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Circular Water and Wastewater Management in State College, Pennsylvania

In recent years, great attention has been paid to activities aimed at implementing a circular economy (CE) in the management of water resources around the world. One of the possibilities for the practical implementation of CE, based on the sustainable management of primary and secondary resources (waste), is the circular management of water and wastewater generated in urban wastewater treatment plants (WWTPs). This work presents examples of good practices in the implementation of CE in the college town of State College, Pennsylvania (United States of America). There are two WWTPs here – one belonging to Penn State University (Water Reclamation Facility) and another operated by the municipality (University Area Joint Authority). Both facilities implement CE goals through various initiatives dedicated to water, raw materials and energy recovery. The scope of these activities include using reclaimed water for irrigation of green areas, production of renewable energy, as well as recovery of biogenic components by processing sewage sludge in compost. This approach, where the university and municipality propose solutions in the environmental and social areas, is consistent with the idea of building social responsibility of units, which is a path to sustainability. Further actions to implement the CE model are expected to counteract ongoing climate change in various regions.

Keywords: circular economy, CE, water, wastewater, State College

Introduction

Climate variability affects all continents, impacting terrestrial and aquatic ecosystems, including water bodies such as lakes, rivers, oceans, and seas (Pintilie) treatment and climate change events. Wastewater reclamation is considered as an alternative source of fresh water in areas with problems of water availability or increased consumption. The objective of this study is to use Life Cycle Assessment (LCA. Since water covers more than half of the Earth's surface, the increase in ocean temperatures has accounted for about 93% of the planet's global warming since the 1950s (European Environment Agency). This warming results from increasing greenhouse gas emissions (GHG), primarily carbon dioxide, which in turn traps more solar energy in the atmosphere (Orlowsky et al.). Most of this trapped heat is eventually stored in the oceans, which affects the temperature and circulation of the water. The rise in temperature also melts polar ice caps. As the total surface area of the ice and snow cover is reduced, it releases less of the sun's energy back into space, further warming the planet. This leads to more freshwater entering the oceans, altering currents (European Environment Agency).

A key element of climate change is its impact on the Earth's water cycle, which continuously moves water from our oceans to the atmosphere, land, rivers, and lakes, and then back to the seas and oceans (Korenaga et al.). Climate change increases the level of water vapor in the atmosphere and makes water availability less predictable. This can lead to more rainfall in some areas while other regions may experience severe dry conditions, especially during summer months (Awad et al.). One key policy aimed at counteracting climate change in many countries is the Green Deal (Smol), which aims to achieve climate neutrality. Its main component is a circular economy (CE), officially adopted by selected countries since the beginning of the 21st century to manage Earth's resources – biotic and abiotic – in a more rational way (Li and Lin). It is worth emphasizing here that one of the most important resources is water, because without it neither society nor industry can function (Ramm). Therefore, the role of water in CE is emphasized as a strategic area for achieving CE goals on all continents, including Europe and America.

Water consumption is associated with other elements inherent in human life, such as the production of sewage sludge, which, as substances resulting from water management, must be treated in accordance to CE principles. For this purpose, urban wastewater treatment plants (WWTPs) are used, which are currently intended to function as resource hubs where water, raw materials and energy are recovered in a sustainable and circular manner (Smol, "Circular Economy in Wastewater…"; Smol, "Is the Green Deal a Global Strategy? Revision…"; Smol, et al. "Circular Economy Model Framework"). In American college towns, students are often the main users of water, so WWTPs must be adapted to handle fluctuating populations depending on academic semesters. This is the case in State College, Pennsylvania, home to one of the largest American universities – the Pennsylvania State University (Penn State). Water and wastewater management solutions are particularly interesting here because the university has its own WWTP, and student housing in the borough is serviced by the municipal WWTP. Both facilities operate according to CE principles, serving as good practice examples for implementing CE in academic units. Such solutions should be transferred to other cities and regions. In Poland, these solutions are not popular because most universities are usually located in large cities and serviced by municipal companies. This work presents water and sewage management in the college town of State College as an example of implementing CE goals in the area of water, energy and raw materials management. The Penn State's Wastewater Treatment Plant and the municipal WWTP, both serving the borough of State College, operate in the line with CE assumptions.

