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Santa Fe Wastewater Treatment Plant Life Cycle Assessment (LCA)

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Purpose

This presentation summarizes the results of a comparative life cycle assessment evaluating the trade-offs between nutrient removal and cross-media environmental impacts of four different options for upgrading Santa Fe, New Mexico's Paseo Real wastewater treatment plant.

For more details see the full report available at [Research and Reports on Nutrient Pollution]

Outline

- Background and Study Objectives
- Overview of LCA Methodology
- Results
- Conclusions

Background

- The New Mexico Environment Department (NMED) has developed an approach for deriving numeric nutrient thresholds to translate the state's narrative criterion based on nutrient concentrations in unimpacted (or "reference") streams.

- For NM's wastewater treatment plants (WWTPs), this means that future NPDES permit effluent limits will be based on the numeric nutrient thresholds that may be more stringent than existing limits.

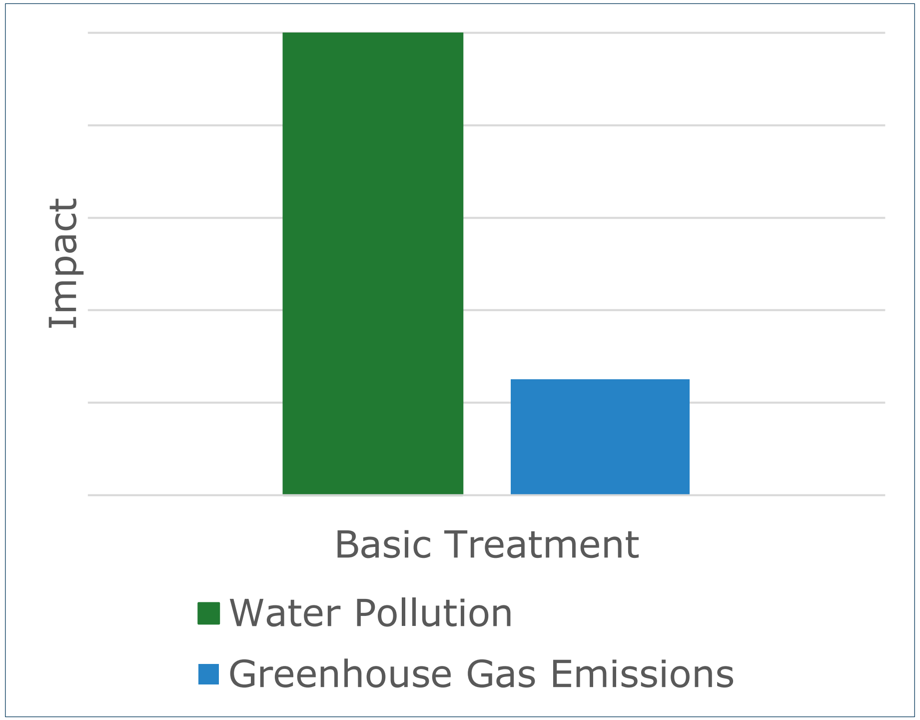
- When effluent limits become more stringent, communities must make decisions for improving or upgrading their WWTP to meet the more stringent limits.

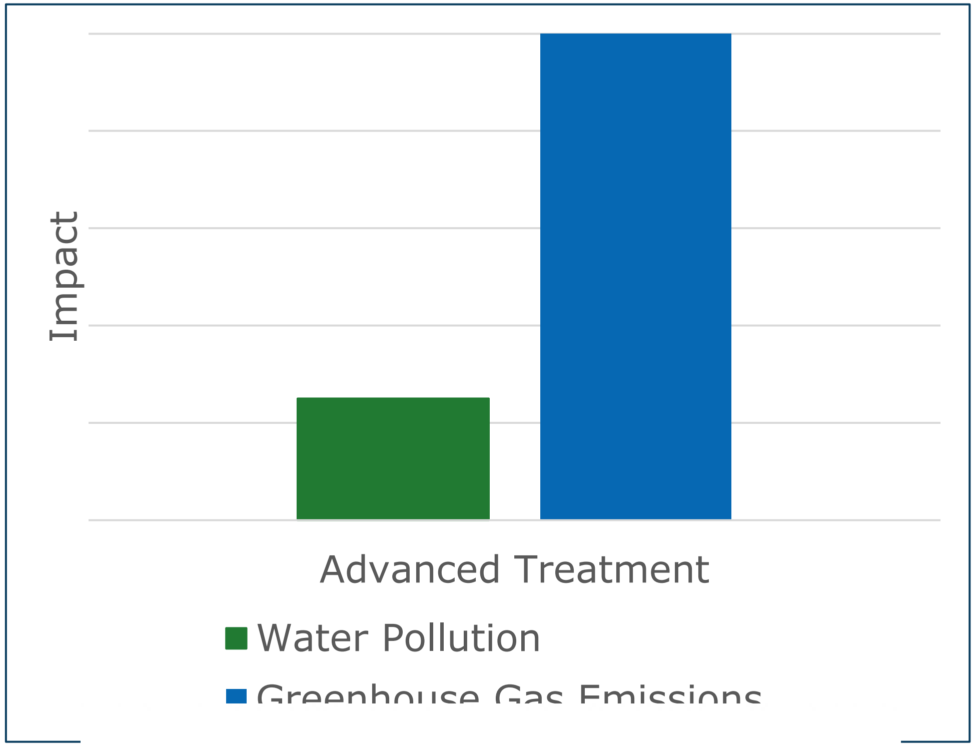
Background (continued)

