Boosting Circular Systemic Solutions through
Virtual Regional Circular Economy Space

Pilot Study 2: Water Reuse and Nutrients Recovery CSS

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Pilot Case Introduction

- Two (2) CSS value chains will be established from multiple wastewater sources:

a) **water for irrigation and nature restoration** (scale: pilot plant treating from 0.2 to 1 m3/h of wastewater);

b) **nutrients for agriculture** (scale: lab/pilot scale valorising from 100 g up to 1 kg/d of biomass).

- Feasibility and applicability of at least **3 alternative scenarios:**

These three alternatives will be evaluated to select the best solution for regional conditions and needs.

Pilot Case Objectives

- This case enables and promotes **water reuse and nutrient recovery in the region of Marche**, integrated with agricultural, industrial and natural environment components;

- A composite CSS will establish, promote and support two value chains for water reuse and nutrient recovery:

- **Scale**:
  - ✓ The peri-urban area of the Municipality of San Benedetto del Tronto with a natural reserve and multiple agricultural and agro-industrial land uses (25.4 km^2 area, population of 47,000, 610,000 tourists in summer).
  - ✓ Sectors involved are seven: Water, food, agriculture, industry, urban/rural, nature eco-services, energy.

- **Key value chain actors**:
  - ✓ Comune di San Benedetto del Tronto/COMSBT (stakeholder, municipal governance);
  - ✓ Flora-horticultural district of Acquaviva-Grottammare;
  - ✓ CIIP (water utility);
  - ✓ Numerous farmers & agro-food industries (olive oil, wine, processed fruit, vegetables, meat, fish, milk derivatives, etc.).

- **Pilot Team**: UNIVPM, UVIC, CIIP.

- **Strategic CE ambition**:
  - ✓ Reuse of wastewater for irrigation and ecosystem restoration; bio-fertiliser production from organic waste.

Pilot Case replicability

a) Wastewater reuse pilot application can be replicated in other WWTPs managed by CIIP and be upscaled to all the territory;

b) In the Marche Region centralised treatment plants are planned or have been realised for the treatment of sewage sludge and organic wastes coming from different areas e.g., CIIP plans a centralised hub for treatment and valorisation of sewage sludge and organic wastes by thermal drying;

c) Hence, a successful practice for treatment of organic waste and recovery of bio-fertilisers can be potentially replicated in the whole regional territory.

Present Status/Background

- The peri-urban area of Comune di San Benedetto del Tronto consists of a **Natural Reserve, an industrial zone around it and the Tronto Valley with industry and agriculture**;

- The Sentina Natural Reserve (Natura 2000) has a coastline with **small dunes and natural vegetation while its main part consists of natural wetlands which provide shelter for many bird species and which constitute sites of touristic, recreational and educational activities**;

- In the last few years, this area has experienced **water stress, especially in summer; Hence, as a possible solution to the water shortage, the reuse of treated wastewater has been proposed by upgrading the WWTP**;
- Currently, **no wastewater reuse is performed in the entire Marche Region**, which is significantly affected by water stress conditions.
- Around the **Reserve and in the Tronto valley there are several agro-food industries and a flora-horticultural district, with high water and fertiliser demand**;
- To date, **conventional water sources are utilised**, including irrigation and feeding the natural ponds of the Sentina Natural Area during drought seasons;
- Fertilisers are also provided by conventional fossil fuel sources.

Present Status/Background

- However, the aforementioned sources of water are limited and not able to satisfy water demand in summer;During the last decades, the area began to suffer from water scarcity, making the issue of water availability critical;

- The water demand for agricultural activities is not fully satisfied, and there is the risk of the smaller ponds drying up, rendering this unique and fragile ecosystem severely endangered;

- Water scarcity can also produce negative impacts to the agricultural economy;

- The regional authority of Marche plans to increase the treatment and valorisation of sewage sludge and other organic wastes in the Region in the near future;

- In this context, in the Basso Tenna WWTP, 30 km from Tronto, CIIP plans to realise a centralized hub to collect the dewatered sewage sludge and other organic wastes from the area, to valorise them in terms of energy and resource recovery through a thermal drying process; The annual amount of sludge treated by the dryer will be approximately 6,000 tons and it can be further fed with other organic wastes from the territory up to a treatment capacity of 8,000 tons; The treatment of these organic wastes represents an important opportunity to recover bio-fertilisers.

