 mg Pt/l) and COD concentrations (up to 34.3 mg/l without sodium thiosulfate), with only moderate reductions following chlorination. Conductivity values were also consistently higher in series (i), likely due to ion exchange effects. Residual chlorine levels were generally higher in series (i), suggesting greater chlorine stability, which may have contributed to the improved microbial inactivation observed. These differences underscore the combined influence of pre-treatment and baseline effluent characteristics on disinfection performance and overall water quality. Tables 10 and 11 present the results of physico-chemical analysis conducted in the samples from series (i) and (ii).

Table 10. Series (i) – physico-chemical analysis results

Physico-Chemical Water Quality Indicator	Unit	"Południe" WWTP Effluent (IEX Pre-Treated)	Contact Time: 5 min			Contact Time: 15 min			Contact Time: 30 min		
			0.5 mg Cl_2/l	2.0 mg Cl_2/l	4.0 mg Cl_2/l	0.5 mg Cl_2/l	2.0 mg Cl_2/l	4.0 mg Cl_2/l	0.5 mg Cl_2/l	2.0 mg Cl_2/l	4.0 mg Cl_2/l
Temperature	°C	18.4	18,6	18,4	18,6	18,8	18,6	18,7	19,3	19,1	19
pH	-	7.33	7,42	7,34	7,41	7,37	7,26	7,38	7,17	7,21	7,23
Conductivity	µS/cm	644	682	709	747	680	707	744	675	702	735
Color	mg Pt/l	19	20	17	13	17	16	16	17	17	13
Turbidity	NTU	0,8	0.9	0.87	0.84	0.84	0.92	0.83	0.87	0.85	0.82
COD	mg/l	14.4	14.7	13	14.1	15.1	14.9	16.4	26.3	14.4	18
Total Chlorine	mg/l	-	0.24	1.45	2.37	0.27	1.36	2.49	0.22	1.34	2.36
Residual Chlorine	mg/l	-	0.16	1.1	1.62	0.06	0.99	1.26	0.07	0.94	1.3

Table 11. Series (ii) – physico-chemical analysis results

Physico-Chemical Water Quality Indicator	Unit	"Czajka" WWTP Effluent (SF Pre-Treated)	Contact Time: 10 min				Contact Time: 20 min			
			0.5 mg Cl_2/l	1.0 mg Cl_2/l	2.0 mg Cl_2/l	4.0 mg Cl_2/l	0.5 mg Cl_2/l	1.0 mg Cl_2/l	2.0 mg Cl_2/l	4.0 mg Cl_2/l
Temperature	°C	16.4	16.6	15.8	15.6	16.1	16.5	16.3	16,5	16,8
pH	-	7,48	7.55	7.69	7.77	7.79	7.55	7.61	7,51	7,68
Conductivity	µS/cm	382	381	387	403	401	391	383	400	412
Color	mg Pt/l	93	91	94	93	86	97	93	91	90
Turbidity	NTU	0.91	0.94	0.94	0.93	0.92	0.94	0.96	0,96	0,98
UV254	cm-1	0.416	0.422	0.418	0.418	0.413	0.416	0.409	0,409	0,411
COD (no sodium thiosulfate)	mg/l	34.3	32.4	31.5	26.5	25.7	31	27.2	2.7	26.6
COD (with sodium thiosulfate)		-	40	31.9	31.5	31.3	28.3	32.8	25.2	31.2
Total Chlorine	mg/l	-	0.3	0.57	1.16	2.34	0.37	0.62	1.18	2.11
Residual Chlorine	mg/l	-	0.27	0.44	0.55	1.59	0.18	0.32	0,7	1.56
BOD_5	mg/l	3.2	13.8	not tested		7.2	3.6	not tested		2.5

Ozonation

Ozonation results demonstrated substantial microbial inactivation in both series (i) and (ii), with dose-dependent improvements observed across all indicators. In series (i) (IEX pre-treated effluent), full removal of *Escherichia coli*, fecal enterococci, and total coliforms was achieved at 83.33 mg O_3/l and 125.00 mg O_3/l. Additionally, Legionella and *Clostridium perfringens* were undetectable at baseline and remained so after treatment. Total microorganism counts at 22°C and 36°C dropped significantly, from >300 CFU/ml to as low as 10–12 CFU/ml. In series (ii) (SF pre-treated effluent), ozonation also effectively reduced microbial loads; however, higher initial concentrations and greater variability were observed. While E. coli and coliforms were fully inactivated at doses ≥50 mg O_3/l, fecal enterococci showed greater resistance, persisting at low levels at multiple doses and flow rates. The total microorganism counts in series (ii) remained higher overall, particularly at lower ozone doses, with reductions becoming more effective at 75–125 mg O_3/l.

These findings again highlight the role of pre-treatment and initial effluent quality in disinfection outcomes. The IEX-treated effluent in series (i) exhibited superior baseline quality and responded more uniformly to ozonation. In contrast, the SF-treated effluent in series (ii) required higher ozone doses to achieve comparable reductions, particularly for more resistant microbial groups. Table 12 presents the results of microbial inactivation achieved through ozonation.

Table 12. Series (i) and (ii) – results of microbial inactivation achieved through ozonation

Microbial Water Quality Indicator	Unit	"Południe" WWTP Effluent (IEX Pre-Treated)	Flow Rate: 3 l/min	Flow Rate: 8 l/min	"Czajka" WWTP Effluent (SF Pre-Treated)	Flow Rate: 3 l/min				Flow Rate: 8 l/min			
			Dose: 83.33 mg O3/l	Dose: 125.00 mg O3/l		Dose: 16.67 mg O3/l	Dose: 33.33 mg O3/l	Dose: 50.00 mg O3/l	Dose: 83.33 mg O3/l	Dose: 25.00 mg O3/l	Dose: 50.00 mg O3/l	Dose: 75.00 mg O3/l	Dose: 125.00 mg O3/l
Legionella	CFU/100 ml	0	0	nb	not tested	not tested				not tested			
Total Coliform Bacteria	CFU/100 ml	>80	23	0	>80	63	2	0	0	4	1	9	0
Escherichia coli Count	CFU/100 ml	>80	0	0	>80	7	0	0	0	0	0	0	0
Fecal Enterococci Count	CFU/100 ml	>80	0	0	>80	13	>80	>80	0	0	0	0	0
Clostridium perfringens Count	CFU/100 ml	0	0	0	0	0	0	0	0	0	0	0	0
Total Microorganisms at 22°C / 72 h	CFU/1 ml	>300	21	10	1370	530	6	10	28	17	8	16	33
Total Microorganisms at 36°C / 48 h	CFU/1 ml	>300	27	12	2430	68	13	16	41	51	14	8	43

The physico-chemical water quality parameters following ozonation revealed clear differences between series (i) and (ii), again reflecting both treatment effects and baseline effluent characteristics. In series (i), IEX pre-treated effluent showed a dramatic increase in color and turbidity when measured without sodium thiosulfate – likely due to reaction by-products – while samples with thiosulfate showed significantly lower values, confirming the oxidative effect of residual ozone. For example, color increased from 19 to 432 mg Pt/l without thiosulfate but dropped to 59 mg Pt/l when neutralized. Similar patterns were observed in turbidity and conductivity. COD values increased notably post-treatment in untreated samples (from 14.4 to 114 mg/l), but remained much lower in neutralized samples, indicating that ozone by-products interfere with COD readings unless quenched.

In contrast, series (ii), which used SF pre-treated effluent, showed more consistent reductions across parameters. Color decreased from 93 to as low as 8 mg Pt/l, and turbidity declined from 0.91 to 0.46 NTU with increasing ozone doses. COD also decreased progressively, with the lowest value (8.25 mg/l) observed at 83.33 mg O_3/l (3 l/min). However, COD values in thiosulfate-treated samples sometimes increased at higher ozone doses, likely due to formation of partially oxidized intermediates.

Overall, series (i) showed a more complex response to ozonation, with significant differences between quenched and non-quenched measurements, whereas series (ii) exhibited clearer trends of pollutant removal. These results emphasize the importance of proper sample handling when assessing oxidation processes and suggest that sand filtration may produce more predictable outcomes in conjunction with ozonation, albeit starting from a lower effluent quality baseline. Tables 13 and 14 present the results of physico-chemical analysis conducted in the samples from series (i) and (ii).

Table 13. Series (i) – physico-chemical analysis results

Physico-Chemical Water Quality Indicator	Unit	"Południe" WWTP Effluent (IEX Pre-Treated)	Flow Rate: 3 l/min	Flow Rate: 8 l/min
			Dose: 83.33 mg O_3/l	Dose: 125.00 mg O_3/l
Temperature	°C	18.4	18.7	18.7
pH (no sodium thiosulfate)	-	7.33	7.57	7.69
pH (with sodium thiosulfate)		-	7.72	7.85
Conductivity (no sodium thiosulfate)	µS/cm	644	664	663
Conductivity (with sodium thiosulfate)		-	750	725
Color (no sodium thiosulfate)	mg Pt/l	19	432	367
Color (with sodium thiosulfate)		-	59	37
Turbidity (no sodium thiosulfate)	NTU	0.8	7.43	1.39
Turbidity (with sodium thiosulfate)		-	6.31	1.1
COD	mg/l	14.4	114	79.6
Residual Ozone	mg/l	-	2.03	3.05

Table 14. Series (ii) – physico-chemical analysis results of wastewater after ozonation

Physico-Chemical Water Quality Indicator	Unit	"Czajka" WWTP Effluent (SF Pre-Treated)	Flow Rate: 3 l/min				Flow Rate: 8 l/min			
			Dose: 16.67 mg O_3/l	Dose: 33.33 mg O_3/l	Dose: 50.00 mg O_3/l	Dose: 83.33 mg O_3/l	Dose: 25.00 mg O_3/l	Dose: 50.00 mg O_3/l	Dose: 75.00 mg O_3/l	Dose: 125.00 mg O_3/l
Temperature	°C	16.4	16.4	16.6	16.3	17.1	16.9	17.5	17.6	17.8
pH	-	7.48	7.84	7.72	7.83	7.64	8.22	8.22	8.13	7.98
Conductivity	µS/cm	382	402	408	407	409	413	415	414	414
Color	mg Pt/l	93	37	19	16	8	22	17	14	10
Turbidity	NTU	0.91	0.9	0.72	0.6	0.49	0.7	0.58	0.5	0.46
UV_{254}	cm-1	0.416	0.333	0.272	0.262	0.239	0.296	0.269	0.254	0.242
COD (no sodium thiosulfate)	mg/l	34.3	37	24.9	24.4	8.25	24.3	23.8	21.6	18.3
COD (with sodium thiosulfate)		-	31.4	37.7	50.6	93.7	28.8	32.9	43.6	75.2
Residual Ozone	mg/l	-								
BOD_5	mg/l	3.2	2	not tested		23.4	0	not tested		14.8

UV radiation

UV disinfection tests revealed distinct differences in microbial inactivation between series (i) and series (ii), reflecting both the UV dose applied and the initial effluent quality. In series (i), where "Południe" WWTP effluent was pre-treated via ion exchange, complete inactivation of all tested microbial indicators was achieved using UV dose of 505 mJ/cm², including E. coli, coliforms, and enterococci. Total microorganism counts were reduced from >300 CFU/ml to 6 CFU/ml at 22°C and 0 CFU/ml at 36°C, indicating high disinfection efficiency even without UV application.

In contrast, series (ii), using SF pre-treated effluent from the "Czajka" WWTP, showed partial microbial reduction across tested UV doses. While *Clostridium perfringens* was absent in all cases, E. coli and coliforms remained detectable at all doses, with *E. coli* counts ranging from 41 to 44 CFU/100 ml. Fecal enterococci were not reduced and persisted throughout, suggesting resistance or shielding effects. Total microorganism counts decreased progressively with higher UV doses but remained substantially higher than in series (i), with 720 CFU/ml at 22°C and 179 CFU/ml at 36°C even at the lowest dose (279 mJ/cm²).

These results underscore the superior microbial quality and treatment responsiveness of IEX-treated effluent in series (i), while also highlighting the limited but dose-dependent effectiveness of UV disinfection in treating more heavily loaded SF-pre-treated effluent in series (ii). Table 15 presents the results of microbial inactivation achieved through UV irradiation.

Table 15. Series (i) and (ii) – results of microbial inactivation achieved through UV irradiation

Microbial Water Quality Indicator	Unit	"Południe" WWTP Effluent (IEX Pre-Treated)	UV dose: 505 mJ/cm²	"Czajka" WWTP Effluent (SF Pre-Treated)	UV Dose:		
					484 mJ/cm²	312 mJ/cm²	279 mJ/cm²
Legionella	CFU/100 ml	0	not tested	not tested	not tested		
Total Coliform Bacteria	CFU/100 ml	>80	0	>80	78	>80	51
Escherichia coli Count	CFU/100 ml	>80	0	>80	41	>80	44
Fecal Enterococci Count	CFU/100 ml	>80	0	>80	>80	>80	>80
Clostridium perfringens Count	CFU/100 ml	0	0	0	0	0	0
Total Microorganisms at 22°C / 72 h	CFU/1 ml	>300	6	1370	430	208	720
Total Microorganisms at 36°C / 48 h	CFU/1 ml	>300	0	2430	105	82	179

The physico-chemical data from the UV disinfection experiments further emphasize the contrast between series (i) and series (ii). In series (i), where "Południe" WWTP effluent underwent ion exchange pre-treatment, changes following UV dose of 505 mJ/cm² were minimal. Key parameters such as pH, turbidity, and color remained relatively stable, and COD decreased slightly from 14.4 to 13.7 mg/l, indicating that mixing alone had little impact on water quality but did not compromise effluent stability.

In series (ii), using SF pre-treated effluent from the "Czajka" WWTP, UV exposure led to more variable results. pH and temperature remained stable across doses, while conductivity decreased slightly at the highest UV dose (484 mJ/cm²), potentially reflecting some organic degradation. Turbidity improved notably at the two lower doses, dropping from 0.91 NTU to 0.55 NTU at 279 mJ/cm². UV_{254} absorbance showed a moderate decrease, indicating partial breakdown of organic compounds. However, COD values did not decrease consistently; while a significant reduction was observed at 484 mJ/cm² (from 34.3 to 14.4 mg/l), values at lower doses were higher (25.4–30 mg/l), suggesting incomplete oxidation. Interestingly, BOD_5 dropped to 0 mg/l at the highest dose and remained low at 2.8 mg/l at 279 mJ/cm².

These results suggest that while UV disinfection can lead to partial improvements in water quality – especially in terms of turbidity and UV_{254} absorbance – its effectiveness in reducing organic load may be dose-dependent and limited without complementary treatment steps. Series (i) remained more stable overall, while series (ii) showed greater variability and less predictable outcomes under UV exposure. Tables 16 and 17 present the results of physico-chemical analysis conducted in the samples from series (i) and (ii).

Table 16. Series (i) – physico-chemical analysis results

Physico-Chemical Water Quality Indicator	Unit	"Południe" WWTP Effluent (IEX Pre-Treated)	UV dose: 505 mJ/cm²
Temperature	°C	18.4	18.4
pH	-	7.33	7.48
Conductivity	µS/cm	644	664
Color	mg Pt/l	19	23
Turbidity	NTU	0.8	0.94
COD	mg/l	14.4	13.7

Table 17. Series (ii) – physico-chemical analysis results

Physico-Chemical Water Quality Indicator	Unit	"Czajka" WWTP Effluent (SF Pre-Treated)	UV Dose:		
			484 [mJ/cm²]	312 [mJ/cm²]	279 [mJ/cm²]
Temperature	°C	16.4	17.7	17.6	17.8
pH	-	7.48	7.54	7.5	7.52
Conductivity	µS/cm	382	348	372	377
Color	mg Pt/l	93	100	99	97
Turbidity	NTU	0.91	1.23	0.66	0.55
UV_{254}	cm-1	0.416	0.334	0.391	0.4
COD	mg/l	34.3	14.4	25.4	30
BOD_5	mg/l	3.2	0	not tested	2.8

5.2.3 Disinfection as an element of the water reclamation system

The pilot experiments were carried out in two stages:

- **Stage I – preliminary treatment** – the tests were aimed at assessing the effectiveness of fabric filtration (FF) and ion exchange (IER) processes as the third stage of wastewater treatment.
- **Stage II – disinfection** – the tests were aimed at assessing the effectiveness of the ozone disinfection process.

STAGE I – PRELIMINARY TREATMENT

In the first stage, the experiments were carried out on two independent installations supplied with the same stream of wastewater treated after a mechanical-biological process with an increased degree of nutrient removal. The quality of the wastewater discharged to the installation met the Polish requirements of the Regulation of the Minister of Economy and Inland Navigation of July 12, 2019. (Journal of Laws 2019, item 1311) for wastewater treatment plants with a population equivalent of over 100,000. The effectiveness of both technologies was assessed on the basis of the following indicators: turbidity, total suspended solids (TSS), total organic carbon (TOC), chemical oxygen demand (COD), total phosphorus (TP) and total nitrogen (TN) in samples before and after the process. **The main requirement of the study was to achieve stable operation of the plant and wastewater quality expressed by a turbidity index not exceeding 1.0 NTU.**

Fabric Filtration

The first system analyzed was fabric filters, which, thanks to the use of special types of fabrics, combine the features and advantages of both surface and volume filtration, which allows for a very high degree of particulate matter removal. The wastewater was fed by gravity into a steel filter chamber with a drum covered with filter fabric with an area of 2 m². Suspended solids and particles were removed from the wastewater during filtration through the fabric. The filtered wastewater flowed into the drum, from where it was discharged through the outlet chamber and overflow weir into the retention tank. The filter cloth was cleaned automatically at specific intervals, and the filtration process was not interrupted during the cloth cleaning cycle. The system operated at a capacity of 5-8 m³/h.

The characteristics of wastewater before and after the fabric filtration process are presented in Table 18. In addition, Figure 24 shows the turbidity values for wastewater before and after the fabric filtration process.

Table 18. Characterization of wastewater before and after the fabric filtration process

Date	TSS [mg/l]			TOC [mg/l]			COD [mgO₂/l]			TP [mg/l]			TN [mg/l]		
	TW	FF	%R	TW	FF	%R	TW	FF	%R	TW	FF	%R	TW	FF	%R
23/24.09.24	6	2.5	58.3	9.7	9.8	-1.0	25.7	25.7	0.0	0.458	0.329	28.2	3.2	2.5	21.9
25/26.09.24	280	3.8	98.6	13	11	15.4	274	31.5	88.5	9.73	0.611	93.7	13	2.4	81.5
26/27.09.24	9,5	3.7	61.1	12	11	8.3	33.5	27	19.4	0.673	0.407	39.5	4.1	2.7	34.1
29/30.09.24	6	3.2	46.7	12	12	0.0	26.9	26.9	0.0	0.562	0.47	16.4	2.7	2.4	11.1
30/01.10.24	6.2	2.6	58.1	9.9	9.9	0.0	25	22.9	8.4	0.577	0.393	31.9	2.7	2.3	14.8
01/02.10.24	6.2	5.2	16.1	11	9.3	15.5	25.9	25.9	0.0	0.569	0.399	29.9	3	2.4	20
02/03.10.24	5.6	3.2	42.9	11	12	-9.1	26.5	26.7	-0.8	0.568	0.393	30.8	2.9	2.5	13.8
03/04.10.24	4.7	2	57.4	10	9.9	1.0	25.9	24.7	4.6	0.472	0.331	29.9	3.3	2.6	21.2
06/07.10.24	8.2	3	63.4	12	12	0.0	27.1	25.6	5.5	0.591	0.423	28.4	2.9	1.9	34.5
07/08.10.24	25	6	76.0	11	10	9.1	31.5	22.6	28.3	1.12	0.513	54.2	2.7	1.7	37.0
13/14.10.24	1100	6	99.5	150	14	90.7	1340	37	97.2	45.5	0.761	98.3	53	2.3	95.7
14/15.10.24	130	5.1	96.1	14	10	28.6	197	25.3	87.2	5.38	0.571	89.4	6.4	2.3	64.1
15/16.10.24	25	2.2	91.2	11	10	9.1	30.8	23.6	23.4	0.605	0.393	35.0	3.9	3	23.1
16/17.10.24	26	5.6	78.5	13	11	15.4	30.1	24.7	17.9	0.538	0.335	37.7	5.7	3.9	31.6
17/18.10.24	10	3.2	68.0	11	10	9.1	27.7	25.3	8.7	0.44	0.311	29.3	5.2	4.5	13.5
Average			67.5			12.8			25.9			44.8			34.5

Description: TW – Treated wastewater; FF – fabric filtration; %R – reduction rate; TSS – total suspended solids; TOC – total organic carbon; COD – chemical oxygen demand; TP – total phosphorus; TN – total nitrogen.

