

Interconnected Digital Twins for Water Contamination Management

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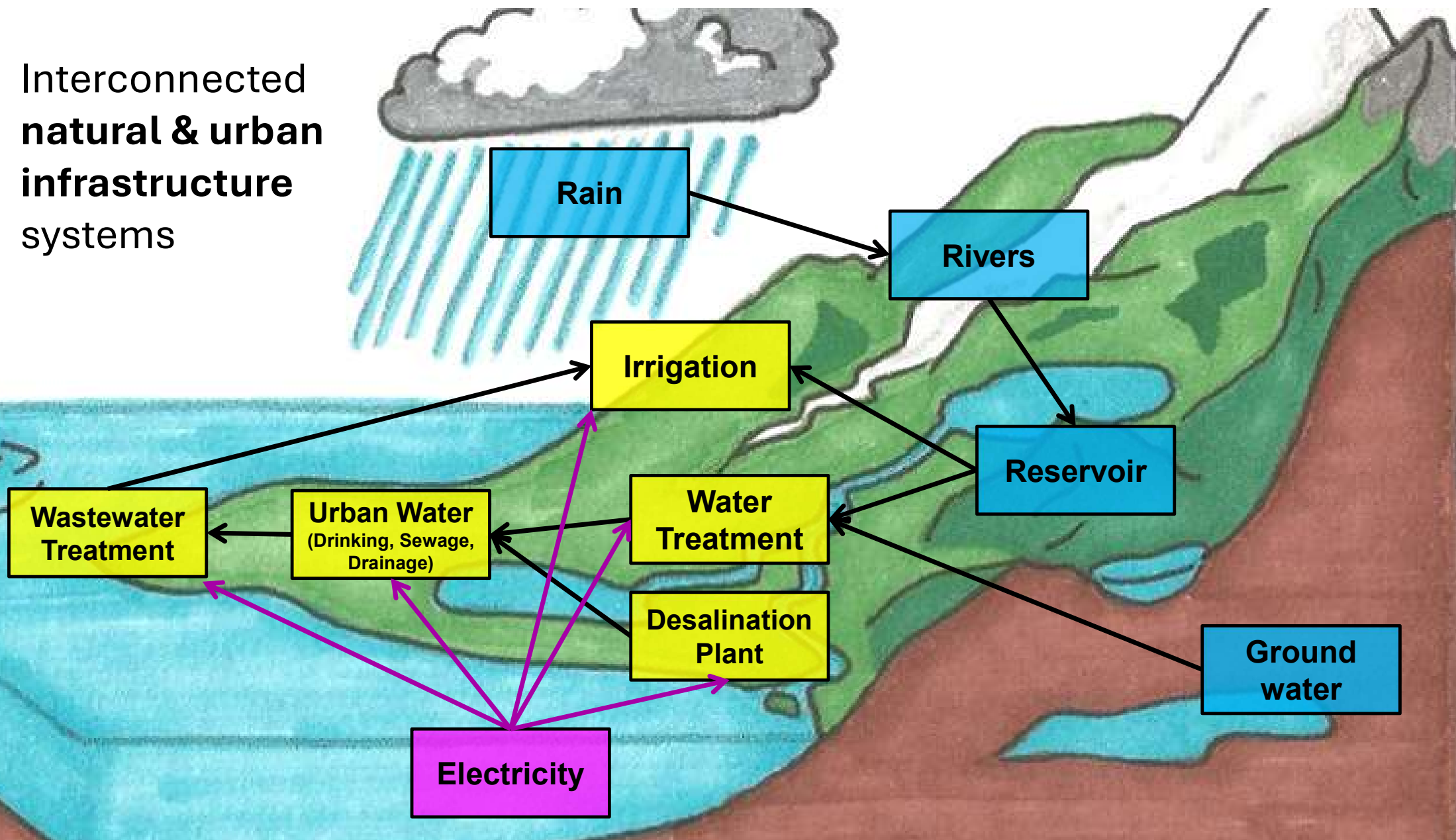
KIOS Research and Innovation Center of Excellence
University of Cyprus

**EGU2025: Session HS5.4.4 Digital water and
interconnected urban infrastructure**

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Interconnected
natural & urban
infrastructure
systems



Pathogen Contamination Risk

- **Floods increase the risk of water contamination** from sewage overflows, and decomposing organic matter
- **Waterborne pathogens:** E. Coli, Campylobacter, Norovirus, enterovirus, etc.
- **Health risks:** Gastrointestinal & respiratory infections, long-term health effects, death
- **Cascading risks due to digital breakdown:** power outage affecting pumping/treatment, automations not working

NEWS

The risk that a massive blackout represents for water supply in Spain

Although backup systems allow for gaining a few hours or days of time, their inevitable depletion leads to the collapse of the entire water cycle. Capture, purification, distribution, and sanitation depend deeply on electricity

Challenging the status quo

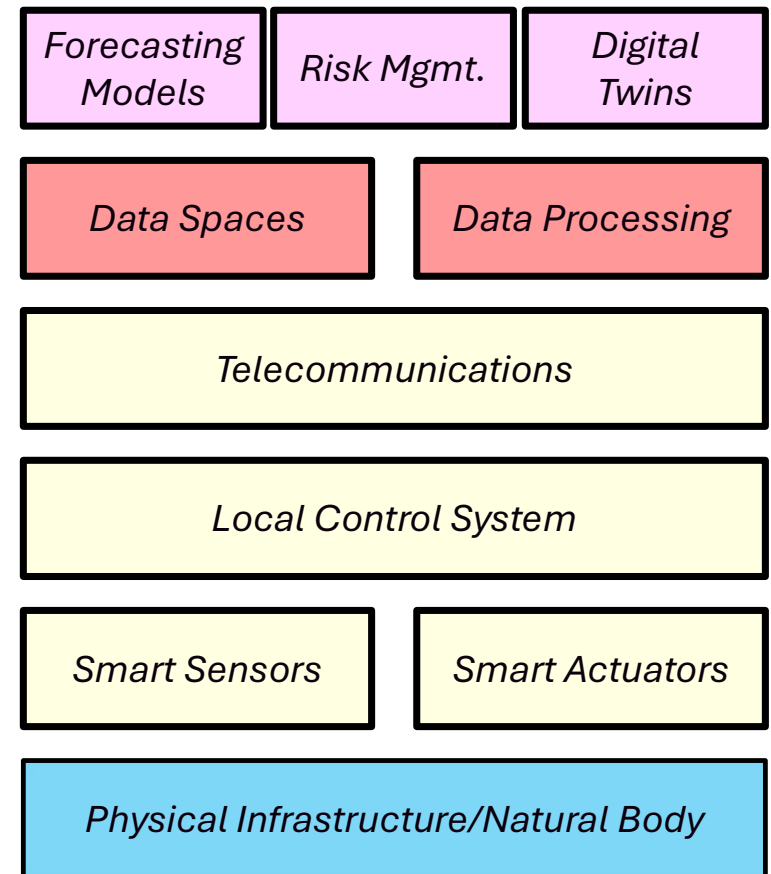
- Typically, each (smart) water, power, and transport system is managed **separately** by a different agency.
- Each agency follows different **regulations** and **responsibilities**.
- There is limited **data sharing** between systems and agencies.
- Scientific **specializations** limited to a subset of these system.
- **Boundary conditions** for **models** (and Digital Twins) are assumed “known”.

Moving towards interconnected digital twins, implies using **digital tools** to monitor, simulate and manage smart systems in a **holistic, distributed** way.

- ✓ Internet of Things/EO
- ✓ Digital Twins
- ✓ Data Spaces
- ✓ Artificial Intelligence

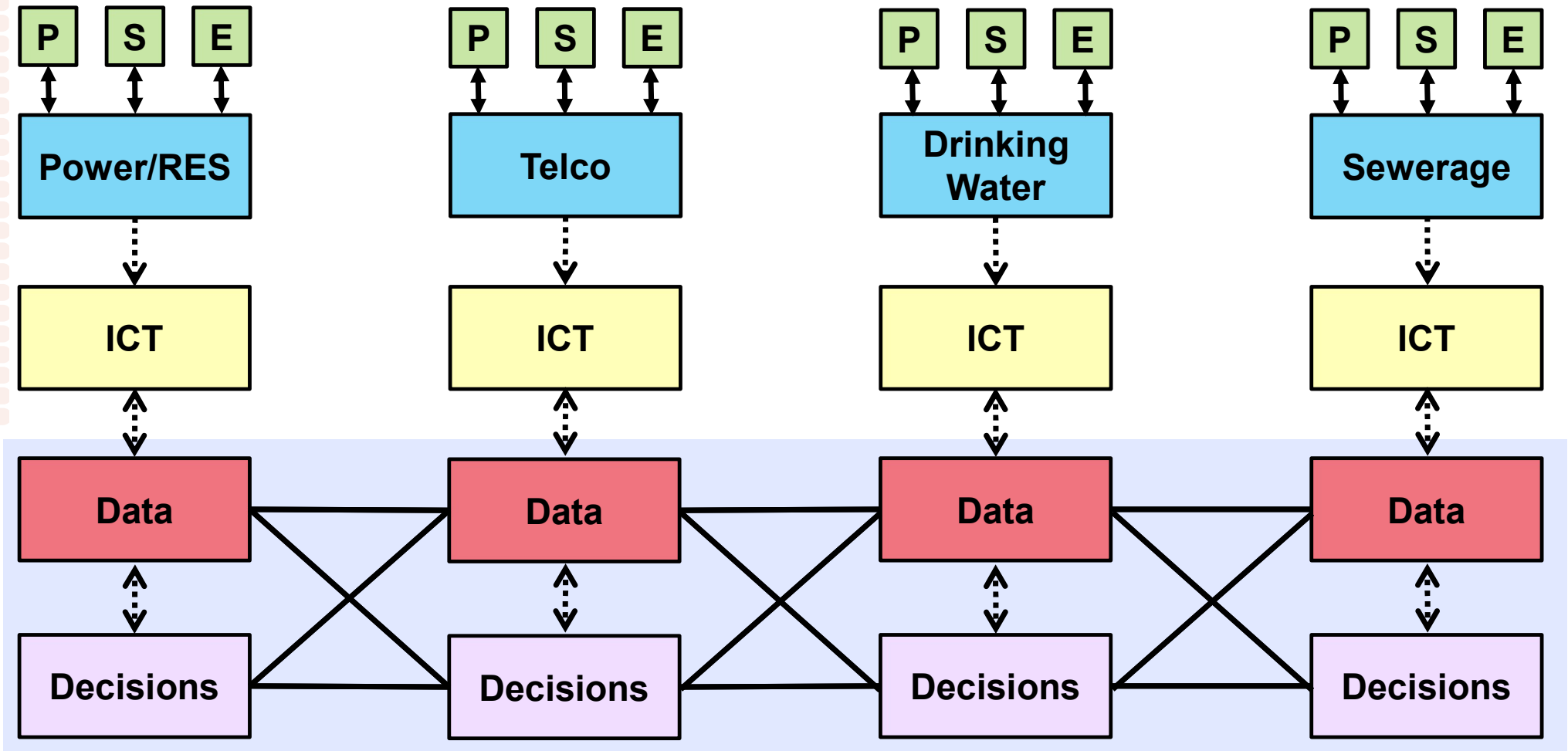
What is a Smart Water System?

