DESSIN
DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR

ATHENS CASE (GREECE)

Sewer Mining for Urban Re-use enabled by Advanced Monitoring Infrastructure (AMI)

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This project has received funding from the European Union's Seventh Programme for Research, Technological Development and Demonstration under Grant Agreement no. 619039

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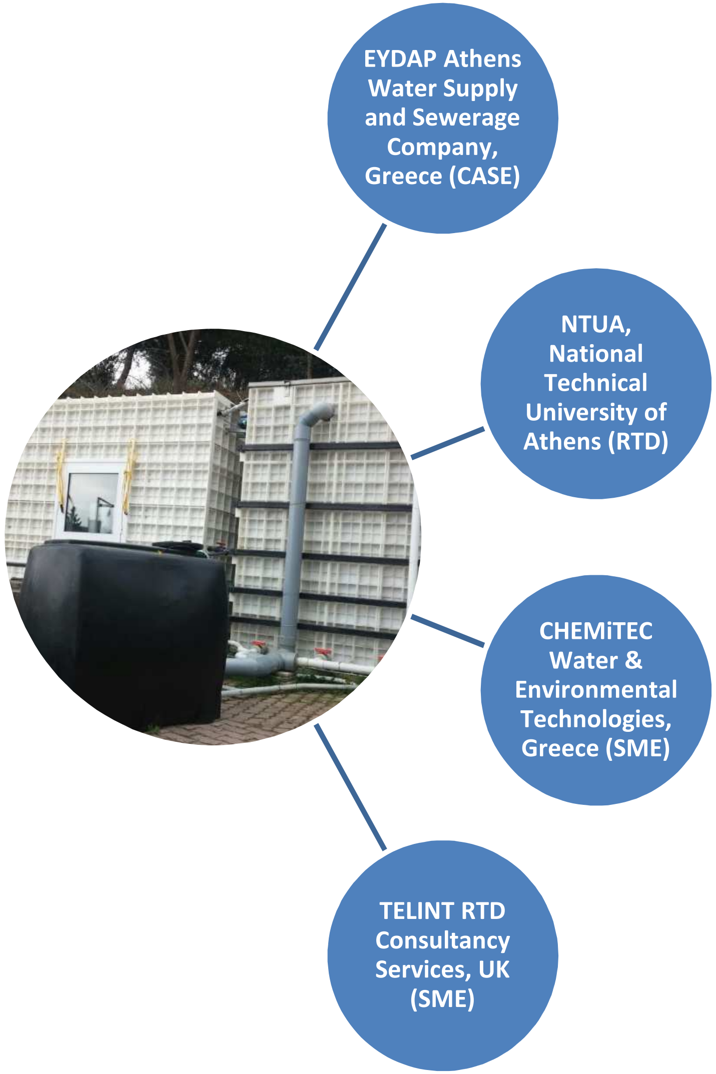
Sewer Mining Pilot (Athens)

Who is who..



Brief description

Context

Athens has suffered rapid urbanisation resulting in **few urban green spaces**. **Reuse**, but at what **scale**? Need for innovative management options and technologies for reuse needed to irrigate (primarily) green urban areas (incl. devastated peri-urban forests).

Current status

- Main WWTP in an **island** (Psytalleia)
- Increased energy costs for transportation
- Periurban forests devastated by fires
- Water scarcity

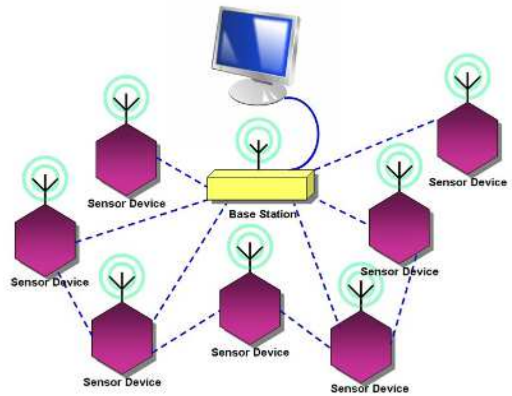
Enter Sewer Mining…

Technologies

The Athens Pilot brings together two emerging technologies:

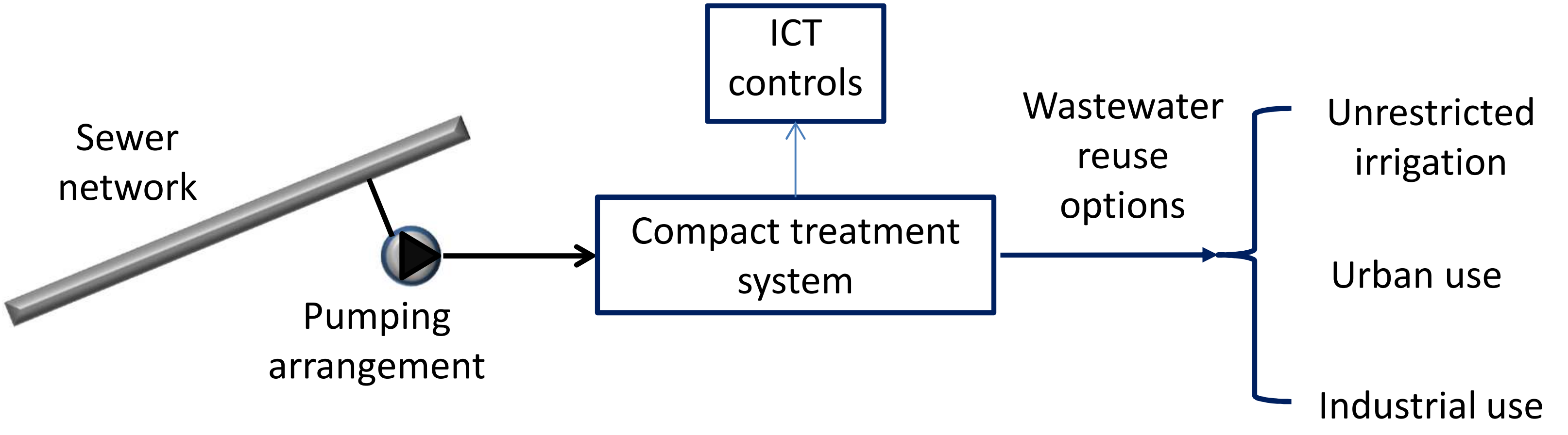
Fully **automated packaged treatment plants** featuring membrane based, small footprint, sewer mining technologies that allow **direct mining of sewage** from the network, close to the **point-of-use** with minimum infrastructure required and low transportation costs for the effluent

Distributed **low energy sensor networks coupled with distributed ICT** intelligence (e.g. Advanced Metering and Monitoring Infrastructure, AMIs) innovative in terms of data fusion (b) data communication (c) interoperability and (d) mobile solutions for **remotely controlling and operating** the distributed infrastructure (against stringent performance criteria, incl. health and water quality standards)



Main concept

The following general concept was developed as a basis of applications of the proposed solution:



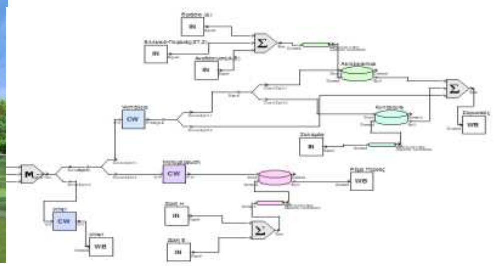
What is to be demonstrated

Athens Case demo objectives:

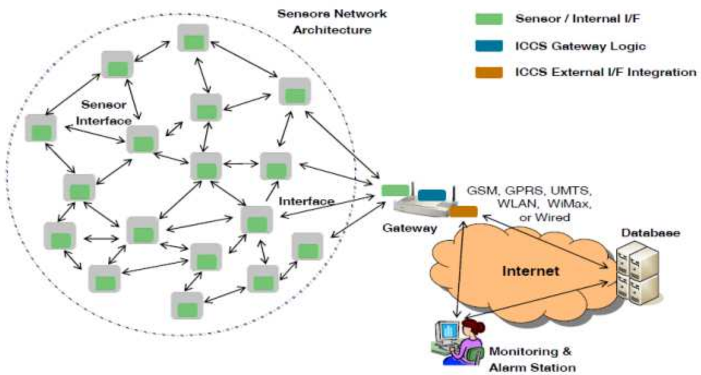
Case Athens explores:

- **Sewer mining**, as a novel concept for distributed water reuse
- **State-of-art ICT solutions** for distributed monitoring and management of multiple sites
- **Small packaged plants** for direct and optimised mining and treatment of sewage from the network
- **Reused water characteristics on the soil**, through onsite experiments, irrigating onsite periurban green
- **Changes in ESS provided** by such technologies, and particularly the mitigation of heat island effects due to irrigation of urban green areas

treat



optimise,
assess
charge
upscale



control

Benefits to be explored

Benefits

Case Athens is an opportunity to:

- **Increase reuse efficiency** with treatment at the point of use
- **Decrease transaction costs** compared to "centralised" reuse (licensing / footprint / local communities)
- **Increase % of reused water** within the highly constrained urban environment
- **Improve urban quality of life** through improved ecosystem services and;
- Create **new market for SMEs** that can provide this service to, e.g. local municipalities

A win-win scenario → SMEs will sell raw sewage using the existing centralised sewerage network of the water company and water companies will be able to sell untreated sewage, while also minimise the load to their centralised treatment facilities

