TÉCNICO LISBOA

UNIVERSIDADE DE LISBOA

INSTITUTO SUPERIOR TÉCNICO

REPORT

Curricular Unit

Advanced management of urban water treatment systems

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in
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TÉCNICO LISBOA

Scope and overview

This document contains the programme of a curricular unit entitled ***"Advanced management of water treatment systems"*** prepared for submission to Habilitation ("Provas de Agregação") in Environmental Engineering at Instituto Superior Técnico, Lisbon University, according to point b), article 5 of the Decree-law 239/2007, of 19th June. The programme's format adopted follows the template currently required by the Portuguese Assessment and Accreditation Agency for University Study Programmes (A3ES), though providing more detail whenever considered relevant (i.e., exceeding max 1000 characters, particularly in *Syllabus*).

The content of this unit reflects my research and teaching experience on water (and wastewater) treatment and ultimately aims at transferring knowledge produced during my 31-year research activity to the water sector. It builds on my 9-year experience in teaching to Environmental Engineering and Biotechnology Engineering degrees at the University of Algarve, as well as in later training actions to students (at master's and doctoral levels) and water professionals.

Water is central to all human activities, to all components of the EU Green Deal and to several United Nations sustainable development goals – UN SDGs. Urban water systems support a critical public service, whose importance is well-recognised by SDG 6 'Clean water and sanitation', and the (waste)water treatment plants are key pieces of these complex and high-investment systems. They need to ensure a safe and sustainable treatment of the drinking water for public supply and of the urban wastewater for discharge or water reuse and are therefore the crucial barriers for protecting the human health as well as the ecosystems and their services. However, while the knowledge development is increasing, the treated water quality requirements (drinking water, water for discharge or reuse), climate change, population growth and ageing, and geopolitics are catalysing a decreased source (raw) water quality and availability of water and energy. The treatment systems must therefore increase their effectiveness and resource efficiency, as it is proposed in the new UWWTD – urban wastewater treatment directive (recast) (submitted for approval by the EU Council), and this calls for a new and advanced way of managing these critical assets, integrating sound and updated skills on water treatment with competencies on problem-solving, strategic planning and data-based decisions.

"Advanced management of urban water treatment systems" is designed as a 6-credit curricular unit of IST/UL's **Master's** or **Doctoral programmes** in **Environmental Engineering**, which can be offered as an elective course to other master's and PhD programmes and students interested in urban water systems, as well as to advanced formation/lifelong education to water professionals. Actually, the unit is as rich as the diversity of the participating students' background.

This unit follows a problem-solving and multidisciplinary (e.g., physics, hydraulics, chemistry, biology, process engineering, and management) approach, which I think must distinguish the environmental engineers from other engineers and environmental scientists. The students are firstly introduced to the current and emerging **challenges** the **urban water** systems are facing related to water quality (namely, chemical and microbial contaminants of emerging concern - CECs) and scarcity (driving water reuse and the use of alternative drinking water sources, e.g., desalination), and to the actions needed on water treatment systems to cope with those challenges and help achieving UN SDG 6, but also SDG 9 'Build resilient infrastructure', SDG 11 'Sustainable cities and communities', and SDG 13 'Take urgent action to combat climate change and its impacts' (**module 1**). The students are then introduced to the key management methodologies/tools, i.e., **asset management** and **performance assessment** (**module 2**). They are then guided through a portfolio of measures and methodologies across the entire spectrum of actions needed on **water treatment/reclamation**, namely (i) **conventional** drinking water treatment (DWT, **module 3**) and conventional urban wastewater treatment and resource recovery (UWWT/RR, **module 4**), (ii) **non-conventional** (advanced, alternative or nature-based) treatment technologies (**module 5**) and their role (when, where and how using them) in **upgrading** DWT (**module 6**) and UWWT/RR, namely in water reclamation (**module 7**), (iv) **risk management** in DWT and in water reuse (**module 8**) and (v) **research or experimental strategy** for process development and innovation (**module 9**).

Module 1, after setting the scene on the challenges and their relation to the UN SDGs, explains the key properties of CECs determining their removal and the legal and regulatory framework evolution on CECs and on water reuse. Module 2 provides knowledge and tools for a data-based and objective-oriented assessment and benchmarking of treatment systems' effectiveness, reliability, resource efficiency and recovery (circular economy) and for planning the actions and investments needed on the long, medium, and short runs (respectively, strategic, tactical and operational plans). Modules 3-7 explain the technologies' concepts/ principles/fundamentals and discuss the application schemes, design and operating conditions, monitoring, energy, and cost-effectiveness aspects. Module 8 introduces the key definitions and explains how to assess and manage the risk in DWT and in water reuse. To help introducing and guiding both master's and doctoral students in their theses on water treatment and water professionals in developing/evaluating projects of innovative solutions, module 9 is dedicated to the key aspects of lab and pilot data acquisition for process development for advanced DW treatment and desalination, advanced UWWT, water reclamation and reuse. Throughout the unit, the students are asked to share their experiences and problems (if applicable; particularly from the participating professionals) and to work out a case study of how to optimise/rehab a given DWT or UWWT/RR for a given set of CECs, under a given context (centralised, semi-centralised and decentralised systems, energy, water sources) and framed by a strategic asset management. The last three weeks are used for the **presentation and discussion** of the **practical case-studies** to be developed throughout the semester as **group assignments (module 10)**.

After completing the unit, the students are expected to have developed **knowledge and skills** for a sound and modern advanced management of urban water treatment systems, namely to (i) be aware of the current and emerging urban water challenges and understand their impact on the treatment systems, (ii) use sound benchmarking methodologies for process selection & operation, (iii) identify critical control points and conditions, (iv) be able to short-list (with pros and cons) technology candidates for addressing a given type of CECs with a given performance and within a given context, and be aware of sound methodologies for benchmarking them for process selection and operation, (v) be able to (co)develop and evaluate design projects (green field and rehab) of enhanced treatment sequences, (vi) know how to operate and monitor conventional and non-conventional (advanced, alternative or nature-based) water treatment technologies towards enhanced CEC control and carbon neutrality, (vii) understand and know how to manage the risks associated with water reuse (a bottleneck to its wide practice), (viii) be aware of the need and gains of long-term, multiobjective-oriented strategic planning in water treatment asset management, and be able to integrate an asset management team, (ix) be able to (co)design a research/experimental strategy for process development. They are also expected to be better prepared for curricular units on complementary key topics of advanced water treatment, namely, on modelling tools for process design and optimisation.