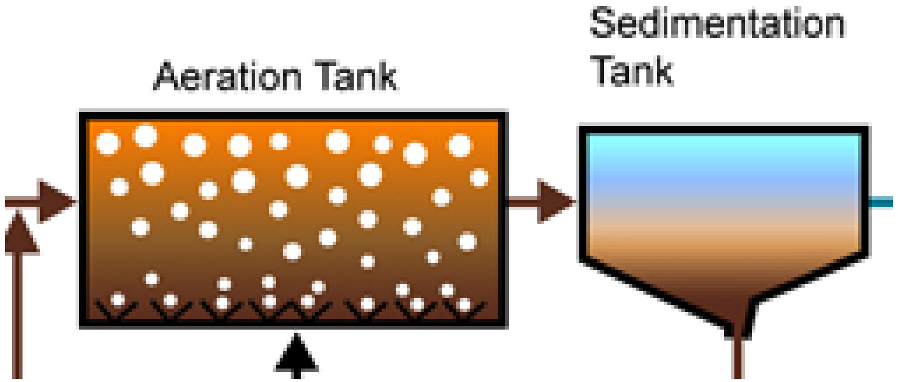
- These decisions can affect many aspects of the environment.
  - Some effects are positive (i.e., environmental benefits), such as cleaner water for recreation and healthier fish and aquatic life.
  - Other effects are negative (i.e., environmental impacts or harms), such as increased energy demand for WWTP upgrades, leading to increased burning of fossil fuels that may harm public health and the environment.

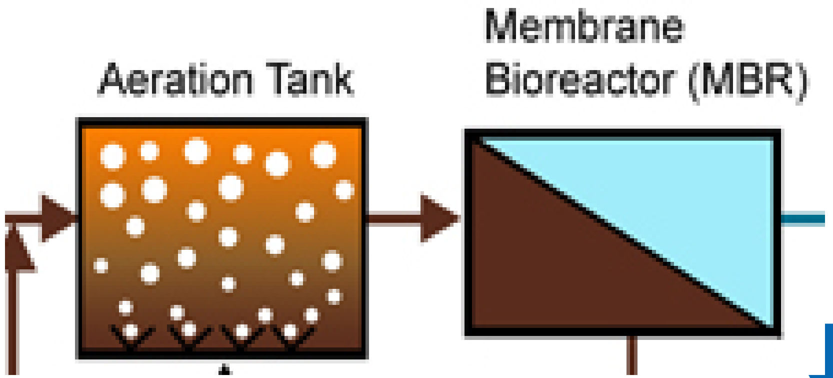
- One concern to be aware of is *burden shifting*, which occurs when an improvement in one environmental aspect can lead to a decline in another environmental aspect(s).
  - Research over the past decade has started to point to the potential for burden shifting (or impact trade-offs) related to WWTP upgrades.

Example of Burden Shifting









LCA Method – Overview

- Life cycle assessment (LCA) is a tool that can help identify, quantify, and compare environmental impacts, benefits, and trade-offs.

- LCA is a standardized method that quantifies and evaluates the environmental impacts and benefits for a product or process over its full life cycle.
  - For a *product*, this might include impacts from the extraction of raw materials and the production, use, and eventual disposal of the product.
  - For a *process*, like wastewater treatment, its LCA can be thought of as an LCA of all the smaller products needed to build and perform that process

LCA Method – Overview (continued)

The Four Main Steps of an LCA

1. Define the goal and scope
2. Create a life cycle inventory
3. Perform a life cycle impact assessment
4. Analyze and interpret the results

Paseo Real WWTP (City of Santa Fe)

- Serves 85K residential customers plus seasonal residents
- Average inflow 5 MGD
- Some effluent used for non-potable reuse
- Remaining effluent discharges to the Santa Fe River
- The Santa Fe River is ephemeral; sometimes segments of the river are entirely composed of Paseo Real WWTP effluent

1. Define the goal and scope

Source: santafenm.gov/wastewater_treatment_process

Case Study: Paseo Real WWTP

1. Define the goal and scope

- Based on NMED's approach for deriving numeric nutrient thresholds, the current and anticipated nutrient effluent limits for discharges to the Santa Fe River are:

	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Current effluent limit	6.9	3.1
Anticipated effluent limit	0.42	0.061

Note: EPA Region 6 is the permitting authority in NM

- It is likely that Paseo Real will be faced with the challenge of balancing the need for improved nutrient removal while limiting additional environmental impacts.

Case Study: Paseo Real WWTP

1. Define the goal and scope

- In 2018, Paseo Real completed a Nutrient Loading and Removal Optimization Study for the facility, which provided a starting point for an LCA to examine environmental outcomes.

- In May 2019, a collaborative effort between U.S. EPA, NMED, and the City of Santa Fe was initiated to conduct an LCA of Paseo Real WWTP.

Study Objectives

1. Define the goal and scope

- Use LCA to quantify potential environmental outcomes of four proposed effluent treatment upgrade options for Paseo Real WWTP.
  - The proposed scenarios where chosen based on their relevance to the PR WWTP and their ability to produce differentiated effluent quality and potential environmental impacts.
- Evaluate trade-offs between nutrient removal and other environmental impacts for different levels of treatment at the Paseo Real WWTP.

Treatment Upgrade Options (Scenarios)

1. Define the goal and scope

Scenario	Expected Effluent Conc. (mg/L)*		Description
	TN	TP	
Baseline (for reference and comparison to upgrade scenarios)	5	1	PR WWTP following implementation of all currently planned facility upgrades and partial effluent diversion to the Rio Grande.
Scenario 1 – Sidestream Filtration	4.5	0.7	Baseline configuration with the addition of filtrate return flow treatment.
Scenario 2 – Tertiary Filters	3	0.05	Baseline configuration with addition of tertiary deep bed media filters and new chemical feed facilities.
Scenario 3 – Reverse Osmosis	2	0.05	Baseline configuration with addition of a microfiltration/reverse osmosis system downstream of the secondary clarifiers.
Scenario 4 – Zero Discharge to Santa Fe River	5	1	Baseline configuration with all current effluent discharges to the Santa Fe River diverted to the Rio Grande.