Upscale opportunities

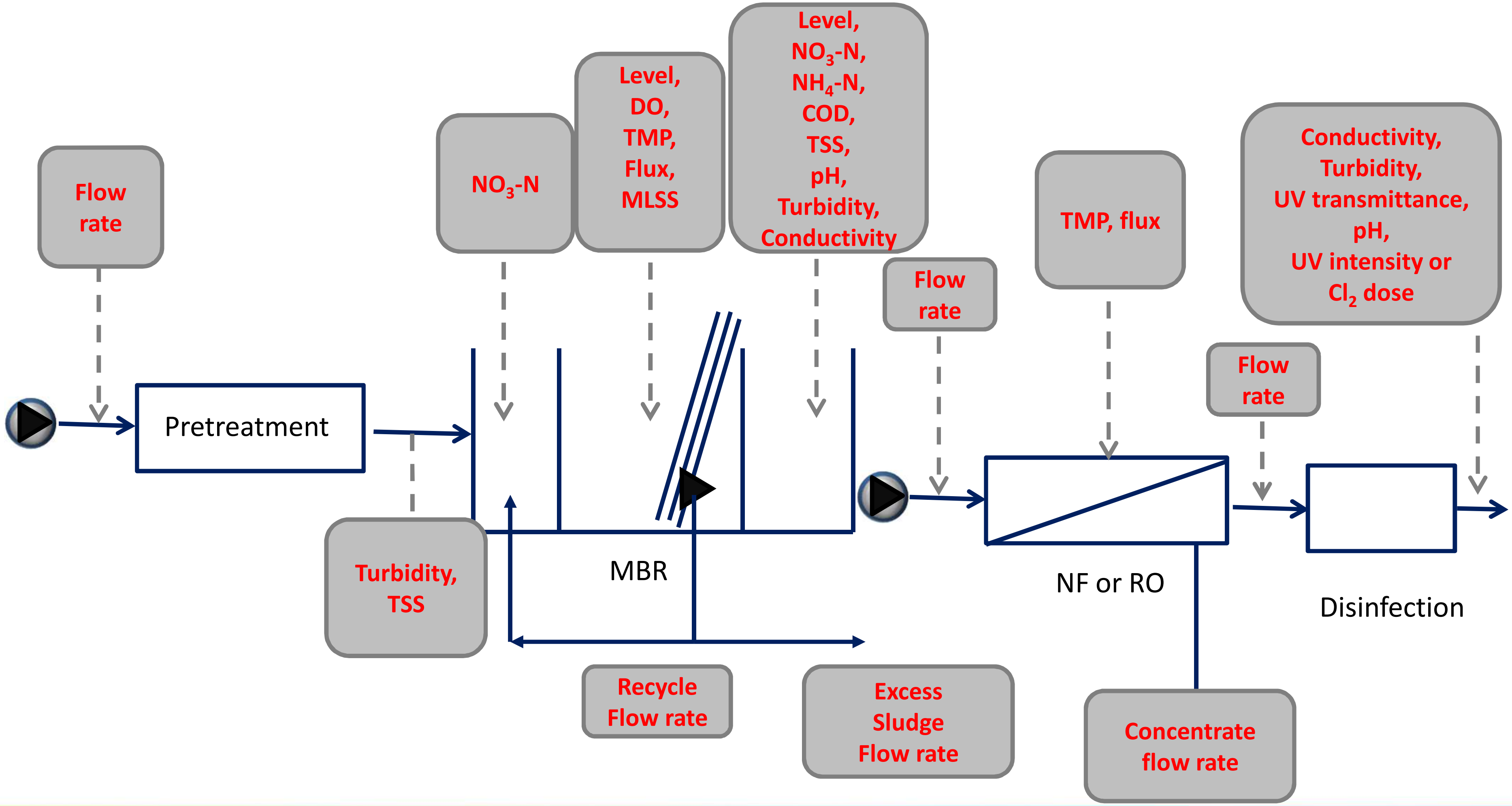
Deployment in the east coast of Attica for:

- Urban green
- Reduced water treatment cost
- Reused water withdrawal to avoid saltwater intrusion

Map of Attica, Greece

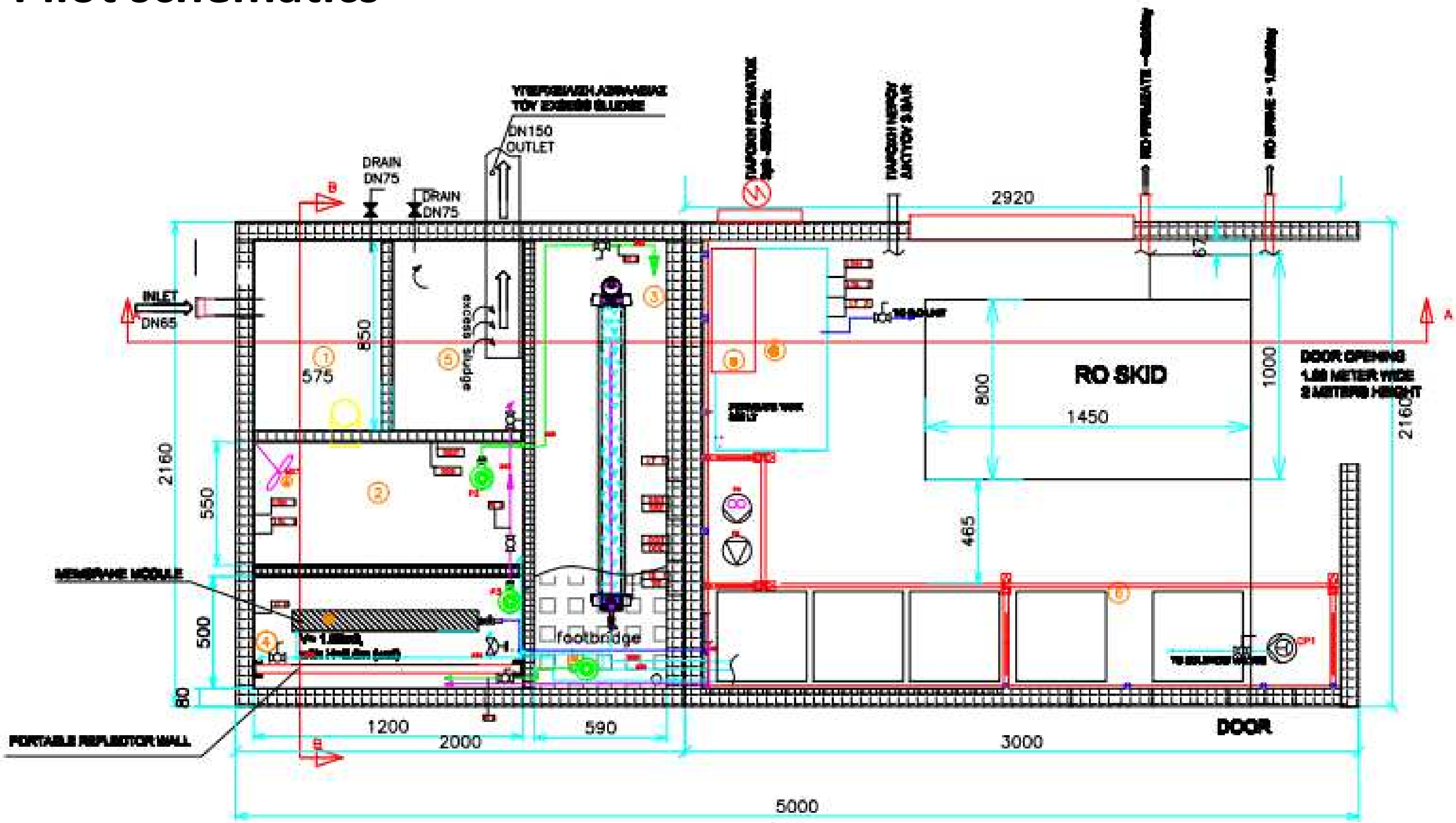
System architecture

On-line monitoring and control of treatment system



Packaged treatment plant

Pilot schematics



Quality targets

Effluent quality

Expected effluent quality after each process is:

UF permeate

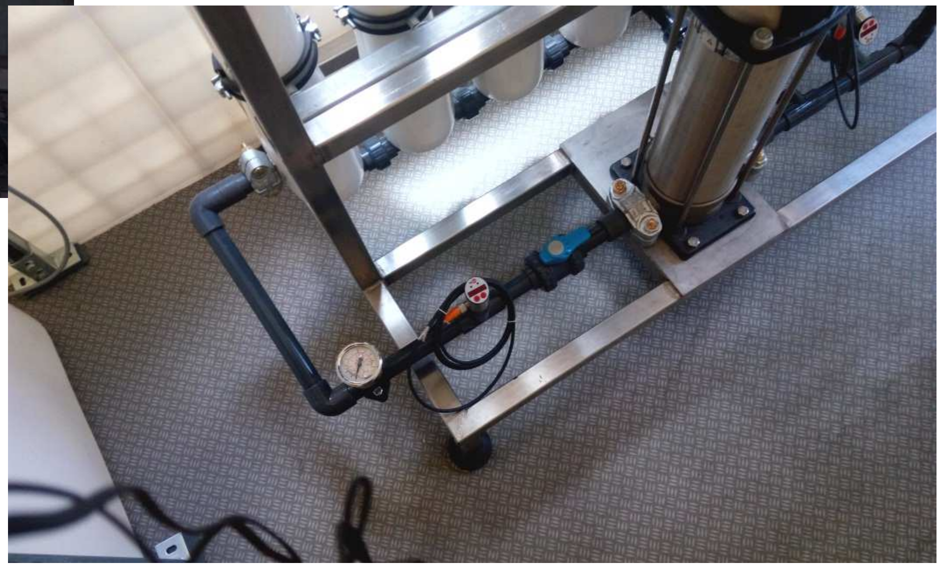
- BOD5 ≤10 mg/l
- COD ≤ 70mg/l
- TSS ≤5 mg/l
- NO3 = 14 mg/l
- VSS= 2 mg/l
- TN = 15 mg/l
- TP=10 mg/l
- NH4-N = 0,50 mg/l
- Fcoli≤100cfu /100ml
- Non Volatiles of Effluent =0 mg/l

RO permeate

- BOD ≤1 mg/l
- COD ≤ 5mg/l
- TSS nil
- CONDUCTIVITY ≤ 200μS/cm

Packaged treatment plant

MBR and RO packaged units



Packaged treatment plant

Packaged treatment plant

Designing for market uptake

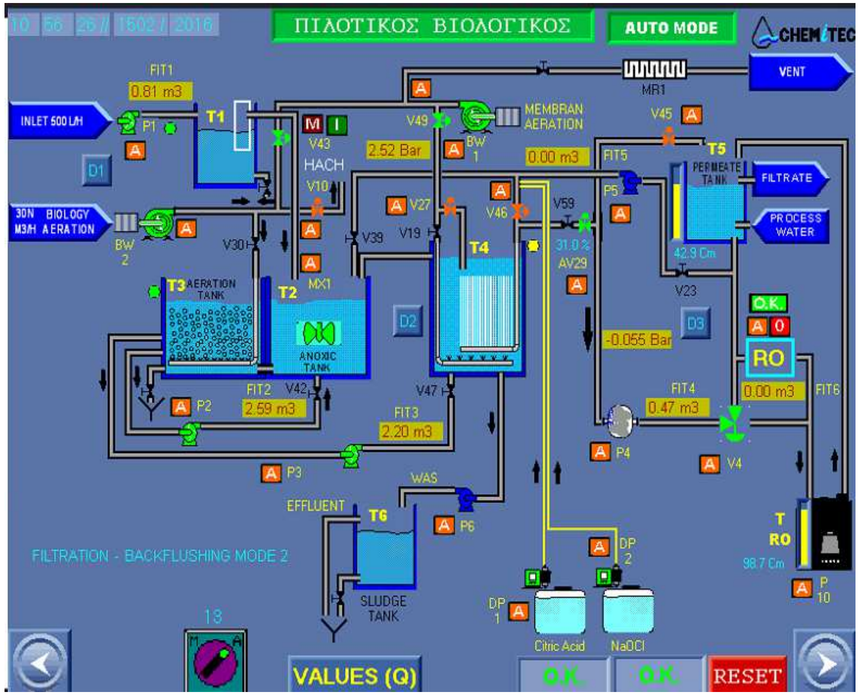
- The MBR/RO unit is a **hybrid technological product** that on the one hand employs membrane technology to treat sewage and on the other hand, in case this function fails, can operate as **conventional** type of WWTP
- MBR and RO units are constructed as individual containers (**modular**) that are joined together in one containerised compact system offering **ease of transportation**
- To be deployed **either individually or in combination** (depending on requirements)
- The designed solution integrating the use of plastic containers allows the system to be **underground positioned**, thus having no aesthetic impacts on the surrounding area

Packaged treatment plant

Programmable Logic Controller

A Programmable Logic Controller system has been installed that allows remote monitoring and control of the unit. Through the PLC monitor the user can:

- **Manage the operation** of every controllable element (pumps, valves, blowers etc.)
- **Monitor flows** in every pipeline, tank levels and the transmembrane pressure (TMP)
- Set **alarm** values
- **Screen the flawless function** of the system
- **Shut down** certain sections of the unit