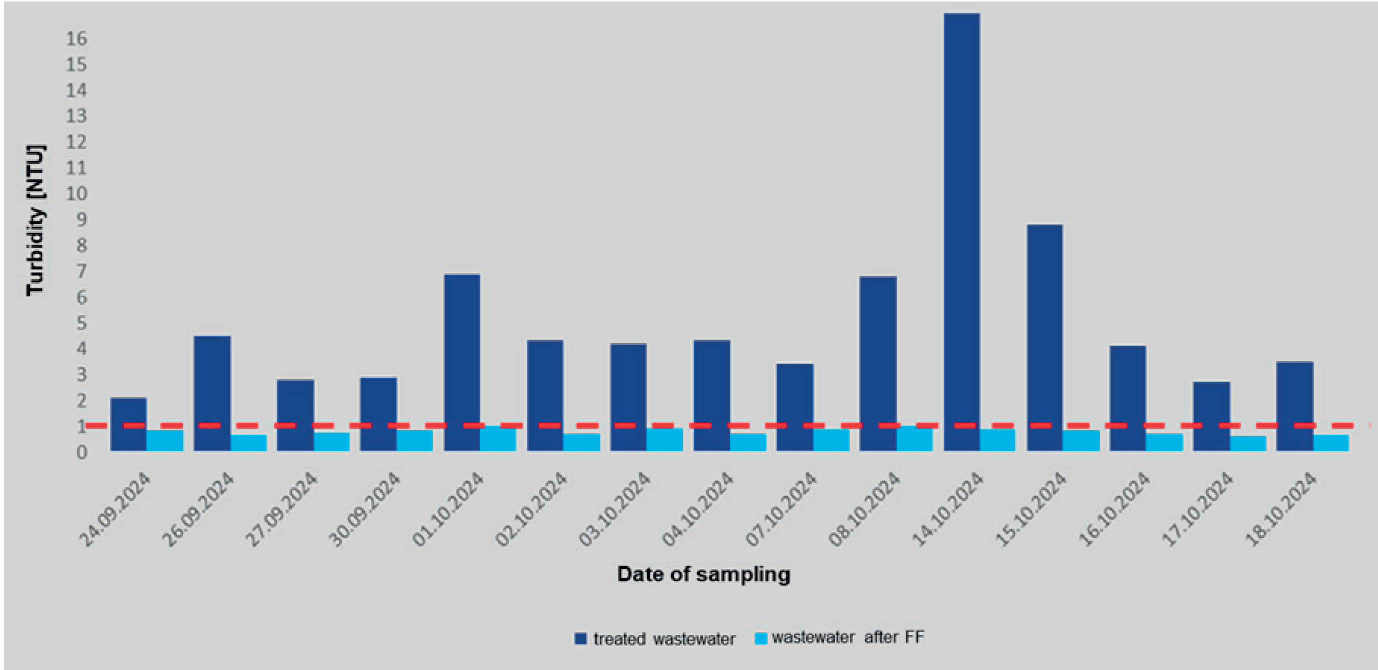


Figure 24. Turbidity values before and after the fabric filtration process

The tests showed that the pilot plant is super effective at getting rid of pollutants from wastewater. Thanks to the fabric filtration tech, the plant not only hit the pollution reduction targets, but also kept things running smoothly and consistently. The quality parameters of wastewater after the third stage of filtration remained at levels not exceeding the permissible values, even in the case of significant exceedances of the parameters in treated wastewater discharged from the wastewater treatment plant, which also served as the feed medium for the pilot plant (Table 18). This proves the system's ability to adapt to changing operating conditions, including the acceptance of significant pollutant loads in the wastewater entering the device. The effect achieved through the use of fabric filtration is crucial for maintaining the proper operation of the entire treatment plant. The results obtained confirm the high efficiency of the system in terms of turbidity removal, which in the analyzed case averaged 80% (Figure 24). The average value of this indicator in treated wastewater was 5.20 NTU, while after filtration through a fabric filter it averaged 0.80 NTU. In the case of removing other contaminants, slightly lower efficiency was observed, amounting to 67.5%, 12.8%, 25.9%, 44.8%, and 34.5% for TSS, TOC, COD, TP, and TN, respectively.

Ion Exchange Resins

The second system analyzed was an installation that combines several types of technologies, such as adsorption, mechanical filtration, and ion exchange filtration. Filtration takes place in seven columns, divided into two parallel streams. Each of the columns is controlled by a microprocessor controller with a display. Columns 1A and 1B filter out mechanical impurities. Columns 2A and 2B reduce organic impurities, turbidity, color and odor. Columns 3A and 3B reduce phosphorus and nitrogen. Column 4 is designed to further reduce turbidity through mechanical filtration. The columns are filled with different filter media: gravel, activated carbon, ion exchange resins, zeolite bed. The system is powered by a 1kW pump. Three reagents are dosed into the system and come into contact with the medium in the reaction tank. These reagents are intended to precipitate some of the pollutants and to support the filtration process in the filter columns. The system operated at a capacity of 1 m³/h.

The characteristics of wastewater before and after the ion exchange filtration process are presented in Table 19. In addition, Figure 25 shows the turbidity values for wastewater before and after the ion exchange filtration process.

Table 19. Characterization of wastewater before and after the ion exchange filtration process

Date	TSS [mg/l]			TOC [mg/l]			COD [mgO₂/l]			TP [mg/l]			TN [mg/l]		
	TW	IER	%R	TW	IER	%R	TW	IER	%R	TW	IER	%R	TW	IER	%R
23/24.09.24	6	2	66.7	9.7	5.5	43.3	26	14	44.7	0.46	0.07	85.8	3.2	2.9	9.4
24/25.09.24	240	2	99.2	14	6.2	55.7	271	14	94.9	9.09	0.13	98.6	12	2.2	81.7
26/27.09.24	9.5	2.6	72.6	12	6.4	46.7	34	13	60.3	0.67	0.25	63.3	4.1	2.0	51.2
29/30.09.24	6	2	66.7	12	6.7	44.2	27	13	50.6	0.56	0.19	66.2	2.7	2.1	22.2
30/01.10.24	6.2	2	67.7	9.9	6.2	37.4	25	12	50.4	0.58	0.16	72.8	2.7	2.2	18.5
01/02.10.24	6.2	5.7	8.1	11	6.1	44.5	26	13	49.8	0.57	0.16	71.5	3.0	2.3	23.3
06/07.10.24	8.2	2	75.6	12	6.4	46.7	27	11	60.5	0.59	0.12	80.5	2.9	2.9	0.0
07/08.10.24	25	5	80.0	11	6.1	44.5	32	11	63.8	1.12	0.15	86.5	2.7	1.7	37.0
10/11.10.24	1400	2	99.9	200	6.9	96.6	1340	15	98.9	39.2	0.54	98.6	40	1.5	96.3
15/16.10.24	25	2	92.0	11	8.2	25.5	31	18	42.9	0.61	0.48	20.2	3.9	2.4	38.5
16/17.10.24	26	5.6	78.5	13	11	15.4	30	25	17.9	0.54	0.34	37.7	5.7	3.9	31.6
17/18.10.24	10	2	80.0	11	9.7	11.8	28	19	30.0	0.44	0.19	57.3	5.2	4.1	21.2
20/21.10.24	410	2	99.5	21	8.8	58.1	498	19	96.2	36.8	0.23	99.4	18.0	3.2	82.2
21/22.10.24	28	2	92.9	12	8.9	25.8	36	18	49.9	1.07	0.33	68.9	3.9	2.9	25.6
Average			77.1			42.6			57.9			72.0			38.5

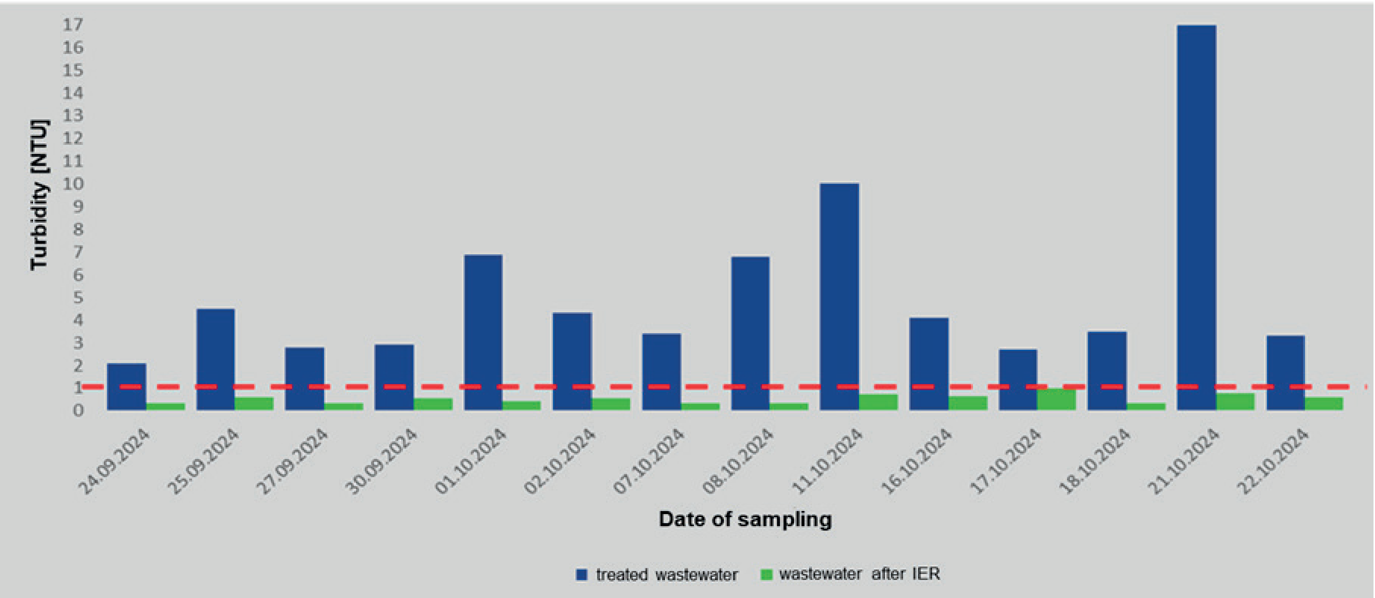


Figure 25. Turbidity values before and after the ion exchange filtration process

The conducted research has shown that the use of ion exchange resins as a tertiary treatment method for wastewater allows for a reduction in all analyzed indicators. The highest reduction, over 86%, was recorded for turbidity. The average value of this indicator in the treated wastewater was 5.00 NTU, while after filtration through the ion exchange resin system, it was 0.50 NTU on average (Figure 25.). In the case of removing other contaminants, slightly lower efficiency was observed, amounting to 77.1%, 42.6%, 57.9%, and 72% for TSS, TOC, COD, and TP, respectively (Table 19). The parameter that was reduced the least effectively (only 38,5%) with this technology was TN, but this was most likely due to the fact that the values of this indicator were relatively low in the treated wastewater even before the third stage of wastewater treatment was applied (Table 19).

Key Takeaways

- **Both technologies met the obligatory turbidity parameter below 1 NTU**, which is crucial for reducing ozone doses and costs.
- The turbidity removal efficiency was very high, over 80%, for both tested technologies.
- **Ion exchange resin technology was selected** because it achieved higher reductions in suspended solids (77%), phosphorus (72%), and organic compounds (57,9% for COD) compared to drum filters. **In addition, ion exchange resin technology required lower investment and operating costs.**

STAGE II – DISINFECTION

Ozonation was used as a disinfection method, utilizing the SPID 300 device. This device operates with an efficiency of 20 m³/h and is capable of producing a maximum of 300 g of ozone per hour, which is the highest dose that the ozone block can generate. This is a compatible, containerized station that allows for continuous process operation.

As for the results, during operation, the flow rate of the installation varied, ranging from 2 m³/h to 4.8 m³/h. Ozone dose (g/h) was adjusted from 20 g/h to 70 g/h. The increase in dose was due to the results achieved for microbiological parameters. Residual ozone in the wastewater ranges from 0.16 mg/l to 0.70 mg/l. Contact time of ozone with sewage varied between 18 minutes and 38 minutes.

Table 20. Technical parameters of installation working

Date	Flow	Ozone dose	Residual ozone	Ozone dose	Contact time ozone with sewage
	[m3/h]	[g/h]	[mg/l]	[mg/l]	[min]
2025-02-13	4.7	20	0.16	4.26	18
2025-02-18	4.8	20	0.23	4.17	18
2025-02-20	4.7	30	0.21	6.38	18
2025-03-04	4.7	50	0.30	10.64	24
2025-03-18	3.5	50	0.41	14.29	33
2025-03-20	3.5	50	0.71	14.29	33
2025-03-21	3.5	50	0.74	14.29	33
2025-03-25	3	50	0.30	16.67	38
2025-03-27	3.3	50	0.16	15.15	35
2025-04-01	3.5	70	0.61	20.00	33
2025-04-08	2	70	0.57	18.42	30
2025-04-10	3.5	70	0.68	18.4	30

PHYSICOCHEMICAL DATA

Temperature

The inlet temperatures range from 14.6°C to 17.2°C, with an average of 16.0°C. The temperature values for the Inlet treatment show a steady increase over time, with the highest temperature recorded on April 1st. The average temperature is 16.0°C, indicating a relatively stable temperature range. The Ion exchange temperatures range from 14.4°C to 17.1°C, with an average of 15.6°C. The ion exchange treatment shows a similar trend, with temperatures ranging from 14.4°C to 17.1°C. The average temperature is slightly lower at 15.6°C, suggesting a more controlled temperature environment.

The temperatures after Ozone process range from 14.6°C to 17.7°C, with an average of 16.4°C. The Ozone treatment consistently shows higher temperatures compared to the other treatments, with an average of 16.4°C. The highest temperature recorded is 17.7°C, indicating that the ozonation process may contribute to higher temperature levels.

The temperature data indicates that the Ozone treatment generally maintains higher temperatures compared to the Inlet and Ion exchange treatments. The Inlet treatment shows a steady increase in temperature over time, while the Ion exchange treatment maintains a more controlled temperature range. The Ozone treatment consistently shows the highest temperatures.

pH

The Inlet pH values range from 7.0 to 7.6. The pH values for the Inlet treatment show a stable range, with the majority of values falling between 7.2 and 7.6. The average pH is 7.4, indicating a slightly alkaline environment.

The Ion exchange pH values range from 7.1 to 7.5. The Ion exchange treatment shows a consistent pH range, with values between 7.1 and 7.5. The average pH is 7.3.

Ozone pH values range from 7.3 to 7.8. The Ozone treatment consistently shows higher pH values compared to the other treatments, with an average of 7.5. The pH values range from 7.3 to 7.8.

The pH data indicates that the Ozone treatment generally maintains slightly higher pH levels compared to the inlet and Ion exchange treatments. The Inlet treatment shows a stable pH range, while the Ion exchange treatment maintains a more neutral pH environment. The Ozone treatment consistently shows the highest pH values, suggesting that the ozonation process may contribute to a more alkaline environment.

Chemical Oxygen Demand

The Inlet COD values range from 24.1 mg/l to 58.2 mg/l. The COD values for the Inlet treatment show significant variation, with the highest value recorded on February 20th and the lowest on April 8th. The average COD value is 35.5 mg/l, indicating a relatively high level of organic pollutants in the water.

The Ion exchange COD values range from 13.1 mg/l to 30.5 mg/l, with an average of 21.1 mg/l. The Ion exchange treatment shows a more controlled range of COD values, with the highest value recorded on February 18th and the lowest on March 20th. The average COD value is 21.1 mg/l, suggesting a more effective reduction of organic pollutants compared to the Inlet treatment.

The Ozone COD values range from 11.4 mg/l to 29.2 mg/l, with an average of 18.6 mg/l. The ozone treatment consistently shows lower COD values compared to the Inlet and ion exchange treatments, with the highest value recorded on February 18th and the lowest on March 20th. The average COD value is 18.6 mg/l, indicating the most effective reduction of organic pollutants among the three treatments.

The COD data indicates that the Inlet treatment generally has higher levels of organic pollutants compared to the Ion exchange and Ozone treatments. The Inlet treatment shows significant variation in COD values, while the Ion exchange treatment maintains a more stable and lower range of COD values. The analysis of the COD data reveals that the Ozone treatment is the most effective in reducing the levels of organic pollutants in the water compared to the Inlet and Ion exchange treatments. The Ozone treatment consistently maintains lower COD values, indicating better water quality. Overall, all treatments are well within the limited value of <125 mg/l, suggesting that the treatments are effective in maintaining acceptable COD levels.

Table 21. Tempetarure, pH, and COD values variation

Date	Temperature [°C]			pH			COD [mg/l]		
	Inlet	Ion exchange	Ozone	Inlet	Ion exchange	Ozone	Inlet	Ion exchange	Ozone
2025-02-13	15.5	15.3	15.8	7.3	7.2	7.3	33.4	17.1	12.2
2025-02-18	14.6	14.8	14.6	7.2	7.2	7.5	43.4	30.5	29.2
2025-02-20	15.6	14.4	15.1	7	7.2	7.4	58.2	30.2	26
2025-03-04	15.3	15.2	15.8	7.4	7.3	7.4	29.7	18.9	25.3
2025-03-18	15.8	15.3	16.9	7.2	7.1	7.7	47.5	19.7	15.2
2025-03-20	15.9	15.8	16.2	7.5	7.5	7.7	27.2	13.1	11.4
2025-03-25	16.5	15.8	17.1	7.4	7.3	7.6	32.5	23.6	20.9
2025-03-27	16.7	16.7	17.7	7.6	7.5	7.6	28.3	23.5	18
2025-04-01	17.2	17.1	17.7	7.6	7.3	7.6	34.8	21.8	19.7
2025-04-08	16.6	15.6	17.3	7.5	7.3	7.8	24.1	17.4	13.6
2025-04-10	16.4	15.3	17	7.5	7.2	7.5	31.4	16.1	13.4
Limited value	< 35 °C			6.5-9.5			< 125 mg/l		

Total Organic Compound

The Inlet TOC values range from 9.7 mg/l to 25 mg/l. The TOC values for the INLET treatment show variation, with the highest value recorded on February 20th and the lowest on April 8th. The average COD value is 13.7 mg/l, indicating a relatively high level of organic pollutants in the water.

The Ion exchange TOC values range from 7.4 mg/l to 14 mg/l, with an average of 9.32 mg/l.

The mean value of Ozone is 9.38 mg/l, which is close to the mean value of Ion exchange. The highest value of Ozone is 14.0 mg/l, and the lowest is 6.4 mg/l, showing moderate variability in the data.

Biochemical Oxygen Demand

The mean BOD_5 value for Inlet is 6.9 mg/l, indicating a moderate level of organic matter that requires oxygen for decomposition. The values range from 2.6 mg/l to 18.0 mg/l, showing significant variability.

The mean BOD_5 value for Ion exchange is 3.8 mg/l, which is lower than the mean value for Inlet. The values range from 0.73 mg/l to 11.0 mg/l, indicating less variability compared to Inlet.

The mean BOD_5 value for Ozone is 5.6 mg/l, which is higher than the mean value for Ion exchange but lower than Inlet. The values range from 1.5 mg/l to 12.0 mg/l, showing moderate variability.

The Inlet parameter shows higher BOD_5 values on average compared to Ion exchange and ozone, indicating that the initial untreated water has higher levels of organic matter.

The Ion exchange treatment effectively reduces the BOD_5 levels, with lower mean values and less variability. The Ozone treatment also reduces BOD_5 levels but shows more variability compared to Ion exchange.

Total Suspended Solid

The mean TSS value for Inlet is 4.2 mg/l, indicating a moderate level of suspended solids. The values range from 1.6 mg/l to 7.0 mg/l, showing significant variability.

The mean TSS value for Ion Exchange is 1.4 mg/l, which is lower than the mean value for Inlet. The values range from 0.2 mg/l to 3.4 mg/l, indicating less variability compared to Inlet.

The mean TSS value for Ozone is 0.3 mg/l, which is the lowest among the three treatments. The values range from 0.1 mg/l to 0.6 mg/l, showing minimal variability.

The Inlet parameter shows higher TSS values on average compared to Ion exchange and Ozone, indicating that the initial untreated water has higher levels of suspended solids. The Ion exchange treatment effectively reduces the TSS levels, with lower mean values and less variability.

The Ozone treatment shows the lowest TSS levels, indicating it is the most effective in reducing suspended solids.

Table 22. Total Organic Compound, Biochemical Oxygen Demand, and Total Suspended Solid values variations

Date	TOC [mg/l]			BOD5 [mg/l]			TSS [mg/l]		
	Inlet	Ion exchange	Ozone	Inlet	Ion exchange	Ozone	Inlet	Ion exchange	Ozone
2025-02-13	13	7.9	6.4	8.0	6.0	4.5	5.7	< 2.0	< 2.0
2025-02-18	16	12	13	7.0	6.0	11	5.4	3.4	< 2.0
2025-02-20	25	14	12	18	11	10	6.8	2.3	< 2.0
2025-03-04	10	9.1	14	5.0	3.0	12	5.2	< 2.0	< 2.0
2025-03-18	16	7.9	8.4	10	3.0	3.0	7.0	< 2.0	< 2.0
2025-03-20	11	7.9	7.9	5.5	0.81	2.3	< 2.0	< 2.0	< 2.0
2025-03-25	12	8.9	9.2	7.0	4.2	7.0	2.0	< 2.0	< 2.0
2025-03-27	10	9.3	8.2	3.0	4.9	4.0	2.6	< 2.0	< 2.0
2025-04-01	12	8.1	8.3	4.3	1.3	3.6	3.4	0.4	0.3
2025-04-08	9,7	7.4	7.2	2.6	1.1	2.5	2	0.2	0.1
2025-04-10	16	10	8.6	6.0	0.73	1.5	1.6	0.6	0.6
Limited value	-			< 10mg/l			<10 mg/l		

Turbidity

The mean turbidity value for Inlet is 3.1 NTU, indicating a moderate level of turbidity.

The values range from 1.7 NTU to 5.8 NTU, showing significant variability. The mean turbidity value for Ion exchange is 0.9 NTU, which is lower than the mean value for Inlet. The values range from 0.4 NTU to 2.2 NTU, indicating less variability compared to Inlet.

The mean turbidity value for Ozone is 0.6 NTU, which is the lowest among the three treatments.

The values range from 0.3 NTU to 1.2 NTU, showing minimal variability.

The Inlet parameter shows higher turbidity values on average compared to Ion exchange and Ozone, indicating that the initial untreated water has higher levels of suspended particles.

The Ion exchange treatment effectively reduces the turbidity levels, with lower mean values and less variability. The ozone treatment shows the lowest turbidity levels, indicating it is the most effective in reducing suspended particles.