**Based on past performance of similar technology at other facilities*

Scenario LCIs

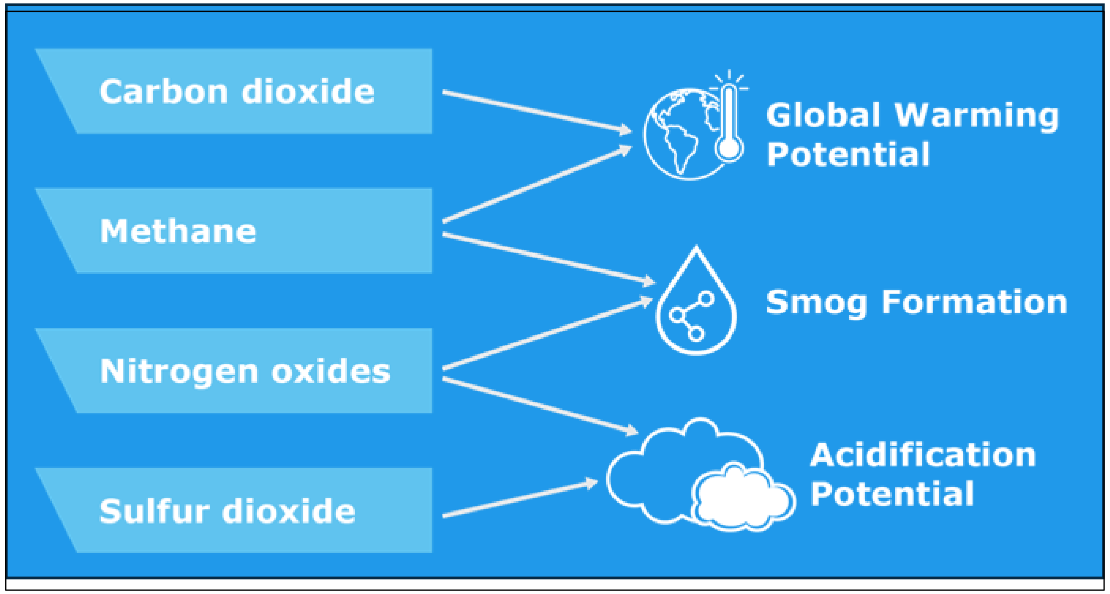
2. Create a life cycle inventory

- A life cycle inventory (LCI) is a comprehensive list of inputs and outputs to and from the system across the entire life cycle of the product or process.
  - Examples of inputs are raw materials, chemicals, and energy.
  - Examples of outputs are releases of solid waste, air emissions, and water emissions.
- Most LCI data were obtained directly from Paseo Real staff, its contractor (Carollo), or facility documents/reports.
- Where LCI data were not measured, data required to run the LCA software were obtained from modeling or peer-reviewed literature.
- LCI inputs were based on average operating conditions.

Life Cycle Impact Assessment (LCIA)

3. Perform a life cycle impact assessment

- A life cycle impact assessment (LCIA) refers to the steps that quantify the type and extent of environmental harms and benefits that may arise based on data collected in the LCI (Step 2).
- To perform the LCIA, the inputs and outputs from the LCI are grouped into and aligned with several common LCA evaluation metrics (next slide).



For example, methane and carbon dioxide are two greenhouse gases (outputs) that contribute to the global warming metric. The contribution of each gas is added up and expressed in terms of one single unit for that metric. For the global warming metric, the unit is “carbon dioxide equivalents.”

Evaluation Metrics

3. Perform a life cycle impact assessment

Metric	Category
Eutrophication Potential	Environment
Acidification Potential	
Smog Formation Potential	
Cumulative Energy Demand	Energy and Climate
Fossil Fuel Depletion	
Global Warming Potential	
Water Depletion	Water Quantity
Water Scarcity	
Ecotoxicity	Toxicity
Human Health - Particulate Matter Formation	
Human Health Toxicity – Cancer Potential	
Human Health Toxicity – Noncancer Potential	