The Penn State's Wastewater Treatment Plant and Circular Economy

The Penn State's WWTP, also known as the Water Reclamation Facility (WRF), was built in the early 1900s in the middle of the town. It provides sanitary sewer service for most buildings on campus, as well as selected borough buildings in the College Heights District. The capacity of the wastewater installation is 4.0 million gallons per day (MGD). The demand fluctuates with the academic calendar, being higher during the academic year and lower during breaks between semesters due to the reduced number of residents and students in the borough. The WWTP includes two technological lines. One line is dedicated to the mechanical, chemical and biological treatment of wastewater from residents, while the other manages sewage sludge and other solids generated during wastewater treatment (Penn State). The liquid treatment installation includes the following elements:

- grit removal dedicated to removing grit and other inorganic particulates from raw wastewater entering the WWTP;
- coarse screening dedicated to removing large debris, such as wood, rags, plastics, and other materials from the influent wastewater;
- primary clarification in the form of three rectangular primary settling tanks (operating in parallel) for removing settleable solids from the wastewater;
- trickling filter process (TFP) that contains activated sludge with biological organics and nutrient removal;
- activated sludge process (ASP) with two circular tanks equipped with an aeration zones for the activated sludge process, with the outer ring of each tank serving as a final settling tank; this process covers the biological removal of organics and nitrogen from the wastewater;
- disinfection in two chlorine contact tanks.

The treatment efficiency achieves 99% removal of biochemical oxygen demand (BOD) and 98% removal of suspended solids from the wastewater. The solid line includes an anaerobic digestion system:

- dissolved air flotation thickener that provides thickening of the solids from the final settling tanks;
- primary anaerobic digestion for treatment of solids from the primary settling tanks and the dissolved air flotation thickener;
- secondary anaerobic digestion to provide additional solid treatment and storage of digested solids prior to dewatering;
- dewatering system for digested solids (so called biosolids) that are collected in a dumpster for disposal at a landfill (Swisher).

The Penn State's WWTP is presented in Figure 1.

Figure 1. The Penn State's Wastewater Treatment Plant
(photo by M. Smol, August 2022)

The Penn State's Wastewater Treatment Plant implements solutions in the field of a circular economy, mainly focused on the sustainable use of and management of reclaimed water. Typically, treated wastewater in Pennsylvania is discharged to natural reservoirs (surface water reservoirs, such as streams or rivers). However, at the Penn State wastewater system, treated effluent is not discharged to a stream but recycled and used through a land application system known as the Living Filter (Woodward et al.). The concept of the Living Filter was created in 1975, and its operation started in 1983 as an innovative wastewater management method (Ferguson). It is continuously improved (Penn State).

The infrastructure covers approximately 600 acres of agricultural and forest land. The latest estimates confirm that around 90% of the irrigated water could recharge the region's water table by up to 1.3 MGD per year. The use of reclaimed water in land application is environmentally friendly. It reduced the need for additional water uptake and consumption. Additionally, as the water slowly percolates through the soil profile, it undergoes further treatment, helping maintain base flows in local streams (including Spring Creek) and mitigating drought impacts. Since this solution was implemented in 1983, Spring Creek's water quality is observed as the best in the last 100 years. The specially established Wastewater Management Committee is responsible for the management of the Living Filter system (Swisher).

The Living Filter is a perfect example of the university's long-standing commitment to sustainability and circular economy (Penn State). A master plan has been developed for implementing a reclaimed water system in a park on the university campus grounds. Part of the reclaimed water at WWTP would be used on green areas of the campus, reducing groundwater uptake by 300,000-500,000 gallons per day. The extended system proposal has already completed the sewage facilities plan and obtained the necessary permissions. Reclaimed water has various circular uses, including toilet flushing, vehicle washing, irrigation, non-potable washdown, and laundry. Currently, wherever possible, new buildings are designed to facilitate the use of reclaimed water when available. This system is planned to be systematically expanded to protect water resources in the region (Swisher). Additionally, soil protection is a crucial aspect of these solutions, as recovered water discharged to natural reservoirs and soils may carry pollutants (Borrelli et al.). Therefore, the physicochemical indicators of the discharged water are constantly analysed, ensuring the requirements of appropriate standards and not causing any harm to the natural environment where the reclaimed water is used.