Electrical conductivity

The mean electrical conductivity value for Inlet is 1536 mg/l, indicating a moderate level of conductivity. The values range from 1449 mg/l to 1620 mg/l, showing significant variability.

The mean electrical conductivity value for Ion exchange is 1547 mg/l, which is slightly higher than the mean value for Inlet.

The values range from 1452 mg/l to 1625 mg/l, indicating similar variability compared to Inlet.

The mean electrical conductivity value for Ozone is 1546 mg/l, which is close to the mean value for Ion exchange.

The values range from 1450 mg/l to 1612 mg/l, showing moderate variability.

All three treatments show moderate levels of electrical conductivity with similar ranges and variability. The mean values for Inlet, Ion exchange, and ozone are close to each other, indicating that the treatments have a similar effect on electrical conductivity.

Table 23. Turbidity and electrical conductivity values variations

Date	Turbidity			Electrical conductivity [mg/l]		
	Inlet	Ion exchange	Ozone	Inlet	Ion exchange	Ozone
2025-02-13	3.8	1.3	0.93	1 502	1 551	1 563
2025-02-18	4.1	2.2	1.2	1 609	1 625	1 603
2025-02-20	4.0	1.4	0.9	1 511	1 541	1 543
2025-03-04	2.9	0.55	0.36	1 574	1 572	1 558
2025-03-18	5.8	0.91	0.4	1 563	1 569	1 569
2025-03-20	2.1	0.44	0.54	1 537	1 562	1 576
2025-03-25	1.7	0.65	0.8	1 620	1 618	1 612
2025-03-27	2.3	0.7	0.56	1 605	1 606	1 606
2025-04-01	2.9	0.65	0.38	1 468	1 467	1 462
2025-04-08	2.8	0.61	0.34	1 449	1 452	1 450
2025-04-10	1.9	0.61	0.28	1 462	1 459	1 461
Limited value	< 5NTU			700-3000 µS/cm		

Total Phosphorus

The values for Inlet range from 0.37 to 2.53 mg/l, with an average of 1.16 mg/l. The Ion exchange values range from 0.20 to 1.81 mg/l, with an average of 0.87 mg/l. The Ozone values range from 0.23 to 1.77 mg/l, with an average of 0.90 mg/l.

The highest TP level recorded was on March 18th, at 1.77 mg/l, which is within the limited value of 2 mg/l. The mean TP level is 0.94 mg/l, indicating that the ozonation treatment generally maintains TP levels well within the acceptable limit.

Phosphate

The Inlet values range from 0.14 to 2.15 mg/l, with an average of 1.00 mg/l. The Ion exchange values range from 0.16 to 1.73 mg/l, with an average of 0.82 mg/l. The Ozone values range from 0.17 to 1.66 mg/l, with an average of 0.81 mg/l. The highest $P\text{-}PO_4$ level recorded was on March 18th, at 1.66 mg/l, which is within the limited value range of 0-2 mg/l. The mean $P\text{-}PO_4$ level is 0.81 mg/l, suggesting that the ozonation treatment effectively keeps $P\text{-}PO_4$ levels within the acceptable range.

Table 24. Total Phosphorus and phosphate values variations

Date	TP [mg/l]			$P\text{-}PO_4$ [mg/l]		
	Inlet	Ion exchange	Ozone	Inlet	Ion exchange	Ozone
2025-02-13	0.9	0.42	0.9	0.72	0.38	0.31
2025-02-18	0.52	0.35	0.35	0.28	0.24	0.26
2025-02-20	0.49	0.31	0.3	0.22	0.2	0.2
2025-03-04	0.37	0.20	0.23	0.14	0.16	0.17
2025-03-18	2.53	1.81	1.77	2.15	1.68	1.66
2025-03-20	2.35	1.81	1.70	2.09	1.73	1.59
2025-03-25	1.10	0.92	0.94	0.96	0.89	0.91
2025-03-27	0.95	0.83	0.82	0.85	0.8	0.81
2025-04-01	1.67	1.29	1.29	1.44	1.18	1.27
2025-04-08	0.72	0.65	0.65	0.58	0.55	0.55
2025-04-10	1.17	0.94	0.93	0.98	0.89	0.87
Limited value	2 mg/l			0-2 mg/l		

Total Nitrogen

The Inlet values range from 7,5 to 19,0 mg/l, with an average of 10,6 mg/l. The Ion exchange values range from 4,0 to 16,0 mg/l, with an average of 8,1 mg/l. The values range from 4,0 to 16,0 mg/l, with an average of 8,1 mg/l. The highest TN level recorded was on February 18th, at 16,0 mg/l, which exceeds the limited value of 15 mg/l. The mean TN level is 8,1 mg/l, indicating that while most measurements are within the acceptable limit, there are instances where TN levels exceed the limit.

Table 25. Total Nitrogen values variations

Date	TN [mg/l]		
	Inlet	Ion exchange	Ozone
2025-02-13	9.9	6.9	6.9
2025-02-18	19	16	16
2025-02-20	13	13	12
2025-03-04	7.5	4.8	4.7
2025-03-18	11	8.7	9.0
2025-03-20	11	8.6	8.8
2025-03-25	7.9	6.6	6.5
2025-03-27	8.6	8.6	8.4
2025-04-01	9.0	5.8	5.8
2025-04-08	9.0	7.4	7.3
2025-04-10	11	8.2	8.2
Limited value	15 mg/l		

Ammonium nitrogen

The mean $N\text{-}NH_4$ value for INLET is 3.38 mg/l, indicating a moderate level of ammonium nitrogen.

The values range from 0.55 mg/l to 15.2 mg/l, showing significant variability. The mean $N\text{-}NH_4$ value for Ion exchange is 2.63 mg/l, which is lower than the mean value for Inlet. The values range from 0.5 mg/l to 12.1 mg/l, indicating similar variability compared to Inlet.

The mean $N\text{-}NH_4$ value for Ozone is 2.79 mg/l, which is close to the mean value for Ion exchange.

The values range from 0.56 mg/l to 12.4 mg/l, showing moderate variability. The mean values for Inlet, Ion exchange, and Ozone are close to each other, indicating that the treatments have a similar effect on ammonium nitrogen levels.

Nitrite dioxide

The mean $N\text{-}NO_2$ value for Inlet is 0.14 mg/l, indicating a moderate level of nitrite dioxide.

The values range from 0.06 mg/l to 0.34 mg/l, showing significant variability. The mean $N\text{-}NO_2$ value for Ion exchange is 0.19 mg/l, which is higher than the mean value for Inlet. The values range from 0.00 mg/l to 0.96 mg/l, indicating significant variability.

The mean $N\text{-}NO_2$ value for Ozone is 0.01 mg/l, which is the lowest among the three treatments.

The values range from 0.00 mg/l to 0.02 mg/l, showing minimal variability. The Inlet parameter shows moderate $N\text{-}NO_2$ values on average compared to Ion exchange and Ozone, indicating that the initial untreated water has higher levels of nitrite dioxide. The Ion exchange treatment shows higher mean $N\text{-}NO_2$ values and significant variability.

The Ozone treatment shows the lowest $N\text{-}NO_2$ values with minimal variability, indicating it is the most effective in reducing nitrite dioxide levels.

Nitrate nitrogen

The mean $N\text{-}NO_3$ value for Inlet is 7.85 mg/l, indicating a moderate level of nitrate nitrogen.

The values range from 5.6 mg/l to 10.0 mg/l, showing significant variability. The mean $N\text{-}NO_3$ value for Ion exchange is 6.50 mg/l, which is lower than the mean value for Inlet. The values range from 3.5 mg/l to 8.8 mg/l, indicating significant variability.

The mean $N\text{-}NO_3$ value for Ozone is 6.7 mg/l, which is slightly higher than the mean value for Ion exchange. The values range from 4.1 mg/l to 9.4 mg/l, showing moderate variability.

All three treatments show moderate levels of nitrate nitrogen with similar ranges and variability. The mean values for Inlet, Ion exchange, and Ozone are close to each other, indicating that the treatments have a similar effect on nitrate nitrogen levels.

Table 26. Ammonium nitrogen, Nitrite dioxide, and Nitrite nitrogen values variations

Date	$N\text{-}NH_4$ [mg/l]			$N\text{-}NO_2$ [mg/l]			$N\text{-}NO_3$ [mg/l]		
	Inlet	Ion exchange	Ozone	Inlet	Ion exchange	Ozone	Inlet	Ion exchange	Ozone
2025-02-13	4.03	2.3	1.89	0.29	0.26	0.01	6.5	5.8	6.2
2025-02-18	15.2	12.1	12.4	0.24	0.96	0.01	5.6	3.5	4.3
2025-02-20	6.09	5.17	5.57	0.34	0.62	0.01	8.2	8.8	9.4
2025-03-04	1.83	1.11	1.67	0.07	0.01	0.02	6.6	4.2	4.1
2025-03-18	1.03	1.31	1.34	0.07	0.01	0.01	10	8.3	8.4
2025-03-20	0.86	0.89	1.05	0.08	0.03	0.00	10	8.2	8.4
2025-03-25	1.31	0.82	0.89	0.06	0.02	0.01	8.2	5.9	6.2
2025-03-27	1.24	1.15	1.6	0.08	0.01	0.01	7.6	7.7	7.8
2025-04-01	1.65	0.98	0.89	0.14	0.05	0.01	6.1	4.7	4.8
2025-04-08	0.55	0.5	0.56	0.08	0	0	8.1	6.8	6.7
2025-04-10	<0.50	<0.50	<0.50	0.08	0.02	0.01	9.5	7.6	7.6
Limited value	0-5 mg/l			-			10mg/l		

Potassium

The mean potassium value for Inlet is 35.7 mg/l, indicating a moderate level of potassium.

The values range from 28.1 mg/l to 48.1 mg/l, showing significant variability. The mean potassium value for Ion exchange is 35.3 mg/l, which is slightly lower than the mean value for Inlet.

The values range from 27.1 mg/l to 43.5 mg/l, indicating similar variability compared to Inlet.

The mean potassium value for Ozone is 35.17 mg/l, which is close to the mean value for Ion Exchange. The values range from 27.3 mg/l to 43.5 mg/l, showing moderate variability.

All three treatments show moderate levels of potassium with similar ranges and variability.

The mean values for Inlet, Ion Exchange, and Ozone are close to each other, indicating that the treatments have a similar effect on potassium levels.

Table 27. Potassium values variations

Date	Potassium [mg/l]		
	Inlet	Ion exchange	Ozone
2025-02-13	31.4	33.4	33.5
2025-02-18	41	43.5	43.5
2025-02-20	35.4	38.3	38.7
2025-03-04	43.6	42.4	41
2025-03-18	31.2	31.5	32.1
2025-03-20	33.1	33	34.6
2025-03-25	48.1	39.7	38.6
2025-03-27	37.5	37.7	37.5
2025-04-01	33.1	32	30.9
2025-04-08	28.1	27.1	27.3
2025-04-10	30.6	29.4	29.2
Limited value	-		

MICROBIOLOGY PARAMETER

Indicator for further work and selection of technological parameters was microbiology parameters. Below are presented the results for the parameters that were to be achieved in the project: Coli bacteria, *Escherichia Coli*, Total Plate Count at 36 and 22 °C, *Enterococcus*.

Table 28. List of experiments conducted on various microbiology parameters

Experiment	Date	Ozone dose [g/h]
1	18.02.2025	20
2	20.02.2025	30
3	04.03.2025	50
4	18.03.2025	50
5	20.03.2025	50
6	25.03.2025	50
7	27.03.2025	50
8	01.04.2025	70
9	08.04.2025	70
10	10.04.2025	70

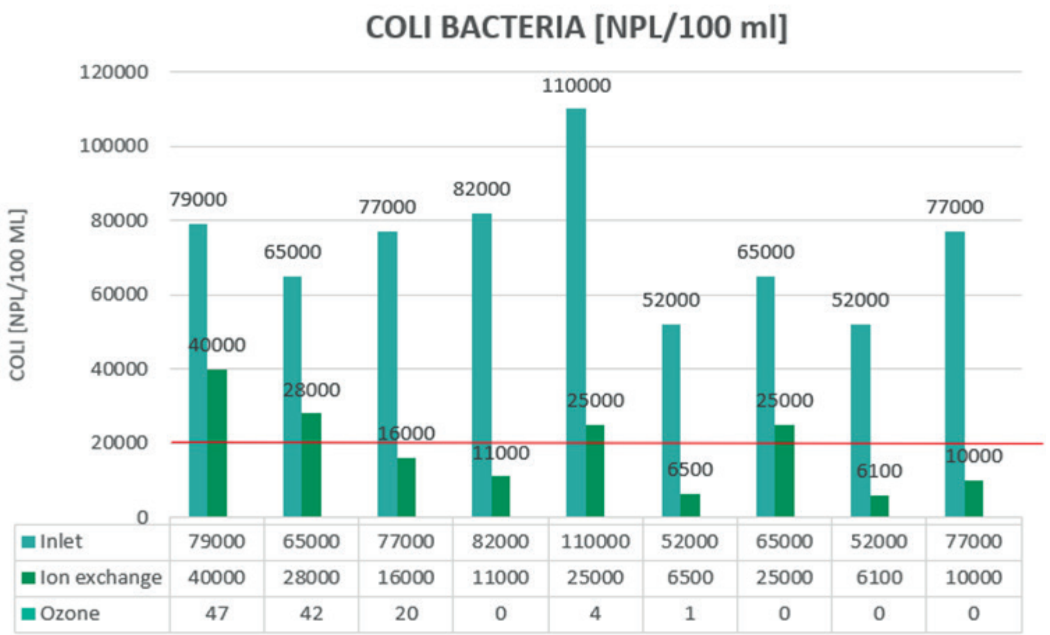


Figure 26. Results of experiments conducted on Coli Bacteria

The mean Coli Bacteria value for Inlet is 71,700 NLP/100 ml. The values range from 52,000 to 110,000 NLP/100 ml showing significant variability. The mean Coli Bacteria value for Ion exchange is 17,340 NLP/100 ml with the range from 5,800 to 40,000. After the ozonation process, the number of Coli bacteria drops drastically. The mean Coli Bacteria for Ozone process is 11.5 NLP/100 ml. The values range for ozone process if from 0 to 47 NLP/100 ml. By increasing the ozone dose to 70 g/h, full disinfection was achieved.

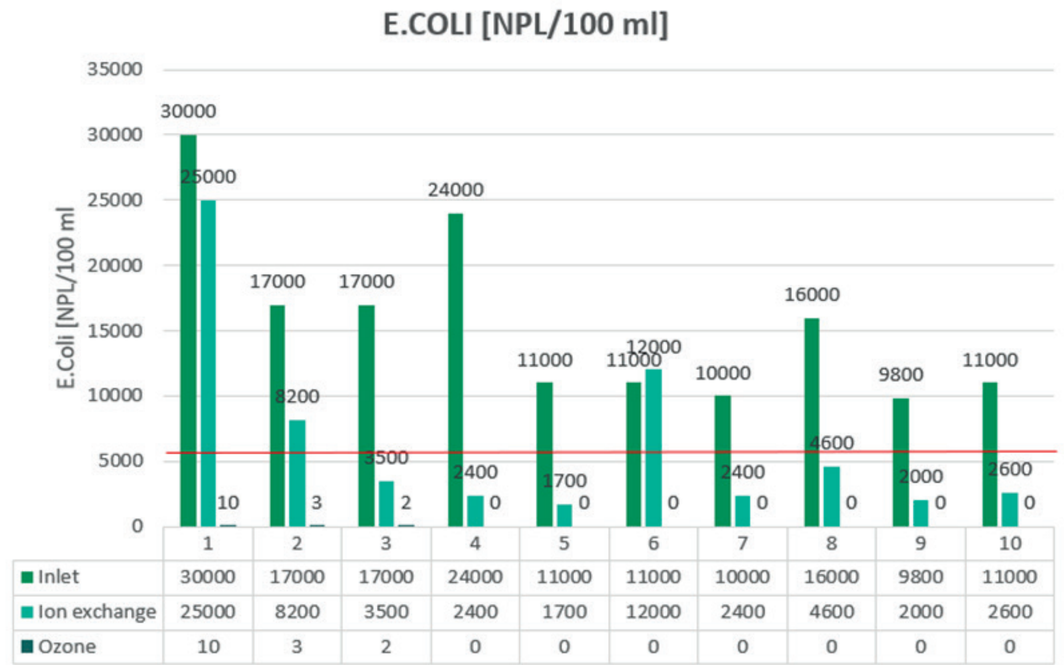
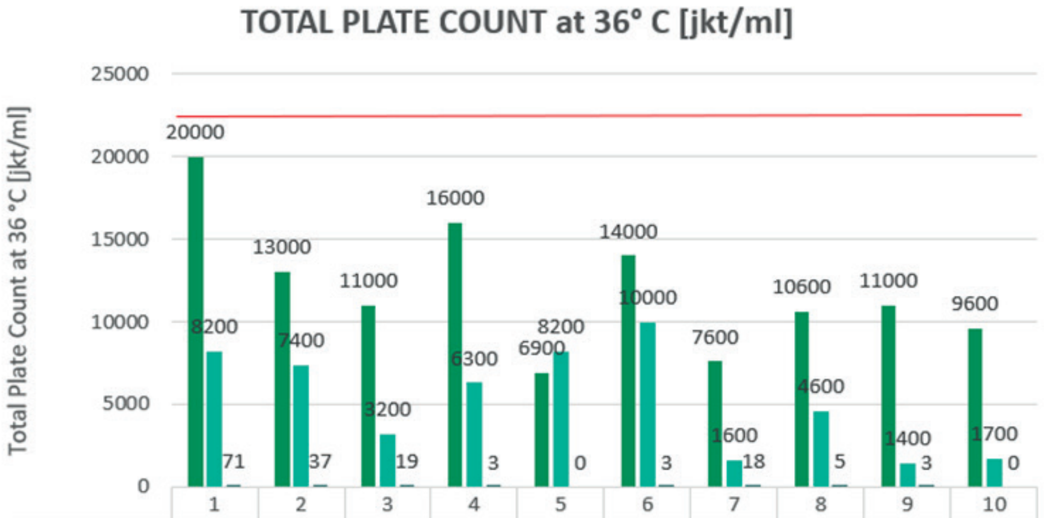


Figure 27. Results of experiments conducted on E. Coli

The Inlet *E. Coli* values range from 9 800 to 30 000 NLP/100 ml, with an average of 15 680 NLP/100 ml. The Ion exchange values range from 1 700 to 25 000, with an average of 6 440 NLP/100 ml. The Ozone values range from 0 to 10 NLP/100 ml, with an average of 1.5 NLP/100 ml.

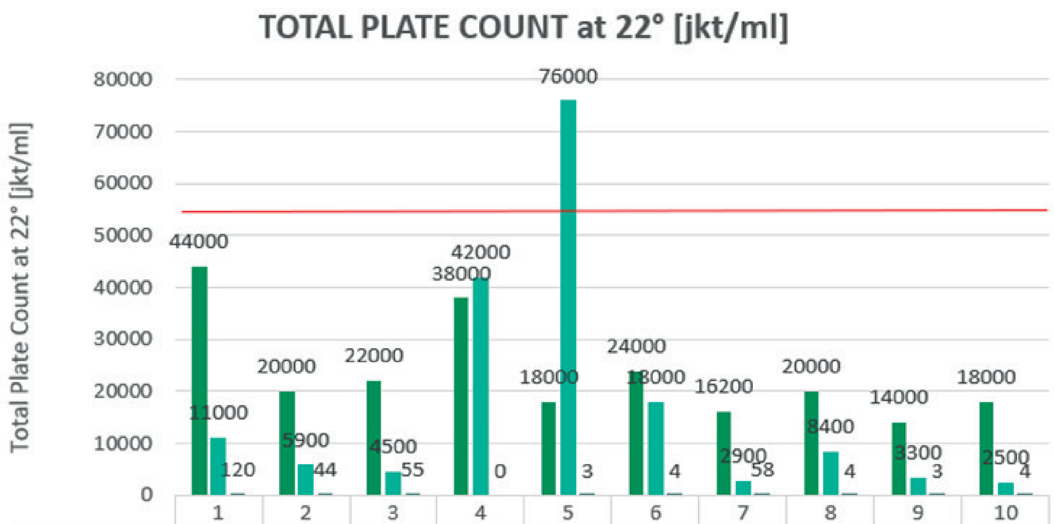
The data shows that the Inlet values have a moderate spread around the mean with some variability. The Ion exchange values have a high variability indicating significant differences in the measurements. The Ozone values are mostly low with a few higher values. This suggests that while the ion exchange process shows variability in its effectiveness, the ozone treatment consistently results in low values indicating successful disinfection. By increasing the ozone dose to 50-70 g/h, full disinfection was achieved.