Data Analyses Performed

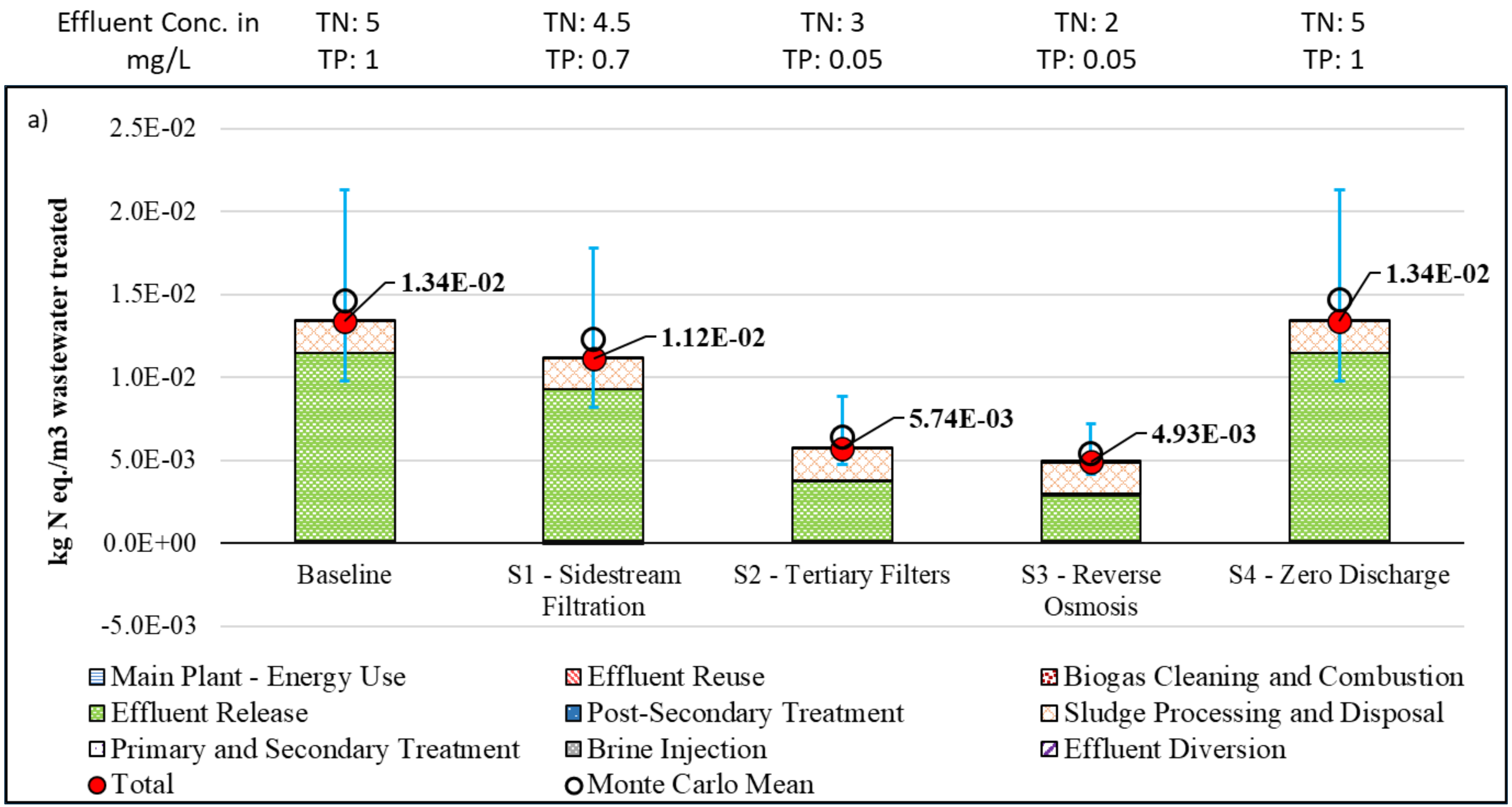
4. Analyze and interpret the results

- Contribution analysis: what are the main processes, materials and emissions contributing to results?
- Uncertainty analysis: how does uncertainty in model inputs affect confidence in results?
- Sensitivity analysis: how sensitive are results to study inputs such as electrical grid, treatment performance or waste management method?
- Tradeoff analysis: do improvements in one impact category lead to increased impacts in another?

Results–Eutrophication Potential

4. Analyze and interpret the results

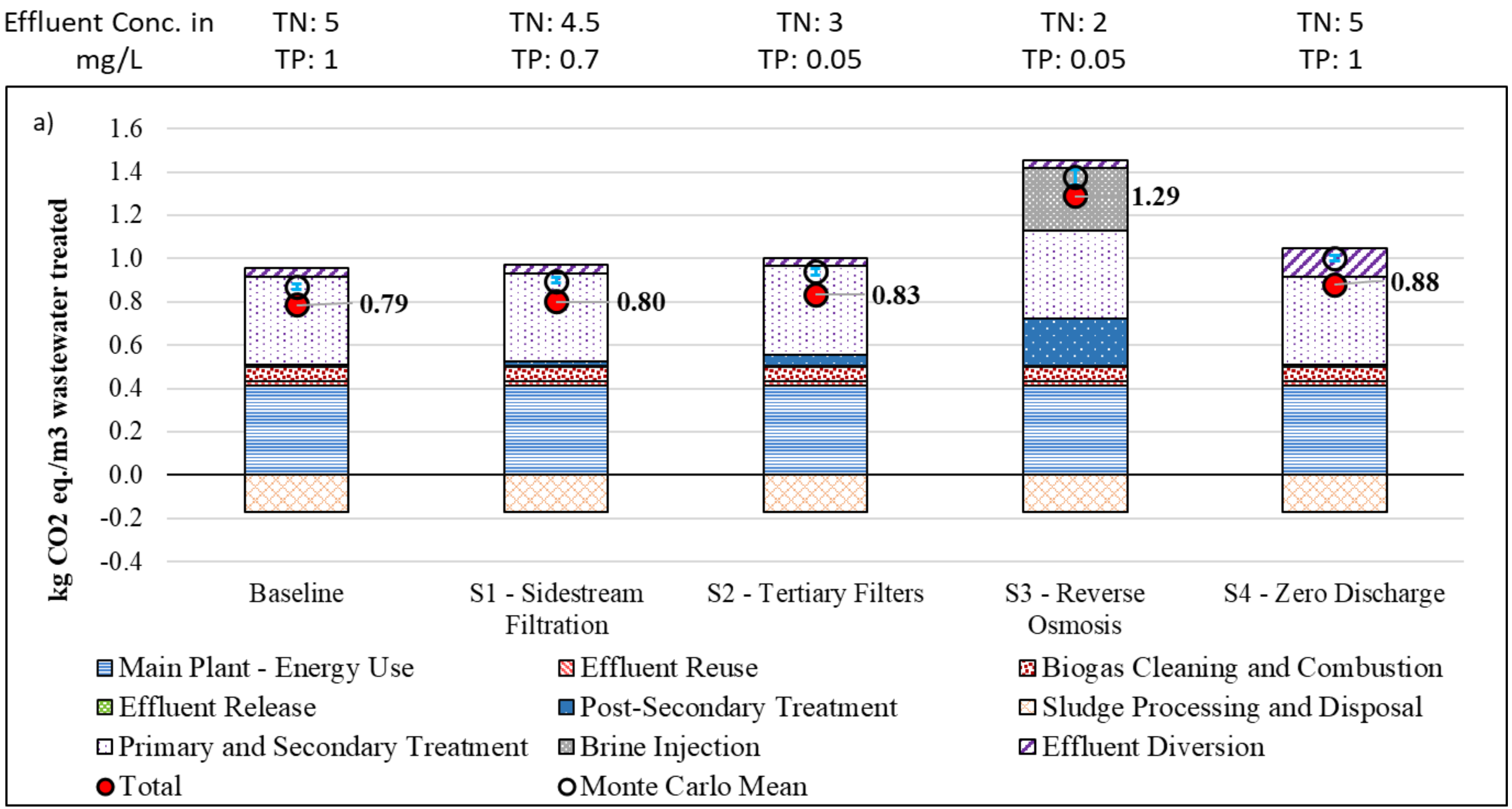
- Tertiary Filters results in lowest impacts, closely followed by Sidestream Filtration
- Eutrophication potential driven by effluent release contribution.