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The **intended competencies** on problem-solving, strategic planning, data-based decisions, critical thinking, and negotiation are, together with the **soft skills** of teamwork and writing & communication, relevant for the graduates' future activity in the water sector and beyond. In turn, the intended specific knowledge and skills are designed for the students to be prepared for transforming strategic planning into practical impact.

The unit evaluation covers the theoretical knowledge as well as the practical and the soft skills and competencies developed by the students, assessed by a group assignment (report and discussion), integrating the subjects covered in the applicable modules and to be worked out throughout the semester in 11 milestones, and by the student's participation in the discussion of the work developed by the other colleagues.

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1 Curricular unit identification

Curricular unit .... Advanced management of urban water treatment systems

ECTS credits 6
.... lectured by semester, 14 weeks a semester
Contact lessons .... 49 h (2 h Theory + 1.5 h Practice or Tutorial a week)
Autonomous work .... 119 h
Total workload .... 168 h

Elective course to .... IST/UL Doctoral programme in Environmental Engineering (3rd cycle)
.... IST/UL Master's in Environmental Engineering (2nd cycle)
.... Other IST/UL master's or doctoral programmes dealing with water
.... Advanced training diploma dealing with water (técnico+)

2 Intended learning outcomes
(knowledge, skills and competencies to be developed by the students)

The ultimate intended **outcome** of this curricular unit is (as self-explained) to develop the students' **knowledge and skills** on "Advanced management of urban water treatment systems", teamwork, and writing & communication, as well as their **competencies** on problem-solving, strategic planning, data-based decisions, critical thinking, and negotiation, success-factors for their later research or professional activity. The unit aims at increasing the students' **knowledge** of physical-chemical and biological fundamentals of conventional and advanced/alternative/nature-based treatment technologies for drinking water production, urban wastewater treatment, and water reclamation, focusing on how the new challenges may be addressed, i.e., how can the chemical and biological contaminants of emerging concern be better controlled, the energy consumption be minimised and the carbon neutrality be achieved, and the water and phosphorus be reclaimed. Successful urban water systems management is not limited to water treatment skills, so the students' knowledge will be increased with respect to asset management, performance assessment & benchmarking, and risk management in DWT and in water reuse.

This theoretical knowledge development will be grounded on practical case-studies to facilitate developing the following intended **(hard) skills** (i.e., to be able to, more details in section 4): (i) understand the current and emerging urban water challenges and how they impact the treatment systems, (ii) use sound benchmarking methodologies for process selection and operation, (iii) identify critical control points and conditions, (iv) short-list technology candidates for addressing a given type of CEC with a given performance and within a given context (centralised, semi-centralised or decentralised systems, energy issues, water sources available), (v) draw, (co)design and benchmark the performance of enhanced treatment sequences (green field and rehab), (vi) operate and monitor conventional and non-conventional (advanced, alternative or nature-based) water treatment towards enhanced CEC control, (vii) understand and manage the risks associated with water reuse, (viii) integrate an asset management team and (co)develop or revise strategic, tactical and operational plans, (ix) (co)design a research strategy for process development.

3 *Syllabus*

The unit involves **9 modules** lectured during 10 weeks of the semester (each using a 1-week workload, except module 5 with twice the workload, section 5). Half this way (week 6), there is a technical visit to a DWTP or UWWTP (3.5 h, 1-week contact workload). The last three weeks are used for the presentation and discussion of the practical case-studies to be developed throughout the semester as group assignments (**module 10**). The unit programme assumes the students have previous knowledge (earlier curricular unit(s) completed) on water and wastewater treatment; therefore, after a critical revision of the technology basics, the modules are focused on treatment assessment and improvement. It further assumes modelling tools for process design and optimisation are the subject of other available units.

Module 1. Current and emerging challenges

Social, environmental, economic, and political drivers related to UN SDGs

- Population growth and ageing (SDGs 3, 11, 12) and economic growth (SDG 8) increasing water demand and contaminants' (incl. CECs) discharge.
- Climate change (SDG 13) decreasing source water availability (droughts and flash rainfalls) and increasing water demand (for irrigation, cleaning), thus promoting water exploitation (WEI+) and scarcity, and decreasing source water quality (increased organics, salts, toxic cyanobacterial blooms).
- The need for implementing resource efficiency and circular economy (water, energy, phosphorus) (SDGs 6, 7, 12), new UWWTD (recast, under approval).
- Geopolitics (water, energy (Russia-Ukraine war), phosphorus (concentrated in Morocco) (SDG 17).

Challenges requiring actions in urban water treatment systems as imposed by EU UWWT and DW directives

- Build climate change-resilient infrastructures (SDGs 9, 13) able to control severe and fast changes in raw water flow and composition (increased concentration and variety of natural/anthropogenic organic matter (NOM/EfOM) and other precursors of oxidation/disinfection byproducts, salinity and CECs entering DWT/UWWT).
- Achieve carbon neutrality in water treatment (DW, UWW, reclaimed water). Biorae finanças
- Transform wastewater treatment plants (WWTPs) into water resource recovery plants (WRRFs).
- Reclaim water to enable and promote safe water reuse - non-potable reuse, indirect and direct potable reuse (IPR, DPR), planned vs unplanned water reuse.
- Reclaim phosphorus (P) for securing food production and decrease potential geopolitical issues.
- Improve the beneficial use of biosolids.
- Enable drinking water production from different sources (surface water, groundwater, seawater, IPR, DPR, mixtures).
- Improve the control of contaminants of emerging concern:
  - CEC definition, environmental-health impacts, and occurrence;
  - chemical CECs - pharmaceutical compounds, hormones, personal care products, pesticides, and other endocrine-disrupting compounds, cyanotoxins, microplastics;
  - biological CECs – cyanobacteria, antibiotic-resistant bacteria (ARB), antibiotic resistance genes (ARGs), disinfection resisting forms, viruses & virions, protozoa (*Giardia* cysts, *Cryptosporidium* (oo)cysts), biological surrogates/indicators - *E. coli*, coliphages, *C. perfringens*, endospores;
  - CEC and other contaminants' properties affecting or determining their control in water treatment.