	1	2	3	4	5	6	7	8	9	10
Inlet	20000	13000	11000	16000	6900	14000	7600	10600	11000	9600
Ion exchange	8200	7400	3200	6300	8200	10000	1600	4600	1400	1700
Ozone	71	37	19	3	0	3	18	5	3	0

Figure 28. Results of experiments conducted on Total Plate Count at 36 °C

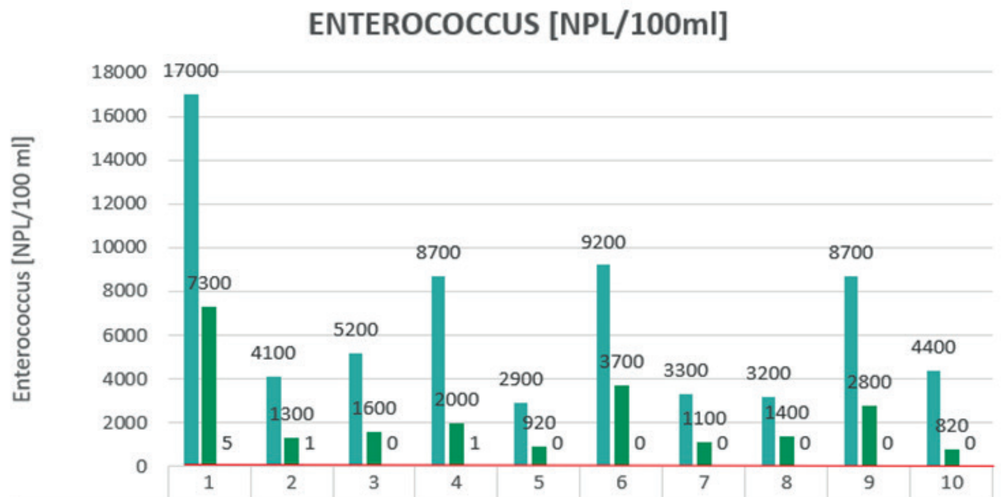
The Inlet TPC at 36 °C values range from 6 900 to 20 000 jkt/ml, with an average of 11 970 jkt/ml. The Ion exchange values range from 1 400 to 10 000 jkt/ml with an average of 5 260 jkt/ml. The use of ion exchange resign results in a significant decrease of TPC in the sample. The Ozone values range from 0 to 71 jkt/ml, with an average of 15.9 jkt/ml. By increasing the ozone dose to 70 g/h, full disinfection was achieved.



	1	2	3	4	5	6	7	8	9	10
Inlet	44000	20000	22000	38000	18000	24000	16200	20000	14000	18000
Ion exchange	11000	5900	4500	42000	76000	18000	2900	8400	3300	2500
Ozone	120	44	55	0	3	4	58	4	3	4

Figure 29. Results of experiments conducted on Total Plate Count at 22 °C

The Inlet TPC at 22°C values range from 14,000 to 44,000 jkt/ml with a mean of 23,420 jkt/ml. Ion exchange values show a wide range from 2,500 to 76,000 jkt/ml indicating significant variability. Ozone values range from 0 to 120 jkt/ml with a mean of 29.5 jkt/ml. The application of an ozone dose of 70 g/h resulted in incomplete disinfection; single organisms are present in the sample.



	1	2	3	4	5	6	7	8	9	10
Inlet	17000	4100	5200	8700	2900	9200	3300	3200	8700	4400
Ion exchange	7300	1300	1600	2000	920	3700	1100	1400	2800	820
Ozone	5	1	0	1	0	0	0	0	0	0

Figure 30. Results of experiments conducted on Enterococcus

The Inlet Enterococcus values range from 2,900 to 17,000 NPL/100ml with a mean of 6,670 NPL/100 ml.

Ion exchange values show variability from 820 to 7,300 NPL/100 ml, with a mean of 2,294 NLP/100 ml.

Ozone values are mostly low, ranging from 0 to 5 NLP/100 ml, with a mean of 0.7 NLP/100 ml. Using an ozone dose of 70g/h , enterococci are not detected in the sample.

Using lower ozone doses, full disinfection was not achieved. Increasing the dose to 50 g per hour allowed the achievement of the required parameters (according to: *Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse and Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption*). The red lines on the charts provided above indicate the limit values that must be met. The absence of enterococci in the samples was successfully ensured.

Table 29. Full disinfection achieved in different experiment phases

Date	Parameter [μg/l]	Inlet	Ion Exchange	Ozone
20.03.2025 Ozone dose: 14.29 mg/l Contact time: 33 min Flow rate: 3.5 m³/h	Legionella	0	0	0
	Helminths eggs	0	0	0
27.03.2025 Ozone dose: 15.15 mg/l Contact time: 35 min Flow rate: 3.3 m³/h	Legionella	0	0	0
	Helminths eggs	0	0	0
01.04.2025 Ozone dose: 20 mg/l Contact time: 33 min Flow rate: 3.5 m³/h	Legionella	0	0	0
	Helminths eggs	0	0	0
10.04.2025 Ozone dose: 18.4 mg/l Contact time: 30 min Flow rate: 3.5 m³/h	Legionella	0	0	0
	Helminths eggs	0	0	0

Additionally, using a dose of 50 g/h and 70g/h, Legionella and Helminths eggs are not detected in the sample.

Moreover, after achieving full disinfection by meeting microbiological indicators, a series of tests for micropollutants were started. Micropollutants are parameters indicated in the wastewater directive and the European Parliament regulation on minimum requirements for water reuse. A reduction in these parameters is observed at each stage. However, after the ozonation process, all the parameters are found to be below the detection limit. Regarding toxicity tests, an increase is noted, but this increase does not exceed the limit values.

Table 30. Changes in parameter values in different experiment phases

Working parameters of pilot installation	20.03.2025 Ozone dose: 14.29 mg/l Contact time: 33 min Flow rate: 3.5 m³/h			27.03.2025 Ozone dose: 15.15 mg/l Contact time: 35 min Flow rate: 3.3 m³/h		
Parameter [µg/l]	Inlet	Ion exchange resin	Ozone	Inlet	Ion exchange resin	Ozone
Benzotriazole	4.1	0.21	< 0.02	3.3	0.22	< 0.02
Methylbenzotriazole (som 4+5)	0.63	0.08	< 0.02	0.67	0.08	< 0.02
Carbamazepine	0.88	0.57	< 0.005	0.96	0.71	< 0.005
Diclofenac	2.3	1.4	< 0.01	2.3	1.5	< 0.01
Gabapentin	0.58	0.49	< 0.02	0.78	0.6	0.07
Irbesartan	0.01	0.01	< 0.01	0.02	0.01	< 0.01
Metoprolol	0.74	0.25	< 0.01	0.76	0.4	< 0.01
Sulfamethoxazole	0.27	0.28	< 0.01	0.22	0.3	< 0.01
Furosemide	0.92	0.64	< 0.01	1.0	0.51	< 0.01
Hydrochlorothiazide	< 0.01	< 0.01	< 0.01	0.29	0.21	< 0.01
Azithromycin	0.47	0.18	< 0.01	0.64	0.26	< 0.01
Clarytromycyne	1.2	0.97	< 0.10	4.3	1.8	< 0.10
Propranolol	< 0.10	< 0.10	< 0.10	< 0.1	< 0.1	< 0.10
Sotalol (ß-Adrenergics)	< 0.10	< 0.10	< 0.10	< 0.1	< 0.1	< 0.10
Trimetoprim	0.08	0.03	< 0.01	0.04	0.02	< 0.01
Citalopram	0.24	0.11	< 0.005	0.19	0.099	< 0.005
Venlafaxine	0.78	0.58	< 0.005	0.56	0.42	< 0.005
Candesartan	0.34	< 0.02	< 0.02	0.26	0.04	< 0.02
Amisulpride	0.32	0.19	< 0.01	0.26	0.19	< 0.01
DELTA-TOX	8	18	24	18	10	17

Table 31. Changes in parameter values in different experiment phases

Working parameters of pilot installation	01.04.2025 Ozone dose: 20 mg/l Contact time: 33 min Flow rate: 3.5 m³/h			10.04.2025 Ozone dose: 18.4 mg/l Contact time: 30 min Flow rate: 3.5 m³/h		
Parameter [µg/l]	Inlet	Ion exchange resin	Ozone	Inlet	Ion exchange resin	Ozone
Benzotriazole	2.6	0.15	< 0.02	4.7	0.58	< 0.02
Methylbenzotriazole (som 4+5)	0.33	0.04	< 0.02	0.76	0.13	< 0.02
Carbamazepine	1.0	0.63	< 0.005	0.69	0.55	< 0.005
Diclofenac	2.5	1.2	< 0.01	2.6	1.6	< 0.01
Gabapentin	0.92	0.64	0.07	0.69	0.67	< 0.02
Irbesartan	0.01	0.01	< 0.01	0.01	0.01	< 0.01
Metoprolol	0.75	0.39	< 0.01	0.63	0.38	< 0.01
Sulfamethoxazole	0.27	0.33	< 0.01	0.22	0.27	< 0.01
Furosemide	1.1	0.26	< 0.01	0.72	0.35	< 0.01
Hydrochlorothiazide	1.1	0.26	< 0.01	0.43	0.35	< 0.01
Azithromycin	0.81	0.41	< 0.01	0.87	0.44	< 0.01
Clarytromycyne	7.4	10	< 0.10	8.9	7.6	< 0.10
Propranolol	< 0.1	< 0.1	< 0.10	< 0.1	< 0.1	< 0.10
Sotalol (ß-Adrenergics)	< 0.1	< 0.1	< 0.10	0.7	0.42	< 0.10
Trimetoprim	0.04	0.02	< 0.01	0.07	0.04	< 0.01
Citalopram	0.19	0.098	< 0.005	0.23	0.13	< 0.005
Venlafaxine	0.59	0.45	< 0.005	0.56	0.28	< 0.005
Candesartan	0.28	0.03	< 0.02	0.34	0.06	< 0.02
Amisulpride	0.02	0.16	< 0.01	0.37	0.27	< 0.01
DELTA-TOX	20	11	16	12	15	16

The ozonation process in the disinfection module allowed for achieving full microbiological disinfection (meeting required limits, e.g., absence of Enterococci) and reduction of micropollutants below the detection limit, confirming the potential for water reuse. Although an increase in toxicity was observed after disinfection processes, this increase did not exceed the limit values.

Summary of disinfection process

The ozonation process was implemented as a disinfection method using a SPID 300 device, which has an efficiency of 20 m³/h and can produce up to 300 g of ozone per hour. During operation, the flow rate varied from 2 m³/h to 4.8 m³/h, and the ozone dose was adjusted from 20 g/h to 70 g/h, with residual ozone in the wastewater ranging from 0.16 mg/l to 0.70 mg/l. The contact time of ozone with the sewage varied between 18 and 38 minutes.

Regarding physicochemical parameters, the ozonation process consistently showed higher temperatures (average 16.4°C) and higher pH values (average 7.55), indicating a more alkaline environment. Ozonation was found to be the most effective in reducing Chemical Oxygen Demand (COD), with the lowest average values (18.6 mg/l), all well within the limit of <125 mg/l. Similarly, ozonation achieved the lowest levels of Total Suspended Solids (TSS) (average 0.33 mg/l) and lowest turbidity (average 0.61 NTU), demonstrating its effectiveness in reducing suspended particles. While Total Organic Carbon (TOC) and Biochemical Oxygen Demand (BOD_5) were also reduced by ozonation, their mean values were comparable to or higher than those after ion exchange, though still lower than the inlet. Other parameters like electrical conductivity, total phosphorus, phosphates, total nitrogen, ammonium nitrogen, nitrate nitrogen, and potassium showed similar effects across all tested treatments (inlet, ion exchange, and ozonation), generally remaining within acceptable limits, though total nitrogen occasionally exceeded the 15 mg/l limit. Notably, nitrite nitrogen ($N\text{-}NO_2$) was most effectively reduced by ozonation, showing the lowest mean value of 0.01 mg/l with minimal variability.

In terms of microbiological parameters, ozonation significantly improved disinfection:

- The number of Coli bacteria drastically dropped to an average of 11.5 NLP/100 ml after ozonation, with full disinfection achieved at an ozone dose of 70 g/h.
- *Escherichia Coli* values averaged 1.5 NLP/100 ml (ranging from 0 to 10 NLP/100 ml) after ozonation, indicating effective disinfection, with full disinfection achieved at 50-70 g/h.
- Total Plate Count (TPC) at 36°C achieved full disinfection with a 70 g/h ozone dose.
- However, for TPC at 22°C, applying a 70 g/h ozone dose resulted in incomplete disinfection, with single organisms still present.
- Enterococci were mostly not detected after ozonation, with no detection when using a 70 g/h ozone dose.
- Legionella and Helminths eggs were not detected in samples after the ozonation process, including at 50 g/h and 70 g/h doses.

Furthermore, after achieving full microbiological disinfection, tests for micropollutants were conducted. All tested micropollutants (e.g., Benzotriazol, Carbamazepine, Diclofenac) were reduced below their detection limits after the ozonation process. While an increase in toxicity (DELTA-TOX) was observed after disinfection processes, this increase did not exceed the established limit values.

Overall, the ozonation process demonstrated its capacity to achieve full microbiological disinfection and reduce micropollutants below detection limits, confirming the potential for water reuse.

Summary of pilot studies

In water recovery processes, ozonation should be considered an effective disinfection method, provided that suspended solids and organic substances are first removed in a stable manner.

The choice of pre-treatment technology must take into account the susceptibility of the systems to hydraulic and load variability typical of treatment plants. Under real conditions, where sudden increases in suspended solids concentration occur (e.g., after heavy rainfall, during changes in technological systems), fabric filters maintain stable operation and do not become clogged, making them a more resilient and operationally safe technology. They are capable of effectively reducing turbidity even at high inlet levels (e.g., 1300 mg/l → 6 mg/L; reduction >99%, deliberate simulations to test the technology under extreme conditions.

On the other hand, ion exchange resin (IER) technology is characterized by higher efficiency in reducing selected wastewater quality indicators, in particular: TOC: 42.6% (vs. 12.8% for FF), COD: 57.9% (vs. 25.9%), TP: 72% (vs. 44.8%), TN: 38.5% (vs. 34.5%).

Thanks to the use of several types of media in a single system (gravel beds, activated carbon, ion exchange resins, zeolite beds), IERs ensure better quality of reclaimed water in applications requiring lower concentrations of biogenic substances or organic compounds.

It is therefore recommended to select the treatment technology depending on the intended use of the reclaimed water and the level of stability of the wastewater feeding the system.

The use of a modular design in water recovery systems allows for flexible management of the final water quality. Depending on the needs of the users (e.g., street cleaning, snow production, irrigation, industrial applications), individual modules can be:

- included or omitted in the process (e.g., additional filtration, carbon post-treatment, or UV disinfection),
- switched automatically by the SCADA control system or manually, depending on the desired output parameters,
- easily reconfigured in the future — e.g., adding a new module for micro-pollutant removal.

Thanks to this flexibility, the water recovery system becomes an operational tool rather than just a linear process, allowing the water quality to be adapted to a variety of usage scenarios and dynamically changing environmental or legislative requirements.

Practical tips for implementers

» **Operation**

Fabric filters (FF) proved to be virtually maintenance-free – they did not require operator intervention during testing and operated stably even with high suspended solids inflows. This makes them particularly advantageous in treatment plants with variable inflows and the risk of sudden hydraulic or load overloads.

The IER system (ion exchange resins), although very effective in removing organic pollutants and biogens, proved to be sensitive to increases in suspended solids concentration. In the event of temporary exceedances of suspended solids, it was necessary to manually disconnect the system, which in practice required close supervision. To ensure continuity of operation, it was necessary to design two parallel process lines, allowing one of the columns to be cleaned without interrupting the operation of the entire system.

The ozonator was reliable, but its integration into the wastewater pretreatment system required further refinement. In emergency situations, such as no wastewater flow through the water recovery station and the ozonator, after restoring the flow, the ozone disinfection system required operator intervention to restore its proper operation. Therefore, it is recommended to implement additional software and mechanical safeguards (e.g., flow sensors, check valves, logic lock systems).

» **Control and monitoring**

The system was controlled manually, which significantly increased the workload of operators. The need to frequently switch operating modes and respond to changing wastewater inflow conditions (e.g., sudden suspended solids) required the constant presence of personnel. It is recommended that at the pilot plant design stage, at least a basic automation system (SCADA or local PLC controllers) with the possibility of configuring emergency scenarios be provided.

Only turbidity was monitored online, which did not allow for ongoing control of other parameters relevant to water recovery (e.g., conductivity, chlorine, *E. coli*). In the future, it is worth considering the inclusion of modules for measuring microbiological parameters or at least the conditions for their development (T, pH, ORP).

» **Integration with the wastewater plant**

The tests were difficult to carry out under actual operating conditions of the wastewater treatment plant. Pilot installations have limited mobility and require stable connection points, which are often lacking. For example, it was necessary to temporarily shut down the installation due to cleaning or servicing of the feed tanks.

In the case of IER, the manufacturer required a water supply for the installation, which had not been planned in advance. The lack of a connection forced the use of water tanks as a temporary water source, which worsened the ergonomics of work.

5.3 Reclaimed water as a source of nutrients

5.3.1 Balance challenge

Reclaimed water can serve as a valuable source of nutrients for plants. In Pilot 2, the emphasis is on analyzing the main macronutrients (nitrogen – N, phosphorus – P, and potassium – K) composition for irrigating inedible plants such as grasses and flowers using reclaimed water. Nitrogen, phosphorus, and potassium are three essential nutrients that play a key role in plant development. Nitrogen, phosphorus, and potassium are fundamental for healthy growth for inedible plants:

- Nitrogen is a primary nutrient that influences plant growth. It is crucial for producing proteins, enzymes, and chlorophyll, which is responsible for photosynthesis. For grass, nitrogen is essential for rapid growth and the intense green color of leaves, as it supports chlorophyll production. For flowers, nitrogen affects the overall development of the plant, including the production of healthy, strong shoots and leaves. However, excess nitrogen may lead to excessive leaf growth at the expense of flowering.
- Phosphorus is a nutrient that plays an important role in plant cellular energy, primarily due to its presence in ATP (adenosine triphosphate), which is the energy carrier in cells. It is also crucial for root development. For grass, phosphorus supports the development of a strong root system, which is particularly important for stability and drought resistance. In flowers, phosphorus supports processes related to blooming and also improves plant health, enhancing its ability to survive in harsh conditions (e.g., winter).
- Potassium regulates many metabolic processes in plants, including water transport, enzyme activity, and protein synthesis. Potassium helps plants cope with environmental stress, such as drought, cold, or disease. Grass requires potassium to effectively manage water, which is key for its durability, especially during dry periods. Potassium also helps maintain healthy plant cells. Flowers, like grasses, benefit from potassium to boost plant resistance to diseases and regulate processes related to seed production and blooming.

All three nutrients must be present in the appropriate proportions for the plant to grow, bloom, and maintain good condition.

Reclaimed water characteristics in context of the nutrient demand of grass

The average daily water need of standard grass during the irrigation season depends on daily temperature and climatic zone. The range of water requirements for irrigation is very wide and ranges from 1 to even 10 liters per 1 m^2.

In the Baltic Sea region, the lawn irrigation season lasts from April to September (e.g. in Poland, Denmark, and Latvia). In the case of countries located to the north, the season is shorter and for Finland, it usually lasts from May to August. It can be assumed that the number of days when irrigation is needed (excluding those with atmospheric precipitation) is on average 150 days.

The best N:P:K fertilizer ratio for grass (lawn) depends on the stage of grass growth and soil condition, but generally a ratio of 3:1:2, 4:1:2 or 2:1:1 is recommended for a healthy lawn.

The amount of nitrogen (N) needed by a grass (lawn) during the season depends on many factors, such as the type of lawn, the type of soil, the climatic conditions and the intensity of use of the lawn. Generally accepted recommendations for fertilizing the lawn with nitrogen indicate that 3 to 6 kg of nitrogen per 100 m^2 should be supplied during the year.

Considering the above assumptions, the seasonal coverage of the nutrient demand for grasses was determined based on research on the pretreatment processes (before the disinfection process) using coagulation, sand filtration, and activated carbon adsorption. These processes are necessary to reduce the turbidity (<1 NTU) and improve the efficiency of disinfection processes. Table 32 presents the concentrations of N, P, and K in treated wastewater, as well as changes in these concentrations after applying various preliminary treatment processes that resulted in turbidity < 1 NTU. The values include concentrations after the volume coagulation, surface coagulation (using three coagulants: $Al_2(SO_4)^3$, PAX-XL19F, and PAX-XL1911), sand filtration (at four different flow rates: 3, 5, 10, and 15 m/h), and activated carbon adsorption (at three different flow rates: 5, 10, and 15 m/h).

Table 32. Concentrations of N, P, and K in treated wastewater (TW) and after pretreatment processes

Indicator:		N [mg/l]	P [mg/l]	K [mg/l]
Treated wastewater (TW)		7.65	1.14	35.57
$Al_2(SO_4)^3$	VC	7.28	0.67	33.67
	SC	6.75	0.63	29.70
PAX-XL 19F	VC	6.99	0.88	35.20
	SC	6.22	0.72	32.57
PAX-XL 1911	VC	6.60	0.84	34.23
	SC	6.17	0.65	31.03
Sand filtration [m/h]	3	6.01	0.52	32.85
	5	6.04	0.53	33.55
	10	6.02	0.55	33.65
	15	6.03	0.56	33.70
Activated carbon adsorption [m/h]	5	0.37	0.29	19.25
	10	0.39	0.31	22.35
	15	0.77	0.35	25.25

Coagulation

Figures 31, 32 and 33 show the coverage of the nutrient demand for grass in the process of volumetric (VC) and surface (SC) coagulation compared to treated wastewater (before processes). Three aluminium-based coagulants were analyzed in the study: $Al_2(SO_4)^3$, PAX-XL19F, and PAX-XL1911.

The coverage for N, P and K in the case of treated wastewater was 23.9, 14,25 and 222.29 %. For all analyzed coagulants, the highest coverage was observed for K and ranged from 186 to 220%, for N the coverage ranged from 19.28 to 22.74%, while for P it was the lowest and ranged from 7.83 to 11.04%.