- Integration of **smart sensors** and **smart actuators** into water systems using **information technology, communications,** and **data spaces**.
- Tools for short-term and long-term **decision-making**, optimization, and control through **digital twins** and **artificial intelligence**.
- Enhancement of **efficiency** and improvement of the **safety, reliability, resilience, quality,** and **robustness** of water supply systems.
- Minimization of risks** due to uncertainties, extreme events, and climate change.



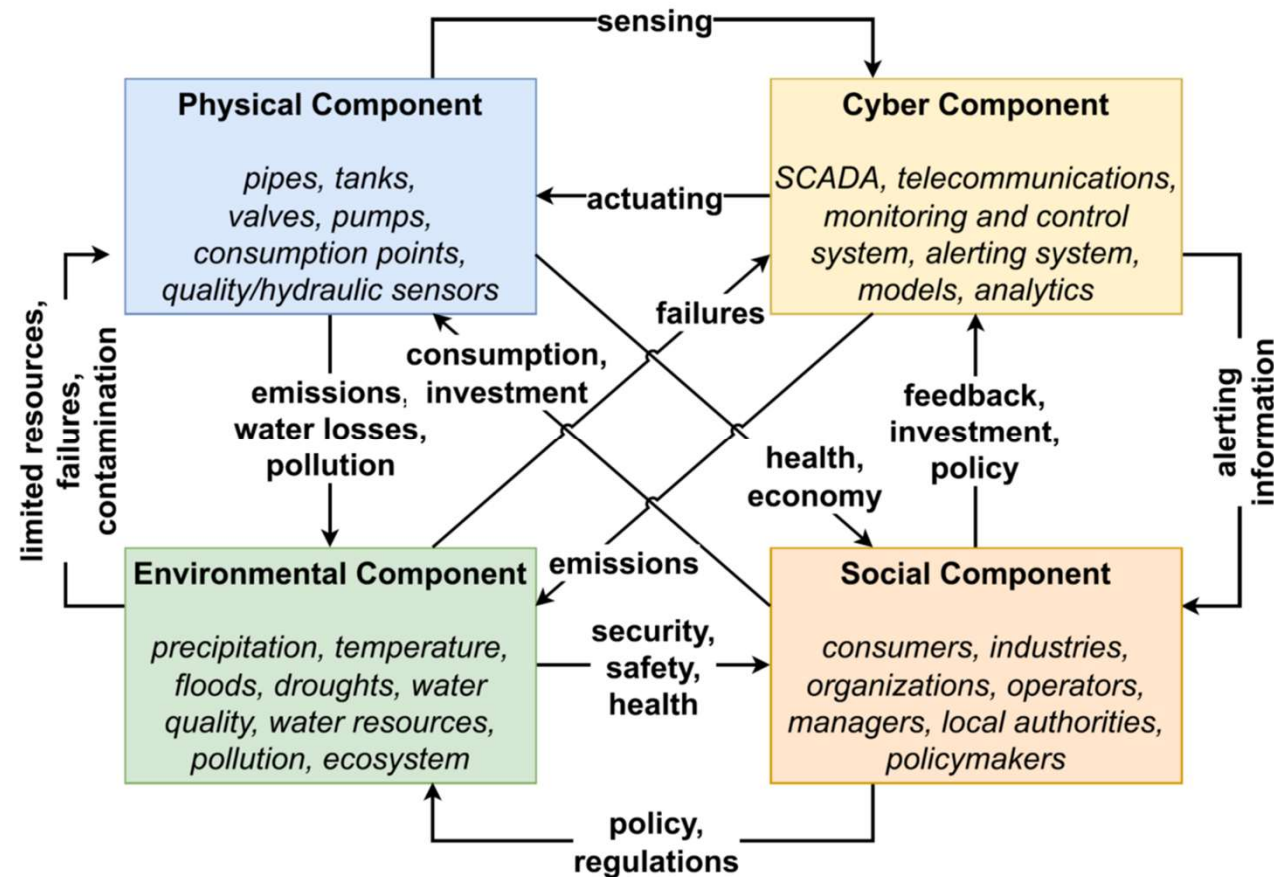
Towards Digital Interconnected Twins

Physical
Social
Environmental

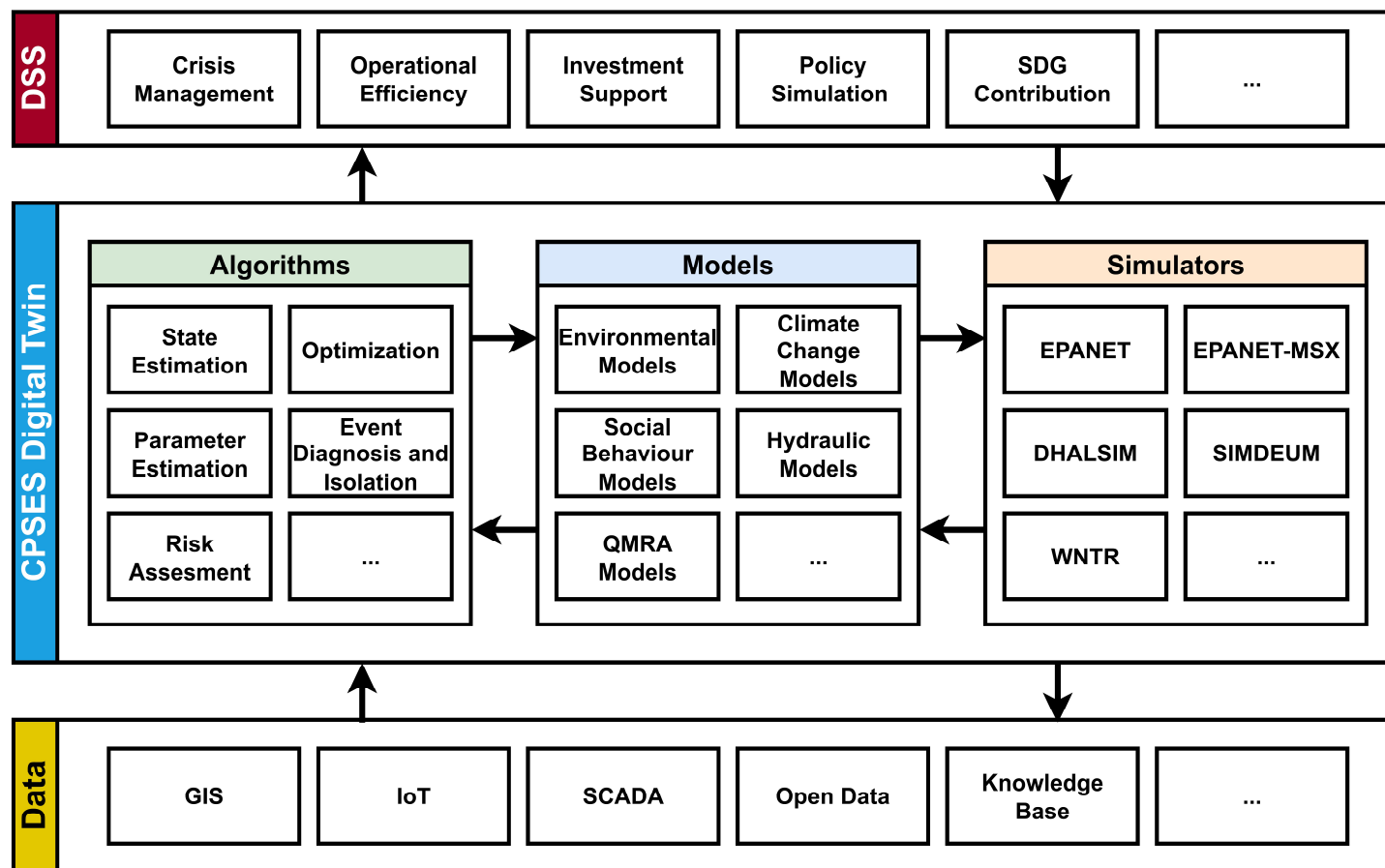


Cyber-Physical-Socio-Environmental System (CPSES)

- Water systems have multiple interdependencies with cyber, physical, social, and environmental components.
- Their interdependencies need to be mapped.
- Digital Twins could model some of these.

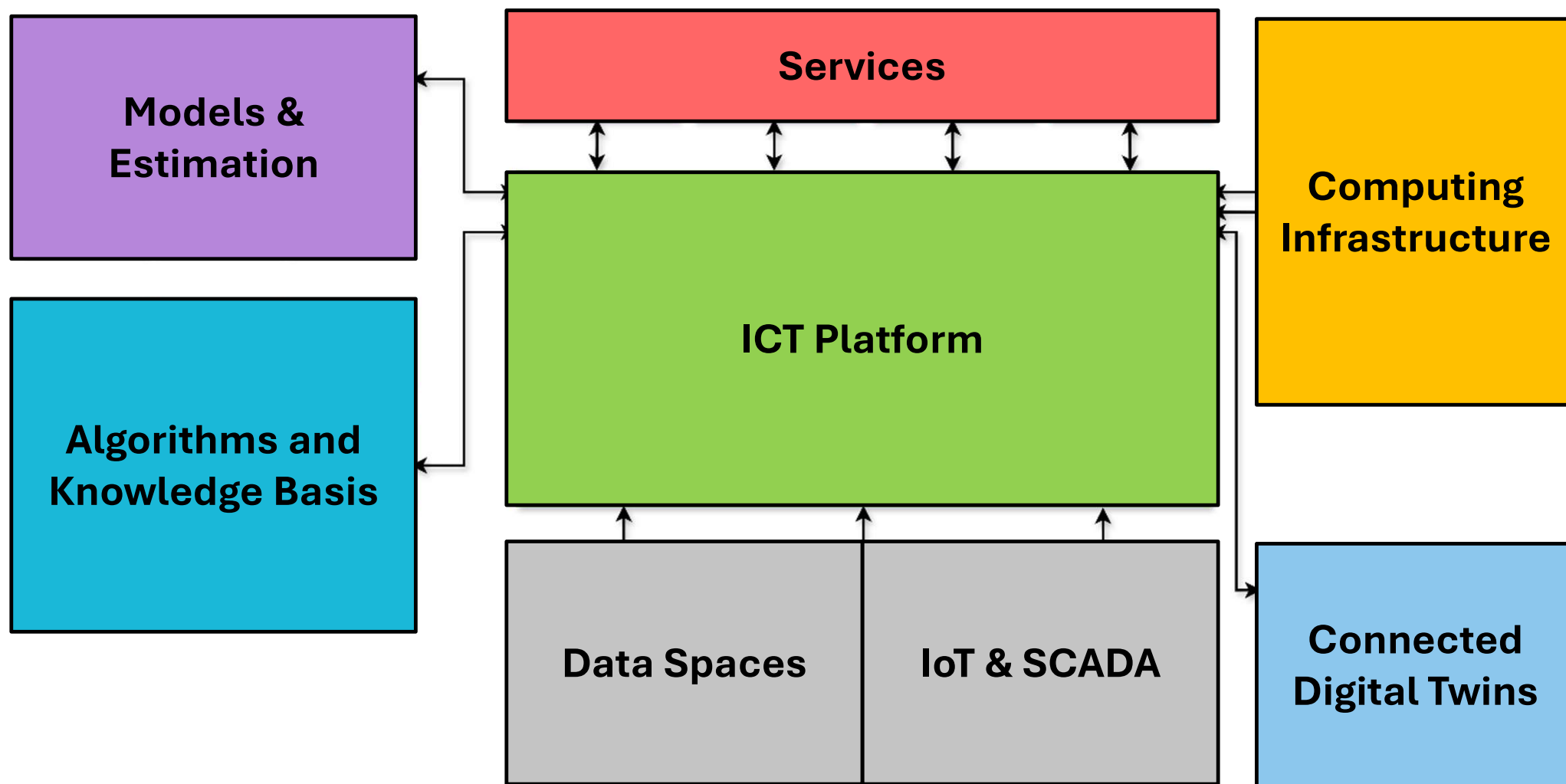


Cyber-Physical-Socio-Environmental System (CPSES)