University Area Joint Authority and Circular Economy

The municipal WWTP, known as the University Area Joint Authority (UAJA), is a municipal authority responsible for wastewater treatment and water recycling for State College borough and the Centre Region in the Pennsylvania. The treatment plant was built in 1964 as a joint effort to provide service to portions of Ferguson, Patton, College, and Harris Townships, as well as the Borough of State College. It currently covers 253 miles of mainline sewers and treats approximately 5.0 MGD of wastewater. The treated water is discharged into the natural reservoir of Spring Creek, a high quality cold water fishery (University Area Joint Authority).

The WWTP includes pathways for wastewater and sewage sludge management (compost production from primary and secondary biosolids). It should be noticed that before wastewater enters the treatment process, the largest debris and garbage are removed and sent to the landfill. During this initial screening, the water is slow-filtered and heavy materials, such as grit, gravel and sand settle out and are removed by the grit removal system. The wastewater then undergoes the following treatment processes:

- primary treatment with the use of physical processes in six primary clarifiers; solids are collected by mechanical scrapers, concentrated in cone-shaped hoppers, and pumped out of the wastewater system to the biosolids composting facility. Floating solids such as grease and oil are also removed, with approximately 40% of solids removed from the liquid phase;
- biological treatment with the use of microscopic organisms such as fungi, protozoa, algae, and various bacteria;
- secondary treatment with the use of alum that is added to the water, causing fine particulates to stick together and sink to the bottom of the clarifiers before moving onto solids handling;
- tertiary treatment with the use of eight anthracite coal mono-media tertiary filters to polish the plant effluent, ensuring that the water discharged to the natural reservoir meets all required physical and chemical parameter limitations;

- disinfection using ultraviolet light;
- discharge – treated effluent is discharged to Spring Creek.

It is worth noticing that UAJA operates a federally mandated and approved Industrial Pretreatment Program to ensure that wastewater discharged to this WWTP is compatible with the safe operation of its facilities and does not cause environmental harm downstream from the treatment plant (University Area Joint Authority).

Figures 2 & 3. Tanks at the University Area Joint Authority
(photos by M. Smol, August 2022)

Figure 4. Water discharged from the University Area Joint Authority to a natural reservoir
(photo by M. Smol, August 2022)

The most important CE example at the UAJA is the production of compost, marketed under the name "ComposT." It is a premium soil conditioner produced from a mixture of high-quality municipal biosolids (sludge) and wood chips. It resembles coarse peat moss, as shown in Figures 5 and 6. ComposT has a high nutrient and organic matter content necessary for healthy and productive soils: total nitrogen 2.0%; available phosphorus (P_2O_5) 3.0%; soluble potassium (K_2O) 0.4%; pH 7.8; moisture content 27%; carbon (C) to nitrogen (N) ratio 13:1; soluble salts 1.7. The advantages of ComposT as soil improver include: improved soil structure; reduced soil compaction; increased water infiltration and soil aeration; increased moisture holding capacity; improved mineral nutrient uptake efficiency; provision of slow-release nutrients for plants. Compost production totals over 9,000 cubic yards per year. Sales of this material results in lower quarterly bills for UAJA customers. The environmental added value of compost production is a reduction in the amount of waste that was previously sent to landfill – approximately 10,000 wet tons, or 20 million pounds. Residents and the borough use ComposT for amending depleted soils, enriching planting mixes, and enhancing the growth of turf, ornamental plant species, as well as horticultural crops. It is also approved for reclamation of disturbed lands. Recovering valuable biogenic components and returning them to circulation is an ideal example of CE implementation in a wastewater treatment plant (University Area Joint Authority).

Figures 5 & 6. ComposT produced at the University Area Joint Authority (photos by M. Smol, August 2022)

Another important example of CE implementation at UAJA is the renewable energy initiative, which includes the installation of solar PV panels. This initiative aims to increase the portion of renewable energy generated or purchased for treatment operations. The energy produced by the solar array is directed to the WWTP's electrical systems, replacing grid-based energy. This significantly reduces energy use and load at the WWTP. Through a bi-directional meter installed during the interconnection process, this excess power is credited against the WWTP's electric account charges up to the annual generation amount. Consequently, the costs of electricity generation and distribution are offset by the power purchase price (University Area Joint Authority).