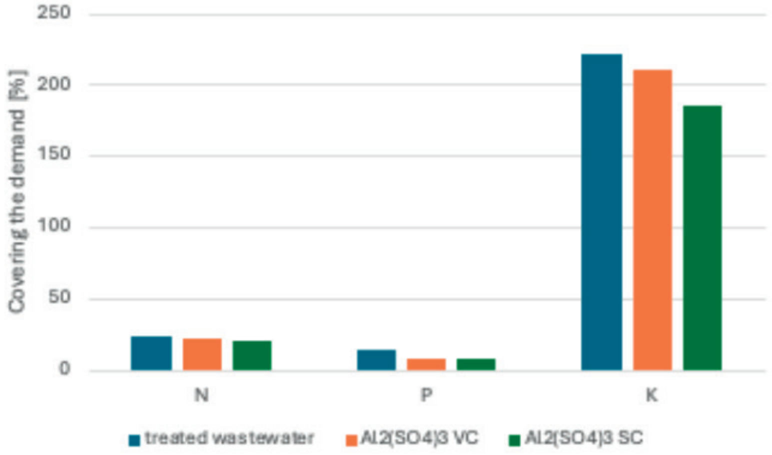


Figure 31. Covering the demand for N, P and K using Al2(SO4)3 in coagulation processes

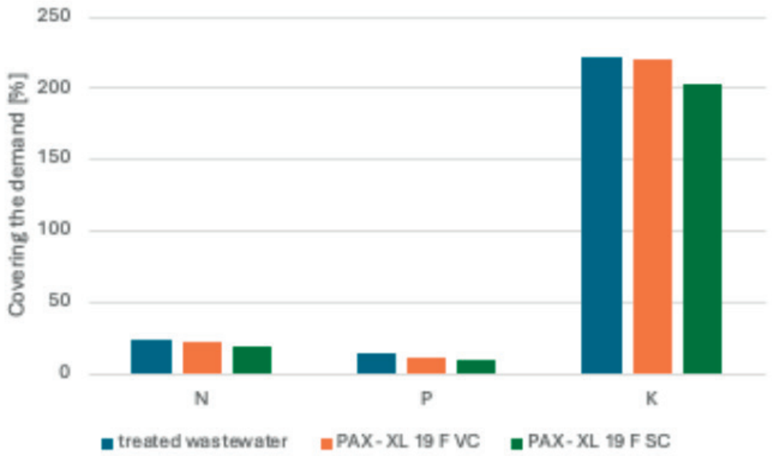


Figure 32. Covering the demand for N, P and K using PAX-XL19F in coagulation processes

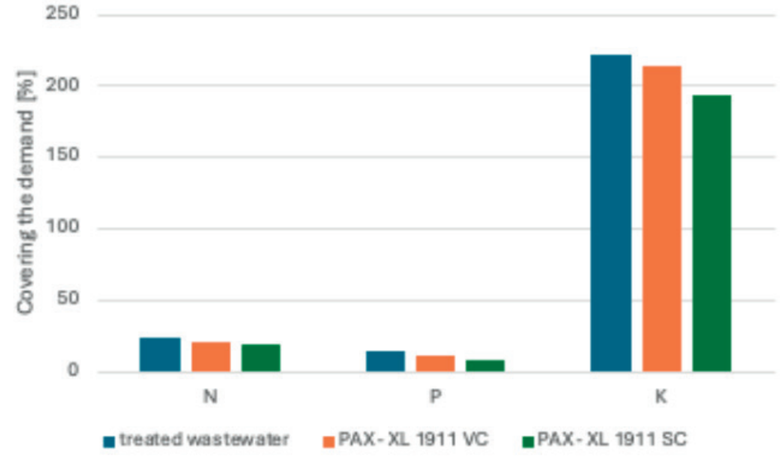


Figure 33. Covering the demand for N, P and K using PAX-XL1911 in coagulation processes

Sand Filtration

Figure 34 shows the coverage of the nutrient demand for grass in treated wastewater and after sand filtration for different flow rates (3, 5 and 10 m/h) compared to treated wastewater (before processes). In this case, the coverage of the demand for K is the highest and amounted to 205.31-210.31%, for N 18.78-18.89%, and for P 6.54-6.64%.

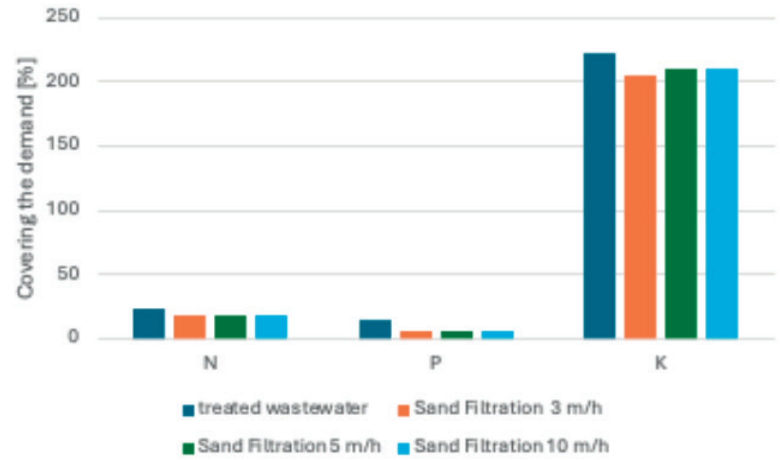


Figure 34. Covering the demand for N, P and K in sand filtration

Activated Carbon Adsorption

Figure 35 shows the coverage of the demand for nutrients for grass in treated wastewater and after the adsorption process on activated carbon for different flow rates (5, 10 and 15 m/h). In this case, the coverage of the demand for K is also the highest and amounted to 120.31-157.81%, for P 3.62-4.39%, and for N it is the lowest and amounted to 1.17-2.39%.

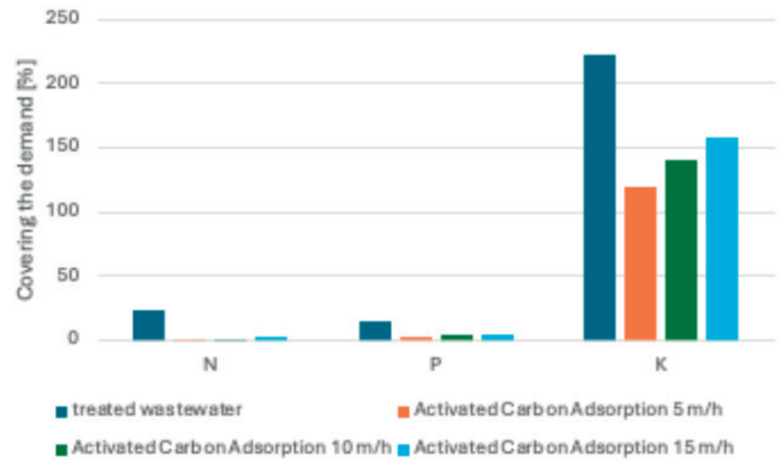


Figure 35. Covering the demand for N, P and K in activated carbon adsorption

Key Takeaways

- Balancing nutrients in reclaimed water showcases its potential as a sustainable resource for inedible plant irrigation.
- In regions with limited freshwater, reclaimed water offers an alternative resource for maintaining landscapes. Additionally, using reclaimed water helps conserve potable water, which is crucial for other needs. Overall, it provides a cost-effective and eco-friendly option for managing plant nutrition in inedible plant care.
- Using reclaimed water for irrigation helps reduce the reliance on synthetic fertilizers, making it a more sustainable choice for landscaping and green spaces.
- Reclaimed water contains essential nutrients like nitrogen, phosphorus, and potassium, which promote healthy growth in these non-food crops.
- The coagulation and sand filtration processes slightly reduce the coverage of the demand for N, P, and K. In the case of activated carbon adsorption, a drastic reduction in demand can be observed.
- The selection of the pretreatment processes should take into account the assessment of its impact on changes in fertilizer properties of reclaimed water.

5.3.2 Pilot experiences

According to **Jūrmala Water Utility** Pilot 2 results, the best growth occurred in plots watered with clean water and chlorine-treated water. In the reservoirs containing treated wastewater without chlorine, an algal bloom was observed. Consequently, we proposed a hypothesis that nutrient reduction in the wastewater could be attributed to a decrease in nutrients, which resulted in poorer grass length and weight outcomes (Figures 36 and 37).

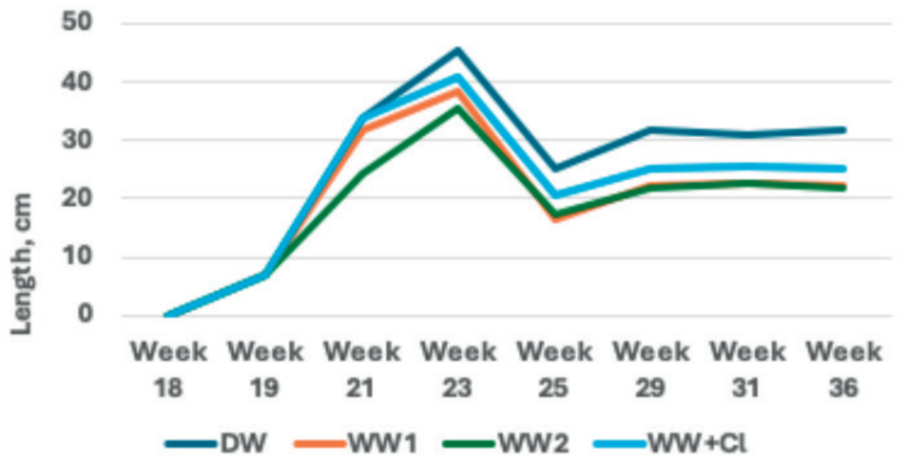


Figure 36. Changes in the length of grass during the experimental period

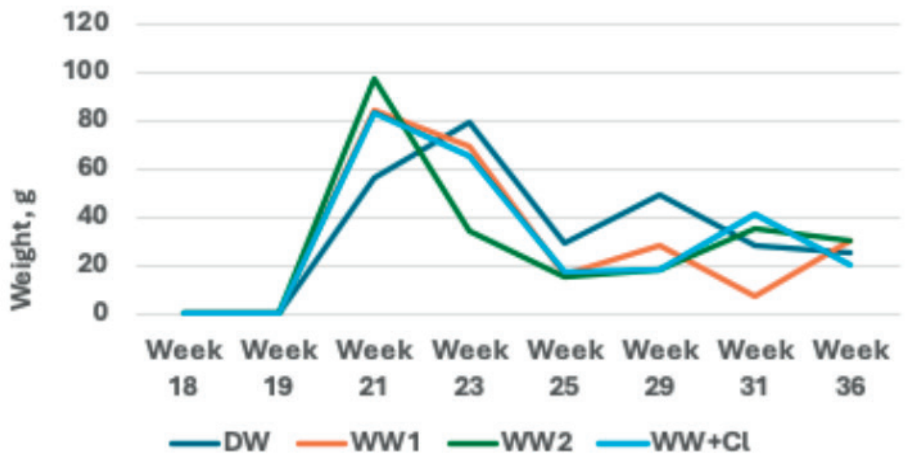


Figure 37. Changes in the weight of grass during the experimental period

Schwander Polska carried out observations in three plots with different irrigation methods, allowing the effects of using different water sources to be compared:

- Plot I – Permeate irrigation with partially removed nutrients (nitrogen and phosphorus). Permeate is an effluent treated biologically and after undergoing membrane microfiltration and UV lamp disinfection. The water is partially devoid of nutrients (nitrogen and phosphorus), making it safer for the environment without causing additional pollution of the soil with these components. Such water can be used as a natural fertiliser to provide the necessary nutrients to plants, improving their growth and development. There is no over-fertilisation of the soil.
- Plot II – Tap water irrigation. This is the classic irrigation method used in traditional agriculture. Tap water, although suitable for watering plants, does not contain any additional nutrients to support plant growth. For this reason, plants may require additional fertilisation to achieve optimal growth.
- Plot III – Permeate irrigation from the second treatment line (nutrients not removed). In this case, the permeate comes from the second treatment line, where nutrients (biogenes) such as nitrogen and phosphorus have not been removed. The biogen content of the water can affect plant growth, but in the long term, excess nitrogen and phosphorus can lead to soil eutrophication. Excess of these nutrients can also reduce soil biodiversity and lead to a reduction in soil quality. This type of irrigation can provide plants with additional nutrients, but with supervision to avoid excessive nutrient accumulation.

The aim of the conducted research was to test how different water sources – including permeate from treated wastewater – affect plant growth, condition and yield. Such experiments are particularly relevant in the context of:

» **Sustainable agriculture: the increasing challenges related to the availability of potable water and the need to conserve it are prompting the search for alternative sources of irrigation water. Water from wastewater treatment plants, especially after appropriate treatment, can be a good solution to recover water resources.**

» **Water recycling: The use of treated wastewater, especially permeate, is part of the trend towards a closed loop economy. This practice can reduce the use of tap water and also reduce further, adverse environmental impact.**

5.4 Experiences from greenhouses

As part of Pilot 3, common corn was cultivated in one growing season. Cultivation began in the spring of 2024, but the exact date depended on the weather. In southern Poland, it was possible earlier than in Kuopio or Ugāle. The stages of the cultivation implementation are indicated in Table 33.

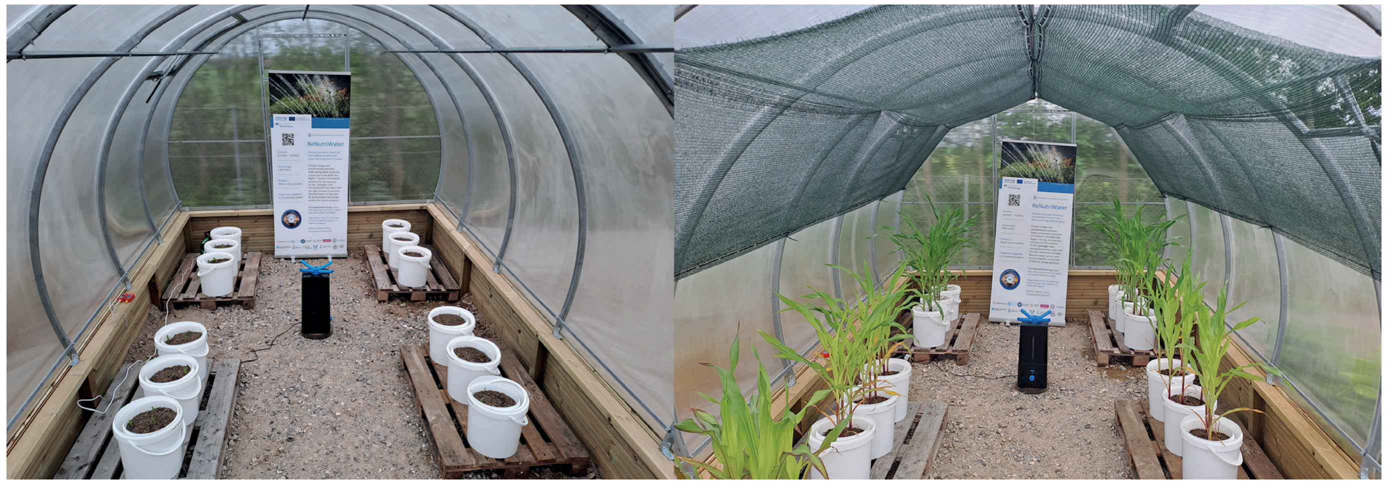


Figure 38. ReNutriWater greenhouse in Samsø, Denmark

Table 33. Stages of task implementation within pilot 3

Part	Tasks	2024 / months											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Soil choosing/ greenhouse construction	Soil searching. Soil sample lab testing (on site)												
	Planning of the experiment												
	Construction of the greenhouse												
	Delivery of soil from the field												
Setting up of the experiment/ plant choosing	Preparation of the experiment: 1) soil testing 2) soil fertilisation												
	Ensuring soil moisture												
	Selection of plants, sowing of the plant seeds												
	Control of humidity in the greenhouse												
Watering/ plant growth	Watering combinations. Elimination of possible pests												
	Water testing												
	Harvesting of plants												

1. Searching for a suitable soil

The soil composition was determined at the beginning of the project, during meetings and consultations. It was established as follows:

- Sand (0.05-2.00 mm): 40-85%
- Silt (0.002-0.05 mm): 0-50%
- Clay (<0.002 mm): 0-20%

Soil samples were subjected to laboratory analyses to determine their mineral composition, nutrient levels and water retention capacity. The aim was to obtain poor soil so that plants would have to use nutrients in water.

2. Selection of the greenhouse

An 18 m² greenhouse made of an aluminium structure and covered with polycarbonate sheets was selected for the experiment.

The greenhouse was designed to protect plants from direct sunlight, ensure stable humidity and temperature conditions, and protect them from heavy rainfall, strong wind, and other adverse weather conditions. Thanks to this, it was possible to precisely control the growing conditions, which was crucial to the success of the research.

3. Selection of pots

Each pot had a removable insert with handles that made it easy to pull out. Holes were made in the bottom of the insert to ensure drainage of excess water (Figure 39).

Dimensions of pots:

- Diameter: 29.8 cm
- Height: 25.7 cm
- Capacity: 14 l
- Insert capacity: 10 l

Figure 39. Pots prepared for sowing and dividing into groups

4. Sowing and caring for plants

For comparison purposes, the plants were divided into groups and watered with different types of water. We had the following options to choose from:

- Irrigation with distilled water,
- Irrigation with distilled water and added fertilizers,
- Irrigation with treated wastewater (disinfected or not),
- Irrigation with reclaimed water (treated wastewater subjected to further processing such as filtration and disinfection),
- Irrigation with reclaimed water (treated wastewater subjected to further processing such as filtration and disinfection) with added fertilizers,
- Irrigation with drinking water.

Figure 40. Germinating corn

Before sowing the seeds, the soil was properly moistened with tap water to create optimal conditions for germination. The seeds were not treated. After sowing the maize, the pots were covered with dark perforated foil to maintain stable soil moisture and temperature. These conditions contributed to the faster germination of the maize seeds. Once the seeds had germinated, the foil was removed, allowing the plants to grow freely (Figure 40).

5. Watering combinations (observation of plant pests)

In Wołkowyja, three irrigation combinations were planned:

- **Combination I:** irrigation with treated wastewater (permeate) from the MBR wastewater treatment, coming from the biological sequence, in which the process of increased nutrient removal (nitrogen and phosphorus) was carried out.
- **Combination II:** irrigation with tap water.
- **Combination III:** irrigation with treated wastewater (permeate) coming from the MBR second process line, in which the technological process was carried out only with removal of carbon compounds without nutrients removal.

Combinations I and III were irrigated with treated effluent (permeate) coming from the wastewater treatment plant in Wołkowyja. The containers holding the wastewater for pot watering were protected from the high temperatures prevailing in the greenhouse.

Greenhouse operation is not easy. We encountered various difficulties. For example, in Kuopio, despite the lack of very high temperatures, the greenhouse was so insolated that it had to be covered with a shading net. In mid-July in Wołkowyja, due to high temperatures and crop burning, it became necessary to move the plants outside the greenhouse (Figures 41 and 42). In the first decade of September, the pots were brought back into the greenhouse. Maize cultivation was carried out until mid-November.

Figure 41. Growing corn starts to have too high temperature in the greenhouse

6. Harvesting, analysing

The plants were monitored. We recorded the growth progress and took photos of the plants for comparison purposes.

Harvest began at different times. The first decision to end cultivation was made in Samsø, then in Kuopio, Ugale and Wołkowyja.

The plants were harvested, cleaned of soil, weighed, and analyzed.

Figure 42. The pots moved outside

6 Message to Target Groups

6.1 Savonia University of Applied Sciences, Kuopio

It all started with an ambitious goal – three pilot projects that set out to do more than just test the quality of treated wastewater. This was about something bigger: could reclaimed water safely return to the cycle of life, watering crops instead of being flushed away? But before a single drop touched the soil, the groundwork had to be rock solid. And it was. The planning phase was nothing short of meticulous. Every relevant EU directive, regulation, and legal nuance was combed through and built into the blueprint. The list of parameters to be analyzed was extensive – almost overwhelming – but flexible. Partners could tailor the list to suit their budgets and technical capacities. Not every component could be measured, but thanks to a thoughtful prioritization system, the most essential ones made it into all pilots, ensuring a coherent set of core results.

Figure 43. Piloting in Savonia University of Applied Sciences

Greenhouses turned laboratories

The action moved into the greenhouses. Maize became the test subject, but for many partners, this was unfamiliar ground. Agricultural research was new territory. Questions came fast: How do we ensure equal conditions for all the test plants? How much water should each pot get, and how do we standardize that across countries?

Guidelines were provided, but in hindsight, they could have been clearer and more hands-on. Despite the variation in methods and local adaptations, the pilots held steady. No major stumbles, no crises. The experiments ran their course, from irrigation schedules to plant monitoring, and data began to pour in.

Awareness, safety, and small victories

Importantly, the safety of those operating the pilots was never compromised. Health risks were considered and mitigated. And beyond the lab results, there was a noticeable ripple effect: public awareness of reclaimed water grew, along with genuine curiosity and support for innovation in wastewater reuse.

Still, not everything went perfectly. If there was one lesson learned, it’s this: keep it simple. Simpler experiments make for stronger comparisons. Don’t overburden the process with too many samples or complex analyses – costs escalate quickly, and clarity can be lost.

Laws, limits, and leading the way

Legal frameworks across countries also played a role. In Finland, for example, using reclaimed water still isn’t permitted for crop irrigation. But that’s not necessarily a roadblock – it’s an opportunity. Being among the first to test emerging solutions means leading the way, not following behind.

There’s still much to explore. How do pharmaceuticals, micro- and nanoplastics, microrubber, and PFAS affect plant health, or human health, for that matter? Are the advanced treatment technologies cost-effective enough for wide-scale adoption at urban wastewater treatment plants?

These questions don’t yet have answers. But the data we’ve gathered is a start. The conversation has begun. And what once seemed like wastewater might just turn out to be a resource waiting to be reclaimed.