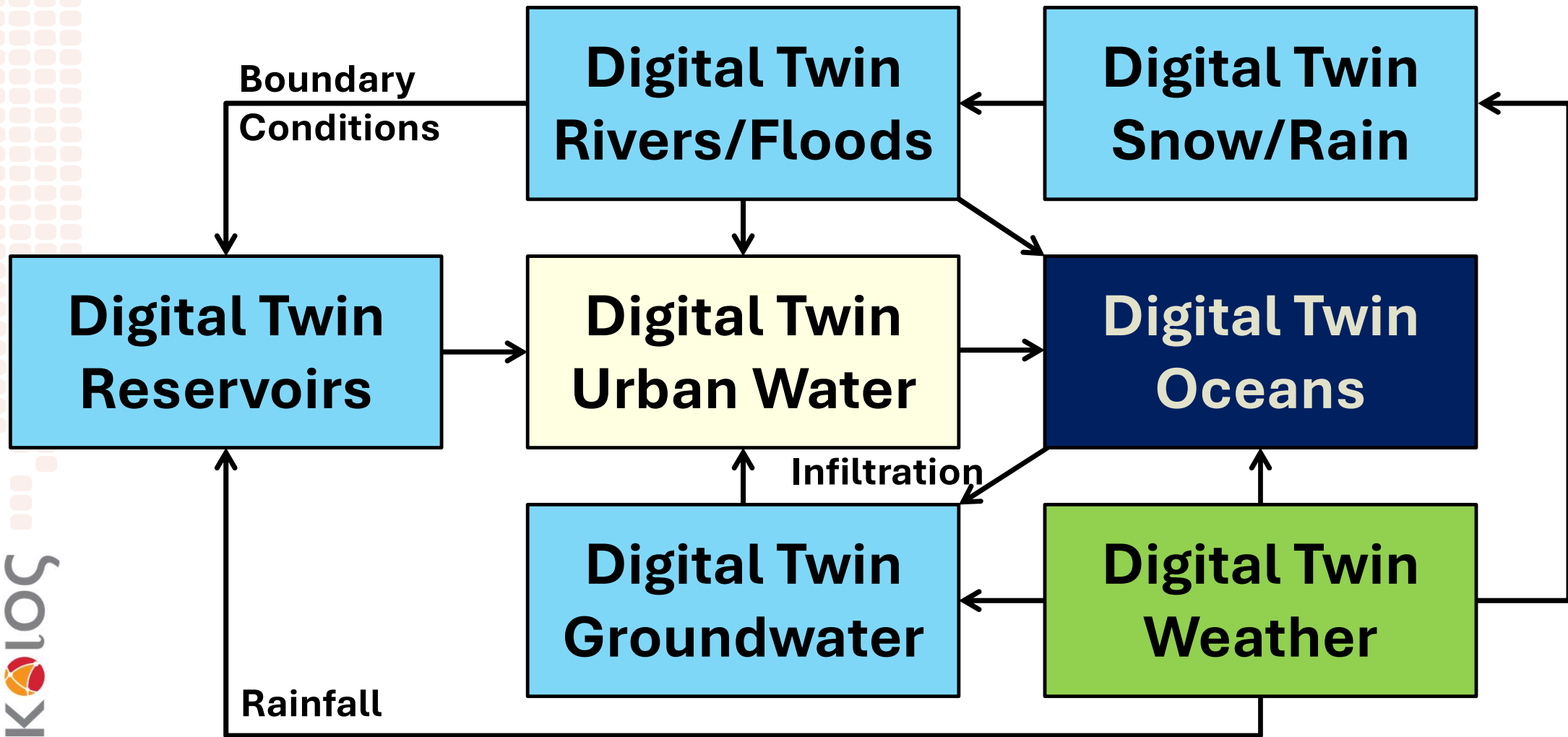


Eliades, D.G., Malialis, K., Vrachimis, S. and Polycarpou, M.M., 2024. Smart Water Networks as Cyber-Physical-Socio-Environmental Systems. *IEEE Transactions on Industrial Cyber-Physical Systems*.