Results–Global Warming Potential

4. Analyze and interpret the results

- Reverse Osmosis has highest impacts.
- Sidestream Filtration, Tertiary Filters and Zero Discharge have impacts more similar to Baseline

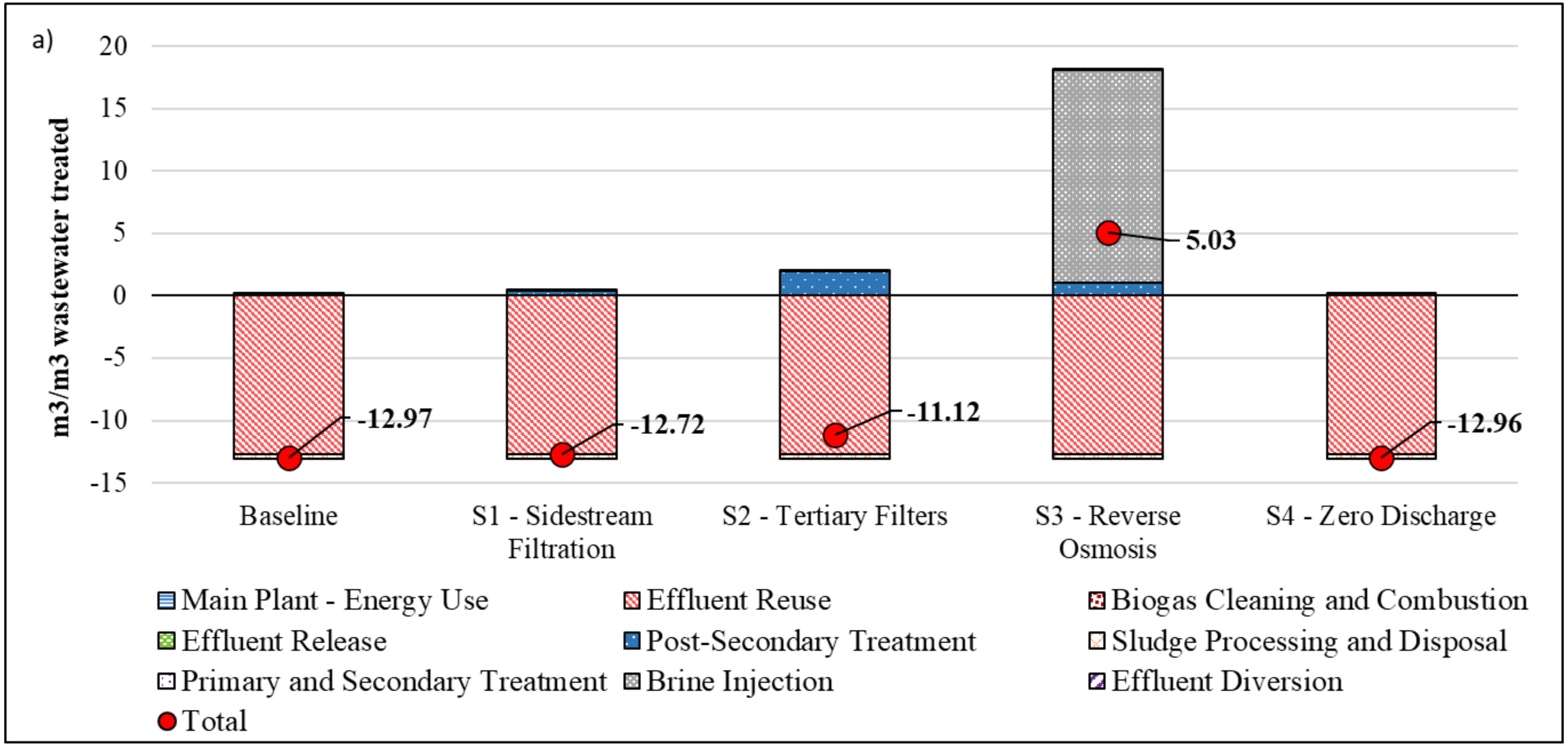


Results–Water Scarcity

4. Analyze and interpret the results

- Reverse Osmosis has highest impacts.
- Sidestream Filtration, Tertiary Filters and Zero Discharge have impacts more similar to Baseline

Effluent Conc. in mg/L	TN: 5 TP: 1	TN: 4.5 TP: 0.7	TN: 3 TP: 0.05	TN: 2 TP: 0.05	TN: 5 TP: 1