Practical component & assignment

Legal and regulatory evolution – analysis of key pieces of EU and PT legislation on drinking water treatment, urban wastewater treatment, water reuse, chemical and biological CECs, and the subsequent need to increase DWT/UWWT flexibility, modular treatment capacity, alternative treatment technologies (in parallel or in series) and enable water quality-based effluent discharge limits.

Physical-chemical and biological fundamentals as needed, for leveraging the students' background knowledge, namely on bulk parameters (COD, BOD_5, turbidity, transmittance), natural and anthropogenic organic matter (NOM and EfOM), CEC and other contaminants' properties affecting or determining their control in water treatment: size, charge, hydrophobicity/hydrophilicity, solubility, volatility, chemical resistance, biodegradability, sorption to sludge, settling/flotation, colloidal character, release of intracellular metabolites.

Prepare the selection of the case-study to be worked out in the **Group Assignment** and start characterizing the associated challenges – milestone 1 (**MS1**) to be achieved in week 2.

Module 2. Asset management and performance assessment

Concepts, definitions, and examples of application

- Asset management vs management of the assets; strategic planning; strategic, tactical, and operational planning and alignment. Plan scope and time horizon.
- Performance assessment. Objectives, assessment criteria, assessment metrics, reference values and targets. The ERSAR system for assessing the Quality of Service.
- Assessment metrics. Performance indicators (PIs) and performance indices (PXs). Plant overall performance assessment (effectiveness, efficiency, resource recovery), operational performance of each treatment step. The example of LNEC's systems for DWTPs and UWWTPs.
- How to build a plan. Diagnosis (baseline characterisation, context characterisation, SWOT analysis); scenarios and prospective evaluation, alternatives, improvement measures (strategies, tactics, operations), resources needed. Plan monitoring and revision.

Practical component & assignment

Explain and illustrate how to use an objective-oriented, data-based performance assessment system for assessing and improving DWT/UWWT; assessment criteria and metrics – PIs and PXs.
Continue working out the **Group Assignment** by defining the case-study selected and the associated challenges (**MS1**, week 2) as well as the strategic objectives and assessment criteria (**MS2**, week 3).

Module 3. Assessing and improving conventional drinking water treatment

Raw waters and associated typical treatment sequences – surface water, groundwater, mixture of both.

For each unit operation/process – review objective(s), concepts/definitions and fundamentals/treatment mechanisms, application schemes/flow diagrams, mass & energy balances; further discuss key design, operation and monitoring variables, and technical, environmental & economic pros and cons of:

- chemical oxidation (ozone, chlorine dioxide preoxidation), pH adjustment, remineralisation, mixing, coagulation, flocculation, sedimentation, granular bed filtration (rapid and slow sand filtration), disinfection (chlorination);
- aeration, softening, ion exchange, chemical precipitation, slow sand filtration;
- sludge thickening, conditioning, dehydration.

Practical component & assignment

Use an objective-oriented, data-based performance assessment system for assessing and improving **DWT**: **performance indicators** – effectiveness (water quality, compliance, reliability), resource efficiency and resource recovery (energy, water, sludge); **performance indices per unit operation/process** – water quality, removal efficiency, operating conditions.
If the practical case-study concerns DWT, continue working out the **Group Assignment** by proposing the improvement measures and assessing their performance using the appropriate benchmarking metrics (**MS3**, week 5). Otherwise, identify the unit operations/processes used in DWT that are also used in the selected practical case study of UWWT/RR, and identify potential improvement measures and the associated key operating conditions and performance metrics.

Module 4. Assessing and improving conventional urban wastewater treatment/resource recovery

Urban wastewaters (composition, flows, charges) **and typical treatment sequences** (C, N, P control; primary, secondary, and tertiary treatments).

For each unit operation/process – review objective(s), concepts/definitions and fundamentals/treatment mechanisms, application schemes/flow diagrams, mass & energy balances; further discuss key design, operation and monitoring variables, and technical, environmental & economic pros and cons of:

- physical unit operations and chemical processes: screening, degritting, oil & grease removal, equalisation, primary sedimentation (conventional, enhanced - lamellar, ballasted or coagulant/adsorbant assisted), secondary sedimentation, filtration, UV disinfection, chlorination;
- biological removal of C, N and P. Suspended biomass systems – activated sludge variants, extended or conventional aeration (mechanical aerators or diffused air systems). Attached biomass reactors – trickling filters, biofilters. Combined systems;
- sludge thickening, anaerobic digestion with co-generation, composting, conditioning, dewatering.

Practical component & assignment

Use an objective-oriented, data-based performance assessment system for assessing and improving **UWWT**: **performance indicators** – effectiveness (water quality, compliance, reliability), resource efficiency and resource recovery/beneficial use (energy, C footprint (direct and indirect emissions), water, biosolids/sludge); **performance indices per unit operation/process** – water quality, removal efficiency, operating conditions.
If the practical case-study concerns UWWT/RR, continue working out the **Group Assignment** by proposing the improvement measures and assessing their performance using the appropriate benchmarking metrics (**MS3,** week 5). Otherwise, identify the unit operations/processes used in UWWT/RR that are also used in the selected practical case study of DWT, and compare the similarities and the differences of their application in DWT vs UWWT/RR in terms of potential improvement measures, key operating conditions, and performance metrics.