Packaged treatment plant

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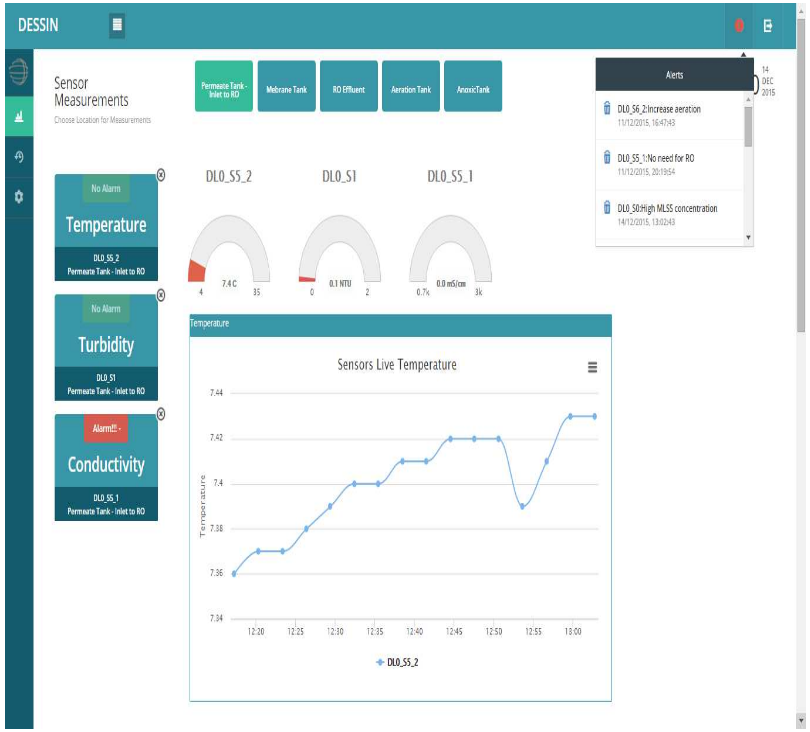
Monitoring Platform

Low energy field sensors (for both wastewater and treated effluent) upload data on a web platform, thus providing the ability of remote monitoring of the unit. The registration process involves:

- **Collection, record and presentation** of data every three minutes
- Presentation of received data through **gauges and graphs**
- **Measurements** of dissolved oxygen, conductivity, turbidity, pH, nitrate, chloride, Ammonium, temperature and suspended solids
- Embedded **real time alerting** capability
- **Historical data** retrieval
- Ability to **export data** in various format files



Packaged treatment plant

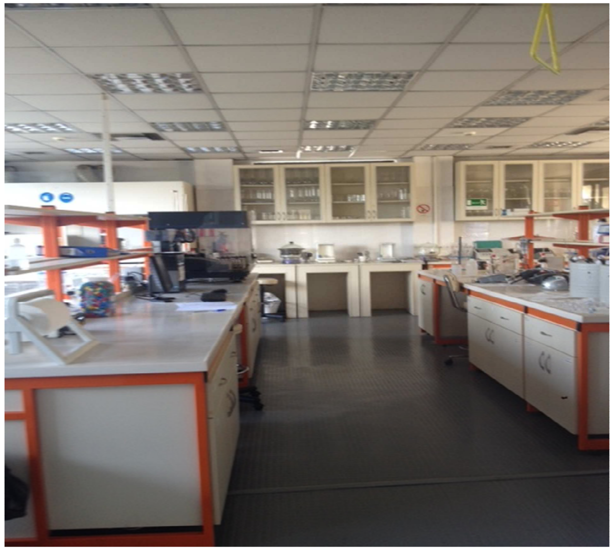
Laboratory Measurements

Laboratory analysis is held at:

- Laboratory of Sanitary Technology at The National Technical University of Athens
- ISO qualified laboratory for chemical and microbiological analysis in the Research and Development department of EYDAP

The laboratory analysis takes place twice a week, providing the ability to :

- do **cross-validation** with the sensor measurements, thus providing feedback on the status of the sensors
- **detect problems** and certain issues of the unit
- **draw conclusions** about the operation of the unit



Packaged treatment plant

Operational Optimization (no off-the-shelf solution at this scale!)

Several steps have been taken towards making the unit fully independent, while improving its stabilization and safety. Some of these enhancements involve:

- New type of level meters
- New blower with higher capacity
- Modification of PLC's warning signals

In the **upcoming months**, the aim is to achieve optimization of :

- Final effluent quality
- Membrane fouling
- System energy demand
- Quantity of sludge produced
- Greenhouse gas emissions

This will be accomplished by varying certain parameters like :

- Sludge retention time
- Hydraulic retention time
- Organic loading and additives employed

ICT View of Athens Pilot

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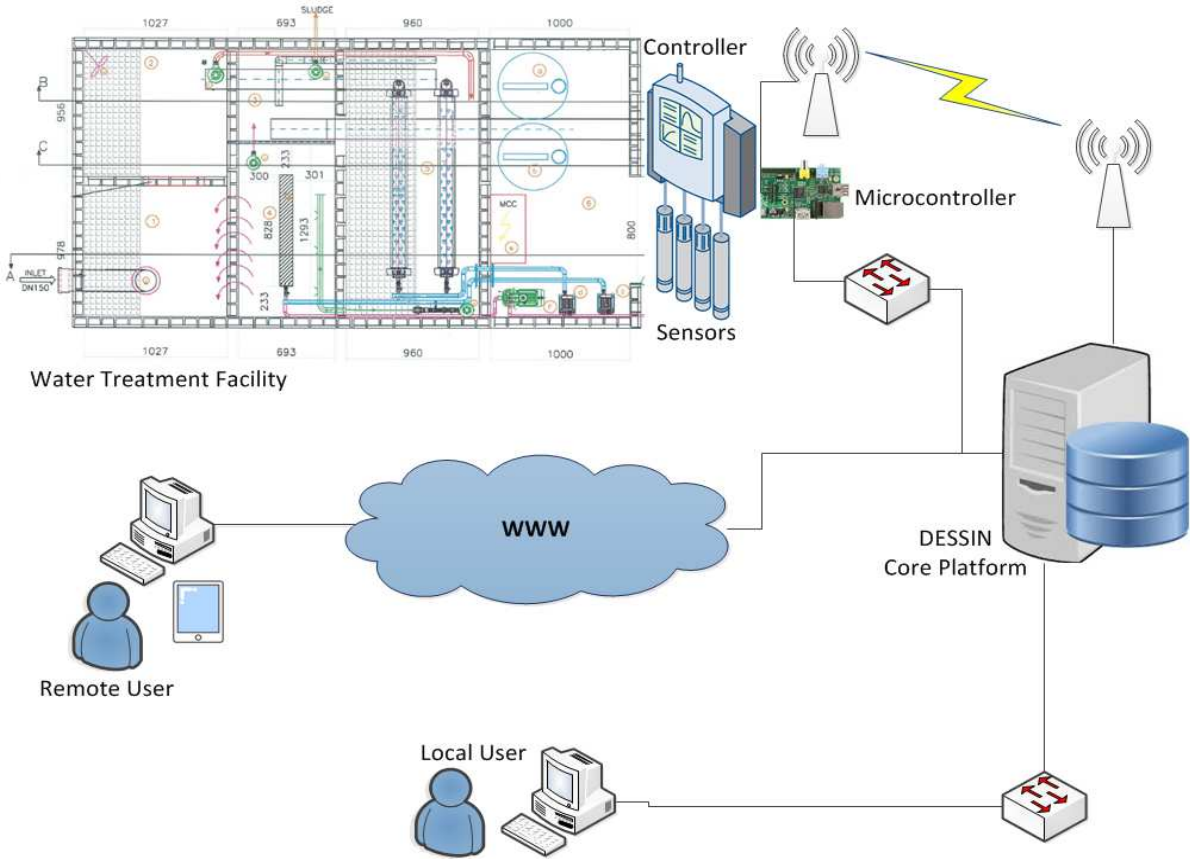
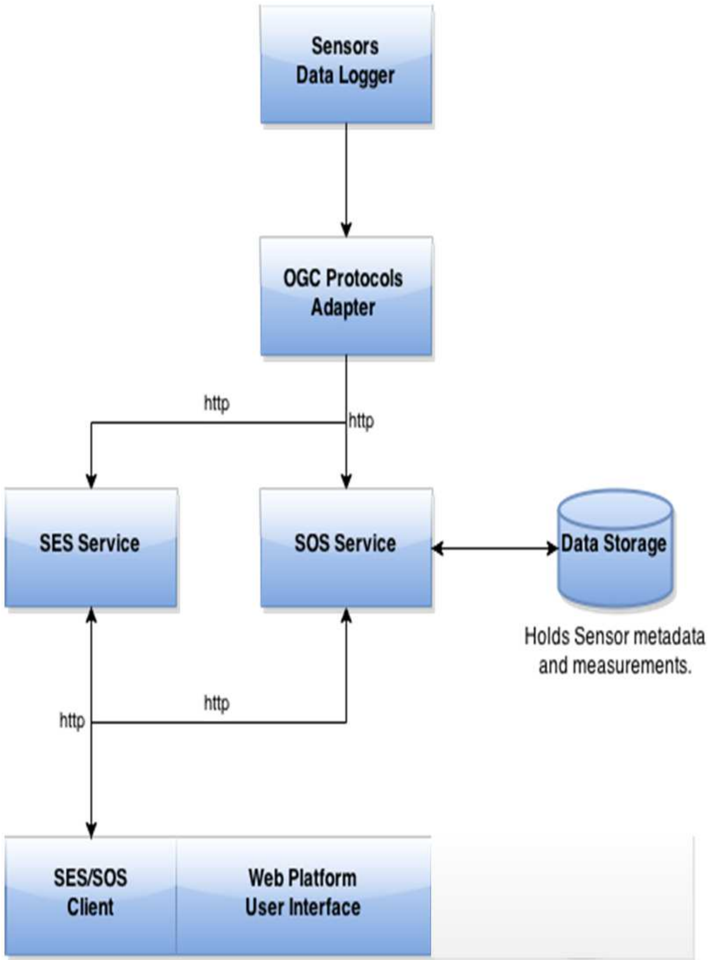
Characteristics

- Interface for retrieving sensor data (Options: Modbus)
- Communication between Controller and DESSIN Platform: Wired or wireless LAN (WiFi)
- Local and remote users are able to connect