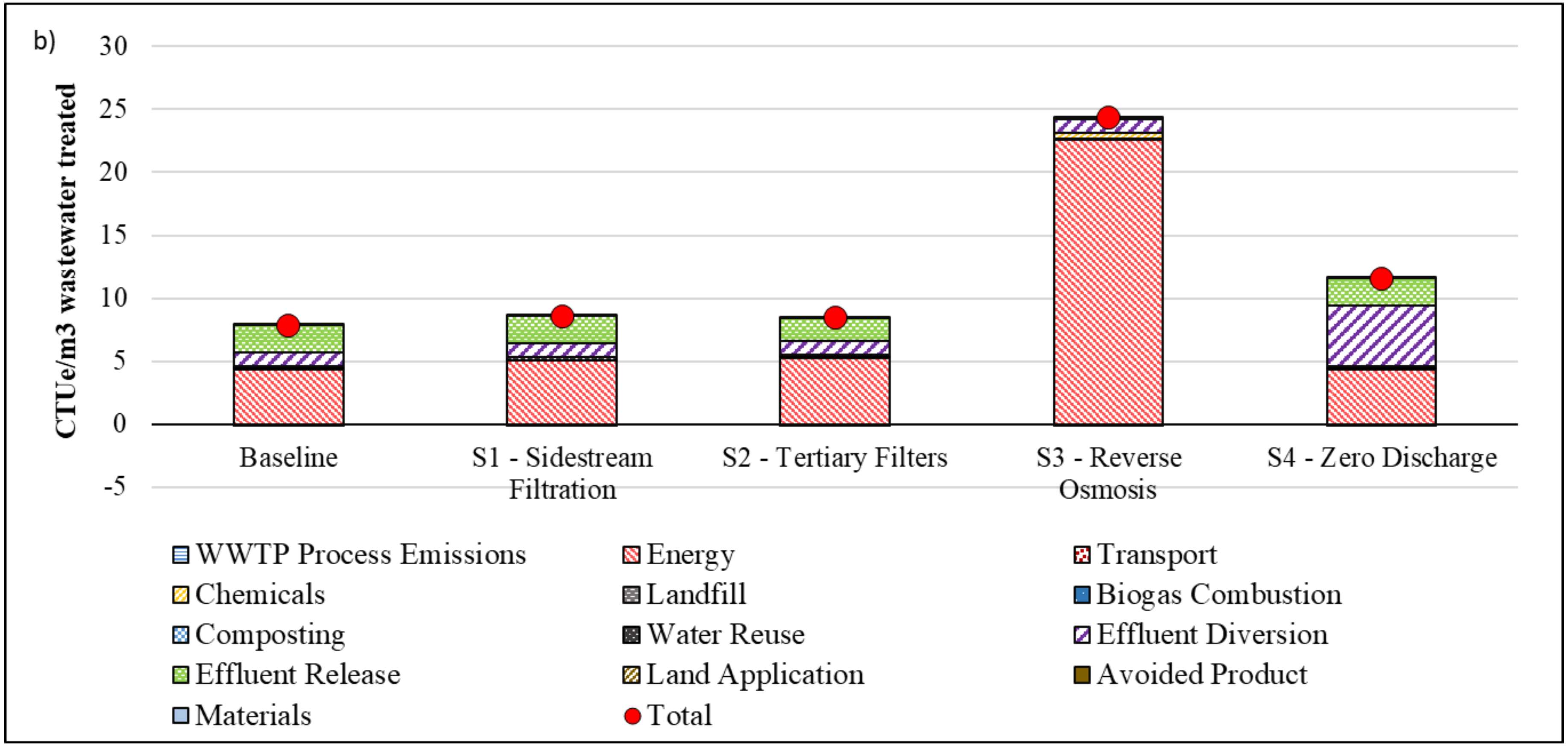


Results–Ecotoxicity

4. Analyze and interpret the results

- Reverse Osmosis results in the highest ecotoxicity, followed by Zero Discharge, followed closely by the other three scenarios, which are not very different from each other
- Ecotoxicity driven by energy use.

Effluent Conc. in mg/L	TN: 5 TP: 1	TN: 4.5 TP: 0.7	TN: 3 TP: 0.05	TN: 2 TP: 0.05	TN: 5 TP: 1