Module 5. Non-conventional (advanced, alternative, nature-based) treatment technologies

Technologies addressing climate change-proof DWT/UWWT requiring improved control of organics, salts, and byproducts; enhanced biological N and P removal, P reclamation; energy efficient use and production, ~~carbon~~ neutrality; rainfall-independent water sources – water reuse (UWWT) and desalination (DWT); CEC control.

For each unit operation/process – objective(s), concepts/definitions and fundamentals/treatment mechanisms, application schemes/flow diagrams, mass and energy balances, equipment; key design, operation & monitoring variables; technical, environmental & economic pros and cons of:

- dissolved air flotation (DAF), multilayer filtration, membrane filtration (MF, UF, NF, RO), adsorption using powdered activated carbon (PAC), granular activated carbon (GAC) and biologically active carbon (BAC), hybrid adsorption/low-pressure membrane processes (PAC/MF, PAC/UF, PAC/NF);
- membrane bioreactors (MBRs), PAC/activated sludge systems, aerobic granular sludge (AGS), upflow anaerobic sludge blanket (UABS) reactor, anaerobic ammonium oxidation (ANAMMOX), moving bed biofilm reactor (MBBR), phostrip, struvite production;
- ozone and advanced oxidation processes (AOPs), electrocoagulation, electrochlorination, electrodialysis;
- nature-based solutions (NBSs): bank filtration in DWT; constructed wetlands (CWs), soil-aquifer treatment (SAT) in UWWT.

Practical component & assignment

Continue working out the **Group Assignment** by identifying upgrading alternatives and associated key operating conditions and performance metrics towards achieving **MS4** in week 10.

Module 6. Upgrading DWT

Challenges/applications: climate change-proof DWT requiring improved control of organics, salts, and byproducts. CEC control. Desalination. Energy use minimisation and carbon neutrality. Sludge valorisation.

Examples to be worked out: Improved control of cyanobacteria, cyanotoxins, NOM, THMFP and microbiological quality control in distribution systems. Improved control of pharmaceutical compounds, personal care products, and pesticides. Integrated treatment of surface and groundwater. Internal corrosion and deposition control. Brackish and sea water desalination – intake options, brine valorisation through eletrochlorination.

For each challenge, discuss potential solutions for upgrading DWT and benchmark their technical, environmental & economic pros and cons. Centralised or decentralised solutions. Multibarrier approach, redundancy, critical control points and parameters. Bulk and surrogate parameters.

Practical component & assignment

If the practical case-study concerns DWT, continue working out the **Group Assignment** by proposing the improvement strategies and assessing their performance using the appropriate benchmarking metrics towards achieving **MS4** in week 10. Otherwise, identify the unit operations/processes used in DWT that may also be used in the selected practical case study of UWWT/RR, and compare the similarities and the differences of their application in DWT vs UWWT/RR in terms of potential improvement measures, key operating conditions, and performance metrics.

Module 7. Upgrading UWWT/RR

Challenges/applications: Energy use minimisation and carbon neutrality. Water reuse. P reclamation. Sludge beneficial use. CEC control. Integrated control of CEC and disinfection.

Examples to be worked out: Improved energy efficiency, production, and C footprint. Water reclamation for non-potable uses, indirect and direct potable reuse. Improved control of pharmaceutical compounds and personal care products (quaternary treatment). P reclamation and struvite production.

For each challenge, discuss potential solutions for upgrading UWWT and benchmark their technical, environmental & economic pros and cons. Centralised or decentralised solutions. Multi-objective solutions. Multibarrier approach, redundancy, critical control points and parameters. Bulk and surrogate parameters. Low investment vs high tech solutions. Engineered vs nature-based solutions.

Practical component & assignment

Continue working out the **Group Assignment** by proposing the upgrading measures and assessing their performance using the appropriate benchmarking metrics towards achieving **MS4** in week 10.

Module 8. Risk management in DWT and in water reuse

Concepts and definitions of hazards (physical, chemical, and microbial hazards), hazardous events, receptors, exposure routes & scenarios, risk, likelihood, consequence/damage, barriers & prevention measures, critical control points (CCPs), risk assessment, risk management. Monitoring, communication, and training.

Methodologies of qualitative risk assessment and risk management. Application examples in drinking water treatment and in water reclamation for non-potable water reuse. ISO standards, EU & PT legal framework.

Practical component & assignment

Continue working out the **Group Assignment** by including a chapter on risk assessment and management in the practical case-study selected (**MS5**, week 11).

Module 9. Research or experimental strategy for process development and demonstration

How to develop a research strategy for water treatment process development and demonstration: critical state of the art, knowledge gaps and needs, goals/objectives, data missing, analytical and modelling tools, lab screening tests, pilot demo (technical-economic data), full-scale demo or benchmarking with consolidated solutions.

How to develop an experimental strategy to support the decision on implementing a non-conventional water treatment process: data missing (case-specific, e.g., specific for the water/UWW, CECs, and product/process targeted) water/UWW-specific), lab tests, pilot demo, full-scale demo, or benchmarking with consolidated solutions.

Application examples in product development or process development for drinking water treatment or water reclamation, e.g., the development of eco-friendly, high-performing activated carbons for adsorption of pharmaceuticals in DWT and UWWT – selection of the target PhCs, lab screening of new vs commercial products, lab feasibility studies of the processes and operating conditions, pilot demo and benchmarking with existing solutions (adequate processes with good commercial products).

Practical component & assignment

Continue working out the **Group Assignment** by proposing a lab/pilot data acquisition plan, if needed for developing/improving an innovative treatment process for the practical case-study (**MS6**, week 12).

Module 10. Discussion of the group assignments

The last three weeks are used for the presentation and discussion of the practical case-studies to be developed throughout the semester as group assignments.