Under the hood of a Digital Twin

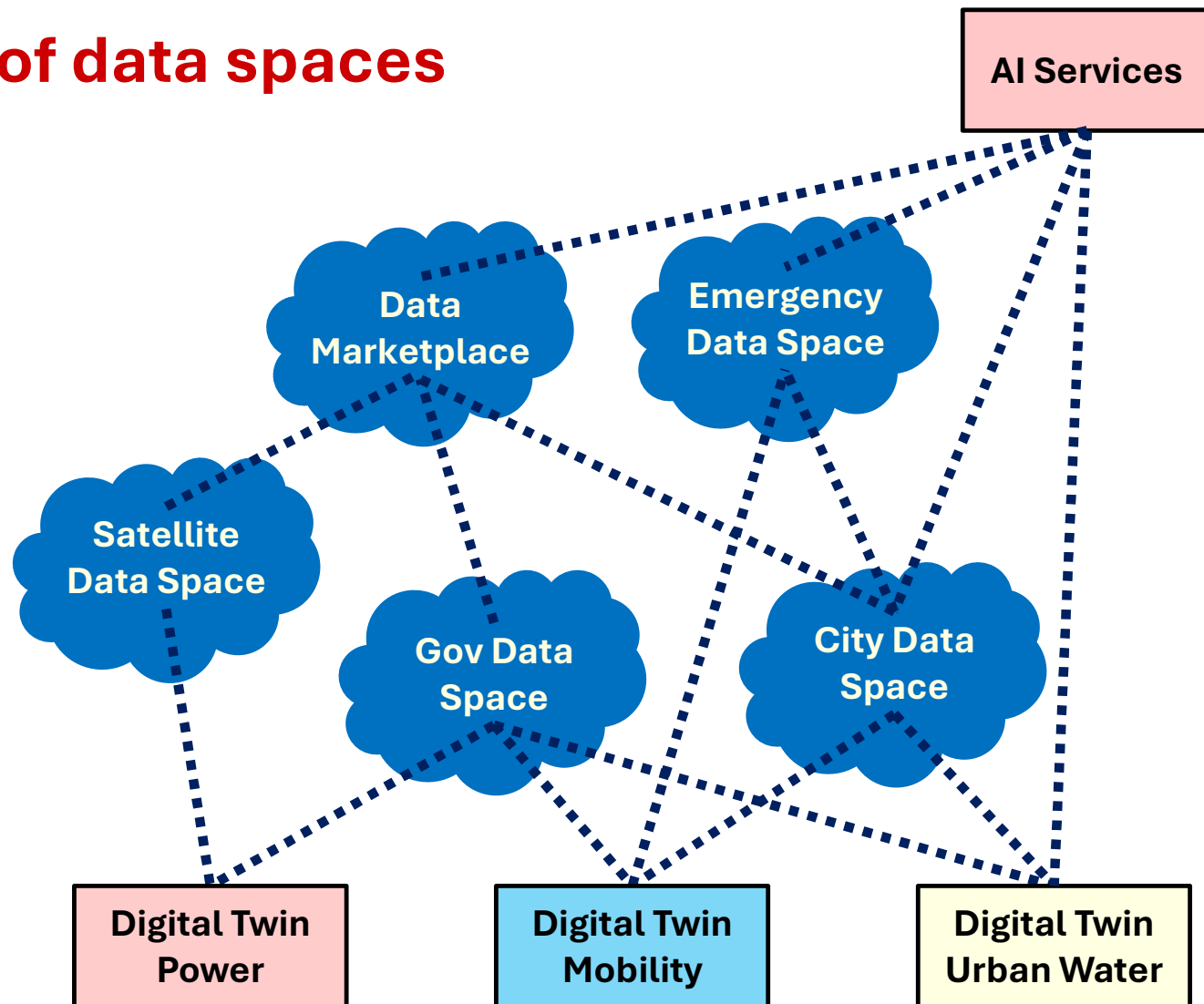


Interconnected Digital Twins



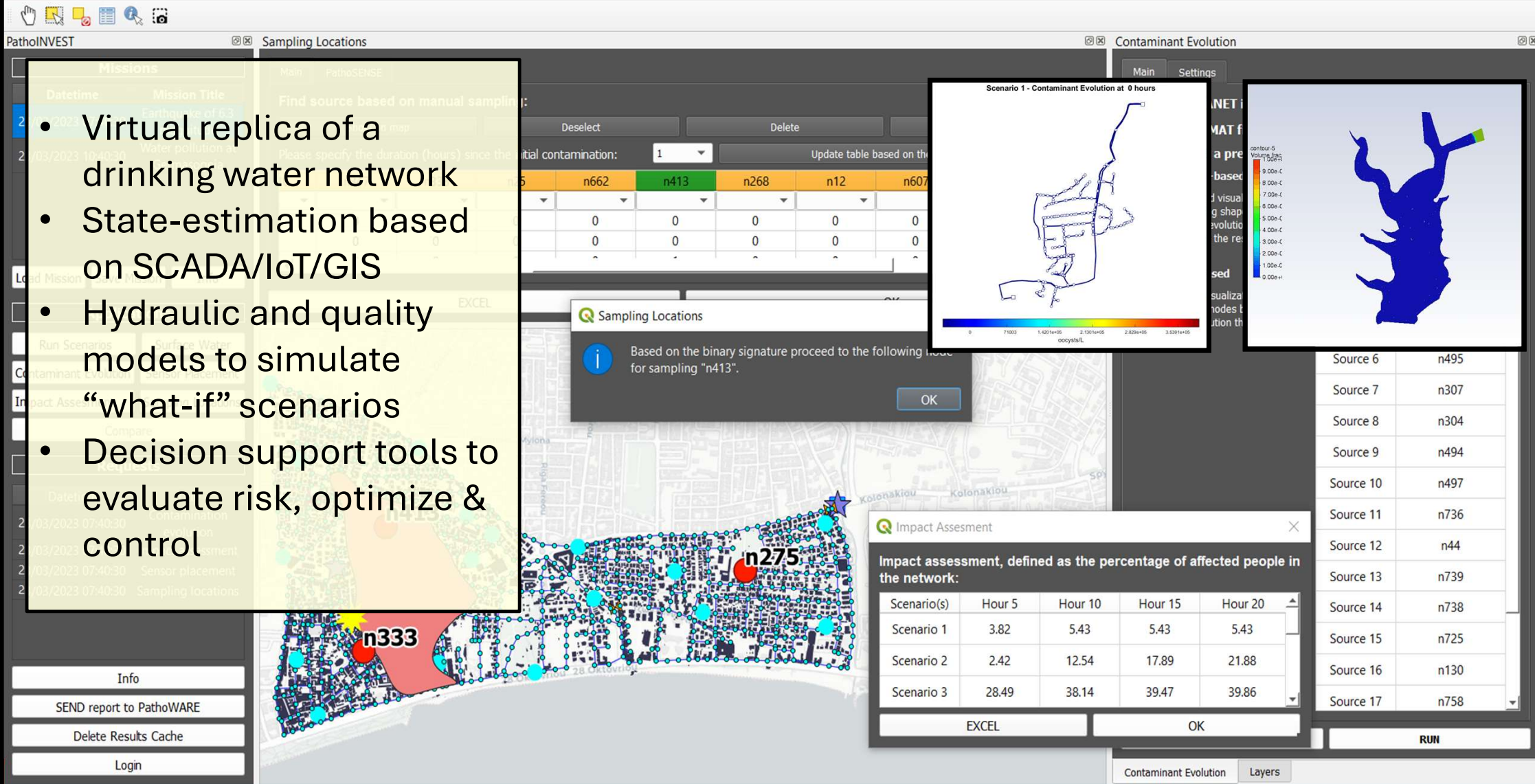
A federated network of data spaces

- The concept of data spaces was introduced in the **European Data Strategy** to support the idea of a single market for data (EU Data Act).
- It goes beyond data sharing by introducing data governance.
- A federated, secure, trustworthy, and interoperable network of data spaces enables AI services.



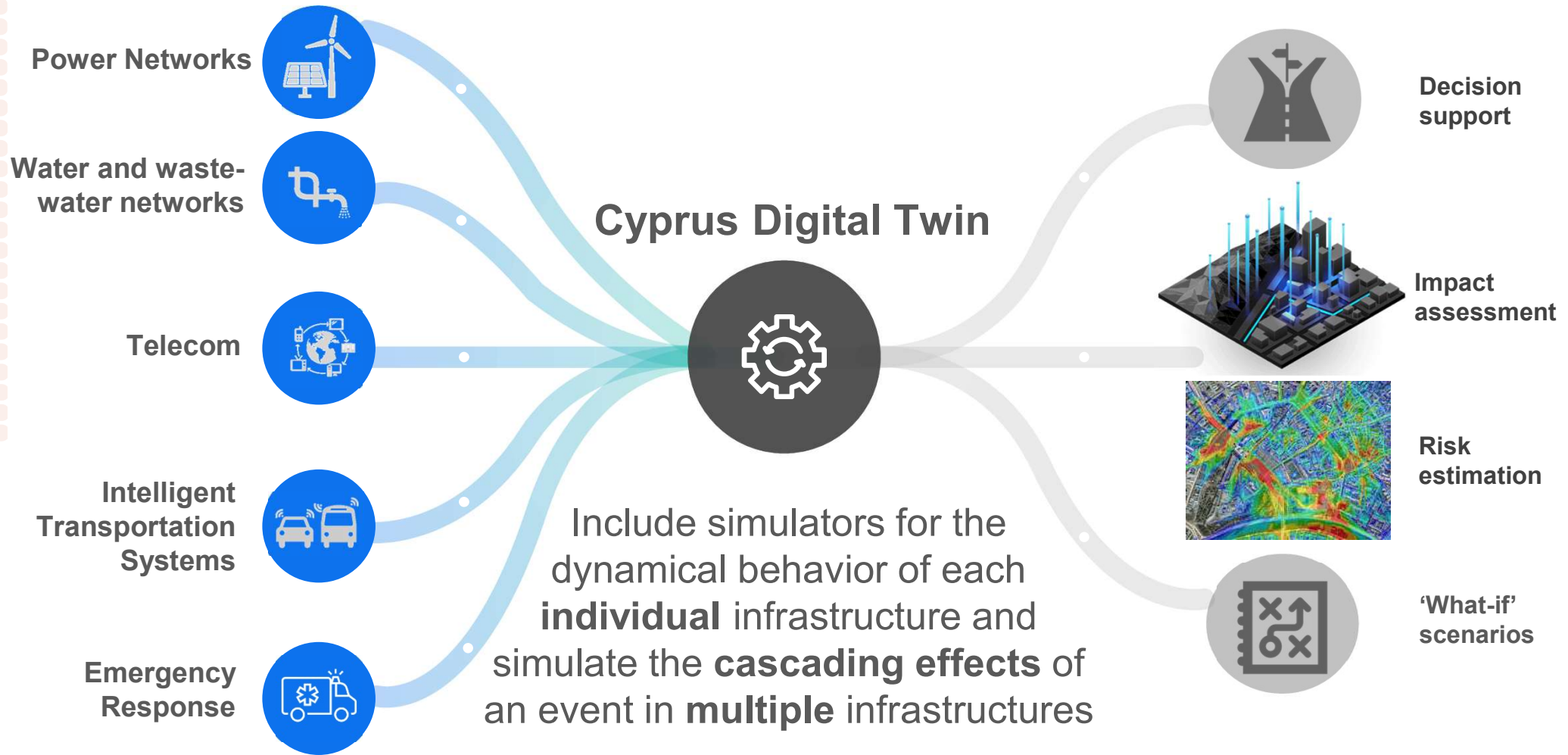
Example: Digital Twin for Urban Water Quality

- Virtual replica of a drinking water network
- State-estimation based on SCADA/IoT/GIS
- Hydraulic and quality models to simulate “what-if” scenarios
- Decision support tools to evaluate risk, optimize & control

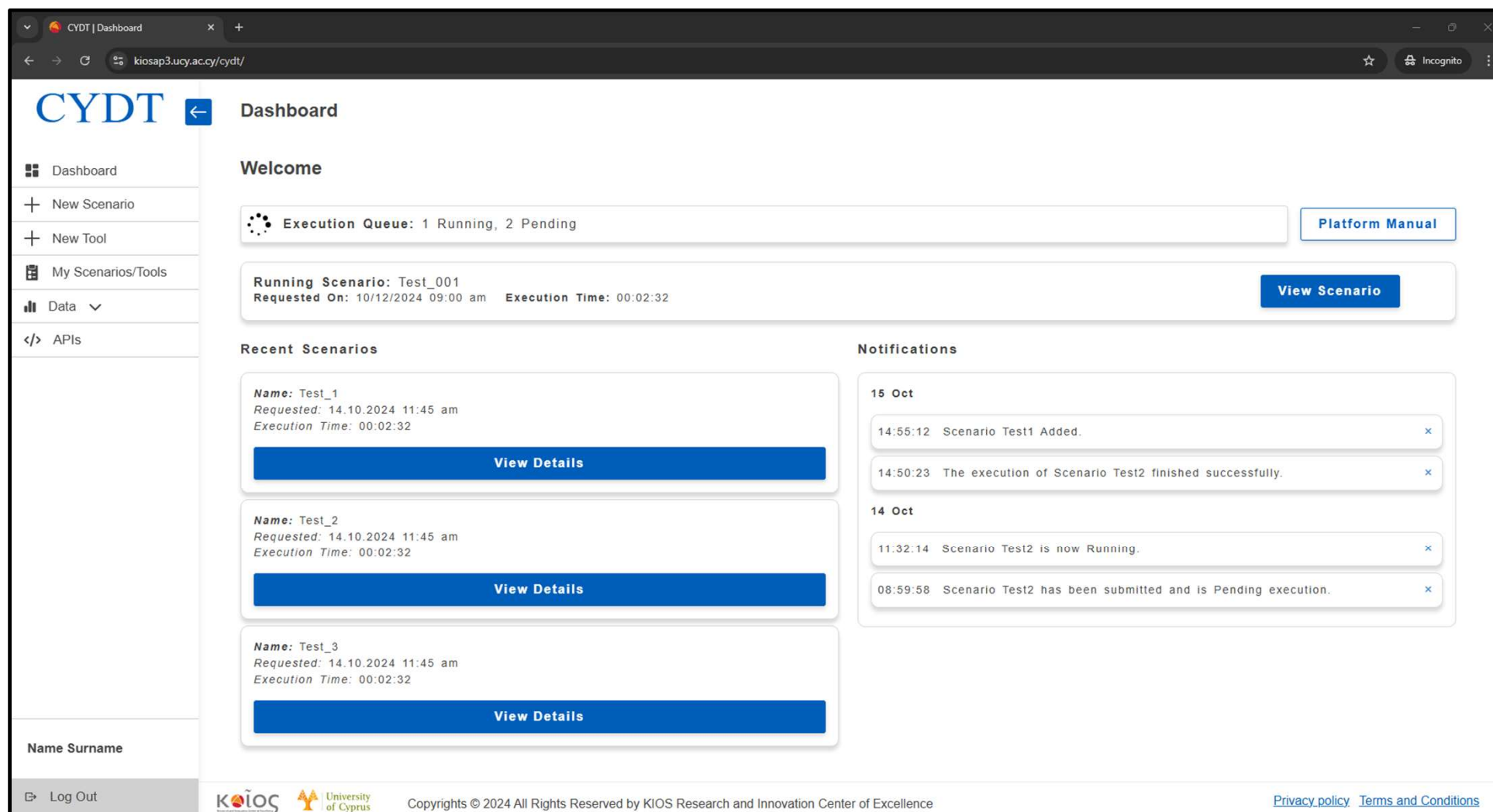


CYPRUS DIGITAL TWIN (CYDT)

CyDT Overview



Web-based HMI – User Dashboard



The screenshot displays the CYDT (Cyprus Yacht Design Tool) user dashboard. The interface is clean and modern, with a white background and blue accents. On the left, a sidebar menu contains links to 'Dashboard', 'New Scenario', 'New Tool', 'My Scenarios/Tools', 'Data', and 'APIs'. The main content area is titled 'Dashboard' and includes a 'Welcome' message. A 'Execution Queue' section shows 1 Running and 2 Pending scenarios. Below this, a 'Running Scenario' section displays details for 'Test_001', including its requested time and execution time, with a 'View Scenario' button. The 'Recent Scenarios' section lists three scenarios (Test_1, Test_2, Test_3) with their respective requested and execution times, each accompanied by a 'View Details' button. A 'Notifications' section on the right shows a list of recent events, such as 'Scenario Test1 Added' and 'The execution of Scenario Test2 finished successfully'. The footer contains the KIOS logo, the University of Cyprus logo, copyright information, and links to the 'Privacy policy' and 'Terms and Conditions'.