6.2 VNK Serviss, Ugāle

Hot days, clear water: a Latvian Pilot that disinfects the future

The summer was relentless in Ugāle, Latvia. Heat radiated off the roads, soaked into the soil, and lingered in the air like a warning. Yet at the VNK Serviss Wastewater Treatment Plant (WWTP), the heat wasn't just weather – it was symbolic. The pilot project unfolding here wasn't just running on schedule; it was pushing forward with the kind of intensity only real relevance brings. When water becomes a matter of national security, every degree matters.

Figure 44. Partners visiting VNK Serviss' WWTP in Ugāle, Latvia

In this small, determined corner of Latvia, the pilot had a clear target: reclaimed water, cleaned well enough to be safely reused for irrigation. And here, a quiet success took root – not just in the maize fields or data sheets, but in the method itself. Latvia's unique contribution came from the labs of the University of Latvia: a disinfection process for treated wastewater that broke away from what other project partners were doing. Unlike conventional chemical treatments, this method had agriculture in mind from the start. Safer, more tailored, and now – thanks to testing – proven effective.

Lessons learned

Of course, success stories rarely come without hard-earned lessons. And in Ugāle, those lessons had less to do with water chemistry and more with logistics. Planning, it turned out, wasn't just about pipes and pumps. It was about people – and parts. Procurement wasn't as straightforward as anticipated. Global supply chains, already tangled by a shifting geopolitical landscape, proved fickle. Equipment delays threatened timelines. Brands that once seemed reliable faltered. Then came the human element. Sickness, holidays, resignations – natural parts of any working environment, but difficult to build into tight pilot schedules. When a project hinges on timing, the absence of even one key person can throw the entire machine off balance. In one case, it nearly fell on a single overburdened staff member to carry the entire pilot forward. It worked – but only just. Next time, they say, there will be a plan B.

The reclaimed water

Ugāle's wastewater is municipal, uncomplicated, and relatively clean. There's no industry feeding pollutants into the system, no chemical cocktails to unravel. That simplicity is a gift – but also a limitation. The method developed here thrives in such conditions. Still, if it's to be scaled or transferred to more complex environments, it may need technological reinforcements and stricter safety protocols. Crucially, reclaimed water can't be stored indefinitely. Once treated and disinfected, it needs to move – quickly. The infrastructure must match not only technical specifications but also market demand. Who will use the water, and when? The answers to these questions must come before shovels hit the ground.

Crops, contamination, and caution

Maize was the safe choice. Heat-processed before consumption, it offers a layer of protection against microbiological risks. It was the ideal crop for this first foray into reclaimed water irrigation. But the team in Ugāle is already looking ahead. Could they go bolder? Could they irrigate carrots, beets, or potatoes – root vegetables that journey straight from soil to supper? That next step won't just test water quality – it will test public perception, regulations, and systems of quality control.

Looking ahead

The pilot at VNK Serviss was, in many ways, a quiet triumph. It delivered results, created knowledge, and forged a method worth building on. But perhaps most importantly, it raised the right questions. Can we trust reclaimed water in our food systems? What does it take to make that trust possible? And how do we ensure that when the next heatwave comes – literal or political – we're ready not just to react, but to adapt? In Ugāle, we're already planning for that future.

6.3 Jurmalas Udens, Jūrmala

Mostly everything in the planned pilot activities went according to the plan. Different water solutions, including treated wastewater from wastewater treatment plant, were tested to water grass and flowers at a pilot site. As well as interactive lectures and issue related practical activities were held at schools and school camps (Figure 45 and 46).

Both interest and engagement on behalf of schools proved to be high – in the year 2024 those were thirteen educational institutions with over 400 attendees across different municipalities in Latvia. This highlighted the importance on educating the younger generation on topics thar are not necessarily included or mentioned in school programs but are crucial in creating a collective understanding on climate smart and friendly society, including knowledge on water related topics.

Figure 45. School children perform various water related practical experiments

Watering of flowers (Figure 47) and grass in the scope of the pilot also proved the usefulness of treated wastewater as an effective watering solution.

Figure 46. Interactive lecture at school on water related issues, including water reuse

There are some aspects that need to be taken in account when planning a similar pilot or practice. One of aspects is the confidential information of the exact composition of watering solution used by greening company. As valuable as it would be for scientific comparison purposes, one must understand that it is company's right not to disclose the watering solution formula unless required by some controlling state organization.

Another aspect to bear in mind, as learned during the pilot, is to foresee and plan wastewater reservoir maintenance if the water is collected in such reservoir prior its use for watering purposes. As described further in Chapter 5, reservoirs containing treated wastewater without chlorine developed an algae bloom. Consequently, a hypothesis was made, that nutrient reduction in the wastewater could be attributed to this bloom process within the reservoir. The plan for the next project period, is to clean the reservoirs thoroughly and, if necessary, repeatedly to establish the frequency of maintenance and the exact effect on nutrient levels.

To duplicate our successes as well as avoid making mistakes it is crucial to understand that wastewater is rich in nutrients but the use of a specific wastewater depends on its specific quality, preferred watering method and state regulations. Therefore, each wastewater should be thoroughly analyzed prior used for watering purposes.

Next steps could include widening the potential use of treated wastewater in areas such as watering of greening areas across the municipality, watering sports fields, storing treated wastewater in reservoirs used for firefighting purposes of residential buildings.

Figure 47. Flowers watered with treated wastewater

Positive practice and public awareness on water reuse and reclaimed wastewater quality go hand in hand, so spread the word and inform the public about water resource availability and its overall use as well as educate the public on wastewater quality indicators, changing the perception from "treated wastewater" to "resource" through environmental education. In order to achieve this goal, certain actions need to be taken – gaining actual science and practice based results, educating the public during school visits and lectures, promoting your success in various conferences and meet-ups. Take combined steps towards a collective goal of climate smart society.

6.4 Samsø

Greenhouse doors open

The greenhouse experiment of the Samsø pilot went well according to the plan. The maize plants were thriving and had no pests during the growing season. The quality of the reclaimed water used for irrigation was good, and it was easy to handle as the two greenhouses were located at the WWTP area.

Dissemination of the project was successful as many local people have shown their interest in the subject. From school children to farmers and people in general the visitors have all been quite open-minded to the possibility of using reclaimed water for irrigation of crops instead of just leading the water to the sea.

When planning such a greenhouse experiment it is crucial to bear all aspects in mind – what kind of methodology, which materials, soil parameters, plants' needs, water quality, analysis instruments, and cooperation of who is going to execute all the practical work.

In the Samsø pilot we experienced a good cooperation between colleagues when taking care of the plants every day and also on the weekly analysis work. We used the existing measurement equipment of the WWTP as far as possible, but we also had to buy some new equipment. It's important for the analysis results to have high quality instruments. Some of the instruments recommended by the project was of poor quality which to some extend is reflected in the results, especially on the soil analysis.

We used buckets approved for food as growing containers for the maize, mainly to avoid any harmful substances from the buckets that could have influenced the results.

When growing the plants we found that air humidity control as well as the solar radiation was important. The plants should have the right amount of sunlight and water to thrive. During the hot summer weeks, the greenhouse was covered with shading cloths.

An improvement for growing the maize could have been drip irrigation. Regular water supply for the plants throughout the day would have been better for the growth than a larger amount of water once a day. We were very careful not to spill any reclaimed water on the plants when irrigating the soil, but this could have been done more easily with drip irrigation.

Figure 48. On site meetings with target groups

Next steps

In this experiment, we have used reclaimed water for irrigating maize, but it could be interesting to see how other crops such as potatoes, carrots, and other root crops react to the reclaimed water. Will some of the potential substances that may remain in the treated wastewater be incorporated in other species of food crops? Also it could be interesting to test even more different substances potentially remaining in the reclaimed water and to see if these would be traced in the crops.

The visitors of the Samsø pilot all showed positive interest but what about the public in general? As the national law is for now it is not possible to irrigate food crops with reclaimed water in Denmark. The Danes are not used to seeing reclaimed water as a resource when it comes to food production. Are we ready to incorporate our wastewater in the agricultural cycle?

To move towards a sustainable bio circular model on the island of Samsø a more systemic anchoring and approach is necessary. Therefore local stakeholder involvement and cross-sectoral collaboration is key to future progress. The ReNutriWater pilot is part of the ongoing development of a green masterplan for the island which is interrelated to our climate adaption, climate mitigation and climate action plans.

7 Decision support tool

7.1 WaterSafe Tool

IT tools are becoming increasingly popular in various sectors of the economy, from industry and energy to agriculture and public services. Their role in process optimization, automation of activities, and decision-making support is becoming crucial in the context of growing challenges related to the efficient use of resources and environmental protection. In particular, their use can significantly contribute to achieving the goals set by the European Union in sustainable resource management and transforming the traditional economic model into a circular economy. One of the promising areas where IT tools can play a significant role is the water and sewage sector. In the face of growing demand for water, changing climate conditions and the need to minimize the impact of human activity on aquatic ecosystems, modern digital technologies can become a key element supporting effective water resource management. Thanks to the use of advanced data analysis systems, it is possible to increase the efficiency of processes related to water treatment and distribution, reduce losses and minimize the negative impact on the environment. The WaterSafe tool was developed with the aim of protecting water resources and promoting the reuse of water from sewage. Its main objective is to enable users – wastewater treatment plant operators, local authorities and other entities managing water and sewage management – to select the optimal water treatment technology. Thanks to its integration with current European Union regulations and analytical functions, WaterSafe is not only an operational support for treatment plants but also a tool enabling effective management of water resources at the local and regional levels. Its use can significantly contribute to the transformation of the water and wastewater sector, supporting the implementation of sustainable development goals and the circular economy.

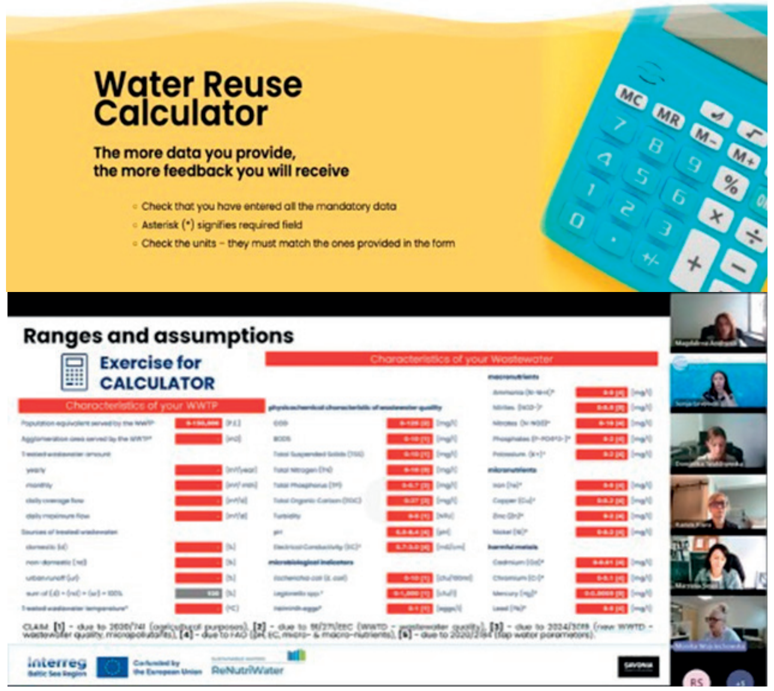


Figure 49. Testing IT tool

7.2 How to use the tool?

By using WaterSafe, it is possible to effectively manage wastewater treatment and water reuse processes in a manner consistent with the principles of the circular economy (CE). This tool not only supports decision-making, but also contributes to the protection of water resources and minimizing the impact of human activity on the environment.

Follow the steps below to use the WaterSafe tool effectively for analyzing and upgrading treated wastewater quality:

Step 1: Enter WWTP and effluent data

Begin by inputting the relevant wastewater treatment plant data (Figure 50). Provide current effluent parameters, including concentrations of key water quality indicators (e.g., BOD_5, COD, nutrients), and if possible, more about pathogens, micropollutants, etc.

Step 2: Select the target water quality class

Choose the desired water quality class you aim to achieve. This can be based on intended use (e.g., irrigation, discharge to surface water, industrial reuse) or relevant legal/regulatory frameworks.

Step 3: Automated analysis by WaterSafe

Once data is entered, WaterSafe will automatically compare your effluent parameters against applicable EU legal standards. It will identify whether each parameter is within legal limits, below the required threshold (substandard), or above the permissible limit (potentially harmful).

Step 4: Receive targeted treatment recommendations

For each parameter that exceeds or falls short of the standard WaterSafe suggests the most effective treatment methods (e.g., filtration, disinfection, advanced oxidation). Additionally, the system provides a comprehensive treatment strategy that optimizes simultaneous correction of multiple parameters, efficiency in terms of cost and technical implementation.

Step 5: Review your customized treatment strategy

The result is an optimized, tailor-made wastewater treatment plan, aligned with your selected target water quality class, regulatory compliance requirements, technical feasibility within your WWTP setup.

Tip: Always review the proposed treatment strategy in the context of your local legal environment, operational capacity, and budgetary limitations before implementation.

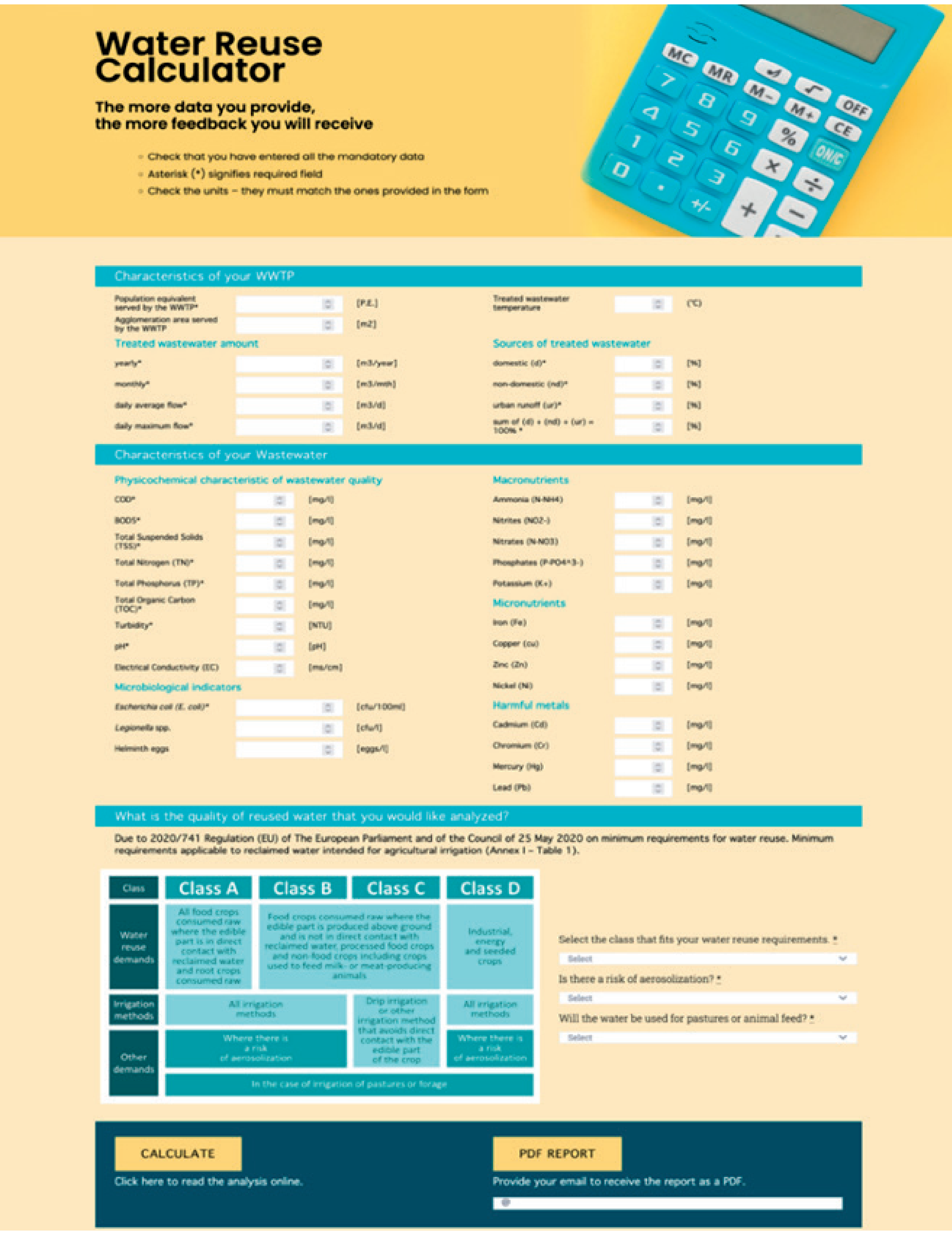


Figure 50. Data entry template

8 Guidelines on risk assessment

Every application must be safe, so a reliable risk assessment is crucial.

Risk management in water management is not a new issue. However, the methodology must be adapted to the city's specific water use needs.

There are no precise guidelines for urban applications, but it is worth relying on the following documents:

» **Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse.**

The regulation presents the principle of managing the water recovery system from municipal wastewater and reclaimed water use in agriculture (Figure 51). Compliance monitoring is an essential element of the system. It will be an important source of data in our risk assessment.

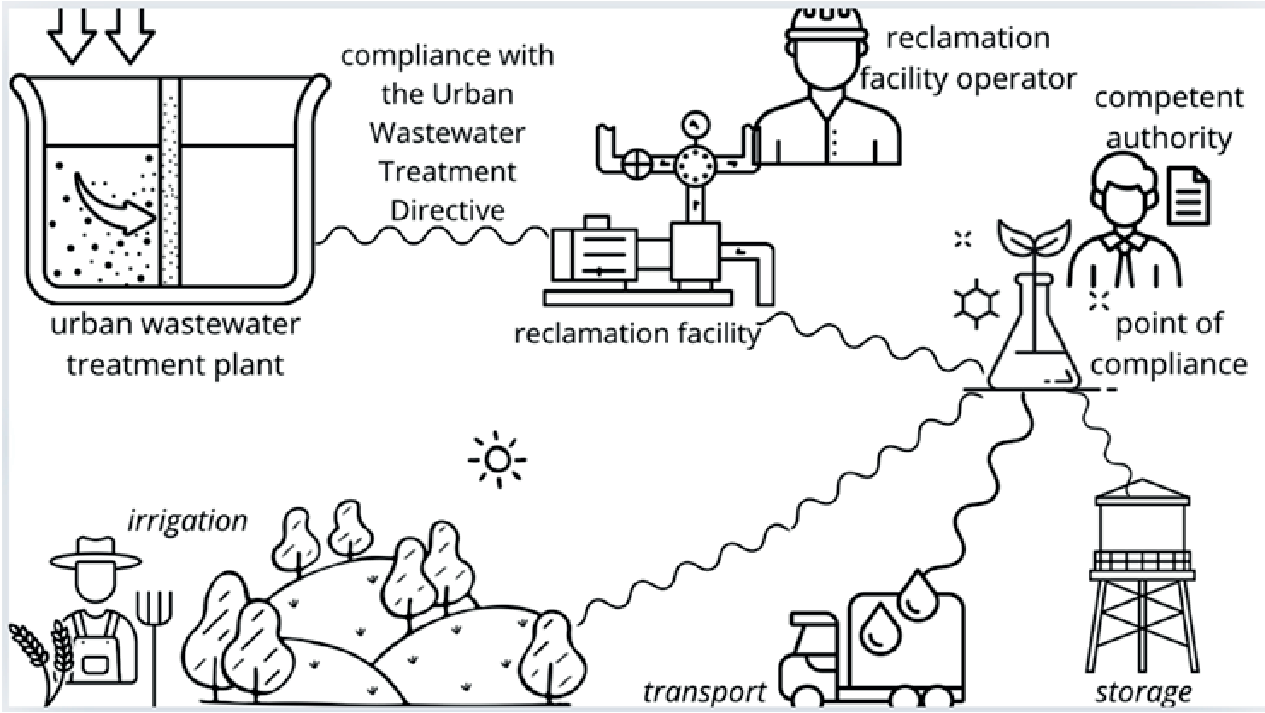


Figure 51. The conceptual diagram of the process of reusing water from municipal wastewater in agriculture, according to the Regulation 2020/741

Risk management is defined in the Regulation as an inherent element of the functioning of water recovery systems. The preamble states that risk management should comprise the identification and management of risks in a proactive way and should incorporate the concept of producing reclaimed water of a specific quality required for particular uses. It is crucial to develop a risk management plan.

The regulation introduces useful definitions

Annex II contains a list of actions that should be taken to mitigate the risk when using water recovered from sewage for agricultural purposes. Key elements of risk management include:

1. Description of the entire water reuse system,
2. Identification of stakeholders,
3. Identification of potential hazards,
4. Identification of the environments and populations at risk,
5. Risk assessment preceded by an analysis of the environmental and social situation. Many EU legal acts are referred to at this point; it is necessary to consider whether they must be considered.
6. Considering the need to introduce stricter requirements than those specified in the Regulation.
7. Identification of preventive measures.
8. Adequate quality control systems and procedures.

9. Environment monitoring to provide quality feedback.
10. Appropriate systems to manage incidents and emergencies.
11. Ensure that coordination mechanisms are established amongst different actors to guarantee reclaimed water's safe production and use.

» **European Commission Notice [Guidelines to support the application of Regulation 2020/741] on minimum requirements for water reuse 2022/C 298/01.**

The Guidelines explain and develop the provisions of the Regulation. They organize the risk assessment methodology described in the Regulation and transparently present the following steps to build a risk management system. The Guidelines detail recovery for agricultural purposes, focusing on qualitative, quantitative, and technological issues (Figure 52). Some tasks go beyond our needs; we will use some system elements proposed in the Guidelines.

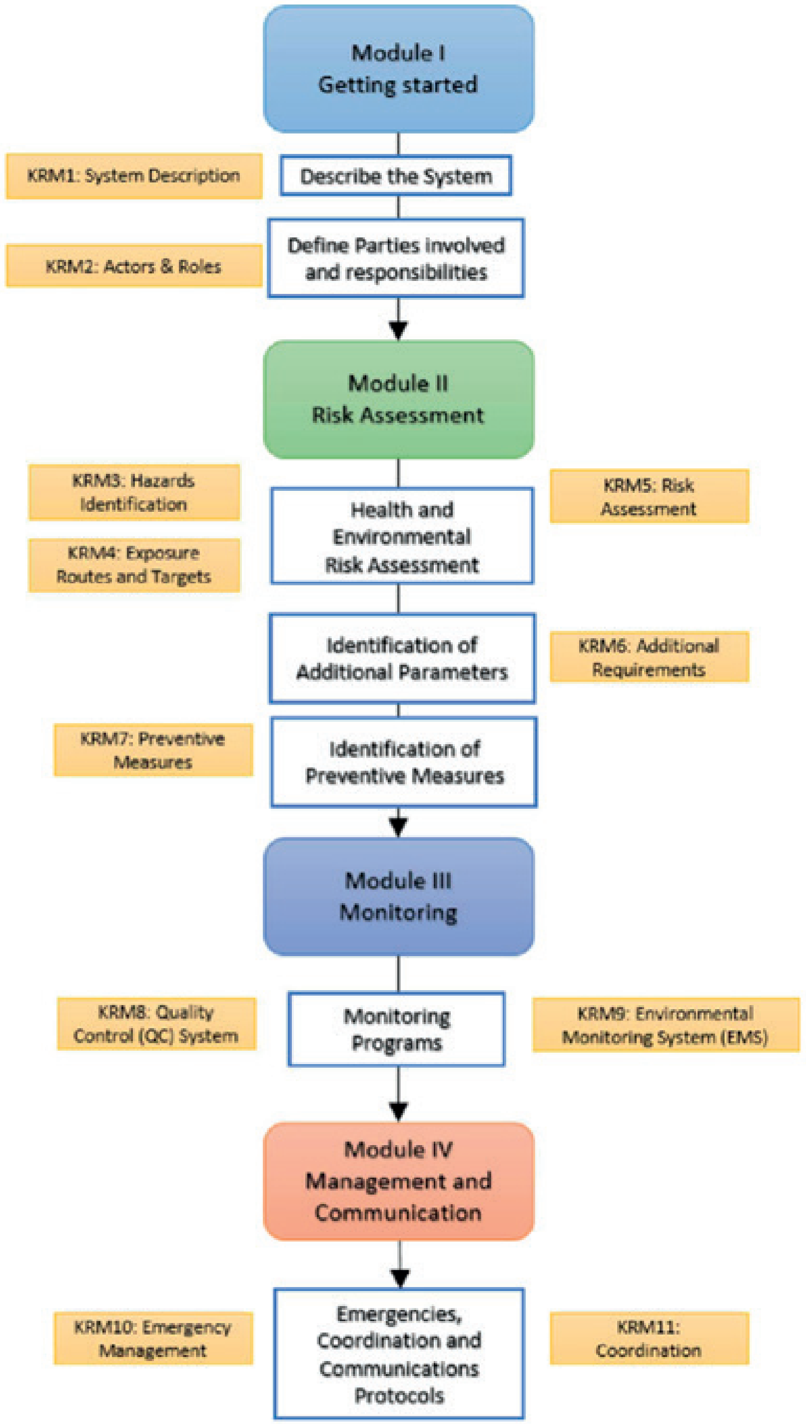


Figure 52. Water reuse key risk management elements (KRMs) organized into four modules to aid the formulation of a risk management plan, as presented in the European Commission Guidelines

» **[Water safety plan manual:] step-by-step risk management for drinking-water suppliers, second edition, World Health Organization, 2023.**

The Water safety plan manual provides practical guidance to support the development and implementation of drinking water safety planning in accordance with the principles of the WHO. The manual is a mature risk management scheme in drinking water supply that has been refined over the years. Its principles have been reproduced in the Regulation and the Guidelines.

» **[Sanitation Safety Planning Manual] for Safe Use and Disposal of Wastewater, Greywater and Excreta, World Health Organization, 2016.**

These guidelines are addressed to entities wishing to safely use wastewater and gray water. Although this is not our goal, the principle of building a risk management plan is clearly described and has inspired us to continue working. Moreover, the proposed risk matrix became the basis for further work on risk assessment in ReNutriWater project.

» **ISO 20426:2018 Guidelines for health risk assessment and management for non-potable water reuse.**

ISO (International Standardization Office) document serves as technical guidelines for assessing and managing the health risks associated with pathogens in reclaimed water. It covers reclaimed water's production, storage, transportation, and use. It applies to the use of reclaimed water made from any source.

ISO presents a simple procedure based on WHO guidelines. It proposes risk matrices and microbiological parameters that should be monitored. The disadvantage of the document is that access to it is paid.

The scope of the Reclaimed Water Safety Plan

Risk management based on pilots should include the steps described below.

1. Assemble the team

- What are the surroundings of the WWTP?
- What competencies do we need?
- Who do we want to involve?

The team responsible for risk management is crucial to the system. It must consist of people who know the technology but also end users. It is very important to invite other stakeholders who may be influenced by the pilot's actions or who may affect its functioning. It is necessary to attract people from public administration, science, agriculture, industry, and NGOs representing nature and citizens.

It is essential to identify all the parties involved in the water reuse system and define their roles and responsibilities.

2. Describe the pilot (processes)

It includes a description of the entire water recovery and reuse system, from entering treated wastewater into the pilot to the point of use. It also covers the urban wastewater treatment plant data, used technologies, and end users. Figure 53 presents an example of dividing the process into stages.

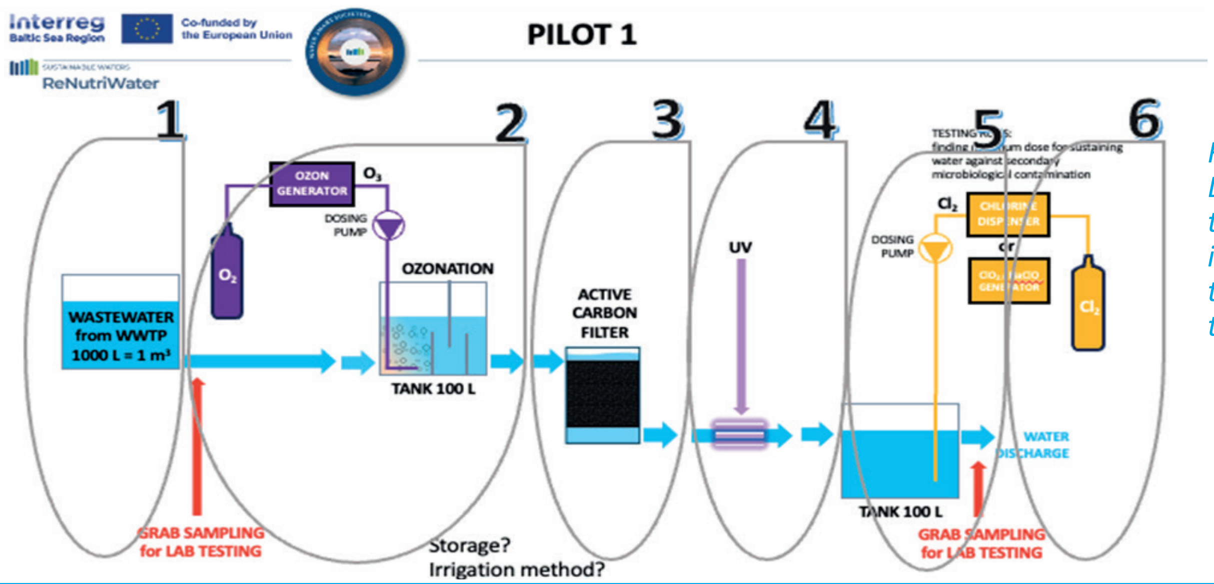


Figure 53. Dividing the process into stages to identify threats

3. Identify hazards and assess the risks

This stage is crucial in identifying threats and hazardous events. The following definitions ca be used:

- Hazard: a biological, chemical, physical or radiological agent that has the potential to cause harm to people, animals, crops or plants, other terrestrial biota, aquatic biota, soils or the environment in general [Article 3 (7), Regulation (EU) 2020/741]. Hazards may have several types and must be clearly described and parameterized.
- Hazardous event: an event in which people are exposed to a hazard within the system. It may be an incident or situation that introduces or releases a hazard to the environment in which humans live or work, amplifies the hazard's concentration, or fails to remove a hazard from the human environment [WHO, 2016a]. So, we can understand this as an adverse scenario that may happen at the pilot's work or in its surroundings. They will be related to direct or aerosol contact of people and animals with reclaimed water and the impact of reclaimed water on plants and soil.
- Risk: a combination of the likelihood of occurrence of harm to health and the severity of that harm [ISO 20670:2018]. In our methodology, the combination is understood as the product of multiplying probability (P) and severity (S). Thus, Risk R=P*S.

Risk assessment begins with identifying hazardous events, i.e., building scenarios. Then, hazards are assigned. The risk associated with the physical characteristics of pilots, microbiology, and physical chemistry of reclaimed water is essential. Threats are divided into four categories:

Q Physical – quantitative (too much/not enough water)

Ph Physical – damage of infrastructure

M Microbiological

CH Chemical (physicochemical)

Certain events can trigger different types of hazards.

Studies and tools (WHO) propose verification scenarios (hazardous events).

We can assess risk based on qualitative, semi-quantitative or quantitative methods.

The quantitative method involves assessing the probability and consequences of risk occurrence, giving them specific parameters. The advantages of quantitative methods are the objectivity of the results, thanks to which they can be compared, and the results have a financial and percentage dimension. It requires very detailed data, which we do not have.

A qualitative method is subject to greater subjectivity and, therefore, error, but on the other hand, it is much easier for the team. The qualitative method involves an individual risk assessment based on experience and good practices. This method uses subjective measures and assessments such as descriptive levels (low, medium, high). The advantage of qualitative methods is that there is no need to quantify the effects and frequency of threats. Based on this method, we indicate general risk areas that require attention. We can use it in the absence of specific information and quantitative data or resources. We will then assign specific numerical values to specific probability and severity. Thanks to this, we will obtain a semi-quantitative method. Therefore, both ISO and WHO indicate that the use of this method is justified (Figure 54).

		SEVERITY (S)				
		Insignificant	Minor	Moderate	Major	Catastrophic
		1	2	4	8	16
LIKELIHOOD (L): Very unlikely	1	1	2	4	8	16
Unlikely	2	2	4	8	16	32
Possible	3	3	6	12	24	48
Likely	4	4	8	16	32	64
Almost Certain	5	5	10	20	40	80
Risk Score R = (L) x (S)		<6	7–12		13–32	>32
Risk level		Low Risk	Medium Risk		High Risk	Very High Risk

Figure 54. Semi-quantitative risk assessment matrix as proposed by WHO and ISO

The entire team must have a similar understanding of risk categories. This is not easy due to the different specializations of team members and an inevitable subjectivity that cannot be entirely eliminated. The description of the categories (to complete).

Once hazards and hazardous events have been identified through a risk assessment, a risk management plan should be developed to minimize potential adverse impacts on end-user health and the environment.

Reliable development of scenarios is the most essential task. Moreover, as a result of work on risk assessment, we will determine whether the adopted matrices meet our needs or whether they need to be modified.

The number of scenarios depends on the functionality of the pilots. However, our goal is to develop the most typical scenarios that can be detailed in further works.

4. Develop and implement an improvement plan to minimize risk

Once hazards and hazardous events are identified through a risk assessment, a risk management plan should be developed to minimize potential adverse health impacts on end-users and the environment. The risk management plan describes how maximum inherent risks for a specific application are managed and which control measures need to be implemented to reduce residual risk to a minimum or acceptable level.

Having selected the hazardous events needing additional control with maximum activities that will lead to risk reduction should be undertaken. We will create an action plan for each pilot that will help increase his safety. This may be a research procedure, additional analyses, operating instructions, internal communication plan, etc.

5. Develop and implement operational monitoring (control measures)

The monitoring plan must provide information on the quality of the reclaimed water. It is an important tool for risk mitigation.

6. Develop a communication and management plan

Management and communication procedures are essential in both standard and incidental conditions as well as in emergencies.

- A standard operating procedure is a set of instructions that guides personnel in performing routine tasks under normal or incidental conditions.
- An incident is a non-standard event requiring corrective action. It is particularly important because it provides operators with knowledge about unusual situations and enriches the experience of pilot operators.
- Emergencies usually occur unexpectedly and require immediate and extensive action.

9 Business models

9.1 Introduction to business models

Current wastewater reclamation technologies yield sufficient results in terms of quality and efficiency. However, implementing wastewater reclamation and reuse in wastewater treatment plants is complex due to technical, economic, and social barriers. A crucial aspect of wastewater reuse implementation involves the investigation of water sector market conditions and analyzing viable pathways for its adoption. To achieve this, business modeling (BM) may be employed as an efficient method of market research and strategy conceptualization. A business model is a framework that describes how an organization generates value. It explains how a company serves its customers, earns revenue, and manages its operations.

In the ReNutriWater project, we conduct business modeling using a business model canvas (BMC) methodology, a conceptual framework for developing, describing, and analyzing business models. It facilitates the innovative exploration of business models in an intuitive visual way. BMC is constructed from nine building blocks representing critical business case aspects, organized into four pillars: ‘product/value proposition,’ ‘financial aspects,’ ‘customer interface,’ and ‘infrastructure management.’ All BMC building blocks and their definitions are combined in Table 34. Defining all of the pillars and building blocks for the given case study allows for a comprehensive economic and business analysis, facilitating the development of a design that can be effectively applied across various economic sectors.

Table 34. BMC building blocks and their definitions

BMC Building block	Definition
Customers	This category identifies the different groups of customers or organizations an enterprise seeks to target based on shared needs and behaviors.
Value proposition	The value proposition category explains why customers select one company over another. It is characterized by a combination of products and services that deliver value to a specific customer segment.
Channels	The channels category refers to the methods and pathways a company utilizes to engage with its customers and deliver its specific value proposition.
Customer relationship	Customer relationship emphasizes the nature of the interactions and relationships a company establishes with each of its customer segments.
Revenue stream	The revenue stream refers to a company's income from its business activities.
Key resources	The key resources building block identifies the critical resources and assets required to implement and support the business model.
Key activities	The key activities involve the main actions that should be implemented and are related to achieving the organization's business goal.
Key partnerships	The key partnerships block identifies the business's key stakeholders and strategic alliances.
Cost structure	Cost structure represents all the operating expenses associated with the implementation of the business model.

9.2 Sustainable business models for the water sector

Compared to traditional business models, sustainable business models (SBM) also consider environmental and societal aspects of the business despite the pure economic evaluation, so reaching the so-called “Tripple bottom line”. Nowadays, sustainable business models aim for more than just benefit society and the environment – they also provide a strong foundation for an organization's competitive advantage. Implementation of SBM may result in benefits for the organization in the long run, namely:

- Increased resilience of operations
- Better image enabling new cooperations
- Enhanced innovations
- Increase in resource management efficiency

The water sector holds significant potential for implementing and developing new SBM, mainly due to its high potential for resource recovery, including water nutrients and energy. If designed well, a sustainable business model for wastewater treatment plants can play a crucial role in boosting the local economy while enhancing the quality of life for the surrounding community.

BMC is a widely used approach for developing SBM in various economic sectors. However, business modeling in the water sector, especially related to the reuse of reclaimed wastewater, is a relatively unexplored field. In the ReNutriWater project, we apply for this purpose a slightly modified version of BMC, which is extended about two building blocks:

- Social impacts and benefits
- Environmental impacts and benefits

Social impacts and benefits refer to a business's effects on people, communities, and stakeholders. These include job creation, social equity, public well-being, and community engagement. Businesses that prioritize fair labor practices, education, and stakeholder collaboration can enhance trust, resilience, and long-term value by keeping best employees. Environmental impacts and benefits relate to how a business affects natural resources and ecosystems. Positive impacts include reducing pollution, conserving resources, and adopting circular economy principles, while negative impacts may involve emissions and waste. Sustainable practices improve efficiency, regulatory compliance, and brand reputation while supporting long-term business success. Such BM framework enables a holistic approach towards the topic and puts emphasis on the sustainable aspects of the organization. The BMC template used in ReNutriWater project is shown in Figure 55.

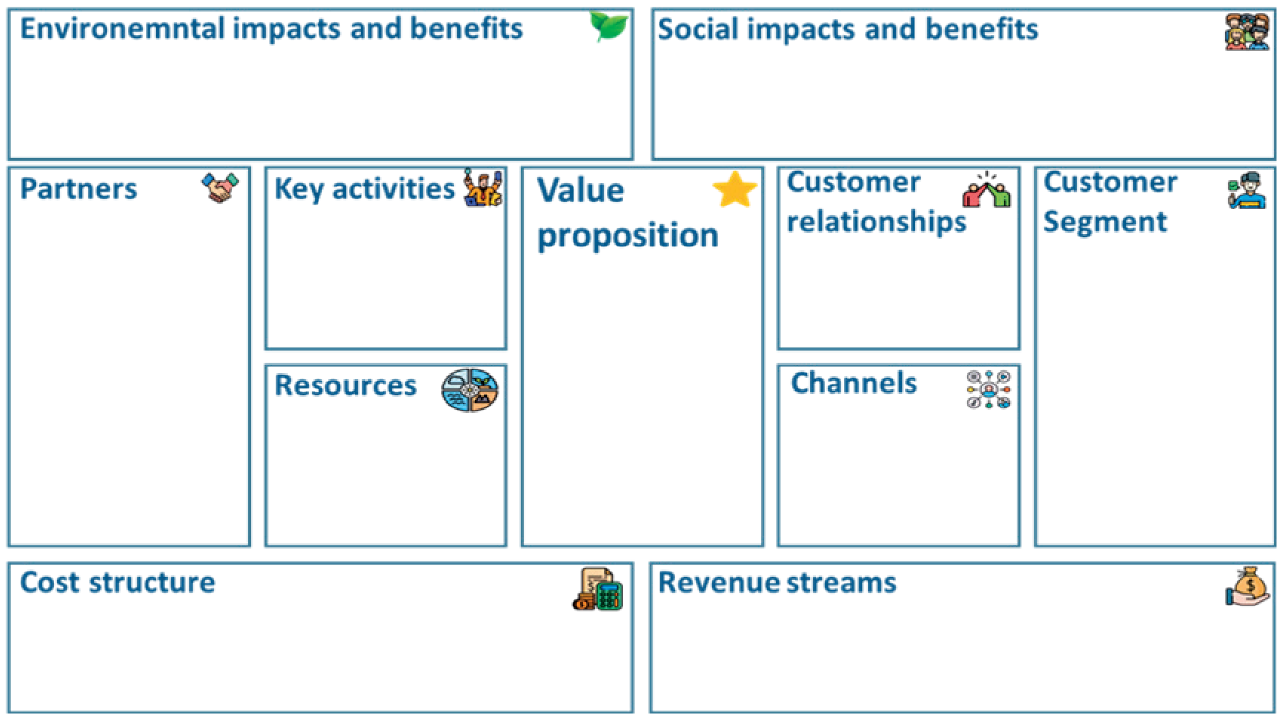


Figure 55. Template of business model canvas used in the ReNutriWater project according to Canva Business Models

9.3 Business models of the ReNutriWater project

To construct business models, we applied four following steps:

1. Desk research and literature review about business models modeling and potential business models in water sector.
2. Designing a questionnaire encompassing all BMC building blocks and additional guiding questions.
3. Conducting a semi-structured in-depth interview with managers of seven pilot plants.
4. Elaboration on obtained data and construction of 7 business models using BMC framework.

Gathered data and developed business models allowed for the preparation of individual business models designed for specific project partners and the deduction of universal business models applicable to model wastewater treatment plants. Further elaboration on business models allowed for the development of a set of strategies and road maps for implementing water reclamation and water reuse.

9.4 Outcomes of Business Modeling in ReNutriWater project

The business model development process within the ReNutriWater project produced significant findings aimed at promoting water reuse practices in the Baltic Sea region, through a structured and stakeholder-oriented approach. One of the key outcomes was determining the value proposition of reclaimed water, highlighting its potential to provide an alternative water source for various applications, including agricultural irrigation, industrial processes, urban landscape maintenance. By emphasizing the economic and environmental advantages of reclaimed water, we demonstrated its potential to reduce freshwater dependency, enhance resource efficiency, and contribute to circular economy objectives.

On the other hand, several barriers were identified affecting the implementation of water reuse, which include regulatory and policy-related limitations, technological challenges in ensuring water quality, economic hurdles such as high investment and operational costs, and societal acceptance concerns due to perceived health risks and cultural perceptions. Additionally, the absence of standardized frameworks for evaluating water reuse projects and the lack of financial incentives were highlighted as critical challenges requiring attention.

To effectively address these barriers, we developed and proposed strategies tailored to different areas within the Baltic Sea region, including rural, urban, and industrial contexts. The process of business model development was enriched by a strong focus on the perspective of wastewater treatment plant managers, whose insights and opinions were gathered to ensure practical relevance and feasibility of the proposed strategies. Their feedback provided an understanding of operational constraints, economic considerations, and regulatory challenges associated with implementing water reuse systems. Moreover, a holistic collection of stakeholder opinions allowed us to incorporate diverse viewpoints and ensure that proposed business models are robust, adaptable, and capable of addressing the multifaceted challenges of water reuse. Ultimately, the ReNutriWater project laid a comprehensive foundation for developing effective and sustainable business models that enhance water reuse practices across various contexts, contributing to the broader goals of resource efficiency and circular economy principles in wastewater management.

