SW01: Introduction

Environmental protection

- Do nothing: pollutants so low they cause no harm or nuisance.
- Dilution: disperse to lower concentration; pollutant mass remains.
- Concentrate & landfill: remove locally and store elsewhere; long-therm liability remains.
- Treat & recycle: remove hazards and recover materials; waste becomes a resource.
- Prevention: avoid waste upstream via cleaner production/ecodesign → 3-R rule (reduce - reuse - recycle).
- Close loop: circular systems keep materials in use and minimize disposal.

1) Technical/additive "end-of-pipe" controls (filters).
2) Non-technical/integrated strategies (cleaner production, ecodesign across the life cycle).

Role of environmental engineers

- Interdisciplinarity: connect engineers with environmental science, ecology, and health.
- Source-pathway-impact: identify pollution and how impacts propagate.
- Design/operation: reduce emissions and optimize treatment and waste systems.
- Systems trade-offs: balance performance, cost, regulation, and sustainability.

Major environmental problems (Swiss & global)

- Air: urban pollution, acid deposition, indoor air, noise, climate forcing.
- Water: nutrients, toxics, pathogens, oxygen depletion, pesticides, oil, heat.
- Biodiversity: habitat loss and species decline/extinction.
- Waste: solid and hazardous waste generation and management.
- Resources/food/land: soil erosion, water scarcity, overuse/overfishing and land degradation.
- Drivers: population growth, inefficient resource use, poverty, weak accounting, poor education.

Emerging issues and toxicity

- Emerging issues: limited evidence; decisions must be taken under uncertainty.
- Context dependence: risk-benefit can differ by region & time.
- Carcinogens: promote cancer; Mutagens: alter DNA; Teratogens: cause birth defects.
- Examples: PFAS, heavy metals (Pb, Hg, Cd), PCBs, persisten pesticides, micropollutants.

Climate change impacts

- Amplifier: increases stress on resources and ecosystems and worsens pollution impacts.
- Health: health stress, extreme events, air-quality effects, and shifting disease vectors.

CO_2, CO_2e, and GHG quantification

- CO_2: direct carbon dioxide emissions (mass of CO_2).
- CO_2e: total warming impact of all the greenhouse gases expressed as CO_2.
- GHG: Green House Gases.
- GWP: heat-trapping comparison vs. CO_2 over a time horizon (often 100 years).

$$CO_2e = \text{mass} \cdot GWP$$

SW02: Separation techniques

Purpose and importance of separation techniques

- Purpose: split mixtures into components via mass transfer to obtain one or more product streams. Separation uses driving forces (gravity, pressure, concentration, charge) to transfer target components into a separate stream.
- Importance: enables purification, pollution control, and resource recovery to protect health and prevent contamination.

Criteria for selecting the right ST

- Phase, particle size, solubility/volatility, recovery type.
- Typically: coarse removal → clarification → fine removal. (eg: screening → sedimentation → filtration)

Real world applications

- WWT: screening/sieving (large debrits) → sedimentation (suspended solids) → fitration/sand (fines) → reverse osmosis (salts/solutes). Dissolved air flotation for oil/fats/grease.
- Air: wet scrubbers absorb/neutralize gases and trap particulate matter. Elecrostatic precipitator removes particulates from flue gas. Activated carbon captures VOCs.
- Soil: supercritical CO_2 extraction for hydrophobic organics (PAHs/PCBs/dioxins). Soil washing for metals/hydrocarbons. Extraction methods support remediation and analysis.