CSS and Circular Value Chains

- Social barriers, related to the acceptance by farmers and food consumers of the use of resources (treated wastewater, bio-fertilisers) recovered by organic wastes in agriculture;
- Technical barriers to the creation of centralised hubs for the management and treatment of sewage sludge and other organic waste including logistic organisation aspects and the realisation of functional infrastructures;
- Economic and market challenges for the commercialisation of bio-fertilisers → These new products need to be competitive in terms of agronomic performance and costs when compared to traditional synthetic fertilisers.

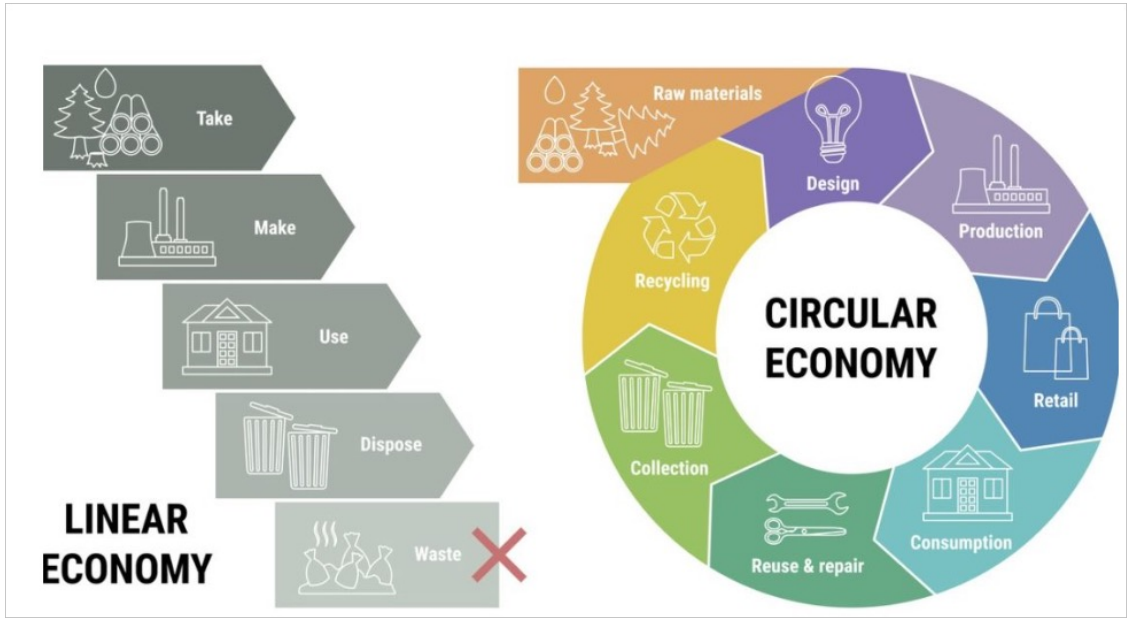


Image: iStock.com/m.malinika

Technical Solutions Demonstrated

- The CSS to be established is composed of 2 value chains, producing, from multiple wastewater sources:

(a) water for irrigation and nature restoration;
(b) nutrients for agriculture.

- The pilot will evaluate **feasibility and applicability of various alternative scenarios on the basis of the environmental footprint and the best approach that addresses different local requirements will be promoted**. Pilot scenarios will include:

a)	b)	c)
• Wastewater reuse with application of **nature-base solutions for mitigation in water source withdrawal**.	• Valorisation of **organic wastes and sewage sludge at the regional level**, with energy and nutrient recovery through a **co-digestion process for sustainable use of energy and mitigation of fossil fertiliser production**.	• **Valorising organic wastes through thermo-chemical processes for nutrient recovery for bio-fertiliser production**.