Note: color-coding of the bars has a different basis that on the last few slides

Additional Results

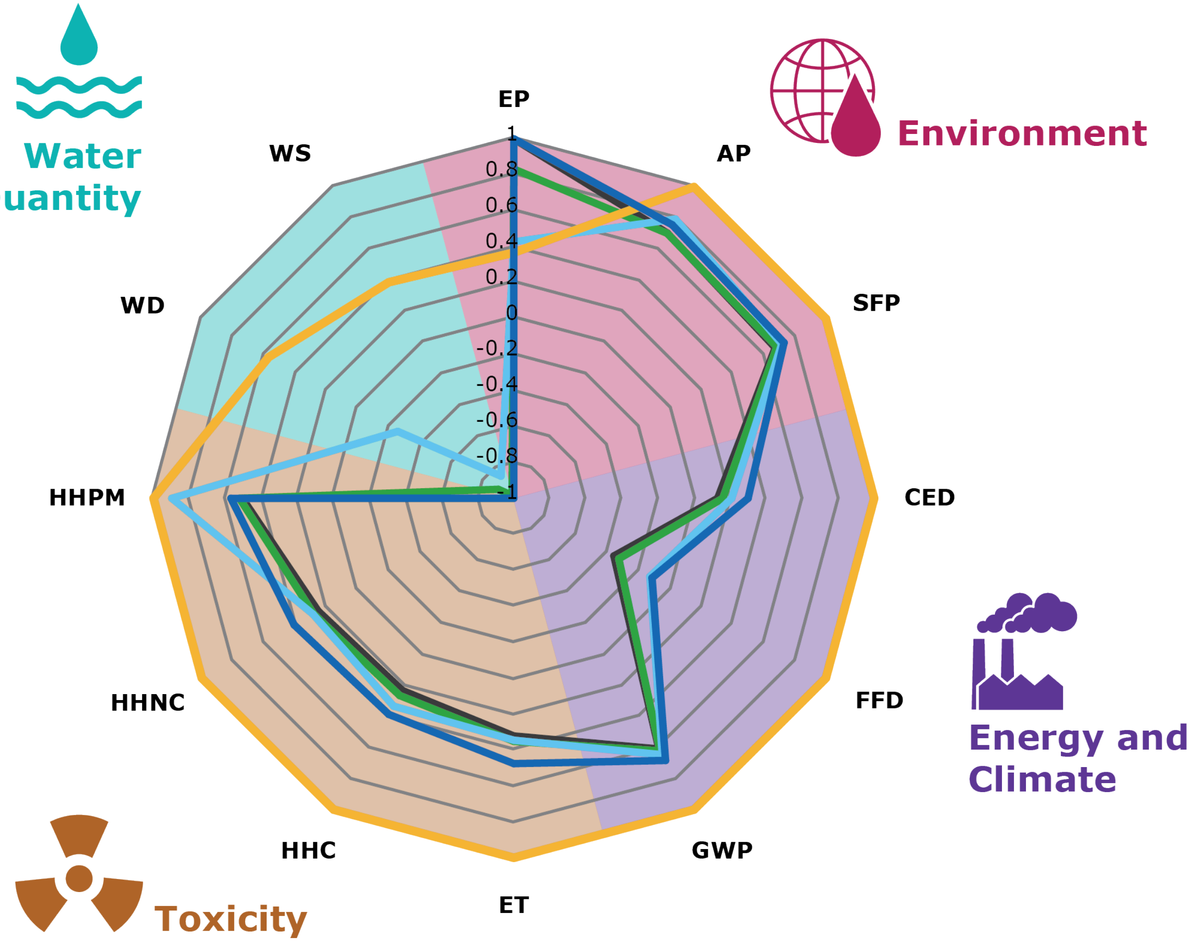
4. Analyze and interpret the results

The full set of LCA results and analyses can be found in the final report, which can be obtained from the following EPA website:

Research and Reports on Nutrient Pollution

Standardized Results

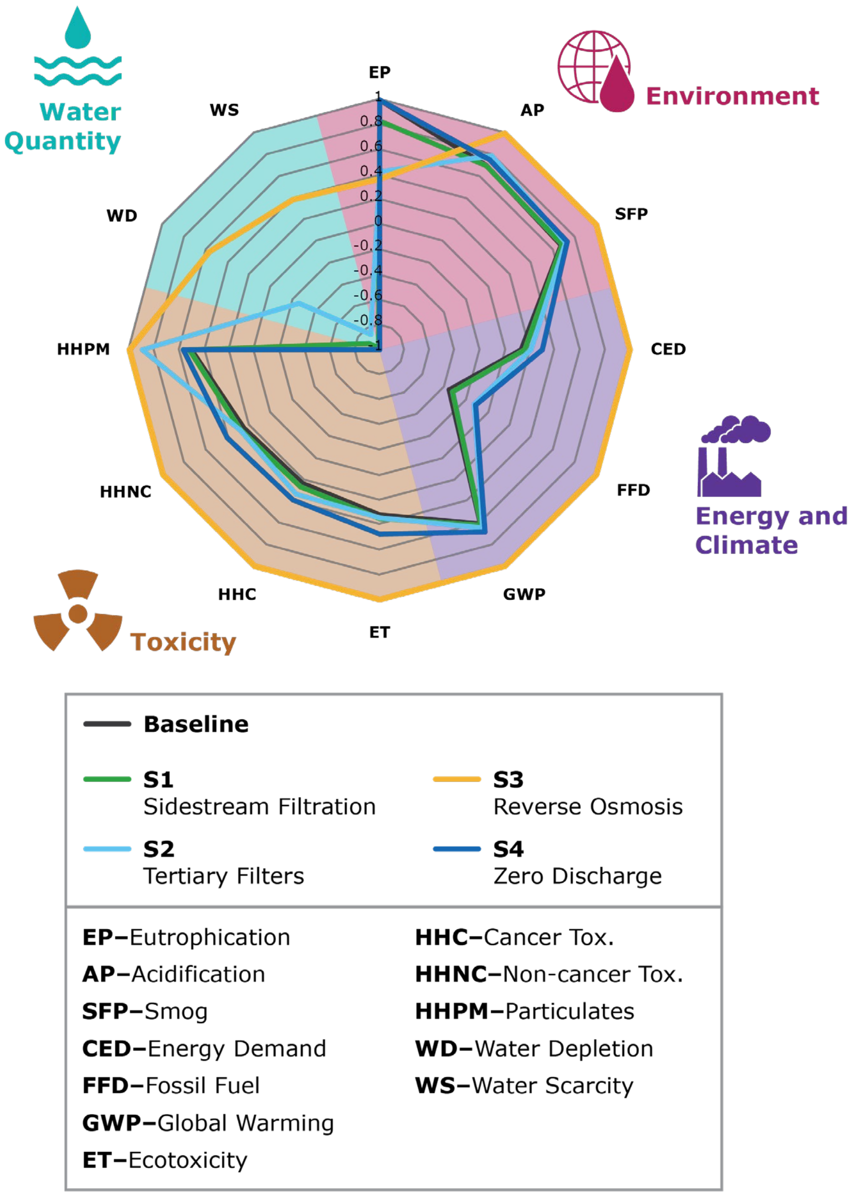
4. Analyze and interpret the results



Baseline	
S1 Sidestream Filtration	**S3** Reverse Osmosis
S2 Tertiary Filters	**S4** Zero Discharge
EP–Eutrophication	**HHC–**Cancer Tox.
AP–Acidification	**HHNC–**Non-cancer Tox.
SFP–Smog	**HHPM–**Particulates
CED–Energy Demand	**WD–**Water Depletion
FFD–Fossil Fuel	**WS–**Water Scarcity
GWP–Global Warming	
ET–Ecotoxicity	