CYDT Dashboard

Dashboard

New Scenario

New Tool

My Scenarios/Tools

Data

APIs

Welcome

Execution Queue: 1 Running, 2 Pending [Platform Manual](#)

Running Scenario: Test_001
Requested On: 10/12/2024 09:00 am Execution Time: 00:02:32 [View Scenario](#)

Recent Scenarios

Name: Test_1
Requested: 14.10.2024 11:45 am
Execution Time: 00:02:32
[View Details](#)

Name: Test_2
Requested: 14.10.2024 11:45 am
Execution Time: 00:02:32
[View Details](#)

Name: Test_3
Requested: 14.10.2024 11:45 am
Execution Time: 00:02:32
[View Details](#)

Notifications

15 Oct

14:55:12 Scenario Test1 Added. [×](#)

14:50:23 The execution of Scenario Test2 finished successfully. [×](#)

14 Oct

11:32:14 Scenario Test2 is now Running. [×](#)

08:59:58 Scenario Test2 has been submitted and is Pending execution. [×](#)

Name Surname

[Log Out](#)

KIOS University of Cyprus

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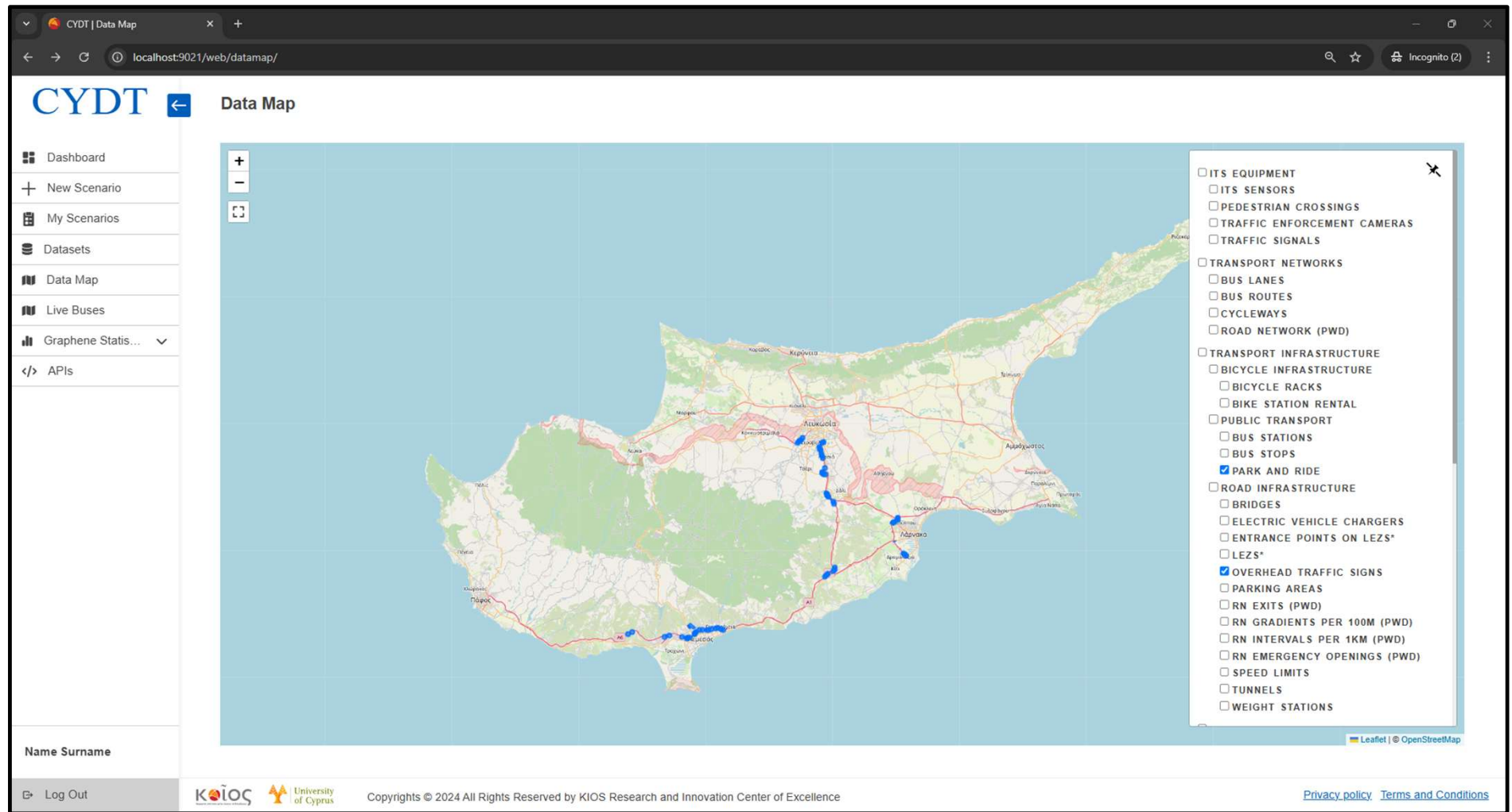
Static/Real-time Data – Datasets

The screenshot shows a web browser window displaying the CYDT Datasets application. The browser's address bar shows the URL `localhost:9021/web/datasets`. The application interface includes a sidebar on the left with navigation links: Dashboard, New Scenario, My Scenarios, Datasets (selected), Data Map, Live Buses, Graphene Statis..., and APIs. The main content area is titled "Datasets" and displays "28 datasets found". It lists several dataset categories, each with a description and two buttons: "Public" and "JSON".

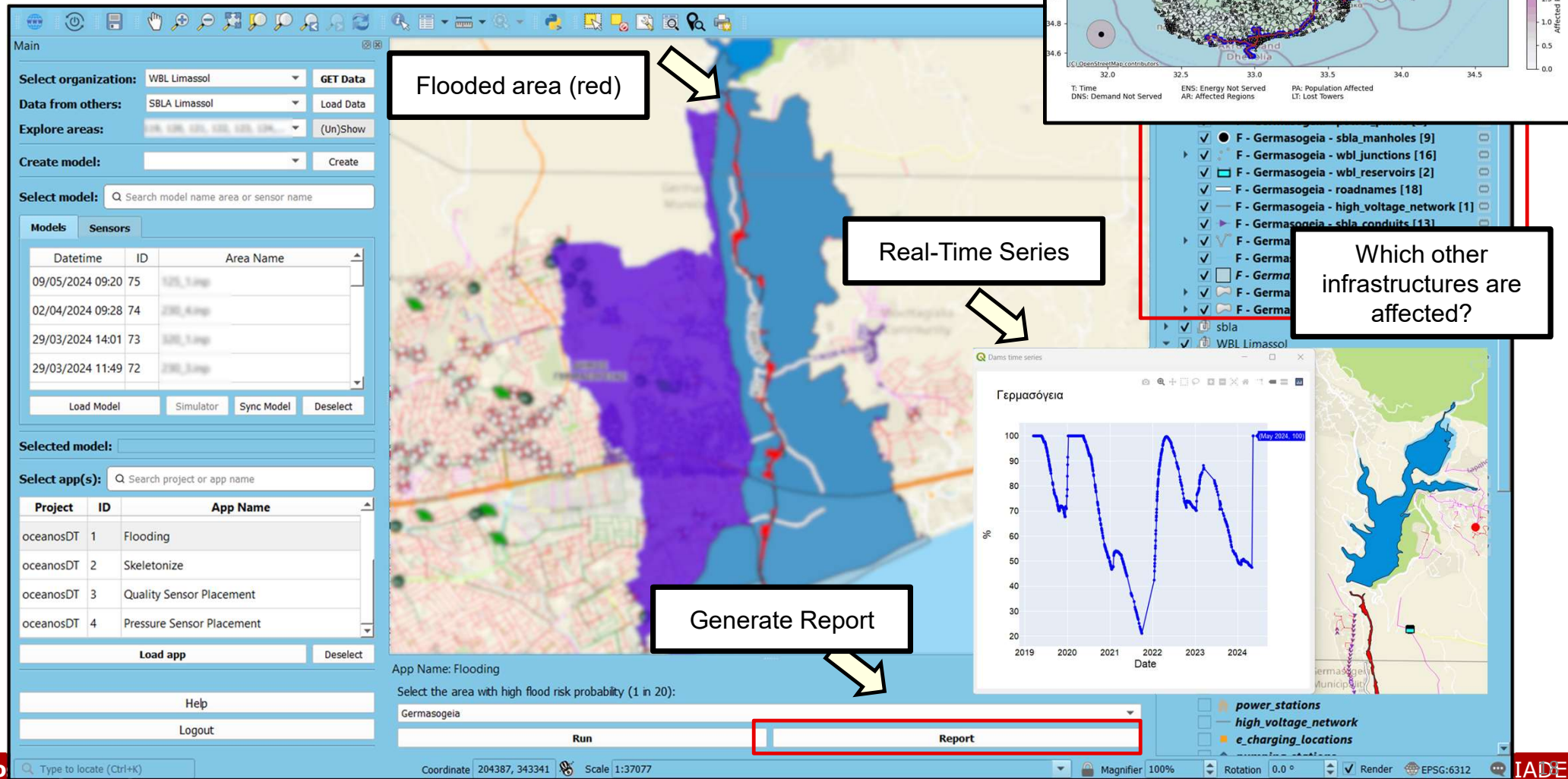
Dataset Category	Description	Public	JSON
Bus Stops	Details of all the bus stops in Cyprus that Public Works Department has registered.	Public	JSON
Bus Routes	Details of all the bus routes in Cyprus that Public Works Department has registered.	Public	JSON
Cycleways	Details of all the Cycleways in Cyprus that Public Works Department has registered.	Public	JSON
Pedestrian Crossings	Details of all the Pedestrian Crossings in Cyprus that Public Works Department has registered.	Public	JSON
Park and Ride	Details of all the Park and Ride in Cyprus that Public Works Department has registered.	Public	JSON
Traffic Signals	Details of all the Traffic Signals in Cyprus that Public Works Department has registered.	Public	JSON
Road Network	Details of the Road Network in Cyprus that Public Works Department has registered.	Public	JSON