Technical Solutions Demonstrated

The evaluation will follow the following steps:

i. **Assessment of hydrogeological water balance between water supply availability and water demand/needs** for the ecosystem restoration, to evaluate the needed reclamation activities of non-conventional water sources;

ii. **Mass balance assessment of sewage sludge, livestock wastes, aquaculture and food industry waste, to evaluate feasibility and requirements of anaerobic co-digestion processes**;

iii. **Pilot plant implementation with a pre-filtration module and a combination of different NBS** (horizontal and vertical constructed wetlands) as refinement treatments to boost wastewater reuse for environmental needs;

iv. **Pilot thermochemical process implementation for testing the co-treatment of dried sewage sludge and dried harvested plants from the constructed wetlands** in various operative conditions. Recovery of nutrients (N and P) from ashes, tested and optimised by using chemical leaching and precipitation;

v. **Demonstration and assessment of the end-products performance** as substitutes to current mineral fertilisers, the key objective being to analyse nitrogen, phosphorus and carbon dynamics of the derived bio-based fertilisers as compared to mineral fertilisers in controlled experimental conditions (pot trials) and field trials;

vi. Overall regional CSS assessment, of both wastewater reuse and nutrient recovery potential with **water-mass-energy-carbon balance estimation**.

Technical Solutions Demonstrated

- A **demo plant will be realised on site, consisting of a pre-filtration device and a combination of different NBSs** (i.e., horizontal constructed wetlands and vertical constructed wetlands) as refinement treatments to boost wastewater reuse from San Benedetto WWTP for the environmental needs of the Natural Reserve and for agricultural reuse;

- In addition, **a thermochemical process at the pilot scale will be studied at UNIVPM facilities**, to simulate and test the cotreatment of the area's:

i. municipal wastewater;
ii. dried (even co-digested) sewage sludge and livestock wastes;
iii. aquaculture and food processing industry wastes;
iv. dried harvested plants from the constructed wetland of the WWTP under different operative conditions (e.g., temperature and ratio between substrates) aiming to optimise nutrient extraction (N and P) from the produced char/ashes by chemical leaching and precipitation processes.

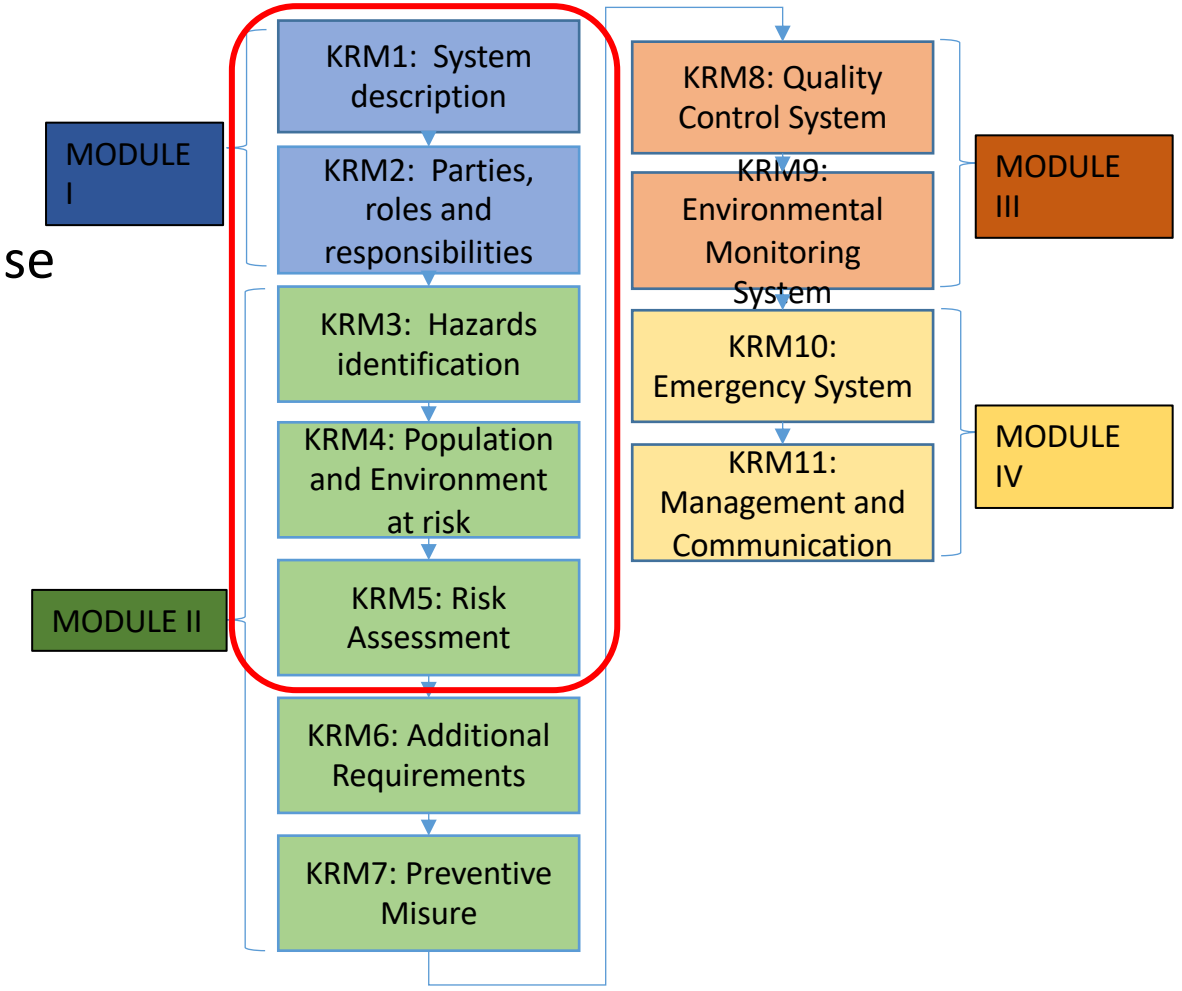
- The **end-product performance** as fertilisers will be demonstrated first at the laboratory scale and then in the field;