Separation techniques

Physical Chemical Biological Advanced/Emerging

Technique	Description	Field of use
Screening/sieving	Physical barrier removes large debrits.	Wastewater (primary treatm.)
Sedimentation	Suspended solids settle by gravity	(Waste-)water
Decantation	Separates immiscible liquids or liquid-solid after settling (density-based)	Water/oil separat.; lab/industry
Filtration	Medium retains solids while fluid passes (residue/filtrate)	Lab purification; air (HEPA); WT
Sand filtration	Granular filtration for fines	(Rain)water; WT
Reverse osmosis (RO)	High-pressure membrane filtration removing solutes	Desalination; water purification
Centrifugation	Separation accelerated by rotation (density-based)	(Waste)water solids handling
Dissolved Air Flotation (DAF)	Microbubbles attach to particles so they float and are skimmed	Industrial WW; FOG-/P-removal
Magnetic separation	Removes magnetic particles	Industrial/W streams
Evaporation	Solvent evaporates, solute remains	Salt recovery; W demineralization; landfill leachate
Crystallization	Forms crystals from solution for separation/purification	Water/chemical processing
Sublimation	Solid → gas to separate volatile solids	Lab/chemical purification
Coagulation/Flocculation	Destabilizes particles so they clump into larger flocs	Water and WW clarification
Precipitation	Converts dissolved contaminants into solids	Metal removal in water/WW
Adsorbtion (activated carbon)	Pollutants bind to porous carbon. Effective for organics and gases	WT and air/VOC control
Absorbtion	Liquid absorbent dissolves/removes pollutants from gas/WW	CO_2 capture; H_2S removal; WW pollut.
Wet scrubber	Common absorbtion device cleaning industrial exhaust with water/solution	Air pollution control (PM + acid gases/VOCs)
Ion exchange	Swaps undesirable ions on resin. Regenerable with salt/acid/base	Water softening; heavy metals
Electrocoagulation (EC)	Uses electric current for coagulation. Reduces use of chemicals	WWT
Liquid-Liquid extraction (LLE)	Separates by differential solubilities between two liquids. Reversible by back-extraction	WW/groundwater/soil remediation; resource recovery
Bioremediation	Microbes degrade contaminants	Soil/groundw. cleanup
Activated sludge process (ASP)	Microbial treatment of organics in aerated reactors	WW/sewage treat.
Constructed wetlands	Plant-microbe system removes pollutants	WW polishing, nature-based treat.
Membrane filtration (MF/UF/NF/RO)	Size-based membrane separation. Removes salts/pathogens/particles depending on the membrane	Water/WW; pretreatment and reuse; desalination (RO)
Distillation	Phase-change separation by volatility	Purification + recovery
Electrodialysis	Ion-selective membranes + DC move ions between solutions	Industrial WW
Supercritical fluid extraction	Uses supercritical CO_2. Reversible by p/T change to precipitate solute	Soil remediation (PAHs/PCBs/dioxides); waste, water sludge; air monitoring
Chromatography	Separation on stationary phase for complex mixtures	Analytical/lab separation
Air stripping	Transfers volatile compounds from water to air (off-gass treatment needed)	groundw./WW VOC removal; ammonia (pH adj.)
Membrane gas absorption	Absorption intensified using membrane contractors	Gas treatment (CO_2/odour capture)

SW03: Ecological sanitation (EcoSan)

Principles and goals of EcoSan

- Goal: shift from linear "end-of-pipe" disposal to circular nutrient/water cycles with safe reuse and lower water use.
- Objectives: hygenically safe sanitation; reduce health risks; prevent surface/groundwater pollution and soil degradation; optimize nutrient and water resource management.

EcoSan technologies

Technology	Description	Outputs/reuse
Urine-Diverting Dry Toilet (UDTT)	Separates urine and feces at source. Dry operation	Urine as fertilizer (after hygenization); feces as soil conditioner (after compost + dry)
Urine-Diverting Dehydration (UDD)	Feces dehydrated (often with ash) while urine is collected separately	Dried feces for soil improvement; urine for fertilizer
Composting dry toilet	Aerobic decomposition of feces (often mixer with bulking agents)	Compost/soil conditioner
Biogas toilet/anaerobic digester	Anaerobic digestion of fecal matter (often with water) in a sealed reactor	Biogas + digestate for soil amendment
Arborloo	Shallow pit latrine used temporarily; tree planted over filled pit	Soil fertility for tree growth
Container-based sanitation (CBS)	Excreta collected in removable containers for off-site treatm.	Centralized treatment products (compost/biogas)
Vermicomposting variants	Decomposition supported by worms	Vermicompost (soil conditioner)
Struvite rerovery (from urine)	Chemical precipitation to recover nutrients (Mg/NH_4/PO_4)	Solid fertilizer (struvite)