Practical component & assignments

Complete the report of the practical case-study developed (**MS7**, week 12), present and discuss it (**MS8**, weeks 12 to 14), issue the final report (**MS9**, week 14) and the technical summary for submission (**MS10**, week 14), discuss all group assignments (**MS11**, week 14).

4 Demonstration of the *syllabus* coherence with the curricular unit's intended learning outcomes

The **theoretical knowledge** is organized in **9 modules** covering all aspects referring to the intended learning outcomes and including, in an early stage, the concepts related to the intended **competencies** of problem-solving, strategic planning and data-based decisions (module 2). The theoretical knowledge will be applied to practical case-studies to be developed as **group assignments**, with **milestones** (MS, Table 1) to be accomplished throughout the semester. This will allow a continuous dynamics of knowledge consolidation and **practical skills** and **competencies** development. After discussing the group assignments (**module 10**), the students will be encouraged to submit their work for publication and or for conference presentation, to further develop their intended **soft skills**. Table 2 presents the correlation between intended skills and competencies vs modules and milestones.

Table 1. Modules/knowledge vs milestones

Module and intended knowledge associated	**Planned milestones for the case-study**
1. Current & emerging challenges	MS1. Case-study selected & challenges characterized
2. Asset management and performance assessment	MS2. Strategic objectives & assessment criteria defined
3. Assessing and improving conventional DWT	MS3. Improvement measures proposed and assessed by the selected metrics
4. Assessing and improving conventional UWWT/RR	
5. Non-conventional treatment technologies	MS4. Upgrading measures proposed and assessed by the selected metrics (DWT or UWWT, depending on the case-study)
6. Upgrading DWT	
7. Upgrading UWWT/RR	
8. Risk management in DWT and in water reuse	MS5. Risk assessment completed
9. Research/experimental strategy for process D&I	MS6. Lab & pilot data plan completed, if needed
10. Discussion of the group assignments	MS7. Report ready for discussion (MS1-MS6 integration) MS8. Oral presentation and discussion MS9. Final report issued MS10. Technical summary ready for submission MS11. All group assignments discussed

Table 2. Intended skills and competencies vs modules and milestones

Intended skill – to be able to...	**Major module(s), MS(s)**
(i) understand the current & emerging urban water challenges and how they impact the treatment systems	Module 1, MS1
(ii) use sound benchmarking methodologies for process selection & operation	Module 2, MS2-MS4
(iii) identify critical control points and conditions	Modules 3, 4, 5 MS3
(iv) short-list technology candidates for addressing a given type of CEC with a given performance and within a given context	
(v) draw, (co)design and benchmark the performance of enhanced treatment sequences (green field and rehab)	Modules 6, 7 MS4
(vi) operate and monitor conventional, advanced, or nature-based water treatment towards enhanced CEC control	Modules 3-7 MS3, MS4
(vii) understand and manage the risks associated with DWD or water reuse	Module 8, MS5
(viii) integrate an asset management team and (co)develop or revise strategic, tactical, and operational plans	Module 2 MS1-MS5, MS7
(ix) (co)design a research strategy for data acquisition & process development	Module 9, MS6
Intended soft skills	
(x) Communication (empathy, active listening, constructive feedback (verbal and nonverbal)) & writing	Module 10 (+ all others), MS7-MS11
(xi) Teamwork (collaboration, cooperation, active listening, idea exchange, peer learning) & autonomy	All modules, MS1-MS11
Intended competencies	
Strategic planning	Module 2, MS2
Problem-solving, data-based decisions, critical thinking, and negotiation	All modules, MS1-MS11

5 Teaching methodologies, evaluation and grading

Each module includes an expositive and a practical part (Table 3). The theoretical knowledge lectured in the theoretical classes (1 h twice a week or 2 h a week) will be grounded on (i.e., illustrated by the professor) and applied to **practical case-studies** to be developed as **group assignments** by the students (2-4 students per group) with the professor's support (tutorial) during the weekly practical classes (1.5 h, once a week) and as autonomous work. Halfway the semester, there is a technical visit to a water treatment plant / resource recovery facility or a research lab. Partial achievements (milestones, Table 2) associated with the theoretical modules are scheduled for the practical class the week after the corresponding theoretical classes (Gantt chart, Table 4). The objective is to keep the students on track, continuously exercising the knowledge application and smoothly developing the intended skills and competencies (Table 2). Consequently, the weekly workload is rather constant throughout the semester, while working out the practical case-study and writing MS1-MS7 (MS7 is the report for discussion) in the first 11 weeks, or preparing/having the discussions (MS8, MS11) and writing the report's final version (MS9) and the technical summary (MS10) in the last three weeks.

Learning support materials are made available, on a weekly basis, at the course electronic tuition website. Main bibliographic references are provided in the first class and made available at the course tuition website.

Table 3. Workload throughout the curricular unit

Module	# Week(s)	Contact lessons (h)			Suggested autonomous work (h)	Predicted total workload (h)
		T	P / gT	Total		
1	1	2	1.5	3.5	8.5	12
2	2	2	1.5	3.5	8.5	12
3	3	2	1.5	3.5	8.5	12
4	4	2	1.5	3.5	8.5	12
5	5 & 6	4	3.0	7.0	17.0	24
technical visit	7	--	3.5	3.5	8.5	12
6	8	2	1.5	3.5	8.5	12
7	9	2	1.5	3.5	8.5	12
8	10	2	1.5	3.5	8.5	12
9	11	2	1.5	3.5	8.5	12
10	12-14	--	10.5	10.5	25.5	36
TOTAL	**14 weeks**	**20**	**29**	**49**	**119**	**168**
T: Theoretical	P / gT: Practical / Group tutorial					

Table 4. Gantt chart

Module	week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1		MS1					Technical visit							
2			MS2											
3														
4					MS3									
5														
6														
7										MS4				
8											MS5			
9												MS6		
10												MS7	MS8-MS11	

The unit **evaluation** covers the knowledge, (hard and soft) skills and competencies developed, assessed by the group assignment (report and discussion), which integrates the subjects covered in the applicable modules and to be worked out throughout the semester (MS1-MS10), and by the student's participation in the discussion of the work developed by their colleagues (MS11). The **final grading** includes two components:

- 20% milestones on time, 35% report, 10% technical summary;
- 25% presentation & discussion of own work, 10% discussion of others' work

  assessed according to the following criteria: selection of material (relevance, amount of material, use of literature), knowledge and understanding (presentation of material, synthesis, critical evaluation), and communication (clarity, fluency command of material, audience, pace, visual & technology).