Future Directions for Circular Economy in WWTPs in the US

The 21st century has brought a completely new situation for WWTPs in the US (Garcia et al.) cities indirectly depend on distant water sources to function, prosper, and grow. To fully account for indirect (virtual. It is associated with a new paradigm of water and wastewater management – the "NEW" paradigm (Nutrients-Energy--Water). It focuses on the recovery of nutrients, energy, and water from wastewater, sewage sludge and other waste generated in WWTPs (Smol et al.). The NEW paradigm is in line with CE principles and aims to provide significant environmental, economic, and social benefits. The environmental goals of circular water and wastewater management include (Kuśmierz et al.):

- increasing the capacity of treatment plants;
- protecting drinking water resources;
- direct protecting river catchments and outflows;
- preserving existing environmental values;
- recovering valuable raw materials, water, and energy.

There are also economic goals (Nikolaou and Tsagarakis):

- reducing energy costs (through renewable energy);
- generating income from the sales of fertilizers/soil improvers;
- reducing water intake costs.

The social goals of water and wastewater management are (D'Adamo et al.) circular economy (CE):

- increasing the attractiveness of regions from an infrastructure perspective;
- developing existing enterprises;
- reducing unemployment and creating new jobs;
- improving the quality of life by connecting residents who previously lacked sewage disposal options to the network.

State College is a very interesting example, as CE practices are now implemented daily in two WWTPs – the university and municipal plants. Other American and European cities should follow these solutions, adapting them to local/regional possibilities for water, raw materials, and energy recovery. Currently, this approach, in which the university proposes solutions in the environmental and social areas, is also consistent with the idea of building social responsibility of universities, based on corporate social responsibility principles (Sady et al.). Such practices are consistent with sustainable development, integrating environmental, economic and social goals to strengthen sustainability (Ali et al.).

WWTPs are being transformed into production plants for resources hubs, including those producing water, hydrogen, bioplastics and biogenic substances, especially phosphorus (Ramm and Smol)the European Commission (EC. This transformation is driven by stricter regulations on water resource protection, significantly increasing protection costs. Therefore, the aim is to maximize the protection of inland and marine waters in catchments, river basins and watersheds at the lowest social costs through new ideas and technologies. The goal is not only to improve the water environment in accordance with regulations, but also to generate profits and resulting social benefits (Gromiec).

Conclusions

Implementing CE practices requires integrated actions across various areas of human activity. In the case of State College, one of CE solutions involves two sewage treatment plants: one belonging to Penn State University and the other operated by the borough. Both facilities implement CE goals through various initiatives, such as using reclaimed water for irrigating green areas, producing renewable energy, and recovering biogenic components. In the context of water recovery and reuse, an important element of these solutions is preventing contamination in reclaimed water, which requires integrated actions involving monitoring and processes aimed at both increasing the efficiency of reclaimed water production and reducing risks to people and the aquatic environment. Energy in WWTPs can be recovered in various ways. In the case of the University Area Joint Authority, it is energy from solar panels, but it can also be energy from sewage sludge, such as in the form of biogas. It is also worth emphasizing that, according to CE principles, waste incineration can recover energy, however, it is the least recommended solution, just above safe landfilling. In general, the thermal transformation of waste generated in WWTPs can be considered a CE practice only when energy recovery is involved. Recovering biogenic raw materials in the form of compost is also an interesting solution that requires less energy consumption than chemical and thermochemical methods. Therefore, it could be an inspiration for other WWTPs globally. It should also be taken into account that these CE solutions, especially in the context of water use for irrigation purposes, should be constantly monitored for environmental and human health threats. This can be achieved by developing risk management plans that include appropriate procedures for monitoring the safety of water recovery methods and its use.

The presented good practices in the implementation of CE in the college town of State College demonstrate the growing responsibility of universities and municipal authorities for the environment and society. This approach should be adopted by other regions struggling with water, raw material, or energy shortages as a pathway to sustainability. Further actions to implement the CE model are expected to counteract ongoing climate change in various regions.

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