Sensor Communication Platform

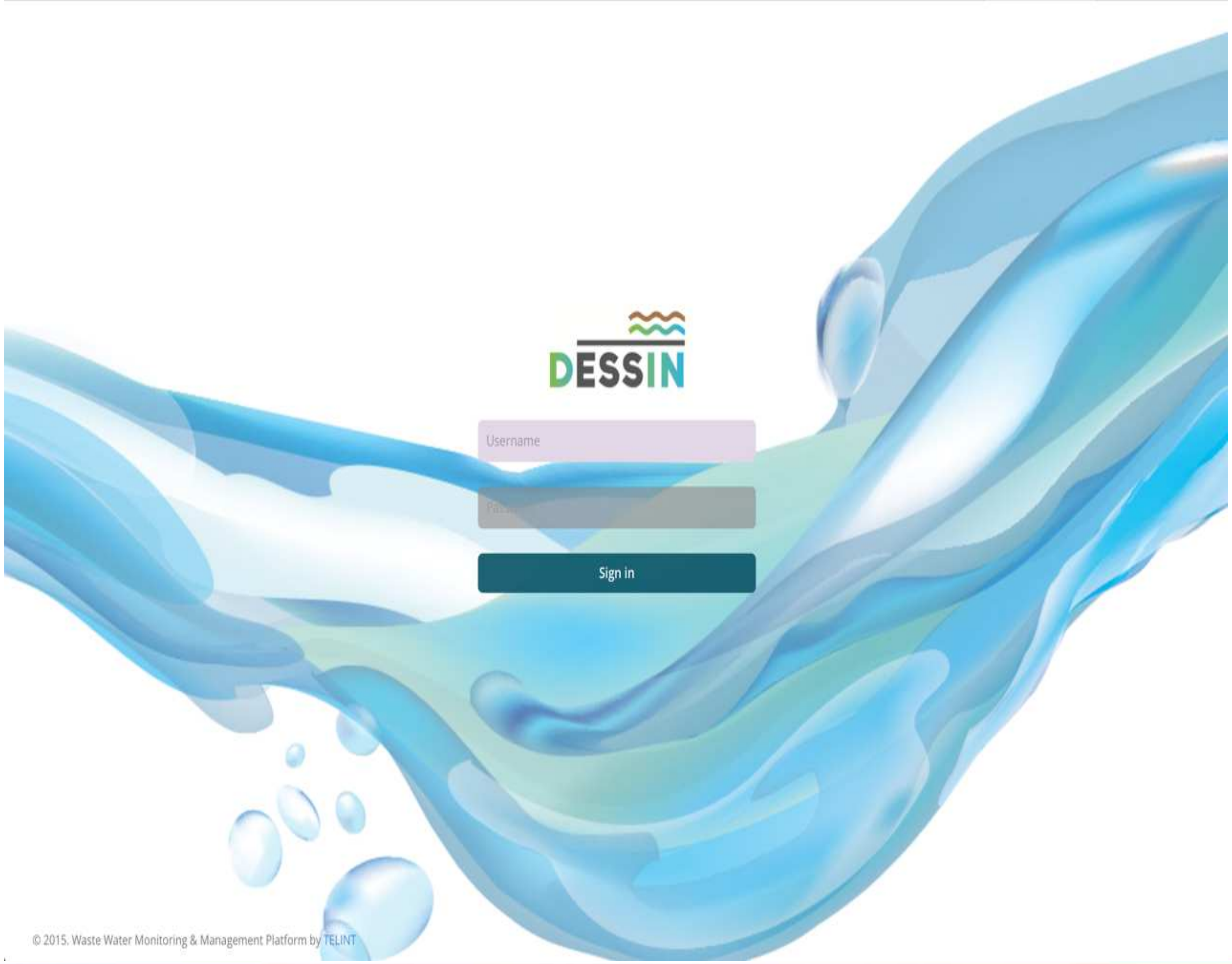
A focus on standards and interoperability



- **Sensor Data Logger / Controller**: Responsible to collect all data from sensors
- **OGC Protocol Adapter**: Responsible to parse data to OGC standards
- **SES (Sensor Event Service) Module**: Web service interface which is responsible for disseminating notifications (events/alerts) without the need to periodically request them
- **Sensor Observation Service (SOS) Module**: Web service interface which allows authorized client to access (read/write) live sensor data, historical data as well as sensor metadata through a web service call
- **SES/SOS Client**: Responsible to handle the http requests from SES/SOS and retrieve the data
- **User Interface/Monitoring Platform**: User monitors the available sensors, measurements, events, alarms

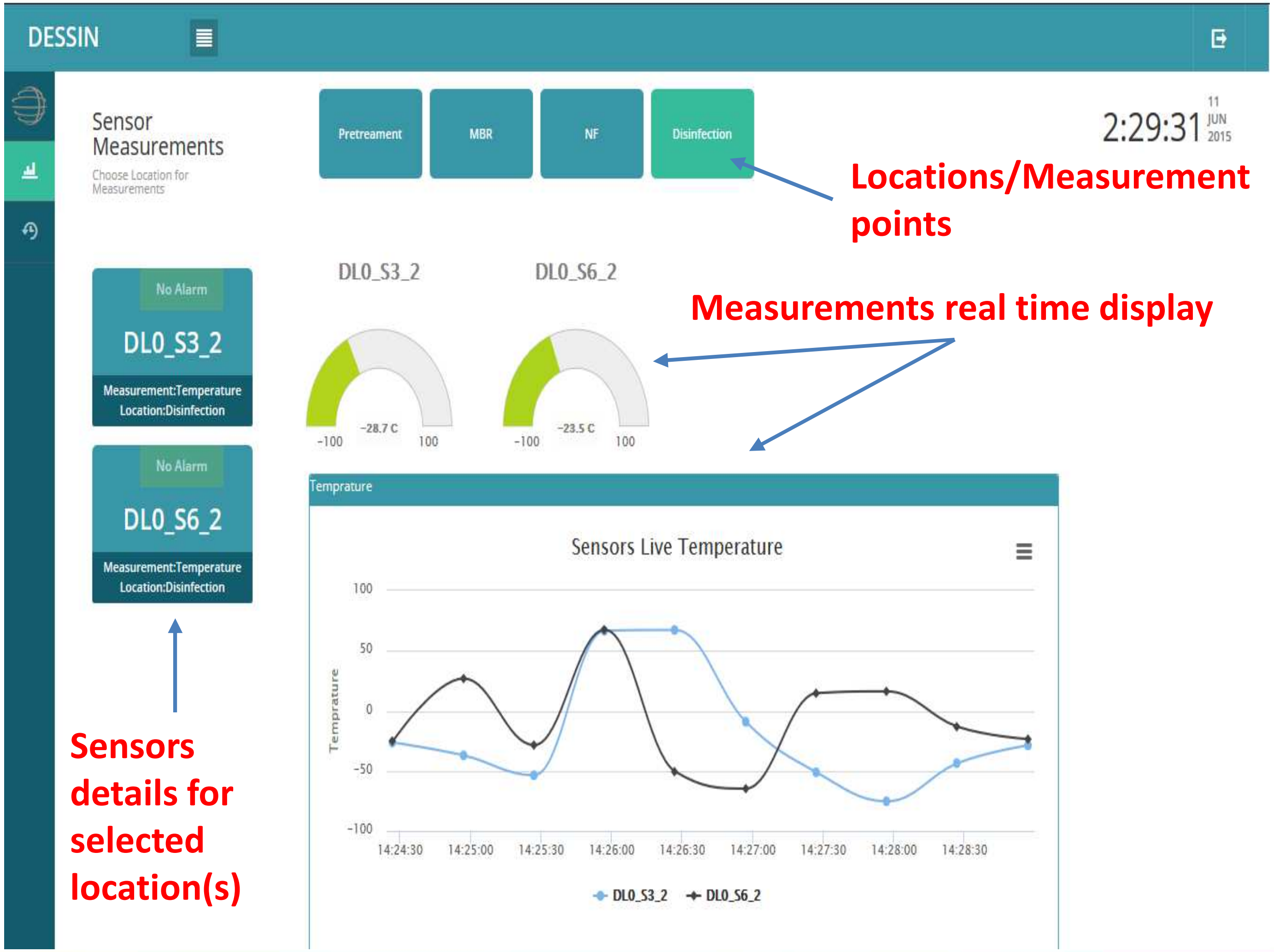
Monitoring Platform

Login page



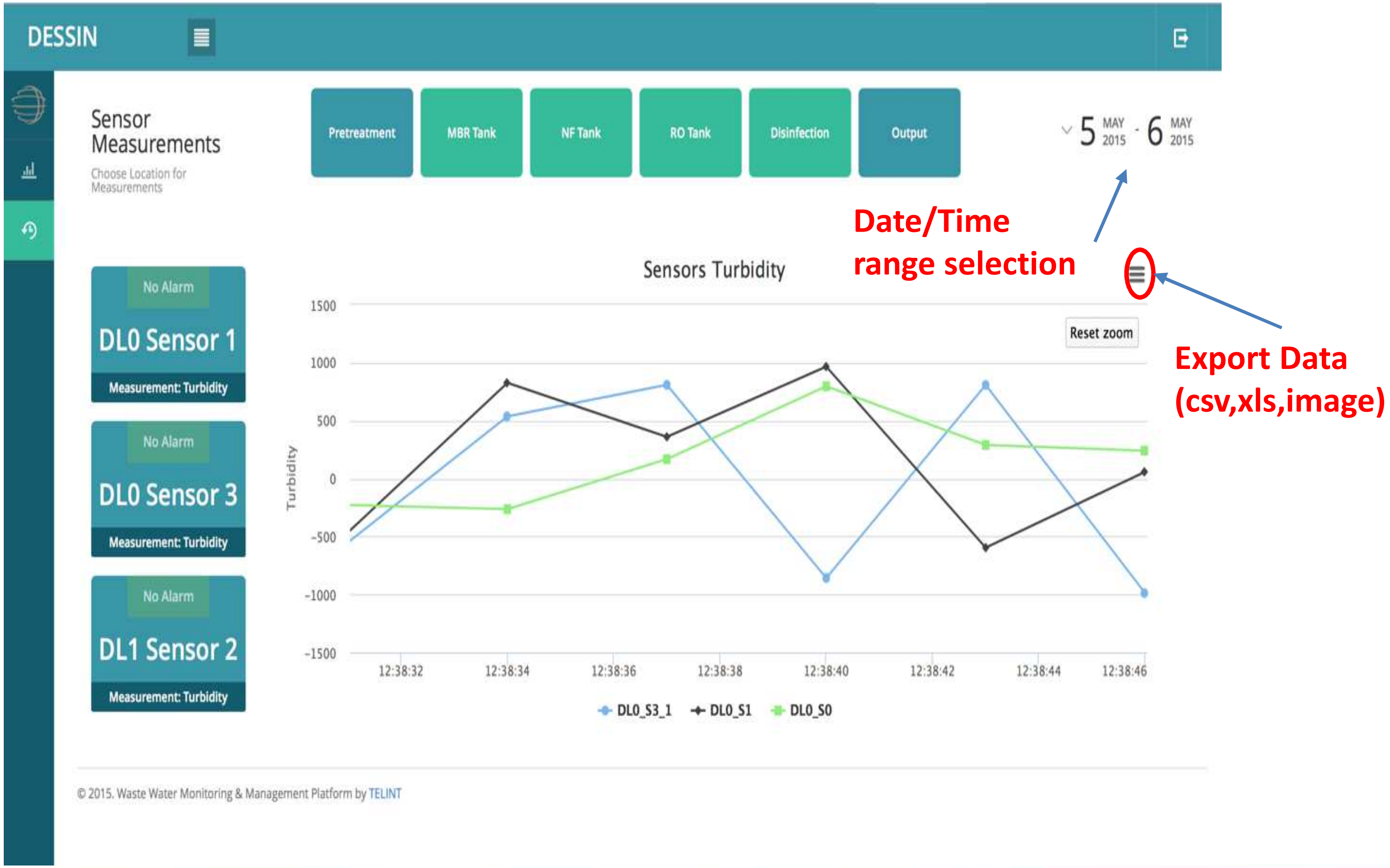
Monitoring Platform

Live data display



Monitoring Platform

Historical data



Upscaling Sewer Mining at the City level

Identification of potential locations for sewer mining units: A Monte-Carlo approach