6 Demonstration of the coherence between the teaching methodologies and the intended learning outcomes

After completing the curricular unit, the students are expected to have developed knowledge, skills, and competencies for a sound and modern advanced management of urban water treatment systems, able to tackle the current and emerging challenges in a sustainable way.

To meet these objectives, and firstly targeting students from Environmental Engineering Master and Doctoral programmes, the teaching methodology relies on a problem-solving and multidisciplinary approach, duly combining theory and practice, group, and individual work.

Regarding the "problem-solving", the students have to develop a group assignment on a practical case-study of drinking water treatment or urban wastewater treatment / resource recovery, namely water reuse and or phosphorus reclamation – how to optimise/rehab a given DWT or UWWT/RR for a given set of CECs, under a given context (centralised, semi-centralised and decentralised systems, energy, water sources) and framed by a strategic asset management. The case-study may be brought by the students (real or invented or a mixture of both, i.e., real and fictional context and assumptions) or be inspired in a case-study referred in the theoretical and practical classes. Actually, the unit may be also offered to other master's/PhD programmes as well as to advanced formation/lifelong education to water professionals, so the work group will be as rich as the academic and professional background diversity of the participating students.

With respect to the "multidisciplinary character", the theoretical modules address the key disciplines of physics, hydraulics, chemistry, biology, process engineering, and management in a way the students can develop critical knowledge & thinking rather than memorise recipes. The modules build on the students' expected backgrounds and leverage them. Module 1 explains the key properties of CECs determining their removal and the legal and regulatory framework evolution on CECs and on water reuse. Module 2 provides knowledge and tools for a data-based and objective-oriented assessment and benchmarking of treatment systems' effectiveness, reliability, resource efficiency and recovery (circular economy) and for planning the actions and investments needed on the long, medium and short runs (respectively, strategic, tactical and operational plans). Modules 3-7 explain the technologies' concepts/principles/fundamentals and discuss the application schemes, design and operating conditions, monitoring, energy, and cost-effectiveness aspects. Module 8 introduces the key definitions and explains how to assess and manage the risk in DWT and in water reuse. To help introducing and guiding master's and doctoral students in their theses on water treatment and water professionals in evaluating projects of innovative solutions, module 9 is dedicated to the key aspects of lab and pilot data acquisition for process development for advanced DW treatment and desalination, advanced UWWT, water reclamation and reuse.

The teaching methodology engages the students in a continuous workflow, objective-oriented, regularly assessed by data-based milestones, promoting teamwork, responsibility for on-time delivery, peer-to-peer learning (defending their own work and discussing the others' work) and writing & communication skills. Therefore, in addition to the unit contents, the teaching methodology promotes itself the development of soft skills and competencies of problem-solving, strategic planning, data-based decisions, critical thinking, and negotiation, which are relevant for the graduates' future activity in the water sector and beyond.

7 Main bibliography

The bibliography proposed includes handbooks, manuals, legislation, regulation, and standards, as well as very focused, easily accessed book chapters (co-authored by the signatory). The complementarity of the proposed items will be explained to the students to guide their focused and efficient use. The students will be further guided on a critical literature review specific to their practical case-study, as appropriate.