A value of 1 (i.e., toward the outer edge of the circle) reflects the greatest environmental harm, while -1 (i.e., towards the center of the circle) reflects the least environmental harm

Standardized Results



4. Analyze and interpret the results

- Reverse Osmosis causes the most environmental harm for most metrics (largest web)
- Eutrophication Potential (EP) is the only measure where Reverse Osmosis has the lowest environmental harm
- Tertiary Filters have intermediate impacts for Water Depletion (WD) and Human Health Particulate Matter Formation (HHPM)

Normalized Results

4. Analyze and interpret the results

- Results normalized to the impacts of one person equivalent to estimate contribution of wastewater treatment to average per capita impacts
- Eutrophication potential and water depletion have largest contributions

Larger contribution

Impact Category	Baseline	S1 - Sidestream Filtration	S2 - Tertiary Filters	S3 - Reverse Osmosis	S4 - Zero Discharge
Eutrophication Potential	4.9%	4.1%	2.1%	1.8%	4.9%
Global Warming Potential	0.3%	0.3%	0.3%	0.4%	0.3%
Acidification Potential	0.2%	0.2%	0.2%	0.3%	0.2%
Smog Formation Potential	0.3%	0.3%	0.3%	0.4%	0.3%
Particulate Matter Formation	0.0%	0.0%	0.0%	0.0%	0.0%
Water Depletion	-2.0%	-1.8%	-0.5%	1.2%	-2.0%

Sensitivity Analyses Take-homes

4. Analyze and interpret the results

- We looked at model inputs and assumptions in multiple ways to provide confidence in final results

- Relative rankings of scenarios relatively robust to sensitivity scenario analyses

- Important parameters
  - Energy consumption
  - Effluent organic nitrogen bioavailability
  - Electrical grid fuel sources

General Conclusions

- Benefits from reduced eutrophication are greatest with Reverse Osmosis, but Tertiary Filters are not far behind, especially when model uncertainty and organic nitrogen bioavailability are considered; Tertiary Filters generally resulted in lower impacts than Reverse Osmosis for other metrics.

- Uncertainty in chemical inputs for Tertiary Filters may drive up impacts for water depletion and particulate matter formation.

- Sidestream Filtration impacts were only slightly greater than the Baseline Scenario, while still providing 17% reduction in eutrophication potential.

- In this arid system, local water scarcity drives water scarcity results

General Conclusions

Greatest Benefit (-1) — Greatest Harm (1)

Metric	Standardized Impact Results				
	Baseline Scenario	S1 – Sidestream Filtration	S2 – Tertiary Filters	S3 – Reverse Osmosis	S4 – Zero Discharge
Eutrophication Potential	1	0.83	0.43	0.37	1
Acidification Potential	0.7	0.7	0.79	1	0.76
Cumulative Energy Demand	0.13	0.16	0.21	1	0.3
Global Warming Potential	0.61	0.62	0.65	1	0.68
Fossil Fuel Depletion	-0.36	-0.33	-0.13	1	-0.11
Smog Formation Potential	0.68	0.69	0.72	1	0.73
Ecotoxicity	0.32	0.35	0.35	1	0.48
Human Health Toxicity—Cancer Potential	0.24	0.27	0.34	1	0.39
Human Health Toxicity—Noncancer Potential	0.25	0.28	0.29	1	0.41
Human Health—Particulate Matter Formation	0.51	0.52	0.9	1	0.57
Water Depletion	-1	-0.9	-0.26	0.57	-1
Water Scarcity	-1	-0.98	-0.86	0.39	-1

General Conclusions

Greatest Benefit (-1) — Greatest Harm (1)

LCA Results	S1 - Sidestream Filtration	S2 - Tertiary Filters	S3 - Reverse Osmosis	S4 - Zero Discharge
Impact	Small increases in potential environmental impacts	Small to moderate increases in potential environmental impacts	Except for eutrophication potential, potential environmental impacts generally much greater than other scenarios considered	Small increases in impacts associated with full effluent diversion
Benefit	Small improvement to nutrient removal	Large improvement to nutrient removal	Largest improvement to nutrient removal	Eutrophication potential impacts diverted from Santa Fe River to Rio Grande

Study Limitations (Reverse Osmosis)

- Certain impacts not captured, particularly for RO. For example:
  - RO-treated water has very low total dissolved solids (TDS), which can be corrosive to downstream materials, leach metals from downstream geologic substrates, and be toxic to aquatic organisms.
  - Impacts of RO brine only take into account the water depletion that results from taking the incorporated water out of the hydrologic cycle. Brine can carry concentrated pollutants and, if not properly confined underground, can contaminate groundwater resources.

- Uncertainty in how nutrients will manifest in the receiving water farther downstream from Paseo Real, or in the Rio Grande in the case of diversion (Zero Discharge). Additional water sampling and modeling may be needed to resolve these questions.

Other Observations and Limitations

- The magnitude of differences between treatment scenario impacts are influenced by sensitivity assumptions.
  - For example, the electricity grid mix sensitivity analysis shows that if each scenario used electricity generated from 100% solar power, potential impacts of Reverse Osmosis are much more comparable to other scenarios across most metrics (although potential impacts of RO remain highest for water depletion and water scarcity).

Other Observations and Limitations

- In a complex study with thousands of numeric entries, the accuracy of the data and how it affects conclusions is a difficult subject. The reader should keep in mind the uncertainty associated with LCI data when interpreting the results. Comparative conclusions should not be drawn based on small differences in impact results.

- The LCI data presented here and in the final report are specific to the Paseo Real WWTP. LCI results may vary substantially for other case-specific operating conditions and facilities.