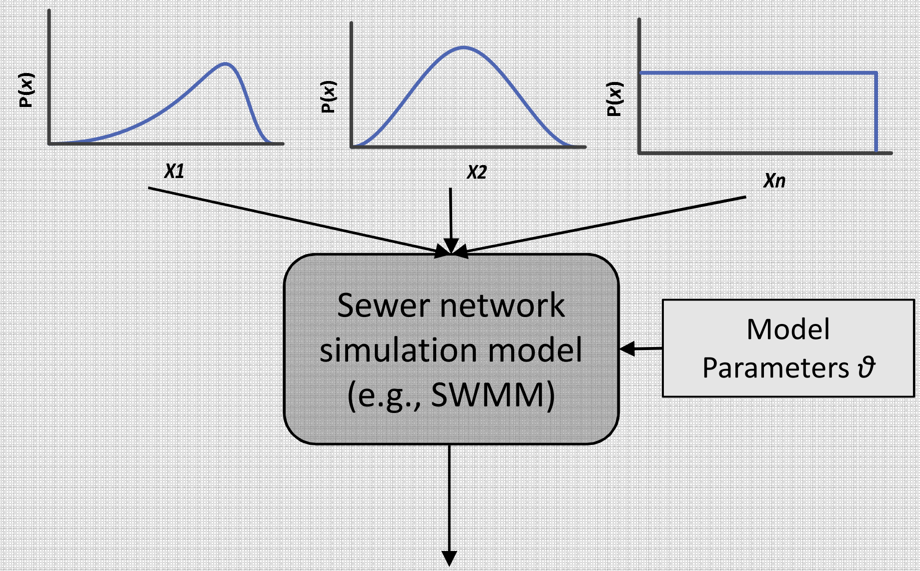
Step 1: Spatial data pre-processing

Identification of:

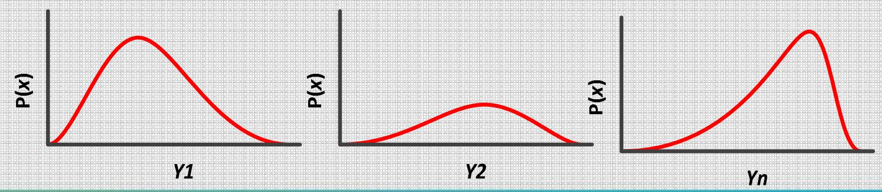
1. Sewage network topology and assets (e.g., manholes, pipes)
2. Hydraulic characteristics (e.g., pipe diameter, slope)
3. Land uses (areas that will benefit from sewer mining – e.g., parks)
   - Locate neighborhood sewer network components (e.g., nodes)

Step 2: Monte-Carlo Simulation

Inputs: Uncertain parameters *X* (e.g., Variation coefficients of wastewater discharge , BOD_5 loading).



Outputs: Quantities of interest (e.g., concentration of BOD_5 at each pipe).



Step 3: Results post-processing

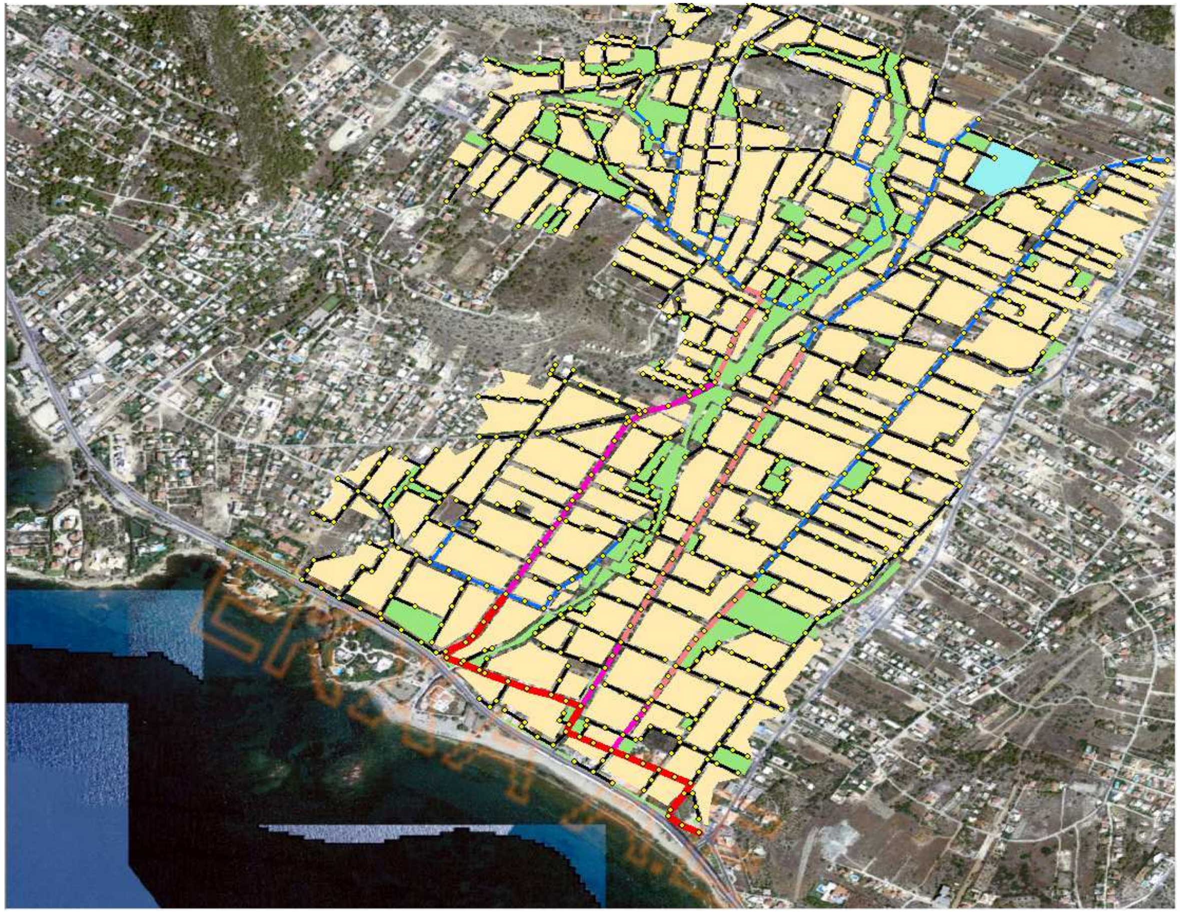
- Calculate metrics (e.g., utility functions, risk functions)

Multi-criteria analysis

- Location(s) selection

An example

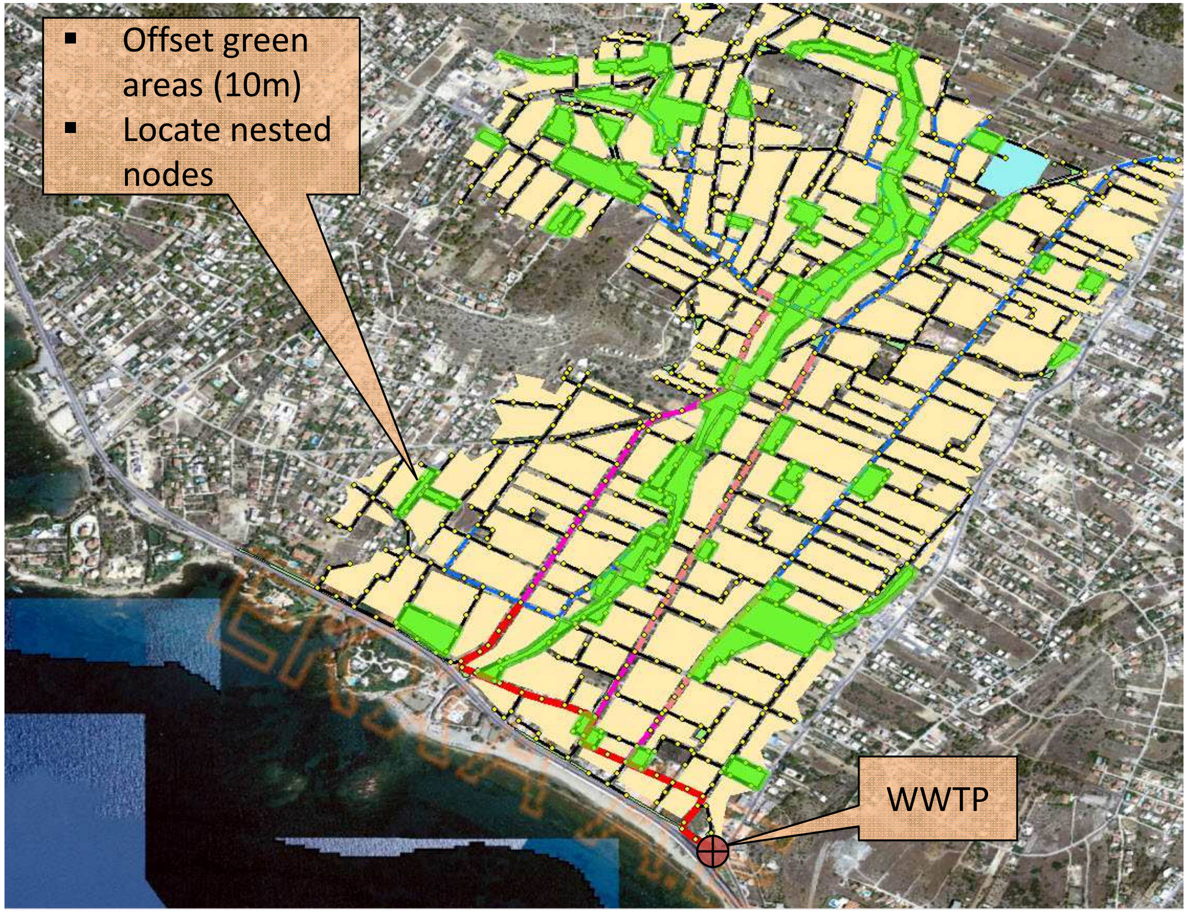
Step 1 (a): Spatial data pre-processing



Import:

1. Sewage network topology and assets (e.g., manholes, pipes)
2. Hydraulic characteristics (e.g., pipe diameter, slope)
3. Land uses (areas that will benefit from sewer mining – e.g., parks)
4. Other spatial data (e.g., aerial photo)

Step 1 (b): Spatial data pre-processing



Why?