Asses design and operational parameters

- Operational principle: avoid unnecessary dilution (dry/low-flush/vacuum) and treat streams separately (urine, feces, greywater, rainwater, organics)
- Treatment logic: urine hygenization by storage/drying. Feces by anaerobic digestion/drying/composting. Greywater via wetlands/ponds/biological treatment/membranes, then reuse (irrigation/recharge).

Toilet decision criteria

Fresh water

- Where does your water supply come from?
- Is water supply reliable?
- How much water is user by family?
- What is the weather like where you live? What is the rainfall?

Your family and home

- How many people are there in your family?
- How much space and land is available for building a toilet?
- What is the cost to build and mantain a toilet?

The environment

- What is your soil type, sandy, rocky or clay, is it salty?
- Do you have groundwater?
- Are you close to any beach or reef?

Data about exctrement

Adults may produce 400 ℓ/year of urine (4 kg N; 0,4 kg P; 0,9 kg K) and 25-50 kg/person·year (0,55 kg N; 0,18 kg P; 0,37 kg K)

SW04: Sustainable production process (SSP)

Role of technology in sustainable development

- Technology enables sustainability via data-driven decisions, renewable energy, and smart infrastructure (incl. water/sanitation, healthcare, agricultural innovation).
- Engineering links sustainability to environmental limits (eg: Planetary boundaries and water-quality hotspots).

Phosphorus in food security and sustainability

- P is indispensable for plant growth and synthetic fertilizers. Without mineral phosphate fertilizers, only about 1/5 of today's world population could be fed.
- Sustainable P management aims at long-term availability + affordability while minimizing losses that damage water quality and biodiversity.

Impact of P extraction, processing, and fertilizer prod.

- High water use (~8-15 t freshwater per t phosphate rock), phosphogypsum waste (large stacks; radioactive concerns), and cadmium contamination from phosphate rock into fertilizers/soils.
- Mismanaged P leads to runoff/leaching → eutrophication (algal bloom) and water-quality degradation.

Sustainable P management strategies

- Optimize use efficiency and recover/reuse P from waste streams (WWTP side streams, sludge/ash, manure, food/industrial waste) to reduce imports and pollution.
- Recovery technological options:
  1) Chemical precipitation: struvite crystallization (produces slow-release fertilizer).
  2) Thermal recovery: incineration of sewage sludge with phosphorus recovery from ash.
  3) Biological routes: enhanced biological phosphorus removal (EBPR) coupled with recovery.
  4) Membrane technologies: concentration and selective separation for further recovery.
  5) Electrochemical methods: electrodialysis for phosphate enrichment.

SW05: Noise pollution and measures

Sound generation, propagation, measurement

- Sound is a longitudinal pressure wave (vibration) travelling in a medium. Sound pressure $p(t)$ is measured in [Pa] and often handled as p_{rms}.
- Propagation: transmission, reflection, refraction, diffraction, adsorption, scattering.
- Measurement:

$$p(t) = p_{tot}(t) + p_0 \; ; \; p_{rms} = \sqrt{\frac{1}{T}\int_0^T p^2(t)\,dt} \; ; \; c = \lambda/T = \lambda f$$

$$dB = 10\log(I_1/I_2) = 10\log\left((p_1/p_2)^2\right) = 20\log(p_1/p_2)$$

$$L = 20\log(p_{rms}/p_0),\; p_0 = 2\cdot 10^{-5}\,Pa \; ; \; I_0 = 10^{-12}\,W/m^2$$

Energetic mean SPL: $\bar{L} = 10\log\left(\frac{\Sigma_n 10^{L_n/10}}{n}\right)$

Further levels

- Maximum sound level, L_{max}: highest SL reached.
- Equivalent continuous SL, L_{eq}: constant sound level that would contain the same total sound energy as the time-varying sound over the measurement period.
- Sound exposure level, L_E: single-event level representing the total sound energy of an event, conventionally expressed as an equivalent level over a reference duration (often 1s).