- Particularly, the **recovery bio-fertilisers may be used for the agricultural activities located in the Sentina Natural Reserve**;

- The **final wastewater effluent of WWTP will be treated by NBS for the implementation of agricultural reuse and ecosystem preservation by supplying water to the natural ponds of the Natural Reserve**.

REGULATORY FRAMEWORK

EU regulation 741/2020
Italian DM 185/2003
Italian DL 39/2023
Draft of new national DPR for water reuse



VALUTAZIONE DEL RISCHIO SANITARIO

P1A SCARICHI DOMESTICI

P1B DEFLUSSO ACQUE PIOVANE

P1C POSSIBILI SCARICHI ILLECITI

P1D SCARICHI INDUSTRIALI

P1E INFILTRAZIONE ACQUE SOTTERRANEE

P1 BACINO/RETE FOGNARIA

P2A PRETRATT.

P2B TRATTAM. PRIMAR

P2C BIOLOGICO (pre-anossico, clici alternati, defosfatazione

P2D SEDIMENTAZIONE SEC.

P2 IMPIANTO DI DEPURAZIONE

P3A FILTR. TERZIARIA

P3B UV + DISINFEZIONE CHIMICA

P3 AFFINAMENTO

C 1

R1 FIUME TRONTO

C 2

T1 CANALE/ ADDUTTORE CONSORZIO ASO, TENNA, TRONTO

T2 SISTEMA DI DISTRIBUZIONE

T3 IRRIGAZIONE E UTILIZZO

T3A AGRICOLTURA

T3B AMBIENTALE.