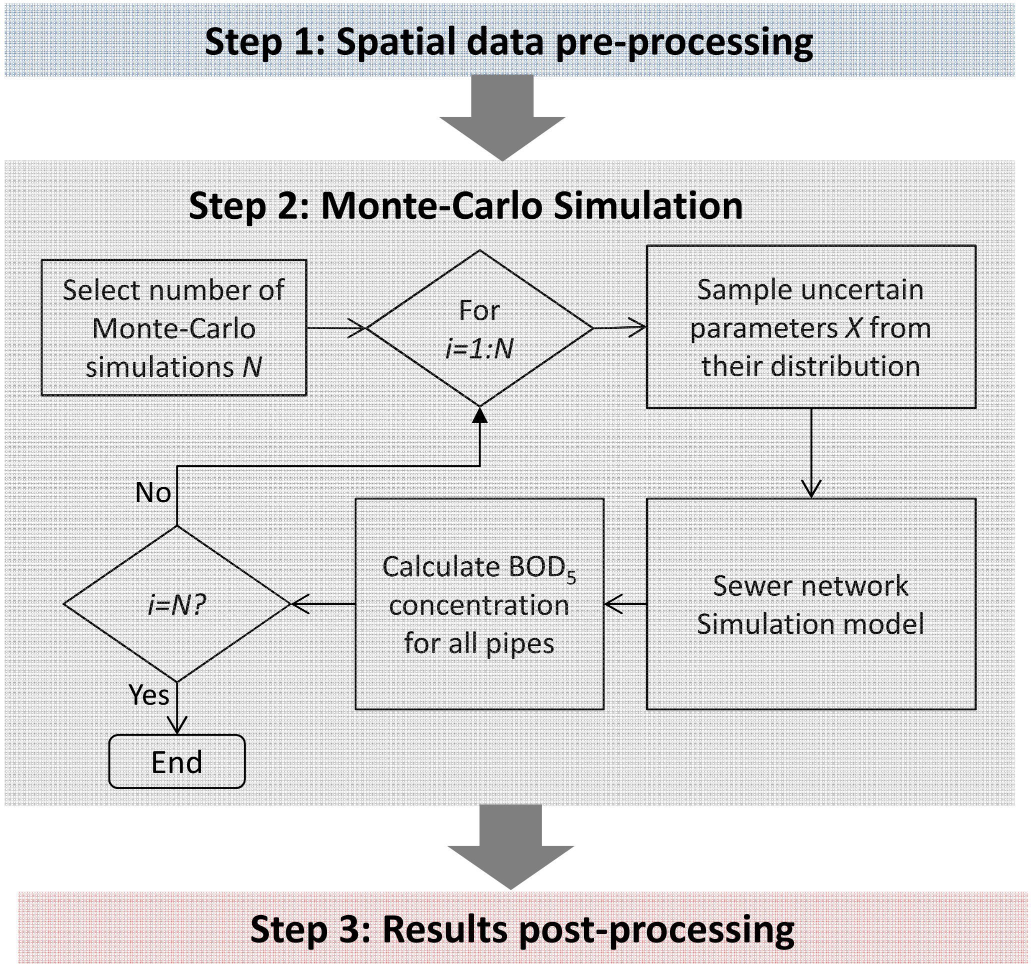
Identify land uses (areas that will benefit from sewer mining – e.g., green areas, parks)

- Locate neighborhood sewer network components (e.g., nodes)

How?

- Add offset to green areas (e.g., 10m).
- Locate the nodes that are inside each offset area.
- Find the path from each "selected" node → Exit (e.g., WWTP).
- This path is **unique** for each node due to the "collective nature" of sewer networks.

Step 2: Monte-Carlo Simulation



Why?

- Monte-Carlo simulation **propagates uncertainties** of input parameters to the outputs.
- Allows the use of **probabilistic objective** functions (metrics).

How?

- Identify uncertain parameters *X*
  - Daily and hourly variation coefficients of wastewater discharge
  - BOD_5 loading
- Identify **quantities** of output of interest: BOD_5 concentration of each pipe

Alternatives?

Similar, a scenario-based approach (instead or in conjunction with Monte-Carlo) could be employed (e.g., worst, middle, high conditions).

Next step?

- Define probabilistic objective functions (metrics).
- Post-process the results

Step 3 (a): Results post-processing

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Step 1: Spatial data pre-processing

Step 2: Monte-Carlo simulation

Step 3 (a) : Results post-processing

Metric *Z* originally proposed by von Bielecki & Schremmer, (1987) and Pomeroy, (1990) for a **single** pipe *I* in order to quantify the probability of H_2S build-up:

$$Z_i = \frac{0.3 \times 1.07^{T-20} \times [BOD_5]_i}{J_i^{0.5} \times Q_i^{1/3}} \times \frac{P_i}{b_i}$$

Where, *i* is the pipe index, T is the sewage temperature (°C), J is the pipe slope, Q is the discharge (m^3/s), P is the wetted perimeter of the pipe wall (m) and B the surface width (m) of the stream.

Modified Index Z of Pomeroy for a "**chain**" of pipes *n*:

$$Z_c = \sum_{i=n}^{N} a_i \times Z_i$$

Where, $a_i = L_i / L_{tot}$, L_i is the length of pipe *i*, and L_{tot} is the total length of pipes of chain *n*.

According to Pomeroy, (1990) if a pipe has Z_i **> 7500 then there are high chances of** H_2S formation which could lead to odour and corrosion problems.

Why?

The purpose of this step is to use metrics (e.g., utility functions, risk functions) that quantify the output of interest (in our case H_2S build-up) for **a chain of pipes** (node → exit node).

How?

- Employ a modified version of the "quasi-quantitative" indicator *Z.*
- **Calculate the E[*Z*] for given reliability level (R>75%) for each path** for each green area using the *N* simulation runs
- For **each green area select the path with minimum** E[*Z*].

Alternatives?

Similar, other metrics can be used that quantify the exact amount of H_2S in terms of mg/l.

Next step?

Multi-criteria analysis and selection of potential locations for sewer mining units.

Calculate the Pareto set (Max{Area}, Min{Z})

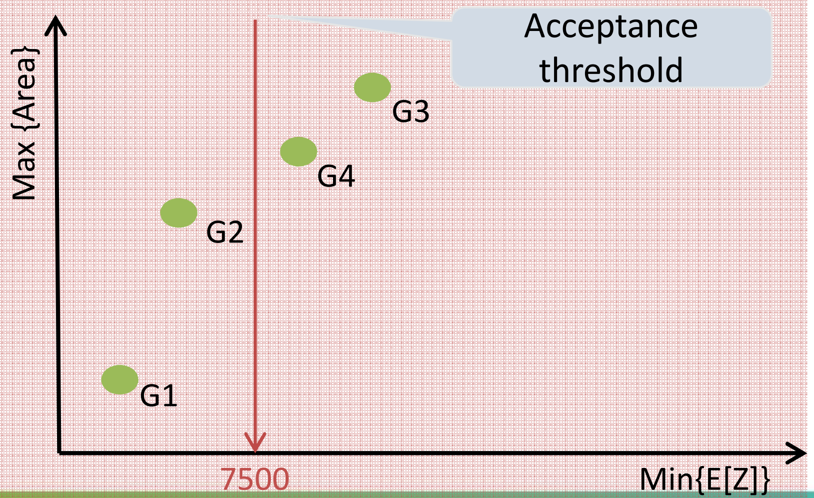
Step 1: Spatial data pre-processing

Step 2: Monte-Carlo simulation

Step 3 (a): Results post-processing

Based on the analysis:

- For each green area the optimal node for the SM placement is already found (step 3a).
- Fuse the information regarding H_2S build-up and green area water demand.
- Green area 1 and 2 are suitable for SM placement.
- Green area 1 and 2 were selected based on a desired reliability level



Why?

The purpose of this step is to use multi-criteria analysis in order to identify potential locations for sewer mining unit placement.

How?

- We have already calculated E[*Z*] for each node thus we can combine this information with:
- Information regarding the water demand in the areas of interest (green areas): We select as rough indicator for water demand the area (m^2) of the park.

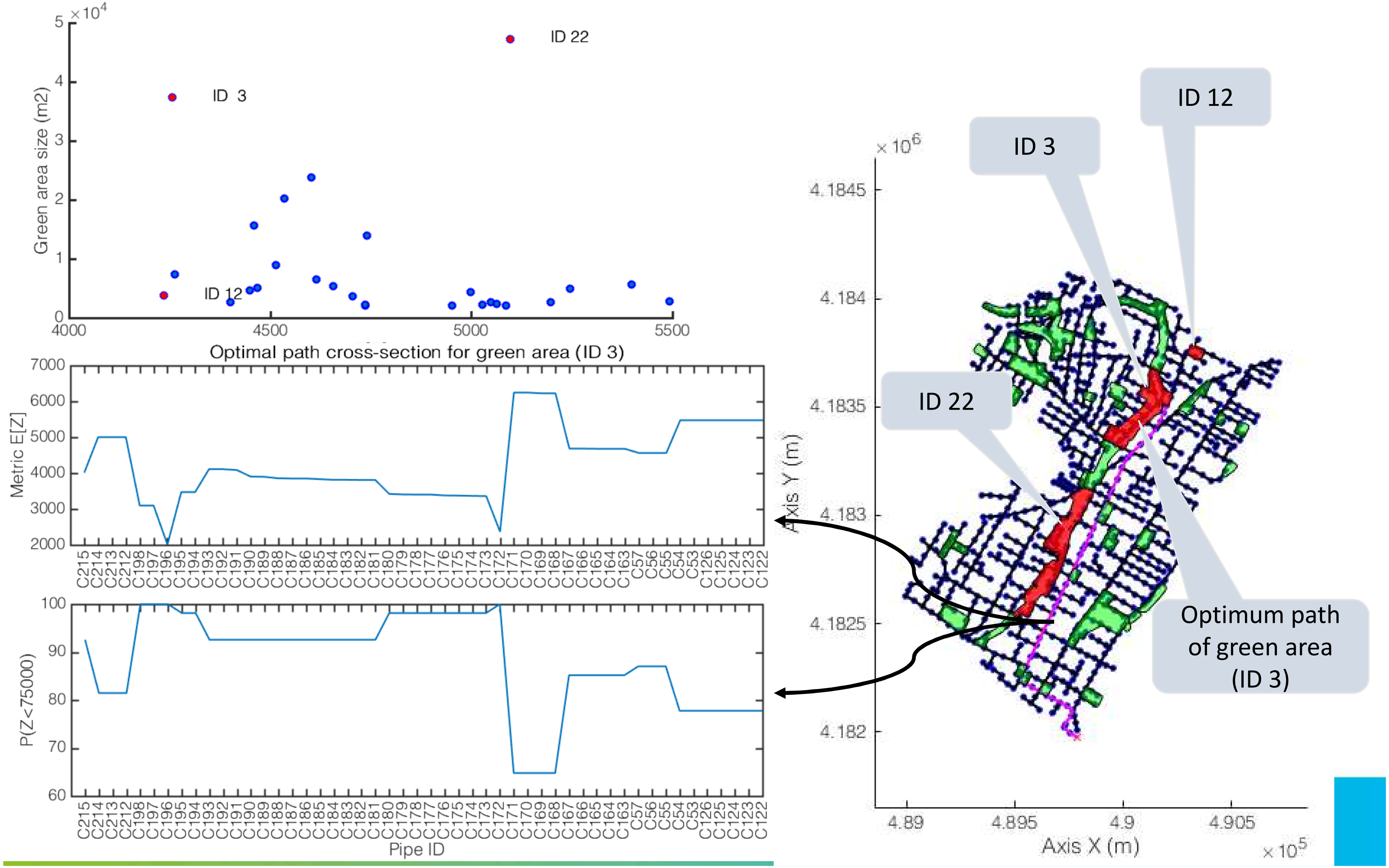
Alternatives?

Similarly, the actual water demand of each area can be calculated if information is available.

Next step?