Emission vs immission

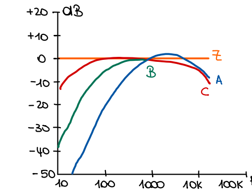
- Emission characterizes the source (SPL, Lw).
- Immission is the received SPL at a location.

SW06: Noise measurement

Frequency weightings (IEC 61672)

- dBZ: no frequency weighting (flat/Z)
- dBA: A-weighting (matches human hearing at moderate levels). Mainly used for environmental noise.
- dBB: B-weighting (historical, mid-level loudness range).
- dBC: C-weighting (more low-frequency content kept).

Used when low-frequency vibrations matter.



Notation with time weightings

- L_X: X-weighting (can be Z, A, B, C)
- L_{XF}: X-weighted level with Fast time weighting (τ = 125 ms).
- L_{XS}: X-weighted level with Slow time weighting (τ = 1 ms).
- L_{XE}: X-weighted sound exposure level.
- $L_{XS,max}$: maximum value of L_{XS} during the taken event.
- mean L_{XE}: energetic mean over multiple L_{XE} values.
- mean L_{XS}: energetic mean over multiple L_{XS} values.
- L_{dn} (dBX): event measured through the day and night.

SW07: Noise protection regulations

Noise and noise health impacts

- Noise is unwanted sound, subjectively evaluated as unpleasent, annoying, and/or disturbing; typically made by others; mainly unnatural and technical.
- It has negative impact on human health and well-being: noise annoyance, disturbance, sleep disturbance and fragmentation, restlessness and discomfort, cognitive impairment, hearing impairment and tinnitus, adverse birth outcomes, cardiovascular disease, morbidity, and mortality.

Noise control engineering

- Noise emission control: technical acoustic, vibro-acoustic, mechanical engineering, material science.
- Propagation control: technical acoustics, environmental acoustics, building acoustics.
- Noise immission control: environmental acoustics, building acoustics, psychoacoustics, hearing protection.

Laws and regulations

Sensivity level	day: Planning value (PV)	day: Impact threshold (IT)	day: Alarm value (AV)	night: Planning value (PV)	night: Impact threshold (IT)	night: Alarm value (AV)
I	Leisure zones					
II	Residential zones and zones for public buildings and installations					
III	Residential and industrial zones (mixed) and agricultural zones					
IV	Industrial zones					

Rating sound level:
$L_r = L_{eq} + K$, where K = level correction for acceptance/tonality.

SW10: Micropollutants in the ecosystem

Types, sources, fate, behavior of micropollutants

- Definition: trace-level chemicals typically < 1 µg/L that can harm organs. Often persistent, bioactive, and not well removed by conventional WWTP treatment.
- Main groups: pharmaceutical and personal care products (PPCPs); pesticides/herbicides, industrial chemicals (eg. phthalates/surfactants/dyes), heavy metals, micro-/nanoplastics.
- Formation/pathways: arise from partial degradation and transformation products (photolysis/oxidation). Transported via urban runoff, WWTP effluent discharge, and sludge application to soils.
- Fate: adsorption to sediments/soils, bioaccumulation, and possible long-range transport. Impacts include endocrine disruption and antibiotic resistance.
- Example of real effects: intersex fish downstream of WWTPs, invertebrate declines, trace pharmaceuticals in drinking-water sources, estrogenicity detected in rivers.
- Novel MPs: recently introduced with no historical data and often missed by routine monitoring.
- Emerging MPs: increasingly detected (better analytics/awareness) but often unregulated and incompletely removed in WWTPs.