Reference generic handbooks	**Module(s)** *key topic*
AWWA (2011). Water quality and treatment – a handbook of community water supplies. 6th Ed., American Water Works Association. McGraw-Hill Education, New York. ISBN: 9780071630115	1, 3, 5, 6 *DWT*
Metcalf & Eddy (2014). Wastewater engineering – Treatment and resource recovery. 5th Ed. Revised by G. Tchobanoglous, H. D. Stensel, R. Tsuchihashi, F. Burton. McGraw-Hill Education, New York. ISBN 978-0-07-340118-8. 2018 pp.	1, 4, 5, 7 *UWWT/RR*
Eckenfelder W.W. (2000). Industrial water pollution control. 3rd Ed, McGraw-Hill, New York. ISBN 0-07-039364-8. 584 pp.	1, 4, 5, 7, 9 *lab, pilot data*
Thematic manuals and book chapters	**Module(s)** *key topic*
Alegre H., Covas D. (2010). Gestão patrimonial de infraestruturas de abastecimento de água: uma abordagem centrada na reabilitação. Guia Técnico n.º 16, ERSAR, LNEC, IST, Lisboa, Portugal. ISBN: 978-989-8360-04-5. Pp. 203-225 (Chap. 8).	2 *asset management*
Rosa M.J., Vieira P., Menaia, J. (2009). O tratamento de água para consumo humano face à qualidade da água de origem. Guia Técnico 13. IRAR, LNEC. Lisboa. ISBN 978-989-95392-7-3. 82 pp.	1, 3, 5, 6 *DWT*
Vieira P., Rosa M. J., Alegre H. (2007). Estações de tratamento de água para consumo humano em Portugal. Informação Técnica de Hidráulica – ITH 44. LNEC. Lisboa. ISBN: 978-972-49-2101-3. 38 pp.	3, 6 *DWT*
Menaia J., Rosa M.J. (2006). Cianobactérias e água para abastecimento público. Manual de apoio ao curso AdP/LNEC "Florescências de algas e cianobactérias nas águas de captação". Carvoeiro, Algarve, novembro, 14 pp.	1, 3, 5, 6 *cyano DWT*
Chorus I., Welker M. (Editors) (2021). Toxic cyanobacteria in water. A guide to their public health consequences, monitoring and management. 2nd edition. World Health Organisation, CRC Press, London. eBook ISBN 9781003081449. 859 pp.	1, 3, 5, 6 *cyano DWT*
Hall T., Schmidt W., Codd G.A., von Gunten U., Kaas H., Acero J.L., Heijman B., Meriluoto J., Rosa M.J., Manckiewicz J. et al. (2005). Best practice guidance for management of cyanotoxins in water supplies. TOXIC 5FP project (EVK1-CT-2002-00107) contributing to the implementation of the Key action "Sustainable management and quality of water". Abo Akademi University (Finland), DHI (Denmark), DVGW-TZW (Germany), EAWAG (Switzerland), KIWA (The Netherlands), University of Algarve (Portugal), University of Dundee (UK), University of Extremadura (Spain), University of Lodz (Poland), WRc plc (UK). Sept., 136 pp.	1, 3, 5, 6 *cyano DWT*
Mesquita E., Menaia J., Rosa M.J., Costa V. (2006). Microcystin-LR removal by bench scale biological-activated-carbon filters. *In* Recent progress in slow sand and alternative biological filtration conference. Eds R. Gimbel, N.J.D. Graham, M.R. Collins. IWA Publishing. London. ISBN 9781843391203, pp. 373-383	5, 6 *cyano DWT*
Ribau Teixeira M., Rosa M.J., Sorlini S., Biasibetti M., Christophoridis C., Edwards C. (2020). Removal of cyanobacteria and cyanotoxins by conventional physical-chemical treatment. Chap. 3 *In* Water treatment for purification from cyanobacteria and cyanotoxins. 1st Edition. Eds A.E. Hiskia, T.M. Triantis, M.G. Antoniou, T. Kaloudis, D.D. Dionysiou. Wiley. Hoboken, NJ, USA. Online ISBN: 9781118928677, pp. 69-97. https://doi.org/10.1002/9781118928677.ch3	1, 3, 5, 6 *cyano DWT*
Raspati G., Menaia J., Raat K., Rosa M. J., Gonzalez B.L., Sivertsen E. (2015). Assessment of current treatment works to handle climate change related pollutants and options to make current multi-barrier systems climate change proof. Chap 4.7 *In* Climate change, water supply and sanitation: risk assessment, management, mitigation and reduction. Eds A. Hulsmann et al. IWA Publishing. London. ISBN: 9781780405001 (eBook), pp. 284-287 https://doi.org/10.2166/9781780405001	3 *climate change-proof DWT*

Thematic manuals and book chapters (cont.)	**Module(s)** *key topic*
Smeets P., Kardinaal E., Eikebrokk B., Menaia J., Mesquita E., Rosa M. J. (2015). Optimised operation of drinking water systems. Chap 4.14 *In* Climate change, water supply and sanitation: risk assessment, management, mitigation and reduction. Eds A. Hulsmann et al. IWA Publishing. London. ISBN: 9781780405001 (eBook), pp. 332-337.	3, 6 *climate change-proof DWT*
Pinho M.N.N.C., Rosa M.J.F. (1995). Membranas e processos de separação com membranas. Instituto Superior Técnico, Lisboa, dezembro, 56 pp.	5 *advanced DWT*
Campinas M., Rosa M.J. (2011). PAC/UF for removing cyanobacterial cells and toxins from drinking water. Chap 12 *In* Expanding Issues in Desalination. Ed R.Y. Ning. InTech. Rijeka, Croatia. ISBN: 978-953-307-624-9, pp. 233-252	5, 6 *advanced DWT cyano*
Campinas M., Viegas R.M.C., Silva C., Rosa M.J. (2017). Technical guidelines of PAC/MF – Powdered activated carbon/ceramic microfiltration for drinking water production. Deliverable of LIFE Hymemb project (LIFE12 ENV/PT/001154). LNEC. Lisboa. ISBN: 978-972-49-2299-7. 32 pp.	1, 5, 6 *advanced DWT cyano, PhCs*
Ternes T.A., Joss A. (Editors) (2006). Human pharmaceuticals, hormones and fragances. The challenge of micropollutants in urban water management. IWA Publishing, Cornwall, UK. ISBN 10 1843390930. 453 pp.	1, 3, 4, 5, 7 *PhCs & other CECs*
Rosa M.J., Campinas M., Viegas R.M.C., Silva C. (2019). LIFE IMPETUS Technical guidelines for improved control of pharmaceutical compounds in urban activated sludge WWTPs. Deliverable of LIFE Impetus project (LIFE14 ENV/PT/000739). LNEC. Lisboa. 49 pp.	1, 4, 5, 7 *advanced UWWT*
Mestre A.S., Campinas M., Viegas R.M.C., Mesquita E., Carvalho A.P., Rosa M.J. (2022). Activated carbons in full-scale advanced wastewater treatment. Chap. 17 *In* Advanced materials for sustainable environmental remediation: terrestrial and aquatic environments. Eds D.A. Giannakoudakis, L. Meili, I. Anastopoulos. Elsevier. MA, USA. eBook ISBN: 9780323904865, pp. 433-474. https://doi.org/10.1016/B978-0-323-90485-8.00001-1	1, 4, 5, 7 *PhCs UWWT*
Silva C., Alegre H., Rosa M. J. (2015). Introduction to energy management in wastewater treatment plants. Chap 3 *In* Sewage treatment plants: economic evaluation of innovative technologies for energy efficiency. Eds K.P. Tsagarakis, K. Stamatelatou. IWA Publishing. London. ISBN: 9781780405025 (eBook), pp. 33-55. https://doi.org/10.2166/9781780405025 (open access 2020).	4, 7 *energy efficiency*
Loureiro D., Silva C., Cardoso M.A., Alegre H., Cabral M., Covas D., Rosa M. J. (2021). Avaliação da eficiência energética nos serviços urbanos de águas. Guia para diagnóstico, seleção de alternativas, monitorização e revisão do plano de ação. Guia técnico Avaler+. LNEC, IST. Lisboa. Financiador: FAI – Fundo de Apoio à Inovação. 100 pp.	3 – 7 *energy efficiency*
WEF (2009). Energy conservation in water and wastewater facilities. Manual of practice (MOP) No. 32. Water Environment Federation. Prepared by the Energy Conservation in Water and Wastewater Treatment Facilities Task Force of the Water Environment Federation. McGrawHill, New York. ISBN 978-0-07-166794-4. 365 pp.	3 – 7 *energy efficiency*
Leitão T.E., Martins T., Mesquita E., Henriques M.J., Rogeiro J., Carvalho T., Rosa M.J., Lobo Ferreira J.P. (2018). Soil-aquifer treatment as a passive solution to enhance treated wastewater quality. *In* Sanitation approaches and solutions and the sustainable development goals. Eds J.S. Matos, M.J. Rosa. Technical course 08. ERSAR, EWA, APESB. Lisbon. ISBN: 978-972-98996-8-3, pp. 69-82	5, 7 *NBS*
Quadros S., Rio P., Mesquita E., Rosa M.J. (2018). Exploring the use of Azorean native plants and rock material for sustainable wastewater treatment through constructed wetland systems. *In* Sanitation approaches and solutions and the sustainable development goals. Eds J.S. Matos, M.J. Rosa. Technical course 08. ERSAR, EWA, APESB. Lisbon. ISBN: 978-972-98996-8-3, pp. 49-67	5, 7 *NBS*