R ACQUE SUPER. 1

R ACQUE SOTTER. 2

R SUOLO 3

R COLTURE 4

R5 FLORA

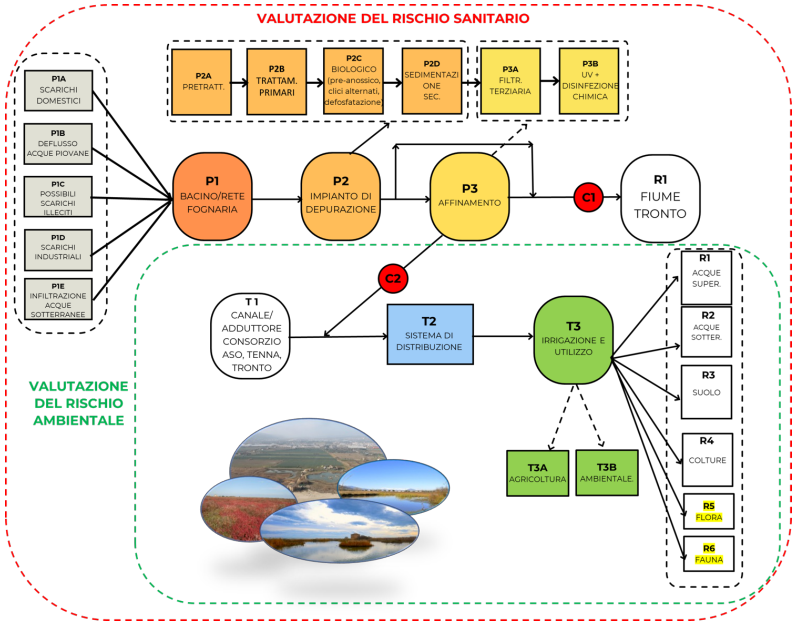
R6 FAUNA

VALUTAZIONE DEL RISCHIO AMBIENTALE

KRM2: PARTIES, ROLES AND RESPONSIBILITIES

Identification of actors, roles and responsability for risk management in each node of the reuse system

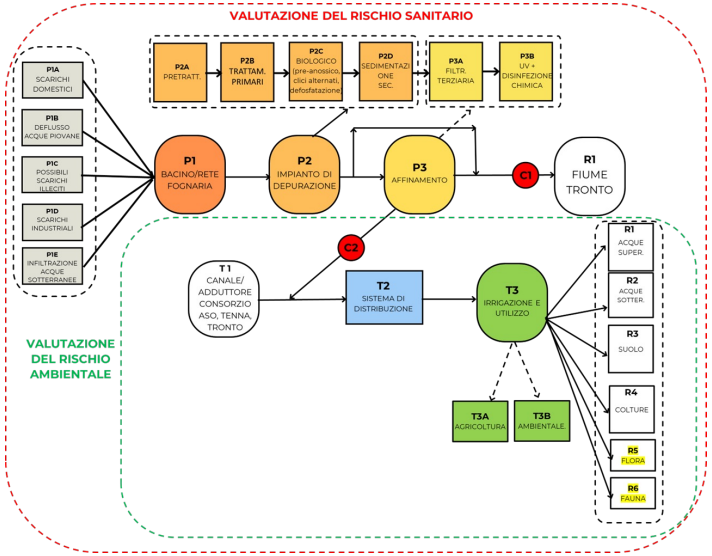
Element/Node of the Reuse System	Code	Actor	Role	Responsability
Catchment and sewer network	P1, T1	Environmental Protection Agency	Assess the compliance with regulation	Control and monitoring of authorized discharges in the sewer network
Catchment and sewer network	P1, T1	Local Authority	Decision about authorization of (industrial) discharges in the sewer network	Authorization of discharges in the sewer network that do not compromise water reuse
WWTP	P2	Water Utility (CIIP)	Management of the WWTP	Identification and management of risks within the WWTP
Adduction System	T2	Irrigation Consortium	Management of the distribution system	Identification and management of risks within the distribution system
.....	.....	.....	.....	.....



KRM3: HAZARDS AND HAZARDOUS EVENT IDENTIFICATION

Hazardous events were identified by:

- Analyzing each node of the water reuse system
- Consultation with managers of the different elements of the water reuse system
- Field inspections and check-lists



CHECK LIST IMPIANTO DI DEPURAZIONE

Nod	Attività	Mar	Dettaglio	Punteg	Specifiche / Note
DATI GENERALI	Nome IMPIANTO DI DEPURAZIONE	☒	FREGENE		
	Indirizzo IMPIANTO DI DEPURAZIONE	☒	Via Tirrenia, 79, 00054 Fregene RM		
	Codice identificativo GIS	☐			
	Data rilievo	☒	11/11/2021		
	Georeferenziazione: Coordinate WGS84	☒	Latitudine: 41°52'3.77"N		
		☒	Longitudine: 12°11'22.08"E		
	Operatori	☒			
	Criticità note	☐			
	Fase preliminare:	☒	scheda impianto, idraulico e funzionale		
		☒	verifiche ispettive precedenti		
		☒	dati di esercizio (parametri operativi)		Estensione periodo 2018-2021
		☒	Valori sensibili, trend storici (Portate, concentrazioni)		Estensione periodo 2018-2021
		☒	Programma di manutenzione		
		☒	procedure di gestione del depuratore		
AUTORIZZAZIONE	*STATO AUTORIZZATIVO*		Autorizzazione allo scarico 2012, Limiti Tab. 1 e Tab. 3 Allegato 5 D. Lgs 152/2006, E.coli < 5000 UFC/100 ml		
	Potenzialità	☒	76000AE		
	Portata media giornaliera	☒	29064 m3/d		
	Portata massima	☒	1816m3/h		
	Corpo recettore finale	☒	Fiume Arrone		
	Estensione	☒	13km2		
	Comuni serviti	☒	Fregene, Focene, Maccarese, Passoscuro, Aranova e Palidoro		
	Contesto territoriale	☐	in area industriale	5	