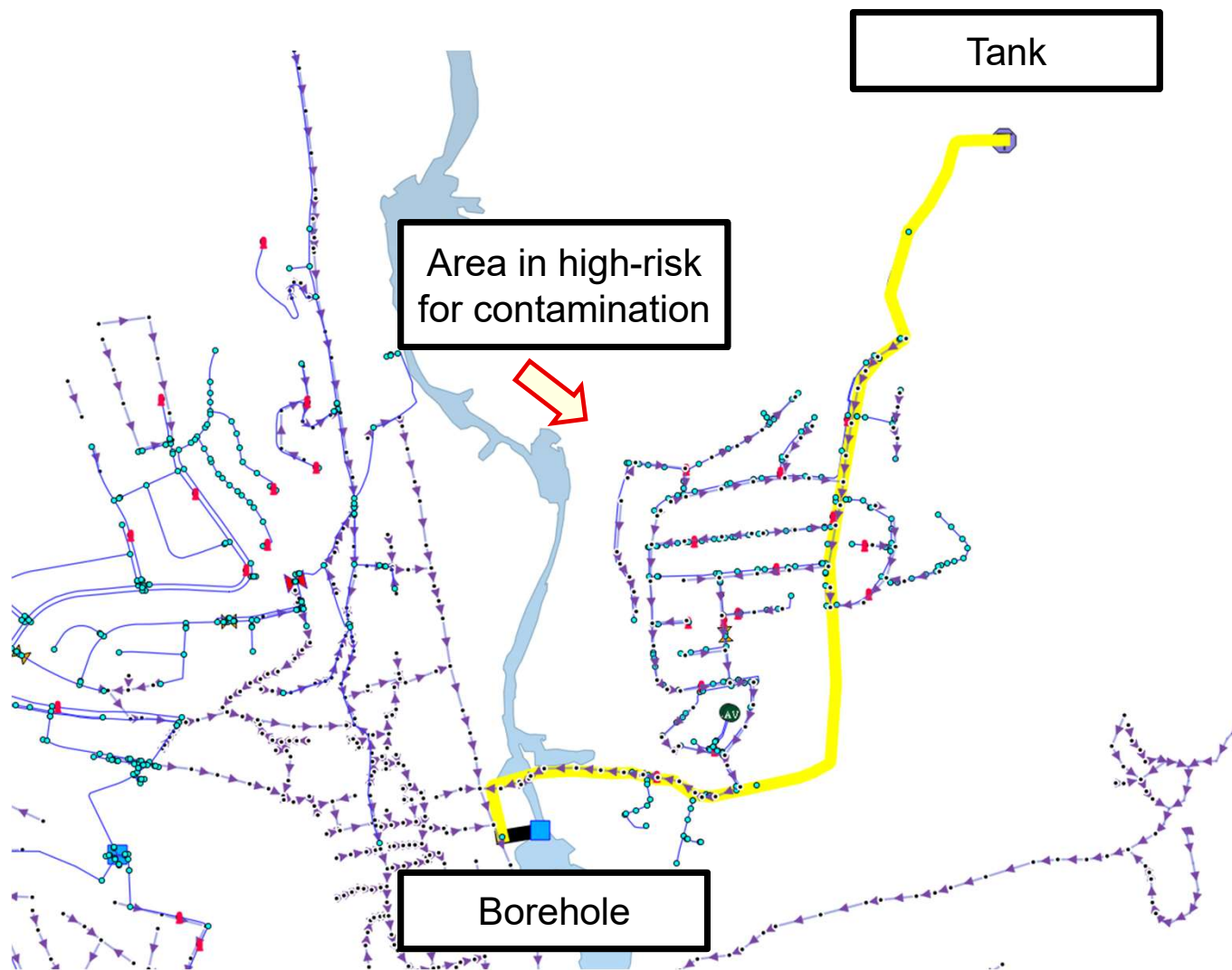
At the bottom of the sidebar, there is a "Name Surname" field and a "Log Out" button.

Static/Real-time Data – Data Layers

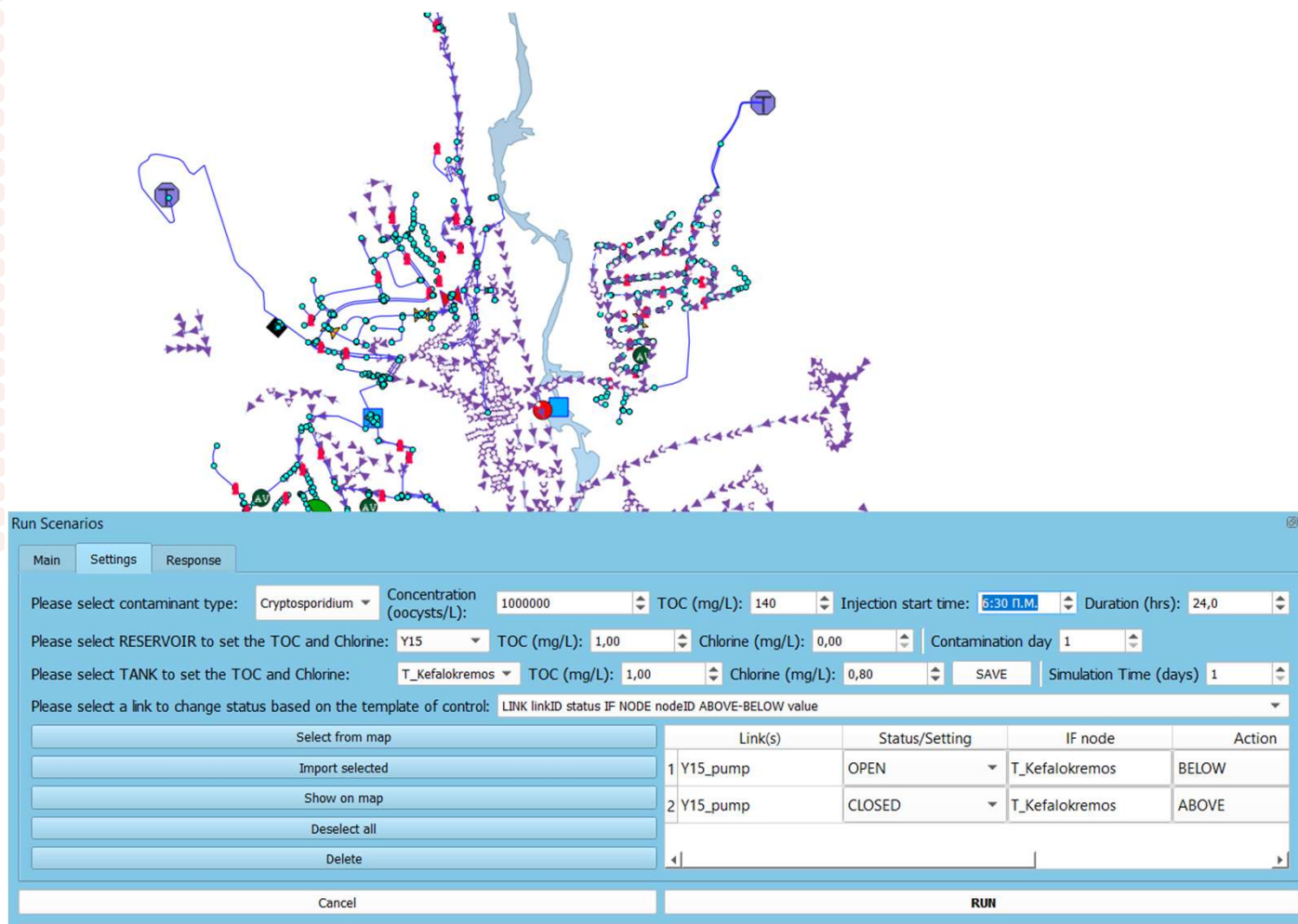


Cascade failures due to flooding





Estimate Contamination Risk



Run Scenarios

Main Settings Response

Please select contaminant type: Cryptosporidium Concentration (oocysts/L): 1000000 TOC (mg/L): 140 Injection start time: 6:30 P.M. Duration (hrs): 24,0

Please select RESERVOIR to set the TOC and Chlorine: Y15 TOC (mg/L): 1,00 Chlorine (mg/L): 0,00 Contamination day 1

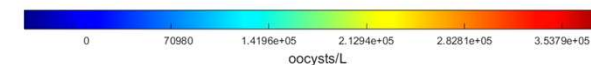
Please select TANK to set the TOC and Chlorine: T_Kefalokremos TOC (mg/L): 1,00 Chlorine (mg/L): 0,80 SAVE Simulation Time (days) 1

Please select a link to change status based on the template of control: LINK linkID status IF NODE nodeID ABOVE-BELOW value

Select from map	Link(s)	Status/Setting	IF node	Action
Import selected	1 Y15_pump	OPEN	T_Kefalokremos	BELOW
Show on map	2 Y15_pump	CLOSED	T_Kefalokremos	ABOVE
Deselect all				
Delete				

Cancel RUN

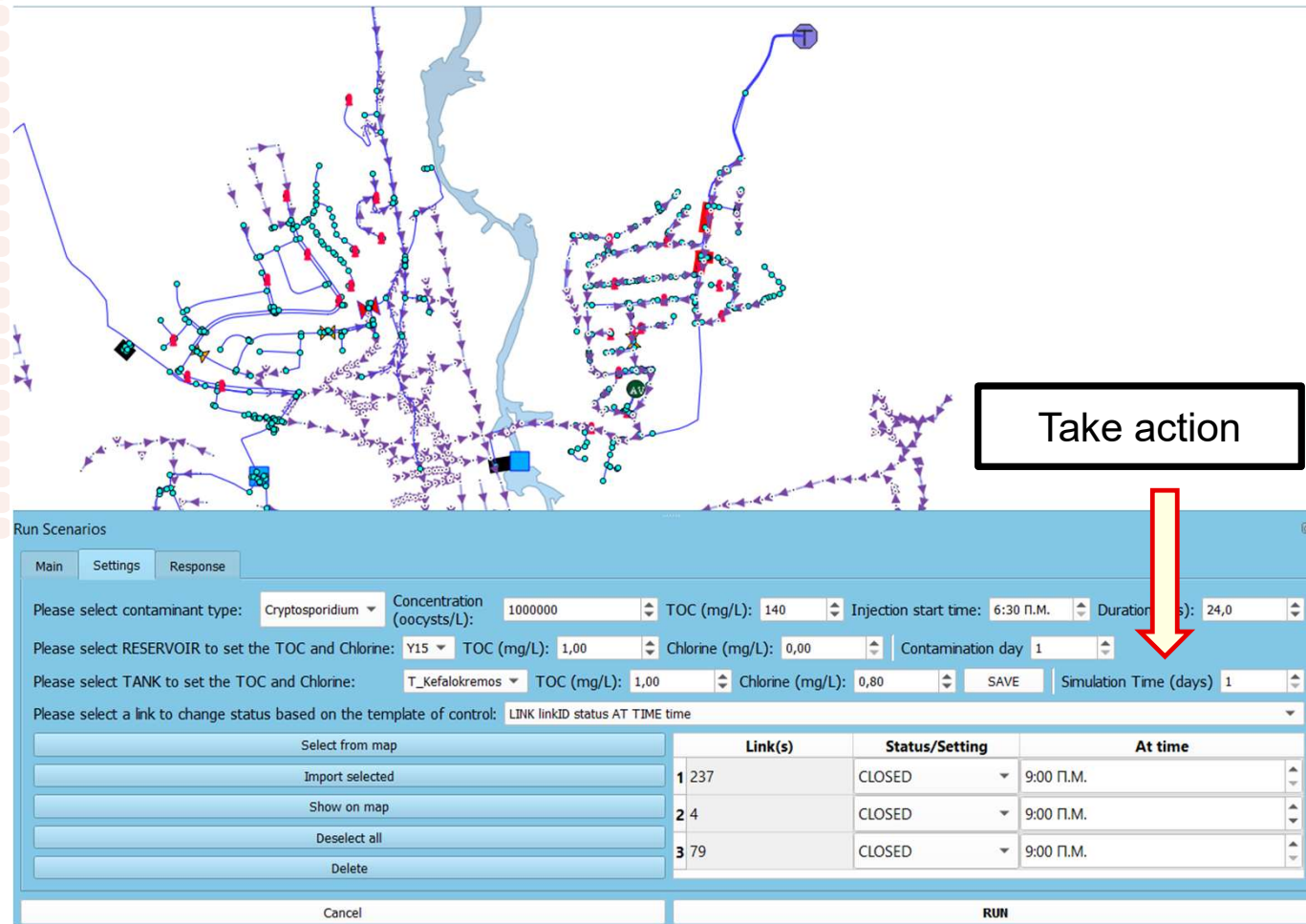
Scenario 1 - Contaminant Evolution at 0 hours