Acronyms and abbreviations

A3ES	Portuguese Assessment and Accreditation Agency for University Study Programmes
AGS	aerobic granular sludge
ANAMMOX	anaerobic ammonium oxidation
AOP	advanced oxidation process
ARB	antibiotic-resistant bacteria
ARG	antibiotic resistance gene
BAC	biologically active carbon
C	carbon
CCP	critical control point
CEC	contaminant of emerging concern
CW	constructed wetland
DAF	dissolved air flotation
DPR	direct potable reuse
DW	drinking water
DWT	drinking water treatment
DWTP	drinking water treatment plant
ECTS	European credit transfer and accumulation system
EfOM	effluent organic matter
ERSAR	Entidade Reguladora dos Serviços de Águas e Resíduos (The Water and Waste Services Regulation Authority)
EU	European Union
GAC	granular activated carbon
IPR	indirect potable reuse
ISO	International Standardisation Organisation
IST/UL	Instituto Superior Técnico / Universidade de Lisboa (TÉCNICO LISBOA)
MBBR	moving bed biofilm reactor
MBR	membrane bioreactor
MF	microfiltration
MS	milestone
N	nitrogen
NBS	nature-based solution
NF	nanofiltration
NOM	natural organic matter
P	phosphorus
PAC	powdered activated carbon
PI	performance indicator
PT	Portugal
PX	performance index
RO	reverse osmosis
RR	resource recovery
SAT	soil-aquifer treatment
SDG	sustainable development goal
SWOT	strengths, weaknesses, opportunities, and threats
THMFP	trihalomethane formation potential
UABS	upflow anaerobic sludge blanket
UF	ultrafiltration
UN	United Nations
UV	ultraviolet
UWW	urban wastewater
UWWT	urban wastewater treatment
UWWTD	urban wastewater treatment directive
UWWTP	urban wastewater treatment plant
WEI+	water exploitation index +
WHO	World Health Organisation
WRRF	water resource recovery facility

Legislation	**Module(s)** *key topic(s)*
Decreto-Lei n.º 152/2017, de 7 de dezembro & Anteprojeto de diploma de transposição da diretiva relativa à qualidade da água destinada ao consumo humano (drinking water quality)	1, 8 *DWT*
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 (recast)	1, 8 *DWT*
Directive 2013/39/EU of the European Parliament and of the Council of 12 August regarding priority substances in the field of water policy (EQSD – environmental quality standards directive) & associated Watch Lists	1, 8 *DWT, CECs*
Decreto-Lei n.º 119/2019, de 21 de Agosto, Estabelece o regime jurídico de produção de água para reutilização, obtida a partir do tratamento de águas residuais, bem como da sua utilização (non-potable water reuse)	1, 8 *UWWT/RR water reuse risk assessm*
Decreto-Lei n.º 16/2021, de 24 de fevereiro, Altera os sistemas multimunicipais de recolha, tratamento e rejeição de efluentes e introduz medidas relativas à geração e recuperação dos desvios de recuperação de determinados gastos (water reclamation is a mission of bulk wastewater treatment systems)	1, 7 *UWWT/RR water reuse*
Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse (for agriculture irrigation) COMMISSION NOTICE Guidelines to support the application of Regulation 2020/741 on minimum requirements for water reuse (2022/C 298/01)	1, 8 *UWWT/RR water reuse risk assessm*
Proposal for a Directive of the European Parliament and of the Council concerning urban wastewater treatment (recast). COM(2022) 541 final, 26.10.2022 –UWWTD recast	1, 4, 7 *UWWT/RR*
Regulation	**Module(s)**
Cardoso M.A., Rosa M.J., Brito R.S., Silva C., Beceiro P., Jorge C.N., Alegre H., Martinho G., Pina J., Ramos M., Rodrigues S., Rodrigues R. et al. (2021). Guia de avaliação dos serviços de águas e resíduos prestados aos utilizadores. 4.ª geração do sistema de avaliação. Guia Técnico 27. ERSAR, LNEC, NOVA. Lisboa. ISBN 978-989-8360-42-7. 354 pp.	2, 3, 4, 6, 7 *DWT, UWWT/RR, performance assessm*
Standards on water reuse	**Module(s)**
ISO 20468 series – Guidelines for performance evaluation of treatment technologies for water reuse systems	5, 7
ISO 16075 series – Guidelines for treated wastewater use for irrigation projects	8
ISO 20426:2018 – Guidelines for health risk assessment and management for non-potable water reuse	8
ISO 31000 – Risk management	8

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