10 Education, awareness building – good practices

This section highlights the significance of increasing awareness and promoting education about the safe and effective reuse of wastewater. It provides a comprehensive guide to understanding both the technical and social aspects of wastewater recycling, with the ultimate goal of making it an accessible and responsible practice for communities, industries, and individuals. The aim of this part is to exchange experiences and viewpoints on thematic areas and project-relevant issues.

10.1 Terms to be used in communication

- **Define key terms in simple and accessible language to ensure clarity for all stakeholders (e.g., "reclaimed water," "safe reuse," "nutrient recovery").**
- **Avoid jargon and technical terms when speaking to the general public. Use relatable and positive framing (e.g., "purified water" instead of "treated wastewater").**
- **The phrase 'yuck factor' should be avoided. Instead of using the term, one could say i.e. "overcoming potential societal hesitation".**
- **Address potential concerns with clear and reassuring language, emphasizing safety, sustainability, and benefits.**
- **Provide a glossary of commonly used terms to maintain consistency across communication materials.**

10.2 Stakeholder meeting scenario

Successful implementation of water reuse projects often hinges on the active engagement and support of diverse stakeholders, including policymakers, water utilities, industries, and the public.

Stakeholder – a person or a group of persons, institutions, associations, or firms that can become involved in the project, directly or indirectly, positively, or negatively.

The process of involving stakeholders may be structured as presented in Figure 56:

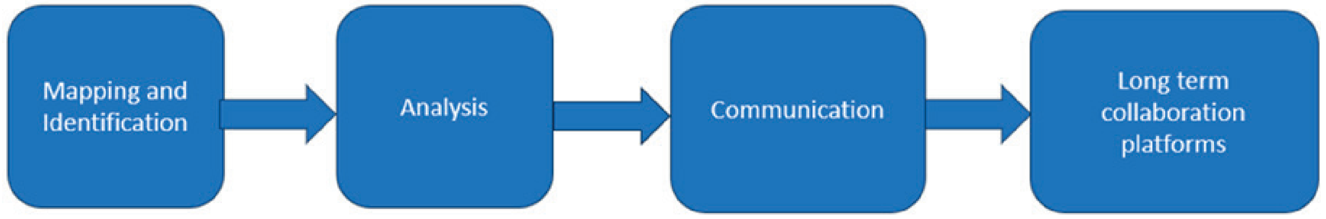


Figure 56. Engage stakeholders

Stakeholder identification and **stakeholder engagement** are crucial steps for the effective organisation and implementation of the stakeholder meetings. Achieving a balanced representation of stakeholders, can be conducive to both the implementation and policy improvement.

In the project, we focused on four target groups:

- Infrastructure and public service providers, mainly urban wastewater treatment plant operators,
- Local public authorities (municipalities),
- Small and medium enterprises (SME) from tourism (hotel operators) and technology providers.
- Interest groups, organizations interested in this challenge.

However, it should be borne in mind that there are many more stakeholders:

- General Public: homeowners, communities, and local citizens.
- Businesses and industries, especially those in water-intensive sectors (e.g., agriculture, construction).
- Schools and universities – engaging youth for long-term impact.
- Local authorities and policymakers – to support and create regulations.
- Water treatment professionals – to ensure technical expertise.

One of the way to identify and engage stakeholders is mapping. The main benefit of mapping is to get a visual representation of all the people who can influence your project and how they are connected.

Start by identifying all the potential stakeholders – people, groups, or organizations affected by your project, those who have influence over it, or have an interest or concern in its success. At this point, try to be as detailed as possible. You can always eliminate those that don't fit but also add others in the later stage of the project.

Web search and brainstorming are both complementary methods. In order not to miss anyone, the following scheme may be used (Figure 57).

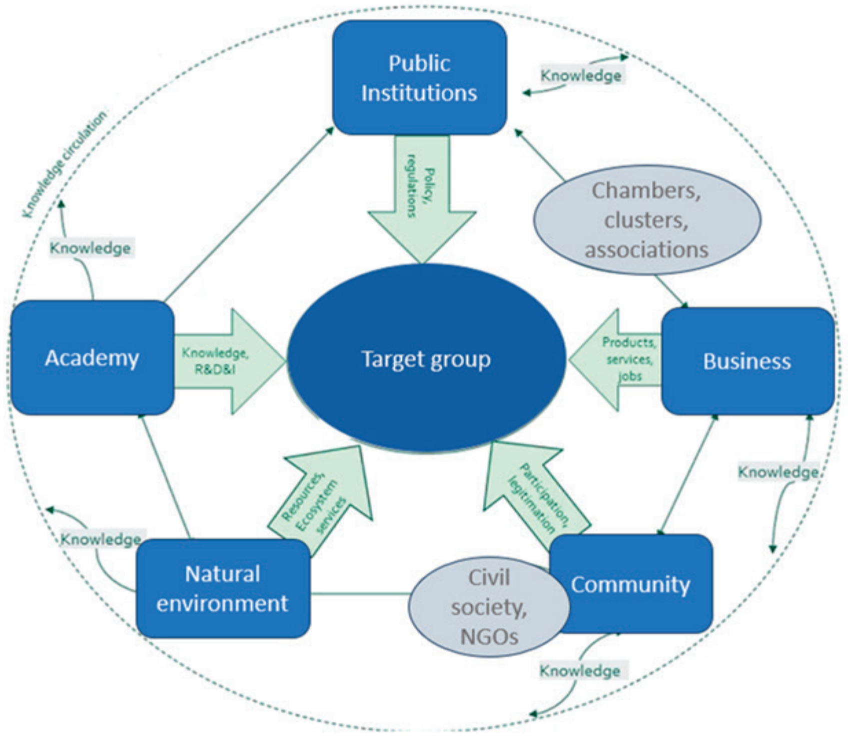


Figure 57. Stakeholder mapping

Analysis

Categorizing them in terms of their relationship to the project and each other is useful for further communication and planning efforts. Prioritizing the stakeholders according to those who have power and can influence your project, and those who have an interest in your project. Depending on the stakeholder's position on the power-interest grid, you can decide on what actions to undertake (Figure 58).

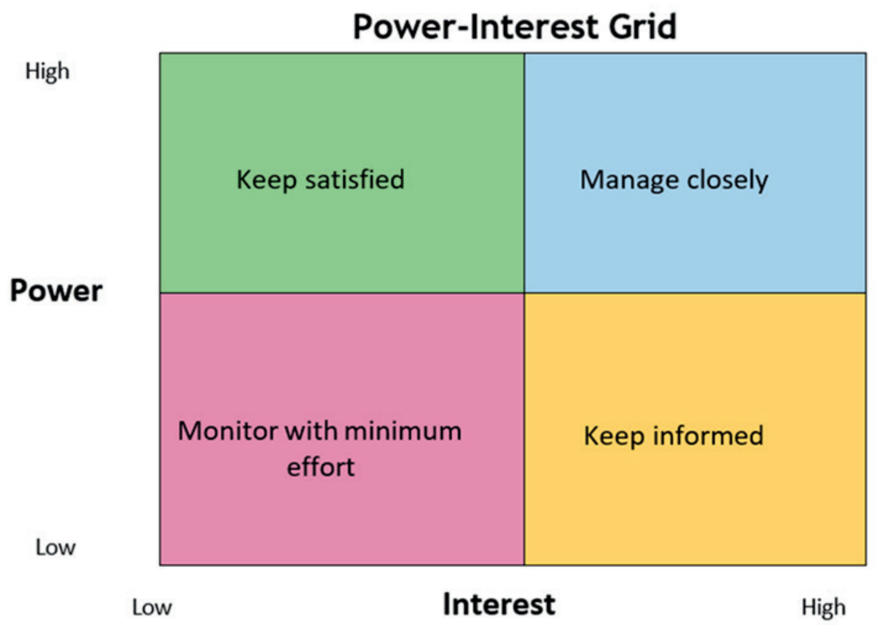


Figure 58. How to take care of stakeholders

- **High influence, high interest**
  These are the most important stakeholders, the ones who can determine whether a project succeeds or fails.
- **High influence, low interest**
  These stakeholders have power, but as long as you keep them informed and satisfied, they won't feel much need to exercise it.
- **Low influence, high interest**
  Keep these stakeholders adequately informed and talk to them to ensure that no major issues are arising. These people can often be very helpful with the details of your project.
- **Low influence, low interest**
  Monitor these stakeholders but do not bore them with excessive communication.

To learn more about your stakeholders and discover how they feel about your project, several methods can be applied: attitude research (questionnaires), workshops, open meetings, interviews, thematic focus groups, etc.

No one guarantees that every stakeholder will end up supporting you. However, the more people and community leaders you can win over, the better your chances of success become. Communication is essential. Bring stakeholders in as early as possible and give them a right amount of information depending on their level of interest and involvement.

Developing a communication plan

Tailored communication:

1. Developing targeted messages and communication ways that resonate with different stakeholders: Face-to-face, online, event, phone, nonformal event. Right amount of information depending on their interest and involvement in the project.
2. You should be clear about whom you are engaging with and why. Stakeholder communication plan should consider interests, benefits, impacts and powers of the stakeholders and determine the time and the level of the participation.
3. Stakeholders may vary widely in every aspect, so for every type of stakeholder you should define the best way of communication. For example, for some stakeholders, face-to-face meetings are the most effective means for communicating and resolving issues, but for some face-to-face meetings may not be practical.
4. Communicating early is important because people will need more time to think before making a decision.
5. Give each stakeholder a right amount of information depending on their interest and involvement in the project. Some people need just an executive summary, while others will want to dive deeper.

A few practical examples of communication work with stakeholders from SCCIC experience in the ReNutriWater project:

- Tailored to audience seminars and trainings. Tailored means different format and content for different audiences: decision makers, youth, interest groups, businesses, community.
- Individual meetings with the high influence representatives of the target group.
- Communication to policy makers at EU level.
- "Knowing by seeing" – organising of stakeholders' visits to pilots in other countries.
- Community involvement: Public events, workshops, competitions.
- Social media, communication campaigns to break psychological barriers.
- "Catching the audience" of other events/trainings and short presentation of project

Developing the agenda and invitation

A well-structured agenda can help partners prevent potential conflicts and stakeholder fatigue which can undermine the purpose and the outcomes of the SMs, by including interactive sessions, selecting topics tailored to the audience, while ensuring equal time to different stakeholders to share their insights.

Some tips for developing agenda:

- choose a limited number of topics that can be sufficiently discussed throughout the meeting,
- set the total duration of the meeting that it would be better if it does not exceed four (4) hours.
- consider allocating time slots to each agenda item, including presentations, discussions, ice-breaker activities, and coffee breaks,
- leave time available for the contributions of different sets of stakeholders, representing companies, public administrations, and academia

Meeting and its logistics

Assign roles and responsibilities: Moderator, Presenter, Timekeeper, Minute-taker

Format: Hybrid (in-person + virtual) to ensure wider participation from remote stakeholders.

Use of interactive tools (e.g., whiteboards, polls, or online collaboration platforms): to gather input and ideas during the meeting and to facilitate interactive discussions rather than one-way presentations.

Materials: Presentation slides to introduce key concepts and data. Handouts or a resource packet with detailed information on wastewater types, treatment technologies, and case studies. Brainstorming templates or flipcharts for note-taking during discussions.

Time Allocation: Keep the meeting interactive and concise (about 90 minutes to 2 hours) to ensure active participation without overwhelming attendees.

Establishment of long-term platforms for collaboration with stakeholders

One of the most challenging and as well pressured way to collaborate with the stakeholders is to organise and manage the long-term collaboration platforms. There are many different platforms created for cooperation with stakeholders in different sectors such as:

- Local supportive groups;
- Multi-stakeholder platforms;
- Networks;
- Social platforms, etc.

Useful recommendations:

- The stakeholders have to benefit from participating.
- Do not raise infeasible expectations.
- Clarify at the beginning the rights and duties, be open and transparent.
- Build up trust between the involved stakeholders.
- Not more than 15 persons are recommended. If needed, involve more stakeholders in subordinated groups or an open forum.
- Involve your regional/national funding authority as they can provide information about regional/ national priorities and funding opportunities.
- Bring public and private stakeholders with different needs together and make them understand each other's needs.

- Do not duplicate structure: if you have something comparable to a platform, add activities and stakeholders if needed.
- Have a skilled 'neutral' moderator in charge.
- A successful platform requires time and a thorough preparation!

Ideas to think about

Monitoring and flexibility, perception that "A one-size-fits-all approach" doesn't work is a key factor of success.

Continuously assessing stakeholder satisfaction and adapting strategies as needed will lead to change.

Building trust: institutional and personal enables effective process.

The impact of smaller steps leads to a big change in a long term.

Post-meeting actions

Communicate with participants: Set up a shared online platform (e.g., email list, group chat, or collaboration tool) for ongoing updates and coordination.

Good examples of a good conversation

Solution-Oriented Approach:
Shift focus from problems to possible solutions and benefits.

Clear and Positive Messaging:
Frame discussions around safety, efficiency, and environmental benefits rather than risks or constraints.

Use of Testimonials:
Share success stories from similar projects to build trust and credibility.

Handling Misinformation:
Address misconceptions respectfully, using data and real-life examples to clarify doubts.

Don't make up:
If you don't know, do not guess or make up facts, but admit that you do not know the answer, but you can try to find out.

11 Summary and recommendations

The project turned out to be an extremely interesting challenge for the project partners. It is impossible to build success without the involvement of various entities (Science, Business, service providers, policy-makers, etc) and diverse stakeholders. It is an excellent introduction to further work on the implementation and safe use of reclaimed water in the Baltic Sea Region (Figure 59).

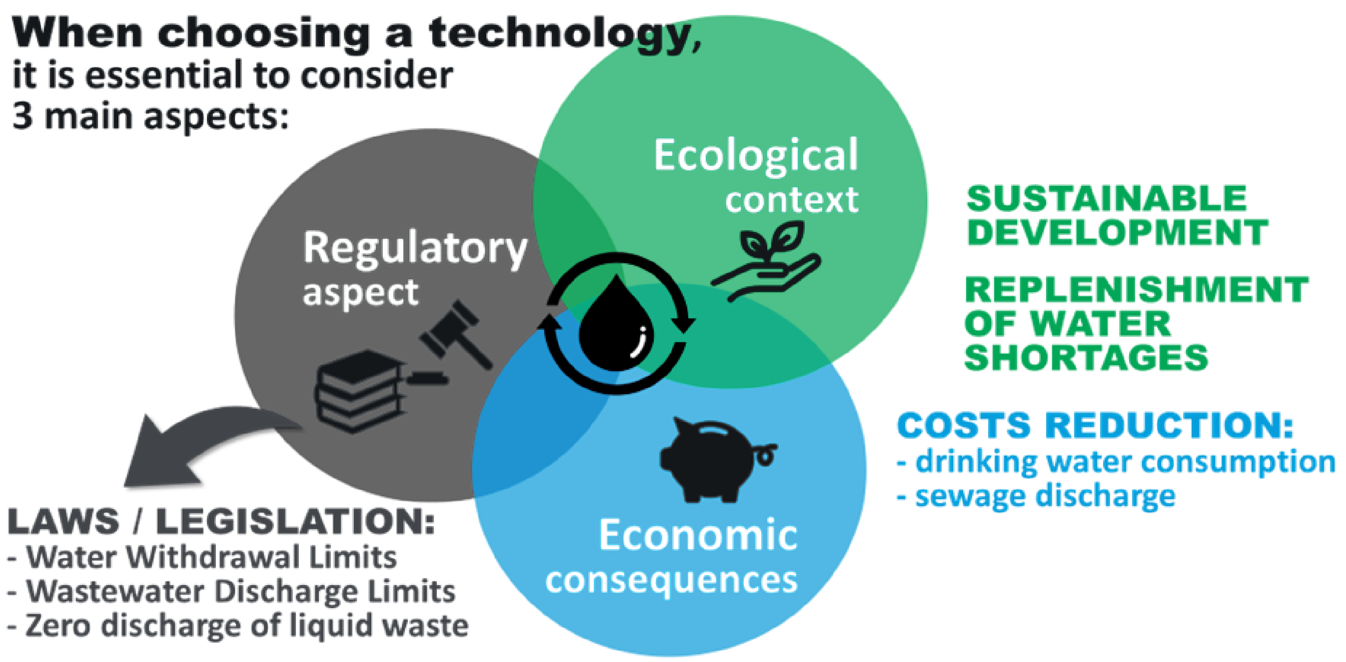


Figure 59. Project contexts

Figure 60. Project consortium in Jūrmala, Latvia 2024

We dedicate this manual to all those who see recovery as an opportunity to reduce the consumption of natural resources.

12 Bibliography

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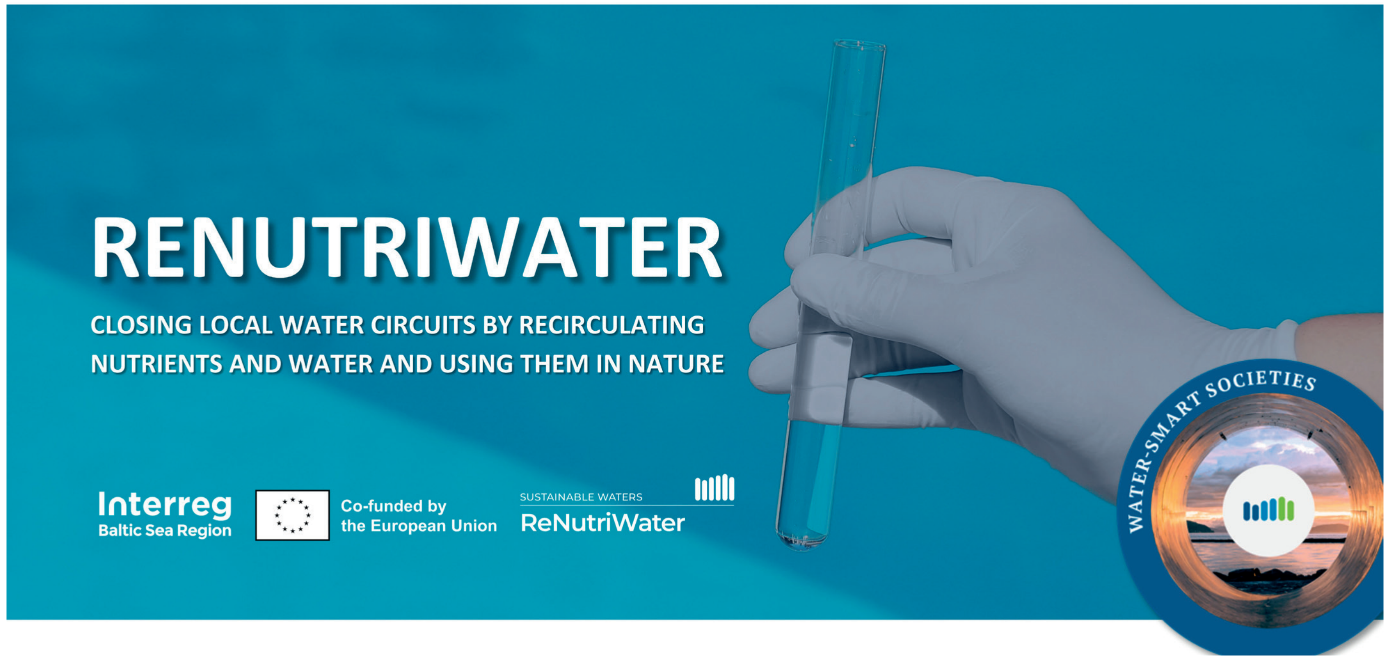
13 List of project partners

PP1. Chamber of Economy Polish Waterworks **(lead partner)**
PP2. Centrum Balticum Foundation
PP4. University of Latvia
PP5. Mineral and Energy Economy Research Institute of the Polish Academy of Sciences
PP6. Savonia University of Applied Sciences **Ltd.**
PP7. Warsaw University of Technology
PP8. Municipality of Samsø
PP9. Schwander Polska **Ltd.**
PP10. Municipal Water and Sewerage Company in Warsaw **SA**
PP11. Samsø Wastewater Utility
PP12. Jurmala Water Utility
PP13. Siauliai Chamber of Commerce, Industry and Crafts
PP14. VNK serviss **Ltd.**
PP15. National Regions Development Agency

14 List of figure credits

Cover picture	**ChatGPT, ReNutriWater 2025**
Group picture on page 2	**ReNutriWater 2024**
Figures 1-52, 53, 56-60	**ReNutriWater 2023-2025**
Figure 52	**European Commission 2022**
Figure 54	**World Health Organization 2016**
Figure 55	**Canva Business Models 2025**



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SUSTAINABLE WATERS
ReNutriWater

ReNutriWater

HANDBOOK

on water reuse

Izba Gospodarcza WODOCIĄGI POLSKIE

CENTRUM BALTICUM

UNIVERSITY OF LATVIA

Mineral and Energy Economy Research Institute Polish Academy of Sciences

SAVONIA University of Applied Sciences

SAMSØ KOMMUNE - vi gør det sammen

SCHWANDER POLSKA

warsaw waterworks

SAMSØ Spildevand

Jūrmalas ūdens

SIAULIAI CHAMBER OF COMMERCE, INDUSTRY AND CRAFTS

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SUSTAINABLE WATERS ReNutriWater

Closing local water circuits by recirculating nutrients and water and using them in nature