KRM4: HAZEXPOSED GROUPS AND ENVIRONMENTS

Hazards were identified by regulated contaminants and microbiological indicators

Table CS8.2. Identification of hazards, route of exposure and populations and environments at risk at the ACEA Fregene water reuse system

	Hazards	**Populations and environments at risk (1)**	**Routes of exposure**
Health Hazards	Microbial parameters (*E. coli*), according to EU 741/2020 and National Regulation on water reuse DM 185/2003	Local community and bystanders	Ingestion, aerosol and/or direct skin contact with reclaimed water
		WWTP and reclamation facility workers	Ingestion, aerosol and/or direct skin contact with reclaimed water
		Farmers	Ingestion, aerosol and/or direct skin contact with reclaimed water
Environmental Hazards	Physical-Chemical parameters, according to EU 741/2020, National Regulation on water reuse DM 185/2003, as well as Italian Decree D.Lgs. n 152/2006	Crops	Crops uptakes or direct contact with reclaimed water during irrigation
		Soil	Infiltration of reclaimed water in the soil
		Surface water	Run-off of reclaimed water
		Groundwater	Infiltration of reclaimed water
		Vulnerable and protected areas	Run off or infiltration of reclaimed water
Hazardous events			
At the catchment area: unexpected overflows or loads in the sewer network, saline water intrusion, unexpected industrial discharges. *At the WWTP*: failures at different treatment stages, nitrification-denitrification, UV malfunctioning, chemical dosage failures, solids escape, sedimentation issues, sensors faults.			

(1) Even if in this case-study they were considered, consumers wouldn't be taken into account in RMP, since they are outside water reuse system boundaries.

KRM5: RISK ASSESSMENT

Tabella 1 *- Matrice utilizzata per il calcolo del rischio sanitario nel sistema di riuso di XXXX*

MATRICE DI RISCHIO			Gravità del pericolo (G)				
			Insignificante	Basso	Moderato	Elevato	Catastrofico
			1	2	3	4	5
Probabilità di accadimento (P)	Raro	1	1	2	3	4	5
	Poco probabile	2	2	4	6	8	10
	Moderato	3	3	6	9	12	15
	Probabile	4	4	8	12	16	20
	Quasi certo	5	5	10	15	20	25
R = P x G			< 6	6 - 9	10 – 15	> 15	
Livello di rischio			Rischio Basso	Rischio Medio	Rischio Alto	Rischio Molto Alto	

TOOL 3.5. Suggested risk definitions for semi-quantitative risk assessment

	DESCRIPTOR	DESCRIPTION
Likelihood (L)		
1	Very unlikely	Has not happened in the past and it is **highly improbable** it will happen in the next 12 months (or another reasonable period).
2	Unlikely	Has not happened in the past but **may occur in exceptional circumstances** in the next 12 months (or another reasonable period).
3	Possible	May have happened in the past and/or **may occur under regular circumstances** in the next 12 months (or another reasonable period).
4	Likely	Has been observed in the past and/or is **likely** to occur in the next 12 months (or another reasonable period).
5	Almost certain	Has often been observed in the past and/or **will almost certainly occur** in most circumstances in the next 12 months (or another reasonable period).
Severity (S)		
1	Insignificant	Hazard or hazardous event resulting in **no or negligible health effects** compared with background levels.
2	Minor	Hazard or hazardous event potentially resulting in **minor health effects** (e.g. temporary symptoms of irritation, nausea, headache).
4	Moderate	Hazard or hazardous event potentially resulting in **self-limiting health effects or minor illness** (e.g. acute diarrhoea, vomiting, upper respiratory tract infection, minor trauma).
8	Major	Hazard or hazardous event potentially resulting in **illness or injury** (e.g. malaria, schistosomiasis, food-borne trematodiases, chronic diarrhoea, chronic respiratory problems, neurological disorders, bone fracture), and/or may lead to **legal complaints** and concern, and/or major **regulatory noncompliance**.
16	Catastrophic	Hazard or hazardous event potentially resulting in **serious illness or injury, or even loss of life** (e.g. severe poisoning, loss of extremities, severe burns, drowning), and/or will lead to **major investigation by regulator**, with prosecution likely.