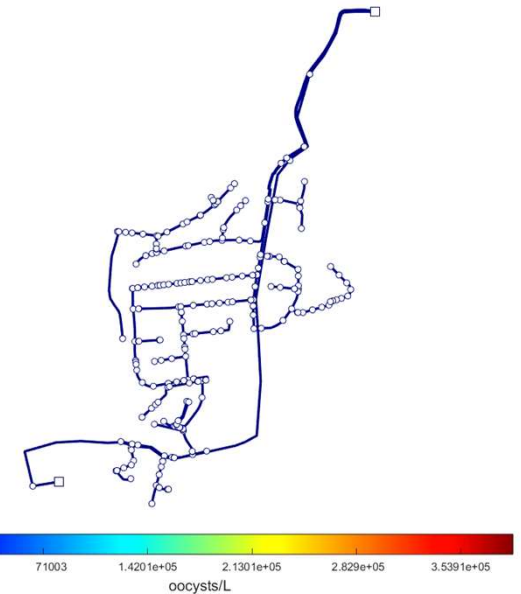
Impact assessment, defined as the percentage of affected people in the network:

Scenario(s)	Hour 5	Hour 10	Hour 15	Hour 20
Scenario 1	0	35.87	78.19	94.6

Evaluation impact of decision



Scenario 1 - Contaminant Evolution at 0 hours

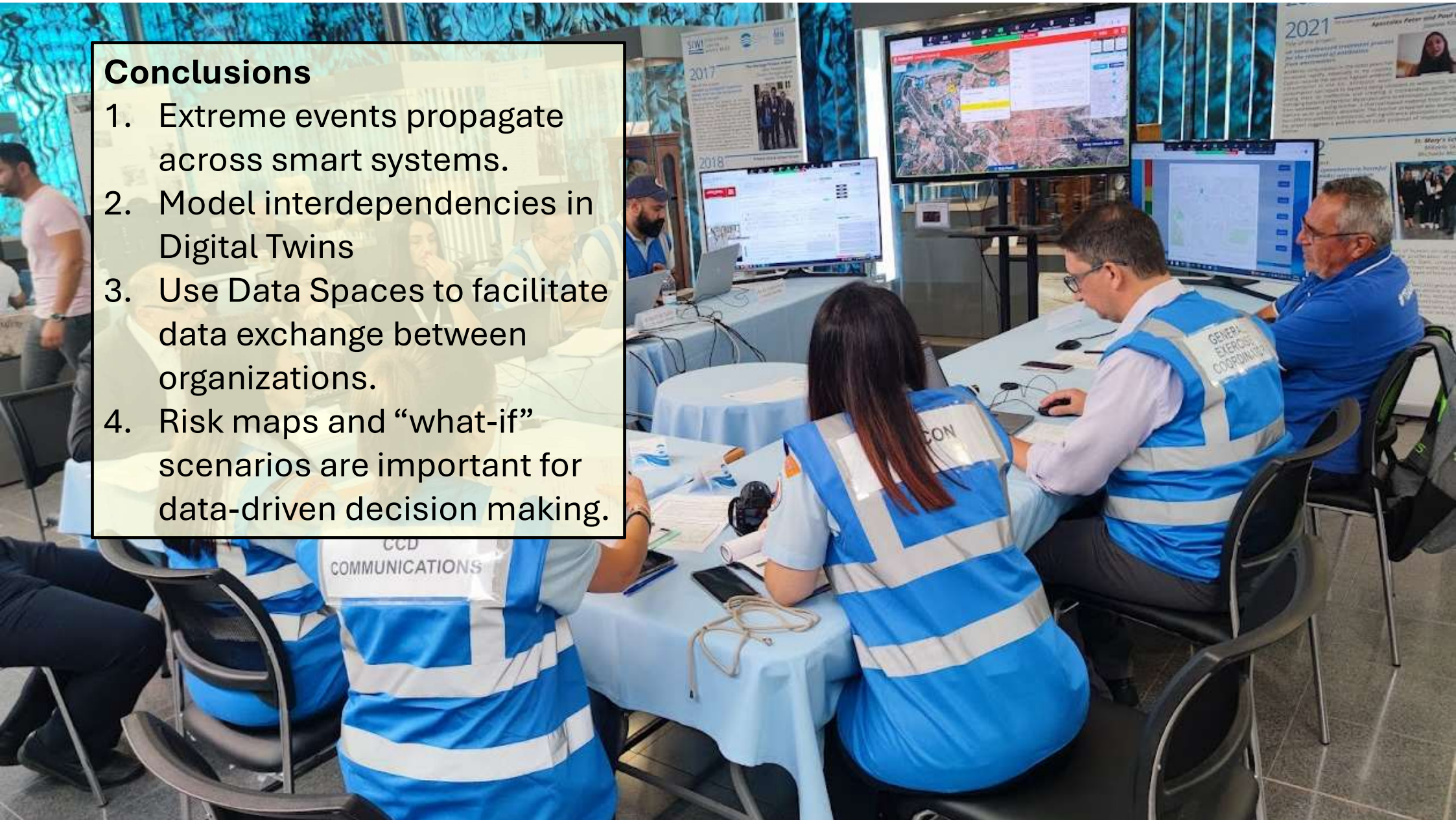


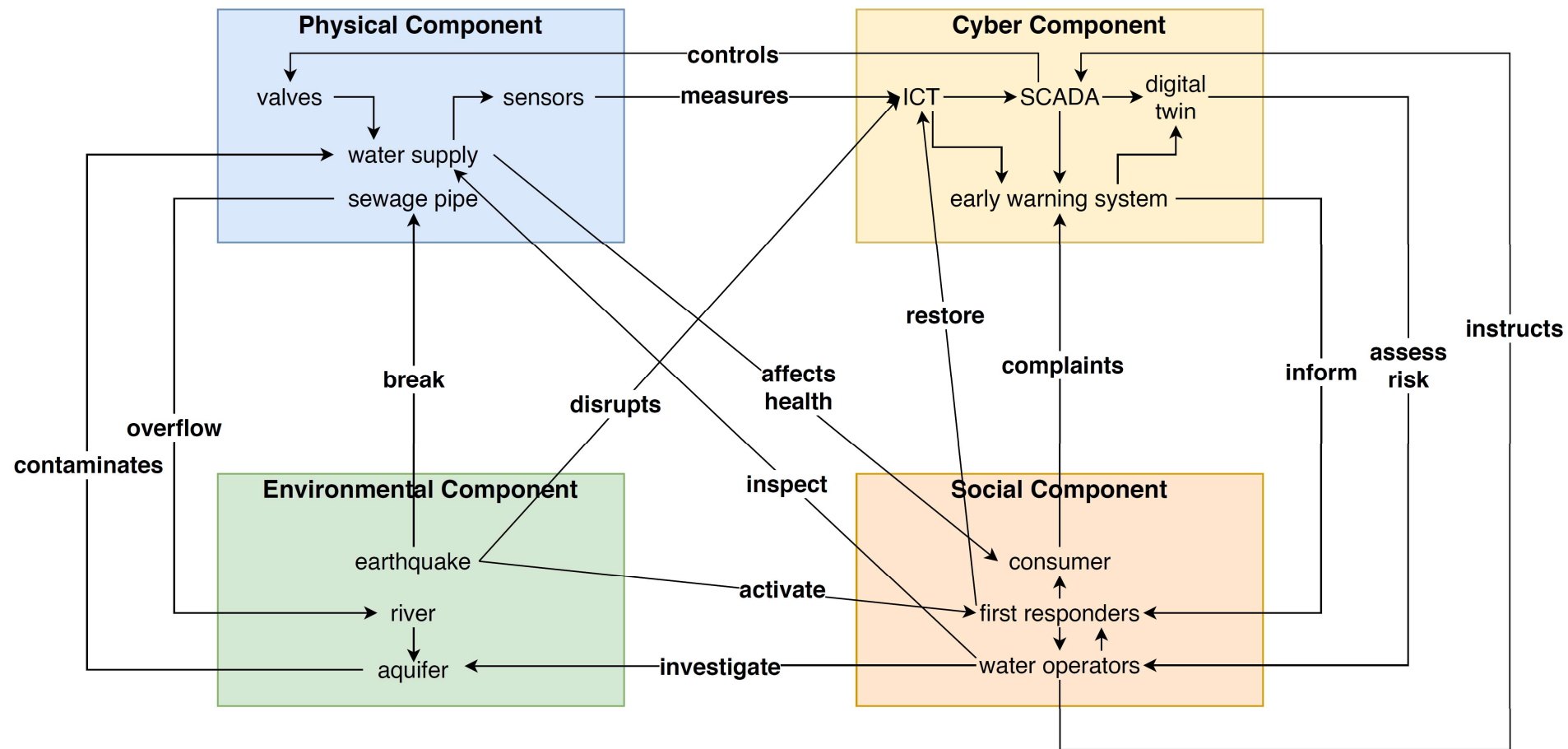
Impact assessment, defined as the percentage of affected people in the network:

Scenario(s)	Hour 5	Hour 10	Hour 15	Hour 20
Scenario 1	0	35.87	52.09	52.09

Conclusions

1. Extreme events propagate across smart systems.
2. Model interdependencies in Digital Twins
3. Use Data Spaces to facilitate data exchange between organizations.
4. Risk maps and “what-if” scenarios are important for data-driven decision making.





Apollo 13: “Houston, we’ve had a problem”

April 13, 1970

- An **explosion** changed the **physical dynamics** of Apollo 13. Trajectory changed; astronauts' lives were at risk.
- NASA created a “**living model**”. Data from telemetry were continuously ingested in models to analyze situation.
- Multiple simulators were reprogrammed with new models to find the best way to resolve the situation.
- Apollo 13 safely returned to earth a few days later.