Exceedances in small vs. large watercourses

- Switzerland pattern: in small/medium watercourses, exceedances are mainly driven by pesticides. In large watercourses, are more typical for medical products.
- Source: agriculture acts as diffuse source (pesticides/drugs). WWTPs are a point source (human pharmaceuticals).
- Seasonality: pesticides (March-June); pharmaceuticals (higher in winter).

Technological solutions for MP removal

- Ozonation: typical reactor depth ~7 m, 6-8 chambers. Split dosing can reduce ozone demand. For ~80% elimination, usually 0,4-0,7 $gO_3/gDOC$ (or 3-5 mg/L).
- Activated carbon
  - PAC: ~80% MP removal needs 5-20 mg/L.
  - GAC: remains 100-200 days with batchwise replacement; avg. 10-20 mg/L. Manage sludge accumulation!
- Overall: ozonation (70-95%); AC (60-95%).
- Advanced oxidation processes (AOPs).
- Membrane filtration.

SW11: Carbon Capture Solutions

Type of captures

- CCS: capture from point source (power/industry) and permanently store underground. Reduces emissions at the source.
- CCU: capture from point source and use CO_2 in products. Emission benefit depends on the use.
- CCUS: combines utilization and storage for larger reductions.
- CDR: removes CO_2 from the atmosphere and stores it long-term, creating negative emissions when storage is permanent.

Negative Emission Technologies (NETs)

- Net zero requires:
  1) Stop avoidable emissions (decarbonization, circular economy, renewables, efficiency/sufficiency)
  2) Capture unavoidable point-source emissions with CCS (eg. waste incineration)
  3) Remove historic emissions via CDR (eg. DAC)
- NET examples: reforestation, soil management, DAC, ...

SW12: Urban drainage/Water management

Role of urban water management

- Secure extraction, treatment, and distribution of drinking/process water in sufficient quantity and quality.
- Collect, treat, and discharge wastewater (or treat for reuse) while ensuring hygenic living conditions.
- Manage stormwater via collection, discharge, treatment, or infiltration. Protect against floods and protect groundwater.
- Includes planning, construction, and operation of all required plants.
- Urban conveyance can be combined/separate, above/below ground. Transport can be gravity/pressure/vacuum. Solutions can be grey or green/blue (natural).
- Lake-water treatment chain: ozonation → quartz sand filtration → activated carbon → chlorine dioxide → reservoir/pipeline.

Combined vs separated sewer systems

- Combined sewerage (CS): one underground pipe network collects blackwater + greywater + stormwater. Discharge goes to WWTP or directly to a water body.
- Separate sewerage (SS): two network - sanitary (black + grey) to WWTP. Stormwater to water body or infiltration after basic treatment. Lower risk of overflows and enables stormwater reuse (irrigation/infiltration/groundwater recharge).

Full municipal WWTP process

Wastewater constituents

- Gross pollutants, floating material, screening: sand, wood, plastics; removal by screens, sieves
- Oxygen-consuming substances: oxygen depletion in rivers, lakes, by sedimentation
- Nutrients: eutrophication, toxicity, N/P, removal by biological conversion.
- Pathogens: risk when bathing/eating seafood. Removal by disinfection/membrane filtration.

Colletive analysis

Indirect (measurable) parameters:

- COD, Chemical Oxygen Demand: oxygen amount required for the chemical oxidation of organic compounds. 1-2 h.
- BOD_5, Biochemical Ox. Dem.: within 5 days. T: 20°C. O amount for the biological degradation of organic compounds.

Direct (measurable) parameters:

- TOC, Total Organic Carbon: Tot. amount of organically fixed carbon.
- DOC (Dissolved Organic C): Tot. amount of organically fixed dissolved carbon.