KRM5: MATRIX FOR RISK ASSESSMENT

IDENTIFICAZIONE DEL SITO			IDENTIFICAZIONE DEGLI EVENTI PERICOLOSI E DEI PERICOLI ASSOCIATI							RISCHIO PRELIMINARE			MISURE DI CONTROLLO ESISTENTI		RISCHIO RESIDUALE			PIANO DI MIGLIORAMENTO	VALIDAZIONE MISURE INTEGRATIVE E MONITORAGGIO INTEGRATIVO			
CODICE NODO	SUB-SISTEMA	DESCRIZIONE NODO	EVENTO PERICOLOSO + CONSEGUENZE	Evidenze a supporto dell'attribuzione della probabilità/possibilità di accadimento	Evidenze a supporto dell'attribuzione della gravità dell'impatto (scenario peggiore)	BIOLOGICO	CHIMICO	FISICO	VIE DI ESPOSIZIONE	PROBABILITÀ DI ACCADIMENTO	GRAVITÀ DEL PERICOLO	RISCHIO	MISURE DI CONTROLLO	OSSERVAZIONI DI SUPPORTO	PROBABILITÀ DI ACCADIMENTO	GRAVITÀ DEL PERICOLO	RISCHIO	NECESSITÀ DI MISURE INTEGRATIVE	Validazione Misure Integrative e/o Monitoraggio integrativo	PROBABILITÀ DI ACCADIMENTO* (* Probabilità di accadimento valutata su stime teoriche)	GRAVITÀ DEL PERICOLO	RISCHIO RESIDUALE FINALE ATTESO POST INTERVENTO
Tutti i nodi	Tutti i sub-sistemi	Tutti i nodi	Interruzioni di servizio/Inefficienza delle unità che necessitano di energia elettrica dovute a black-out/interruzione di energia elettrica di almeno un'ora.	Avvenuto in passato	Mancato rispetto dei limiti normativi per tutti i parametri regolamentati	x	x	x	1. contatto dermico 2. Ingestione 3. Inalazione	2	5	10	1. Allarmi monitorati da TLC, secondo procedure aziendale 2. Presenza generatore di emergenza per le utenze privilegiate che viene controllato semestralmente 3. Presenza doppio UPS di alimentazione 4. Comunicazioni da parte del fonitore in caso di interruzione programmate 5. Istruzioni operative per la gestione delle emergenze (da implementare) 6. Telecamere di visualizzazione area impianto connesse con vigilanza privata		1	5	5				5	0
Tutti i nodi		Tutti i nodi	Interruzione del servizio causato da eventi catastrofici o calamità naturali	Evento poco probabile ma che non si può escludere che avvenga in futuro. I trend sui cambiamenti climatici potrebbero avere impatto sulla ripetibilità (es. alluvioni)-	Mancato rispetto dei limiti normativi per tutti i parametri regolamentati	x	x	x	1. contatto dermico 2. Ingestione 3. Inalazione	1	5	5	1.Sistema antincendio (solo linea fanghi impianto depurazione) 2.Piano emergenze 3. Telecamere di visualizzazione area impianto connesse con vigilanza privata	*Sistema antincendio presente in impianto di depurazione (linea fanghi)*	1	5	5				5	0
Tutti i nodi		Tutti i nodi	Rischio di mancata comunicazione tra le diverse parti responsabili del sistema di riuso	Evento plausibile, soprattutto in certe circostanze che possono realisticamente verificarsi	Possibilità di utilizzare acqua affinata non rispettando i limiti di normativa per i parametri classificati come: Patogeni, Macro-inquinanti	x	x	x	1. contatto dermico 2. Ingestione 3. Inalazione	5	5	25	1. Condivisione delle informazioni tra le parte come da Piano di Gestione del Rischio 2. Elaborazione protocollo di comunicazione tra i soggetti coinvolti		3	5	15				5	0