- Selection of **potential locations** for sewer mining units.
- Further **analysis and modelling of sewer mining unit** for the selected locations.

Study area results

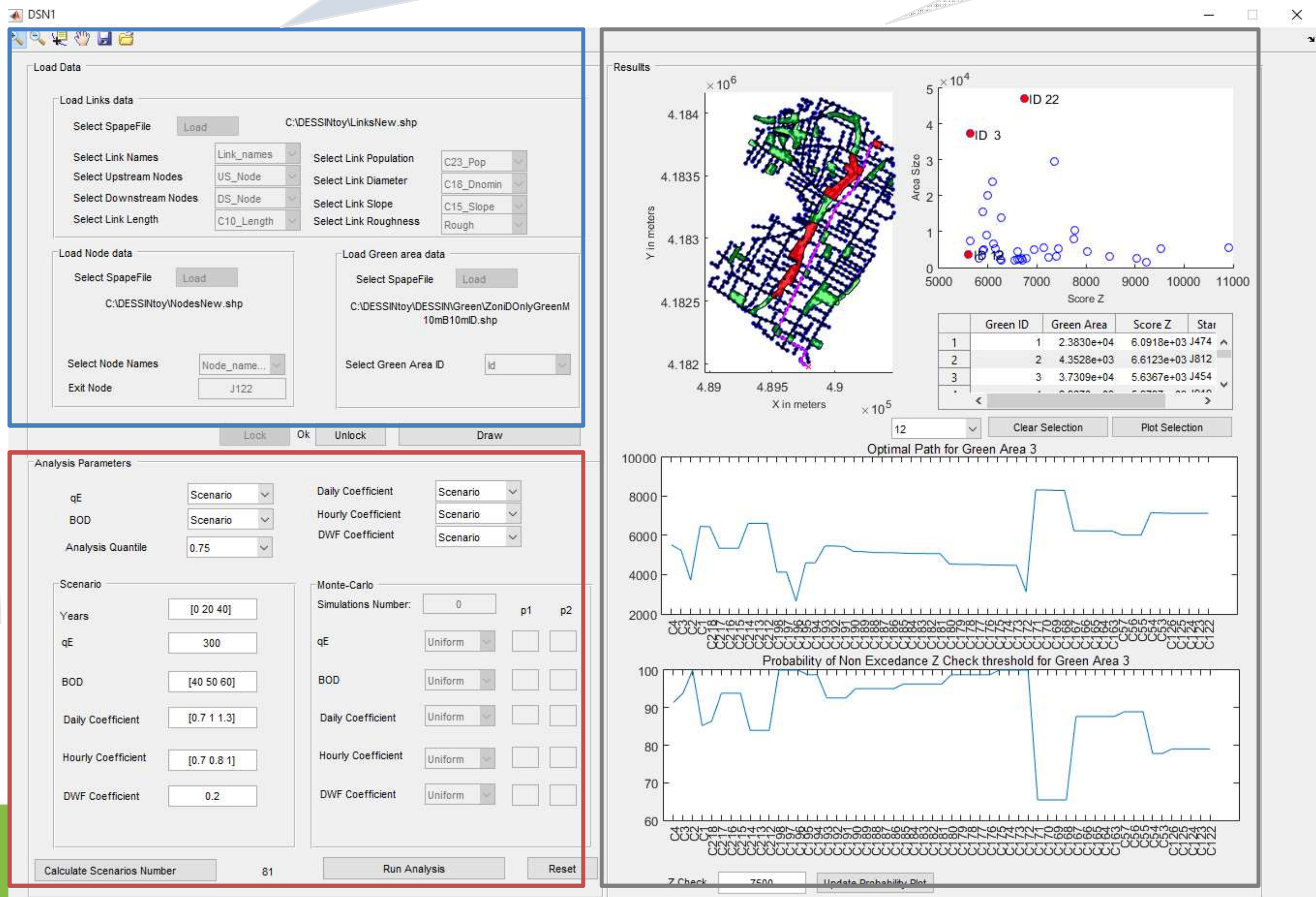


The Sewer Mining Placement Tool

Step 2: Setup Monte-Carlo Simulation

Step 1: Load spatial data and pre-processing

Step 3: Results post-processing



But what is the potential benefit?
Mapping Ecosystem Services

CICES Section	CICES Division	CICES Group	CICES Class	ESS type
Provisioning services	Materials	Water	Ground water for non-drinking purposes	Water provision for irrigation of urban green/urban agriculture
				Water provision for aquifer recharge
Regulating services	Mediation of waste, toxics and other nuisances	Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems	Water purification
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates	Preservation (protection from drought) of vegetation cover
		Liquid flows	Hydrological cycle and water flow maintenance	Groundwater fostering by injecting high quality water in a polluted aquifer
		Ventilation and transpiration	Ventilation and transpiration	Air ventilation through planted vegetation

* CICES (Common International Classification of Ecosystem Services)

Mapping of ESS in Athens Pilot

CICES Section	CICES Division	CICES Group	CICES Class	ESS type
Regulating services	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats	Biodiversity preservation and improvement
		Soil formation and composition	Weathering processes	Nutrient retention
		Atmospheric composition and climate regulation	Micro and regional climate regulation	Heat island effect mitigation
Cultural services	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Intellectual and representative interactions	Educational	Educational excursions
			Aesthetic	Improvement of aesthetic pleasure

* CICES (Common International Classification of Ecosystem Services)

ESS monitoring

Heat island effect mitigation

The Athens Pilot will demonstrate the impact of the solution on urban heat island effects, by comparing the intensity of heat island effects between three plots in KEREFYT demo site of similar geographic conditions:

- Plot without vegetation (the roof of the building),
- Plot with naturally irrigated vegetation, and
- Plot irrigated with treated water

The monitoring experiment for quantification of impacts will include:

- **On site monitoring:** Three weather stations will be installed measuring temperature, wind and radiation in each plot
- **Modelling:** The urban water cycle model (UWOT) will be employed to simulate potential evapotranspiration from each plot

ESS monitoring

Water from the compact unit…

ESS monitoring

… to the area allocated for the pilot

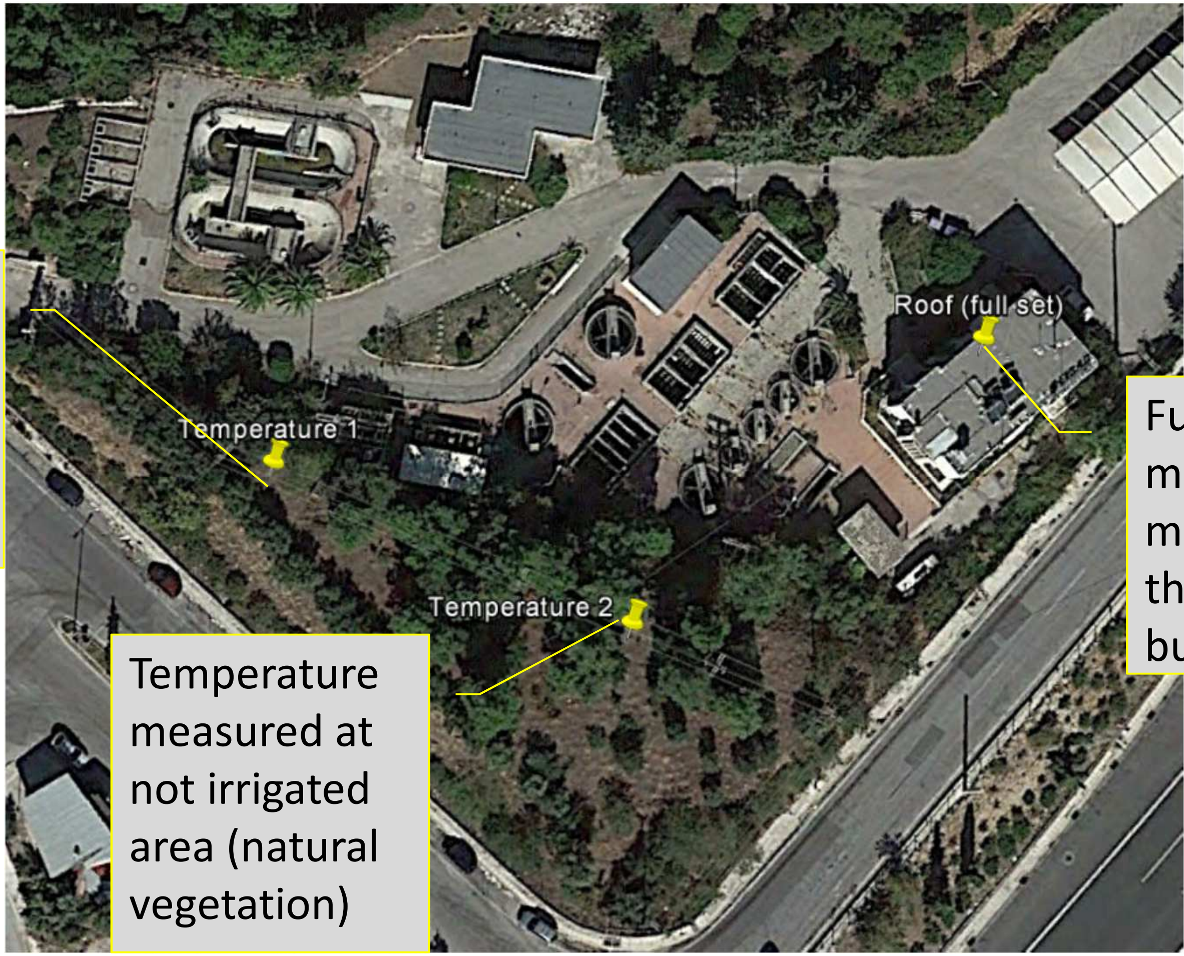
And get this guy to be photographed having a picnic on the irrigated lawn…