02 07 55 20	CDR	I believe we've had a problem here.
02 07 55 28	CC	This is Houston. Say again, please.
02 07 55 35	CDR	Houston, we've had a problem. We've had a MAIN B BUS UNDERVOLT.
02 07 55 42	CC	Roger. MAIN B UNDERVOLT.
02 07 55 58	CC	Okay, stand by, 13. We're looking at it.

What is a Digital Twin?

- **Computational “living” model** of a real system
- Integrates physical, mathematical or machine learning **models**
- Integrates **operational data** (sensors, actuators), and historical data
- Updates **dynamically**, considers changes
- Evaluate **“what-if” scenarios**
- Operates on **various time scales**
- Enables analytics, optimization, risk management and control
- Used as a **virtual certification/validation** (testing before applying a new system)

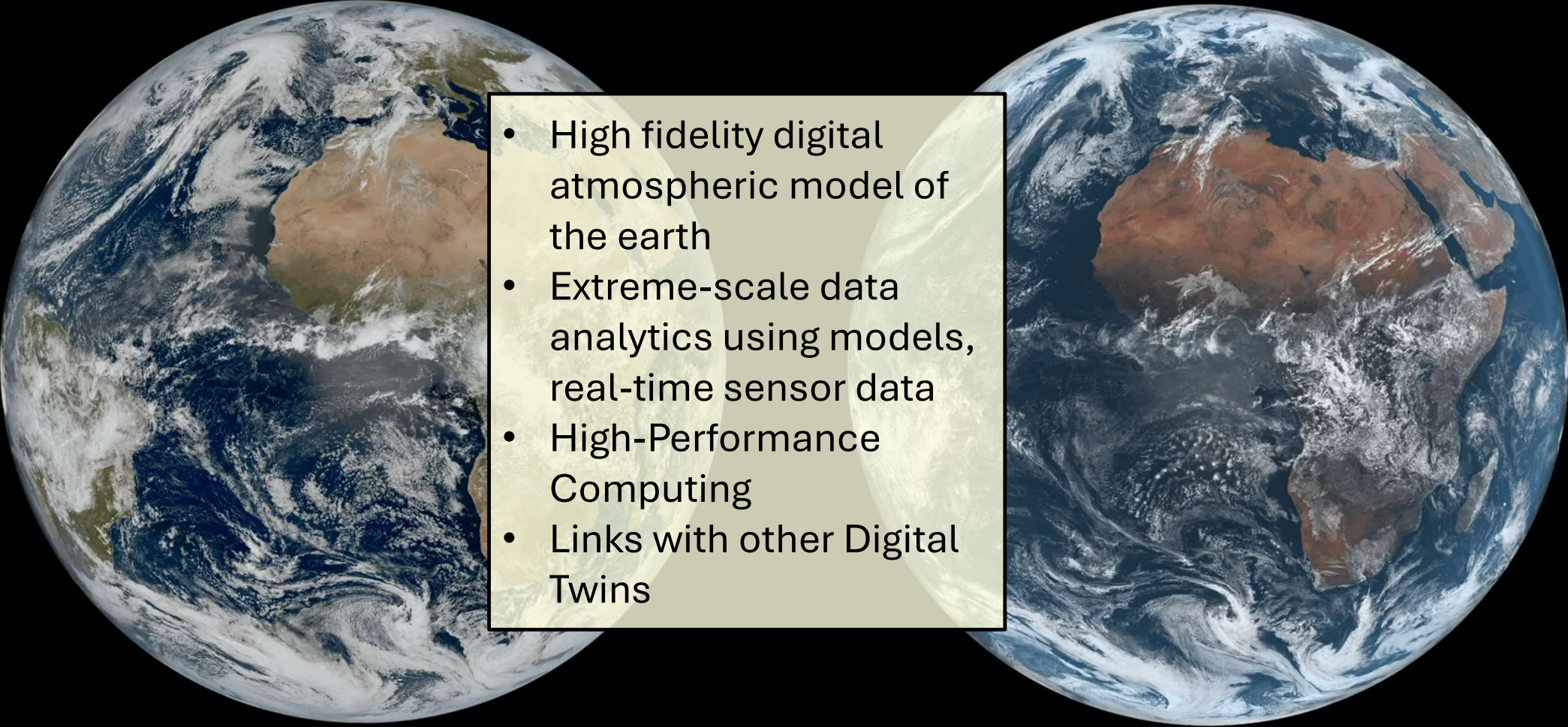


*“The **digital twin** concept... enable[s] a suite of comprehensive multidisciplinary **physics-based models**... incorporating these capabilities in the **production and operation** of spacecraft.”*

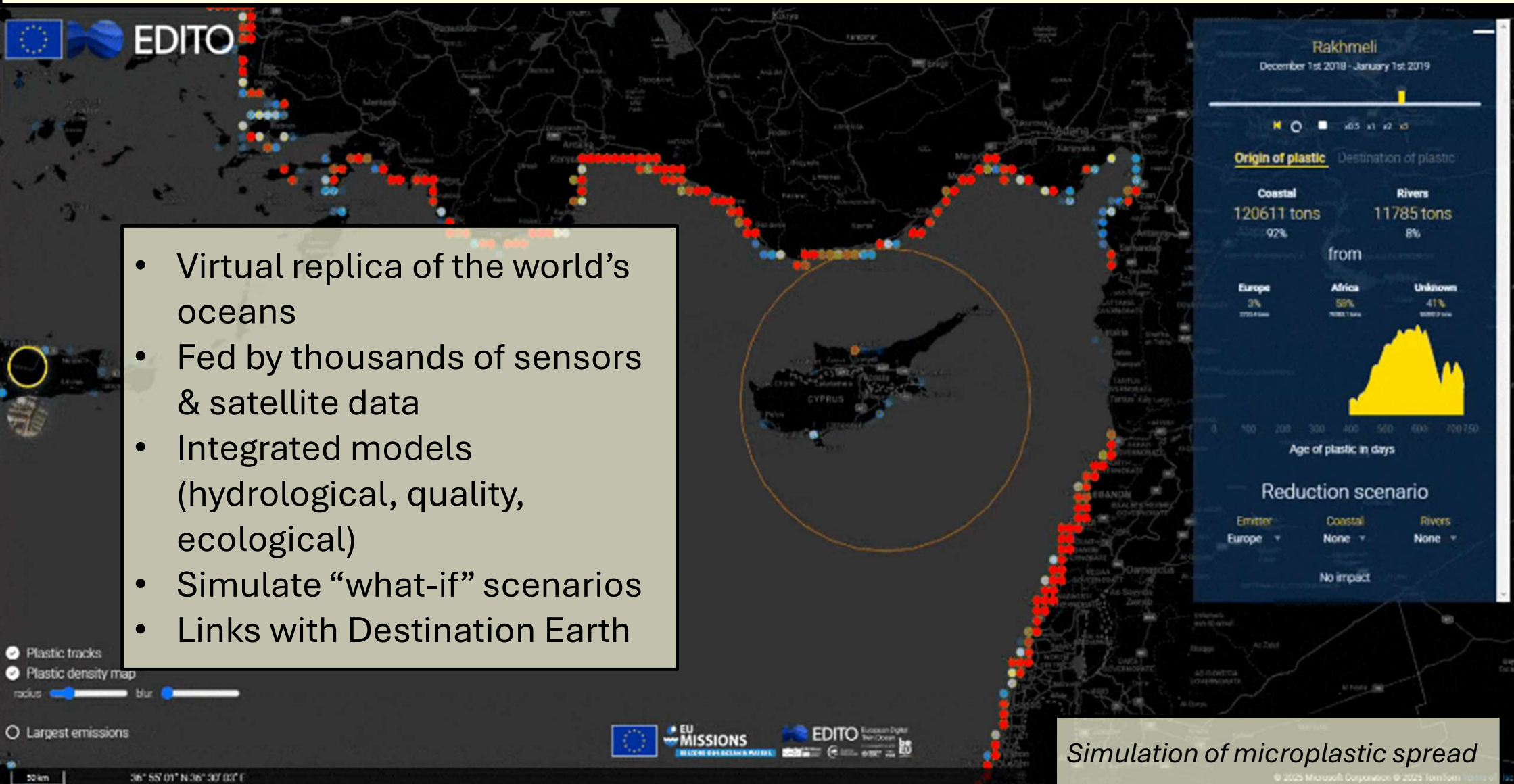
Destination Earth (DestinE)

MTG-I1 FCI

ECMWF IFS 2.8-km forecast

- 
- High fidelity digital atmospheric model of the earth
 - Extreme-scale data analytics using models, real-time sensor data
 - High-Performance Computing
 - Links with other Digital Twins

Digital Twin Oceans (DTO)



Digital Twin for Contaminations

The screenshot displays the PathoINVEST software interface, which is divided into several functional panels:

- Missions Panel:** Lists missions with columns for Datetime and Mission Title.

Datetime	Mission Title
23/03/2023 07:40:30	Earthquake of 6.3 magnitude
23/03/2023 10:40:30	Water pollution at Germasogeia
- Applications Panel:** Contains buttons for Run Scenarios, Surface Water, Contaminant Evolution, Sensor Placement, Impact Assessment, and Sampling Locations.
- Requests Panel:** Includes buttons for Compare, Info, SEND report to PathoWARE, Delete Results Cache, and Login.
- Sampling Locations Panel:** Features a table for finding sources based on manual sampling.

	n347	n333	n25	n662	n413	n268
0	0	0	0	0	0	0
0	0	0	0	0	0	0
- Map Panel:** Shows a map of a city area with sampling locations marked as red dots. Specific locations are labeled n413, n333, and n275. A red shaded area indicates a contaminated region.
- Impact Assessment Panel:** Displays a table for impact assessment, defined as the percentage of affected people in the network.

Scenario(s)	Hour 5	Hour 10	Hour 15	Hour 20
Scenario 1	3.82			
Scenario 2	2.42			
Scenario 3	28.49			
- Contaminant Evolution Panel:** Shows a simulation of contamination propagation with a color-coded map and a legend.

Contour	Volume (m³)
5	1.00e-01
4	9.00e-02
3	8.00e-02
2	7.00e-02
1	6.00e-02
0	5.00e-02
-1	4.00e-02
-2	3.00e-02
-3	2.00e-02
-4	1.00e-02

Yellow callout boxes highlight key features:

- Sensor Placement:** Located in the left sidebar.
- Solve Contamination Source Isolation problem:** Located in the center of the map panel.
- Estimate contaminated area and risk:** Located at the bottom center of the map panel.
- Simulation of contamination propagation:** Located in the top right corner.
- Run multiple scenarios and estimate impact risk:** Located in the bottom right corner.

Additional elements include a 'Water Europe' logo and a 'Digital Water Award Winner' badge in the bottom right corner.