P1+P2+P3		Rete fognaria + Impianto di depurazione	Effetto cambiamenti climatici: potrebbero osservarsi in futuro un maggior numero di fenomeni estremi di precipitazione. Fenomeni estremi di precipitazione compromettono l'efficienza dell'intero processo depurativo	Frequnza di accadimento moderata-alta. Evento plausibile, soprattutto in certe circostanze che possono realisticamente verificarsi	Mancato rispetto dei limiti di normativa per tutti i parametri regolamentati da normativa	x	x	x	1. contatto dermico 2. Ingestione 3. Inalazione	3	5	15	1. Piano di emergenza con possibile interruzione del servizio (da implementare) 2. Sorveglianza da parte di personale tecnico 3. Misuratore di portata 4. In programma: avvio nuova vasca di equalizzazione (commessa DX64)		2	5	10	Finalizzazione piano di emergenza			5	0
P1	BACINO/RETE FOGNARIA	Rete fognaria	Effetto cambiamenti climatici: Aumento dei fenomeni di siccità e stress idrico potrebbero avere ripercussioni sul livello della falda acquifera con incremento dei fenomeni di intrusione salina. Questo può causare elevati livelli di cloruri, salinità e conducibiltà nell'acqua affinata	Non avvenuto in passato, non si può escludere che avvenga nel futuro	Mancato rispetto dei limiti di normativa per salinità, conducibilità, SAR (macro-inquinanti), cloruri (ioni con tossicità medio bassa)		x		1. contatto dermico 2. Ingestione	1	3	3	1. Programmi di monitoraggio 2. Interruzione riuso nel caso di concentrazione cloruri e conducibilità superiori ai limiti di legge		1	3	3	Monitoraggio cloruri e salinità Finalizzazione piano di emergenza			3	0
P1		Deflusso delle acque piovane/Rete fognaria	Sovraccarico idraulico a seguito di deflusso acque piovane con conseguente inefficienze di trattamento e di rimozione	Avvenuto in passato, evento molto probabile anche in futuro	Mancato rispetto dei limiti normativi per le seguenti classi di parametri: Macro-inquinanti; Nutrienti; Parametri microbiologici	x	x	x	1. contatto dermico 2. Ingestione 3. Inalazione	5	5	25	1. Controllo periodico impianti fognari (manutenzione) 2. Telecontrollo impianti sollevamento con soglie di allarme per livelli e funzionamenti pompe 3. By-pass 4. Misuratore portata ingresso impianto; 5. on/off pompe, sonde di livello; 6. Procedure interne e piano di emergenza (da implementare) 7. Avvio nuova vasca di equalizzazione		3	5	15				5	0
P1		Deflusso delle acque piovane/Rete fognaria	Possibile aumento delle concentrazioni di TSS e della torbidità in ingresso impianto per sovraccarico di solidi dopo eventi piovosi, con possibile conseguente incremento degli agenti microbiologici per effetto vettore e possibile riduzione dell'efficienza di disinfezione a causa dell' effetto screening sulle lampade e possibile non conformità E.coli, patogeni e/o TSS all'uscita impianto	Avvenuto in passato, evento molto probabile anche in futuro	Mancato rispetto dei limiti normativi per le seguenti classi di parametri: Macro-inquinanti; Parametri microbiologici	x	x	x	1. contatto dermico 2. Ingestione 3. Inalazione	4	5	20	1. filtrazione terziaria, manutenzione/pulizia UV 2. Sonde solidi e torbidità in uscita impianto (presenza analizzatori); 3. Sensori trasmittanza incorporati nelle lampade UV; 4. Manutenzione periodica lampade; 5. Misuratore portata ingresso impianto; 6. on/off pompe, sonde di livello; 7. monitoraggio esercizio ed efficienza filtri terziari; 8. campionamenti periodici anche specifici per eventi piovosi 9. avvio funzionamento nuova vasca di equalizzazione 10. presenza di analizzatori in continuo ingresso/uscita (e collegamento al tlc) 11. Piano di emergenza per riuso (KRM10)		3	5	15	Messa in servizio e validazione trattamenti terziari prima del riuso			5	0

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