Site Layout

ESS monitoring

Location of sensors

Temperature measured at the irrigated area of the pilot

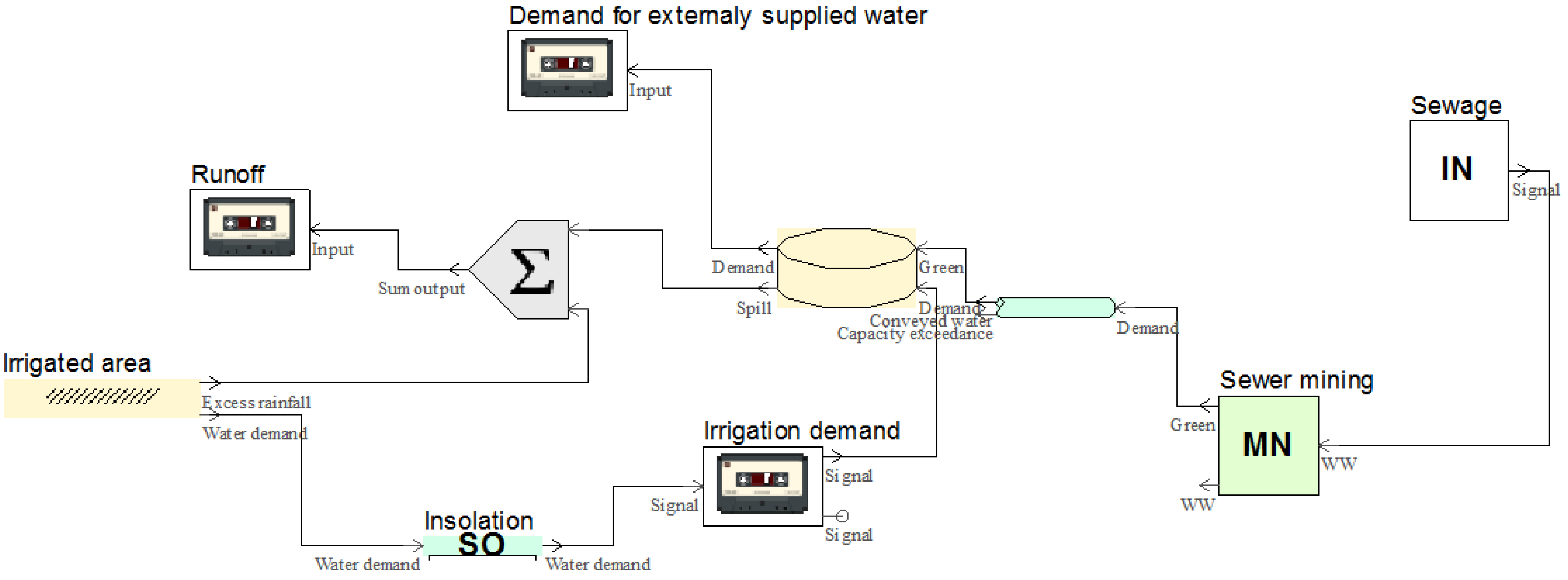


Full set of meteorological measurements at the roof of KEREFYT building

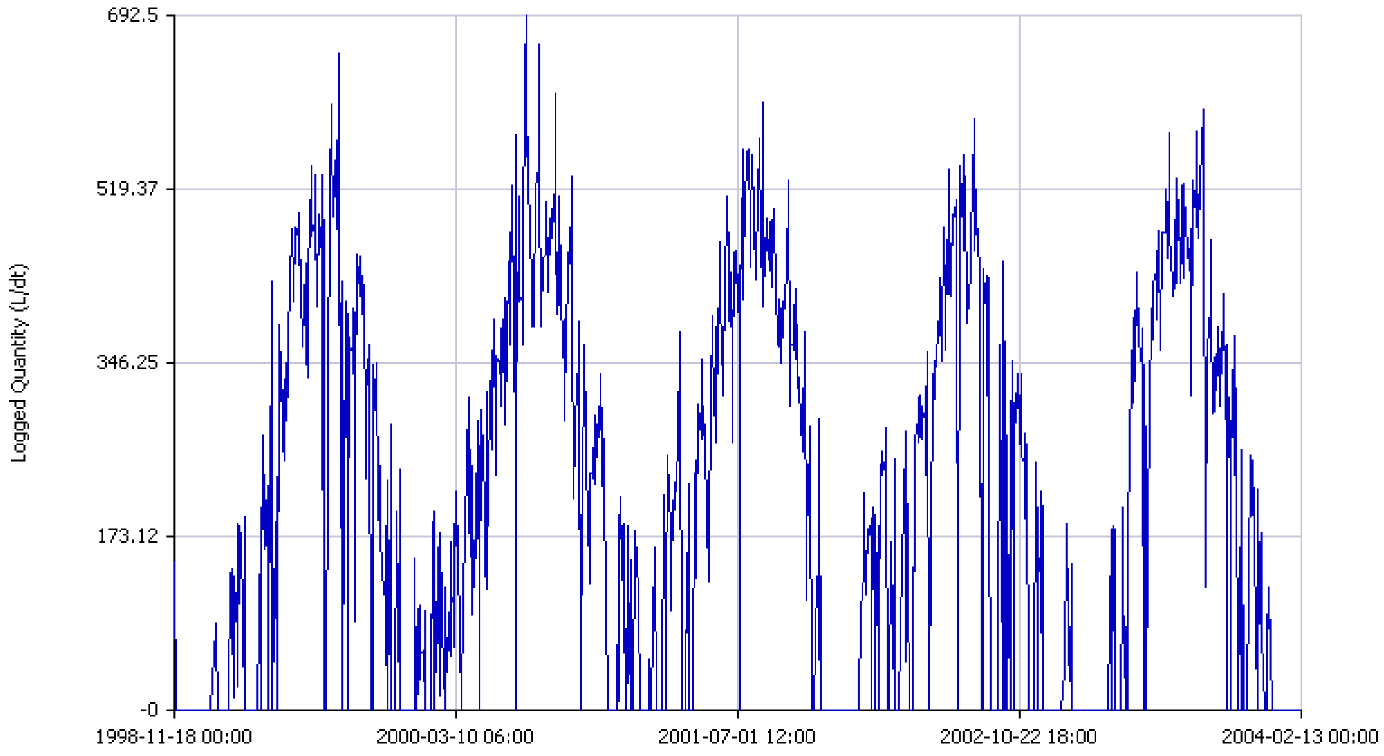
Temperature measured at not irrigated area (natural vegetation)

ESS modelling for upscaling

Simulating the process with the Urban Water Optioneering Tool (UWOT)



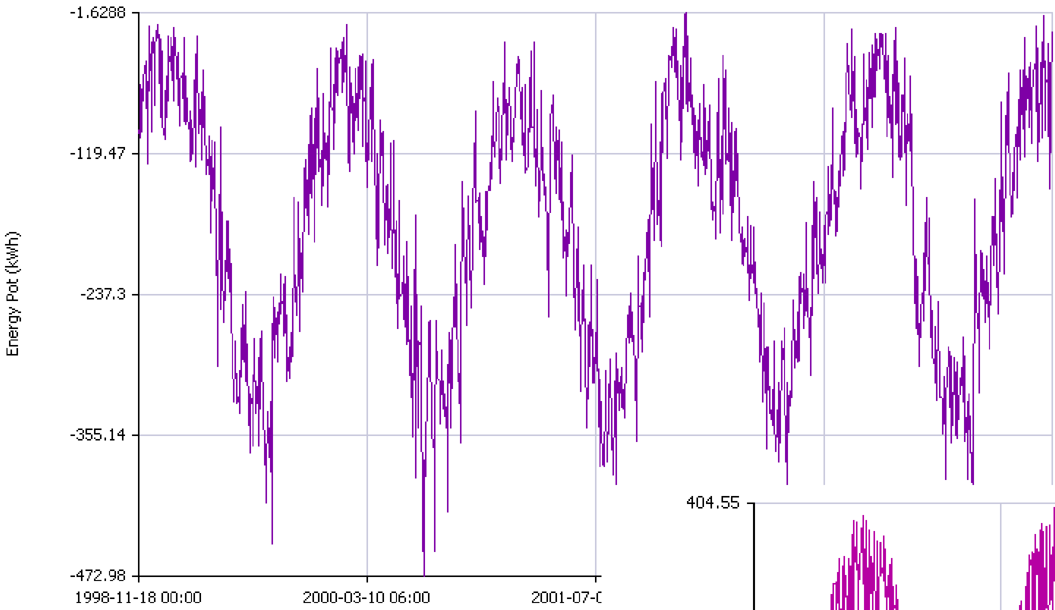
Modelling demand



Estimated water demand for irrigation, covered exclusively with treated water

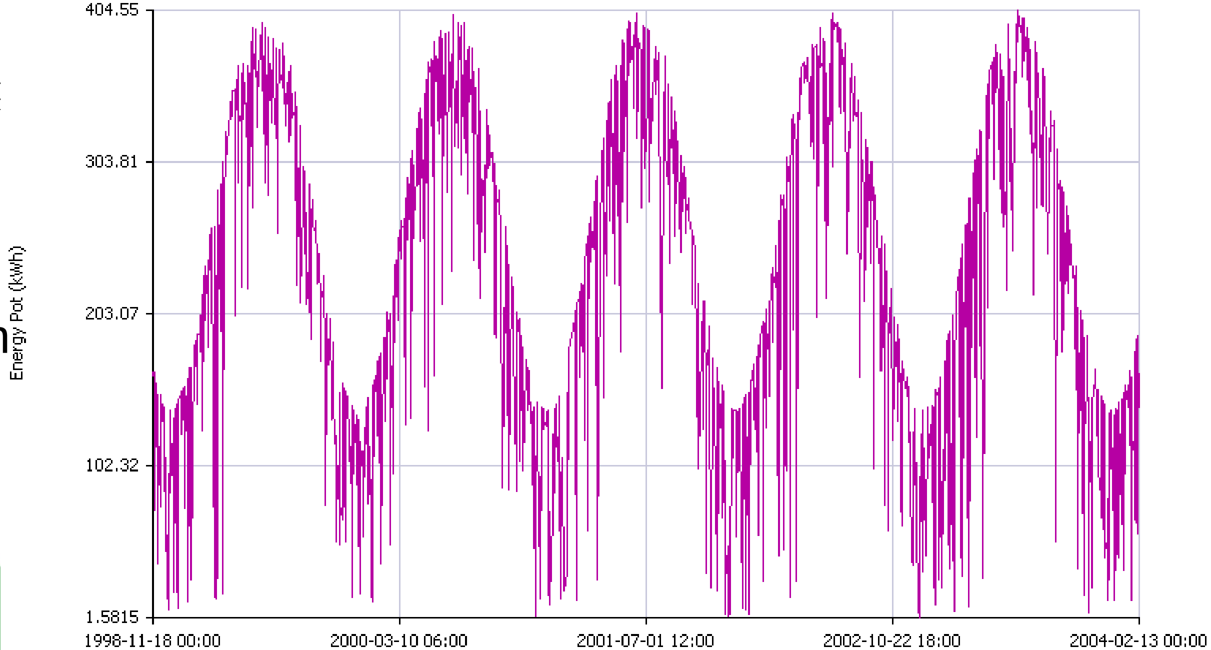
Modelling Energy

Energy balance (simulation)



Latent heat

Insolation

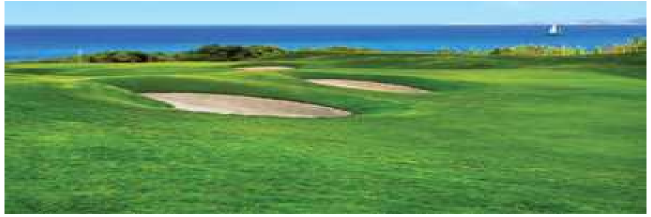


The pilot has attracted attention already..

- A new Associated Partner**, Metrolab** (SME) joined the team through own funds
- The **Hellenic Republic Asset Development Fund** visited and gave us the green light for a similar project in a environmentally sensitive area.

Next Steps

- Operational **optimization** of packaged treatment plant using the monitoring platform and the Logic Controller system and **laboratory testing**
- **Data collection** and processing of sensors installed at KEREFYT **for ESS evaluation** to quantify the impact of the **irrigation** application at a small scale
- Demonstrate the impact of the solution at the city-as-a-catchment scale (**modelling**) and identify **opportunities/barriers (e.g. regulation changes)** and assess the **governance/policy** implications of the proposed solution
- **Market analysis** and **business case** has started – related also to **full economic costing of water – WFD** (a case where the political decision of % recovery of FEC directly affects the size of the water tech market)
- Development of the pilot **showcase** (real + virtual) targeting **3 major end-users**…



Thank you!

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DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR