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LOTUS

LOW-COST INNOVATIVE TECHNOLOGY FOR WATER QUALITY MONITORING AND WATER RESOURCES MANAGEMENT FOR URBAN AND RURAL WATER SYSTEMS IN INDIA

# Deliverable D 6.1

# Report on the detailed specification of the use cases, sensor requirements, and success criteria

## Lead: IIT Guwahati

## Date: 07-02-2020

*Public*

**LOTUS** is co-funded by the European Commission under the Horizon 2020 research and innovation programme under Grant Agreement N° 820881 and by the Indian Government, Ministry of Science and Technology.

# Project Deliverable

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**Abstract**

The overall scope of the LOTUS project concerning LOTUS sensor and solution of different use cases is captured in this document. As part of the LOTUS project, the water quality sensor will be developed, and it will be deployed to monitor drinking, irrigation, river, ground and wastewater quality. The detailed requirements given by stakeholders are summarised in this doc. This document will be a reference point to establish technical requirements for LOTUS sensor and solution by the technical team.

**Keywords**

LOTUS water quality sensor, Advance solution for monitoring of water quality in WDN, Irrigation network, groundwater, river water

# Disclaimer

# The LOTUS Project

LOTUS is a project funded by DG Environment under the European Union Horizon 2020 Research and Innovation Programme and by the Indian Government. It brings together EU and prominent Indian organisations with the aim to co-create, co-design and co-develop innovative, robust, affordable low-cost sensing solutions for enhancing India's water and sanitation challenges in both rural and urban area.

The LOTUS solution is based on an innovative sensor and includes tailor-made decision support to exploit the capabilities of the sensor as well as a specific approach to co-creation. LOTUS aims to be co-designed and co-produced in India, and have a wide, diverse and lasting impact for the water sector in India due to intense collaborations with commercial and academic partners in India.

Based on the low-cost sensor platform, solutions for the early detection of water quality problems, decision support for countermeasures and optimal management of drinking and irrigation water systems, tailored on the functionalities of the new sensor, will be developed and integrated with the existing monitoring and control systems.

This sensor will be deployed in five different use cases: in a water-network, on ground-water, in irrigation, in an algae-based wastewater treatment plant and water tankers. The packaging of the sensor, as well as the online and offline software tools, will be tailored for each of the use cases. These last will enable us to test the sensors and improve them iteratively.

The project is based on co-creation, co-design and co-production between the different partners. Therefore, an important stakeholder engagement process will be implemented during the project lifetime and involve relevant stakeholders, including local authorities, water users and social communities, and will consider possible gender differences in the use and need of water. Broad outreach activities will take place both in India and in Europe, therefore contributing to LOTUS impact maximization.

The further development and exploitation (beyond the project) of the novel sensor platform will be done in cooperation with the Indian partners. This will create a level playing field for European and Indian industries and SMEs working in the water quality area.

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## Acronyms and Definitions

| Acronyms | Defined as |
|---|---|
| **As** | Arsenic |
| **DSS** | Decision Support system |
| **Fe** | Iron |
| **F** | Fluoride |
| **EC** | Electrical Conductivity |
| **TDS** | Total Dissolved Solid |
| **IWS** | Intermittent water supply |
| **DO** | Dissolved Oxygen |
| **ORP** | Oxidation Reduction Potential |
| **GMS** | Groundwater modeling system |
| **MODFLOW** | Modular finite-difference flow model |
| **MT3DMS** | Modular three-dimensional transport model |
| **CSTR** | Continuously stirred tank reactor |
| **NMPC** | Non linear model predictive control |
| **EKF** | Extended Kalman Filter |

# 1 Executive Summary

The LOTUS sensor will be demonstrated in 5 use cases namely,

- Use case 1: Water Distribution Network Guwahati
- Use case 2: Tanker based water distribution network
- Use case 3: Irrigation water distribution network
- Use case 4: Groundwater and river water monitoring
- Use case 5: Wastewater treatment

The purpose of this document is to capture the goals and the requirements of each use case in order to provide the basis for decisions on the sensor development and to enable an effective implementation and validation. The following aspects of each use case are captured

- The overall scope of the case
- The objective of the case
- KPIs to benchmark the success of the use case demonstration
- List of components required for the use case demonstration
- List of important parameters that needs to be or should be monitored for each use case
- Requirements for the installation of the LOTUS sensor and further hard- and software
- Stability and maintenance aspects
- Current status of use case with respect to the implementation of the LOTUS solution

# 2 Use case 1: Water Distribution Network Guwahati

## 2.1 Scope of the use case

The water distribution network of Guwahati city resembles other WDNs laid in various cities in India. This facilitates the application of the current use case study to multiple cities across India. The current WDN is located in the west zone of Guwahati (south). The total length of pipes laid is about 450 km spanning over an area of 100.95 sq.km. The water supply area is split into 13 DMAs, and 4 of these DMAs (33km pipe length) will be considered for the LOTUS sensor analysis. Another WDN with intermittent water supply (IWS), laid in Zoo road-Tenali in Guwahati, will be considered for extended water supply demonstration in LOTUS project.

## 2.2 Objective

The objectives in this use case are categorized based on the networks

- Real-time monitoring and control of drinking water quantity and quality supplied through South Guwahati WDN. The following objectives are designed to achieve these goals:
    1) Development of EPANET (water distribution system modelling software) model of Guwahati WDN for simulation of the network followed by the strategic installation of LOTUS sensors in the WDN.
    2) Development of a data logging system (cloud and offline) to store the data received from LOTUS box for analysis, real-time simulations and online monitoring.
    3) Development of decision support system (DSS) that couples the mitigation strategies with developed online-tools like real-time contaminant detection, optimal chlorine dosage tool, a system for recognition of pipe bursts and leakages, and monitoring system for flushing and cleaning the network
    4) Development of specific dashboards for end-user (general public) and Guwahati Jal Board that displays real-time quality data, the current state of the WDN and mitigation measures.
- Improve the supply regime in Zoo-road Tinali IWS network.
    1) Collection and analysis of available historical data of IWS network like supply timing, duration, cycles, etc. for strategic selection of DMA/zone for demonstration.
    2) Supervision of the selected DMA/zone and developing EPANET-p model for strategising the extended supply regime.

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3) Development of advisory document for transfer from IWS to extended supply, up to 12 hours.

## 2.3 KPI

The key performance indicators of Guwahati WDN use case are listed in the table below:

**Table 1 KPI for Guwahati WDN**

| KPI | Target |
|---|---|
| Functionalities implemented and tested | LOTUS sensor (sensor chip, support and electronic and LOTUS Box) board, cloud connectivity, data logging system, decision support system |
| Common Vulnerability Scoring System (CVSS) index for Security | ≤4 |
| Dissemination of alarm or alert events to stakeholders | Sending alerts to the mobile number and email/app to users based on the profile created on the LOTUS platform/app. |
| False alarms caused by IT | <5% |
| Reduction in manpower (for operation) cost in IWS or continuous network | >10% |
| Reduction in instances where the chlorine level breaches the upper and lower limits. | >25% |
| Time for suggestions of intervention from the moment contamination has been detected | 5 min |
| Reduction of water wastage in IWS | 30% |
| Improved supply time in IWS demonstration zone | > 12 hours |
| Reduction in Non-revenue water (NRW) from the current level in the IWS demonstration region* | 10% |

*- Loss of revenue due to water leakage or improper metering. To be done upon the availability of data.

## 2.4 Software/hardware components and connectivity

Supervisory control and data acquisition (SCADA) is available at the Guwahati Jal Board and currently used for monitoring flow and pressure at DMA entrance of WDN. Figure 1 describes the connectivity options between the LOTUS sensors and SCADA. The data from LOTUS sensor should able to transfer directly to SCADA using LOTUS box and, in another aspect, multiple LOTUS sensor can be connected to intermittent data transfer unit (similar to RTUs), then data will be transferred to SCADA.

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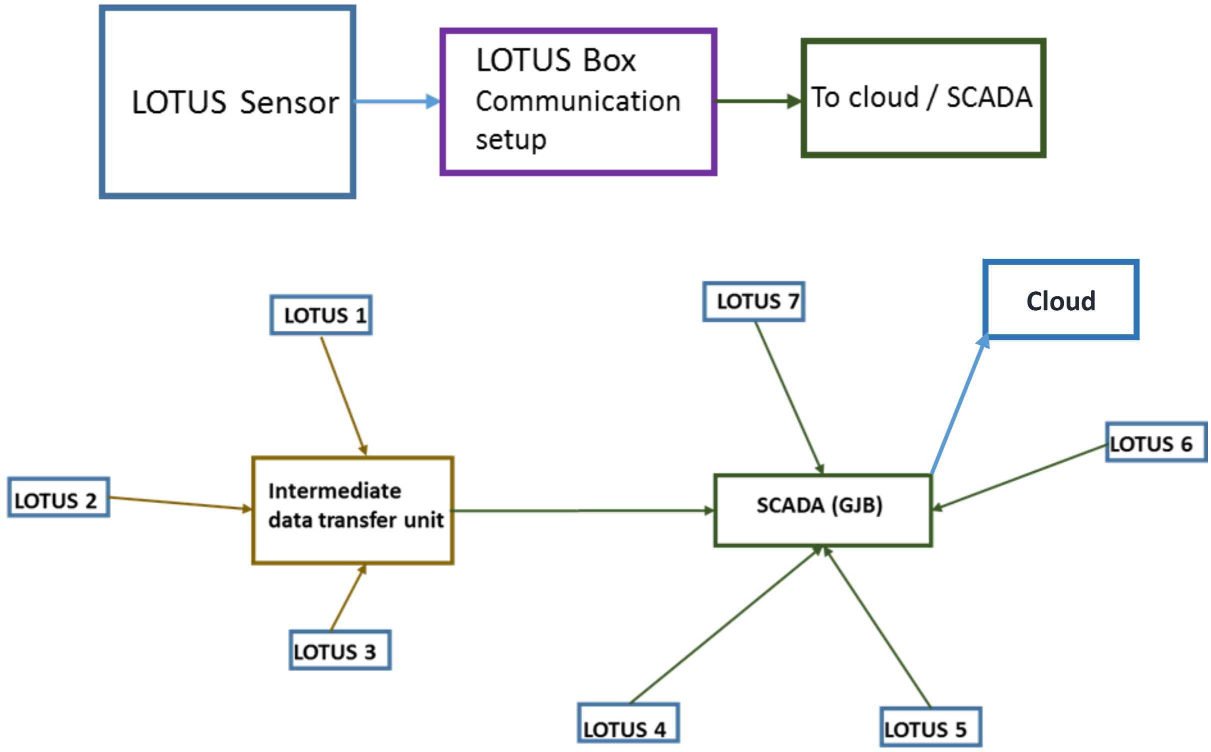


**Figure 1 Representative diagram for LOTUS sensor and SCADA connection**

# 2.5 LOTUS sensor requirement

## 2.5.1 Parameters to be monitored

For this use case, the parameters of interest are the following ones:

**Table 2 Guwahati WDN quality parameters**

| Parameter name | Range of measurement | Accuracy+ | Importance |
|---|---|---|---|
| Temperature | 0 – 50 C | ±0.5% | High |
| Pressure | 0.5bar to 25bar | ±0.1% | High |
| flow rate | 5 - 6000 $m^3$/hour | ±1% | High |
| Conductivity expressed as TDS | 100 – 2500 mg/l* | ±1% | High |
| free chlorine | 0.05 - 5mg/l | ±1% | High |
| pH | 5 – 9 | ±1.5% | High |

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| | | | |
|---|---|---|---|
| Iron | 0.05mg/l - 2mg/l | ±0.5% | High |
| microbial content | Yes/No | Not applicable | Medium |
| Arsenic | 0.01 - 5 µg /l | ±0.5% | Medium |
| Nitrates | 10 - 500mg /l | ±1% | Medium |
| Pesticide | 0.01 - 200µg/l | ±5% | Medium |
| Fluoride | 0.1 - 5mg/l | ±5% | Low |
| Turbidity | 0.1 - 50NTU | ±5% | Low |
| Hardness (Mg + Ca) | 100 - 2000mg/l | ±5% | Low |
| Carbonate ($CO_3$) | 100 - 2000mg/l | ±5% | Low |
| bi-carbonate ($HCO_3$) | 100 - 2000mg/l | ±2% | Low |

+ accuracy refers to maximum relative percentage error between actual to measured value by LOTUS sensor. * conductivity and TDS can be interchanged.

## 2.5.2 Installation

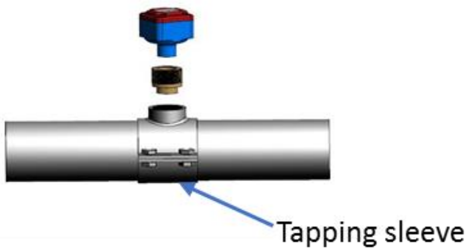


**Figure 2 Tapping sleeve for sensor installation**

The sensors will be mounted on the pipelines using a tapping sleeve. The preliminary study indicated that pipes of various sizes (100 mm to 700m) are installed in the locations considered for LOTUS sensors. Thus, the corresponding sizes of fittings are required. A safety membrane/filter cap is required at the sampling point to negate the effect of iron or dust or microbial deposition on the sensor chip. The sensor chip should withstand a sudden increase in pressure and flow conditions observed during the start and shut down operations.

The available power supply in all the locations, except for one, are electric posts or transformers. A supply line from the electric post/transformer to converter/adapter is required. A battery system is recommended to provide uninterrupted power supply to the LOTUS sensor. An inline hydro-generator has to be installed in the pipes in combination Li-ion/Li-po battery for the location without permanent power source.

### 2.5.3 Environment

This use case deals with the monitoring of drinking water. The water is treated in a water treatment plant, however, during network startup, one can expect washout of slits deposited in the pipe, and that may damage the sensor chip if it is not protected with a membrane filter cap.

### 2.5.4 Sampling rates and speed of response

The above listed parameters are important as per the utility operators. However, the parameters that will be considered for LOTUS sensor will be decided by the LOTUS consortium. The LOTUS sensor should at least take one reading of these selected parameters every 5 mins. And should be able to communicate these recorded values every hour to SCADA/cloud.

### 2.5.5 Stability and maintenance

**Table 3 Expected sensor life and maintenance requirement of LOTUS sensor**

| Components/activities | Lifespan/time period |
|---|---|
| LOTUS sensor | 10 years |
| LOTUS sensor maintenance and calibration | Every 6 months |
| Membrane cap filter | Replaced every 6 months |

### 2.5.6 Mechanical conditions

The Guwahati WDN operates on gravity-based flow with the reservoir built at an elevation of 167m. For safety purpose, the LOTUS sensor must be designed to withstand pressure nearly 1.5 times the operating head (up to 25 Bar). The maximum flow from the reservoir is expected to be around 3500 $m^3/h$. The temperature in Guwahati city varies from 10 C to 35 °C with an average yearly humidity of 80%. The precipitation level varies from 6mm in during December to 300+ mm during June-July period. The sensor should be IP68 compliant as a few of the locations considered for LOTUS sensor placement can be flooded during monsoon or due to leakage.

## 2.6 Sensor Integration

In addition to the LOTUS sensor, flow sensors will also be installed in the Guwahati WDN. The output from the flow sensors should be concatenated with the output from LOTUS sensor chip.

## 2.7 Available actuation and outlets for info collected

The data from the LOTUS sensor will be transferred from LOTUS box to cloud and from cloud to SCADA. The chlorine dosage system will be controlled by advanced control tools proposed in this project

## 2.8 Required components

1) Requirements at the LOTUS sensor locations
   - Power supply to the LOTUS box by either the grid/hydrogenerator.
   - Connectivity to cloud or SCADA (at administration office) from LOTUS box.
2) Modification of the currently available SCADA for receiving and storing the data from LOTUS box.
3) Tools for analysing the sensor data, detecting contamination and locating chlorine dosage point and concentration based on the data supplied by SCADA.
4) Interconnectivity between all the components: LOTUS sensor, data collection system (RTUs), Control room (SCADA) and cloud (DSS tool) must be established. It is necessary to maintain connectivity at least during sampling time to make an hourly update on the LOTUS platform. In case of a connection failure, data should be extractable using USB from LOTUS box.

## 2.9 Dashboards and interfaces

1) Dashboards should be developed for two different users: Administrator and End-user
2) The end-user (general public) dashboard should display (GIS) the water flow, pressure, quality parameters and supply time (IWS).
3) Administrator’s dashboard should include the following:
   - Display of the WDN quality and flow parameters (GIS).
   - Alarm system based on problems/threat incurred.
   - DSS display for optimal strategy/solution for the contamination detection and problems incurred.

## 2.10 Current scenario

The potential sensor locations for Guwahati water distribution network is shown in the following figures. Figures 1 and 2 display the sensor locations in DMA-1 and DMAs 2,3 and 4, respectively, denoted by blue circles (**O**). 28 sensor locations have been identified in the WDN including the WTP

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and reservoir. These locations have been verified physically and corresponding details regarding the location, connectivity, power, pipe sizing have been gathered. Analysis of intermittent supply will be carried out in Zoo road - Tinali region of Guwahati city where the laid distribution network is already in operation

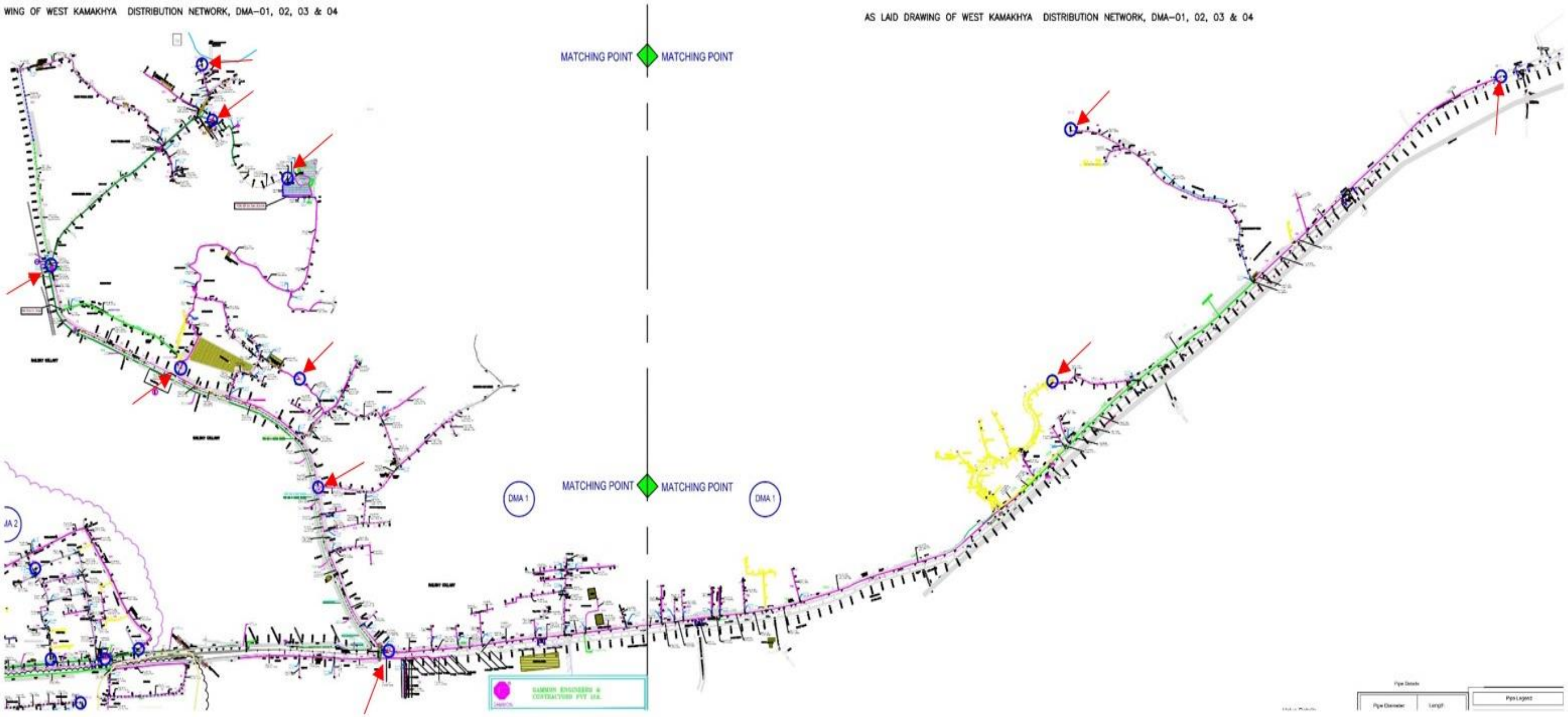


**Figure 3 Sensor Location in DMA-1 of Guwahati water distribution network**

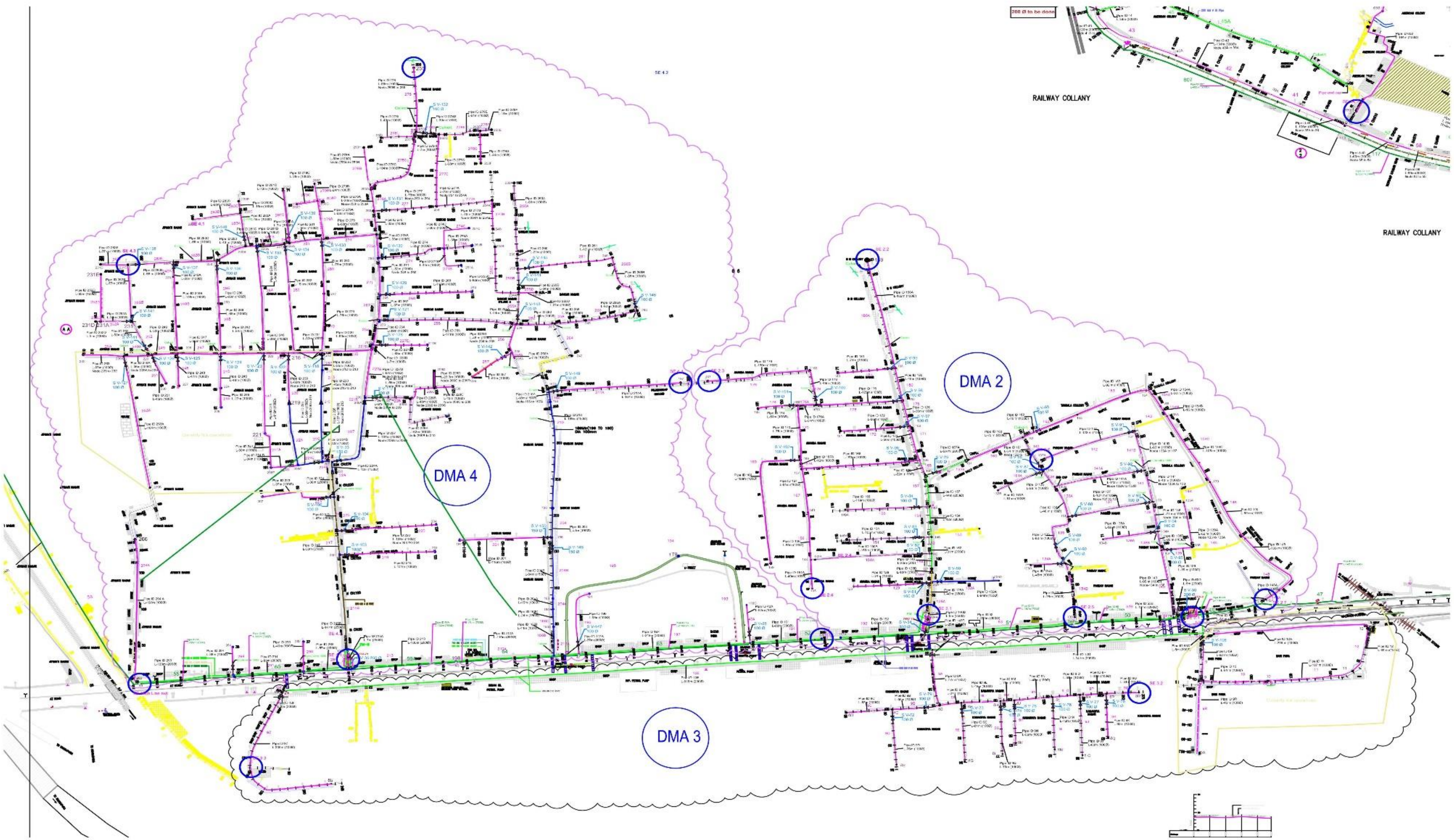


**Figure 4 Sensor Location in DMA-2,3 & 4 of Guwahati**

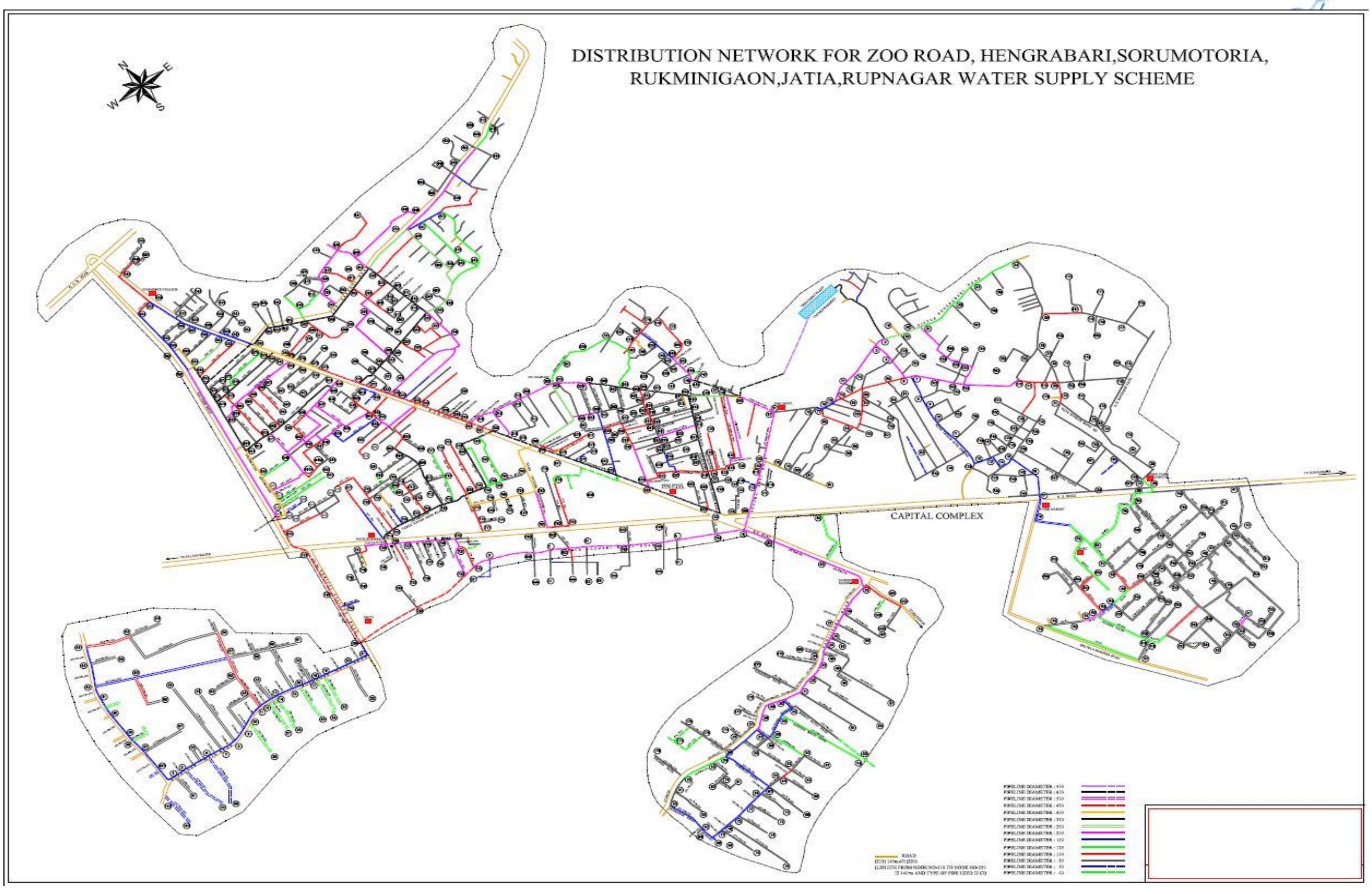


**Figure 5 Zoo Road -Tenali Intermittent water supply network**

# 3 Use case 2: Tanker based water distribution network

## 3.1 Scope of the use case

The lotus solution for tanker use case includes both sensor, chlorine dosage unit and software solution. In this use case, the standalone tanker scheduling solution for demand and supply match will be demonstrated with a large number of Tanker system (~ 100 Nos). Secondly LOTUS project we will demonstrate the LOTUS sensor along with an integrated scheduling solution for 10 trucks. However, one chlorine dosage will be installed in the tanker and another one at the borewell station.

## 3.2 Objective

The objective comprises the monitoring, control and online regulation of water quality in tanker based drinking water supply network.

1) Design and installation LOTUS sensors, disinfection system and power supply unit at the centralized water treatment facility and on the water tankers.
2) Develop the data logging system (cloud and offline) to receive and store output from LOTUS sensors from the treatment plant and tankers.
3) Develop decision support system comprising tools for tanker quality monitoring, optimal operation of disinfection system, tanker scheduling and tanker cleaning period.
4) Develop dashboards for each of the users: the general public, vendors(suppliers) and administration.
5) Observation and evaluation of the LOTUS system with respect to the tanker-based distribution network for a period of one year.

## 3.3 KPI

**Table 4 KPI for tanker-based water distribution**

| KPI | Target |
|---|---|
| Number of functionalities implemented and tested | LOTUS sensor (sensor chip, support and electronic and LOTUS Box) board, data logging system, disinfection system and decision support system |
| Energy-saving based on the scheduling of tankers* | >10% |



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| | |
|---|---|
| Response time for activating the disinfectant system based on the sensor parameters | < 2 min |
| Time for chlorine dosage and complete dissipation of chlorine into the tanker water | < 10 min |
| Response time for scheduling and sending notifications to vendor and user | < 2 min |
| Duration of sustainable accuracy of the sensor | > 2 years |
| Reduction of acute water shortage at schools, hospitals during high demand season | > 20 % |

* - This will be required to bring down the overall cost of water.

## 3.4 Software/hardware components and connectivity

Sample architecture for the tanker use case is shown below.

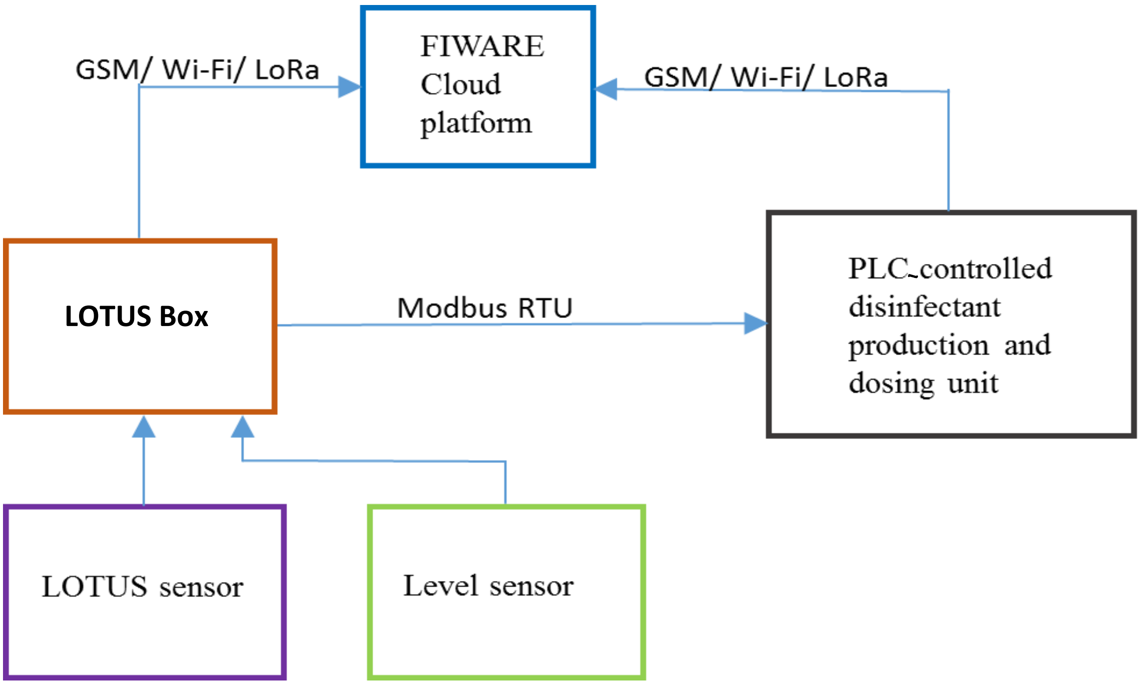


**Figure 6 LOTUS system for the tanker use case**

# 3.5 LOTUS sensor requirement

## 3.5.1 Parameters to be monitored

**Table 5 Tanker based water distribution quality parameters**

| Parameter name | Range of measurement | Accuracy | Criticality level |
|---|---|---|---|
| Temperature | 0 – 50 C | ±1% | High |
| Carbonate ($CO_3$) | 0 to 1000 mg/L | ±0.5% | High |
| Conductivity | expressed as TDS 100 – 4000 mg/l | ±1% | High |
| pH | 5 to 10 | ±1.5% | High |
| Chlorine | 0.05-5 mg/L | ±1% | High |
| Iron | 0 to 10 mg/L | ±0.5% | High |
| Microbial content | Binary (Yes/No) | Not applicable | High |
| Nitrates | 0 to 500 mg/L | ±1% | High |
| Arsenic | 0 to 500 µg/L | ±0.5% | High |
| Hardness (Ca, Mg) | 0 to 1000 mg/L | ±5% | High |
| Pesticide | 0 to 500 mg/L | ±5% | High |
| Fluoride | 0 to 15 mg/L | ±5% | High |
| Turbidity | 0 to 25 NTU | ±5% | Medium |

+ accuracy refers to maximum relative percentage error between actual to measured value by LOTUS sensor.

Chlorine is the parameters to be considered in the use case. The Arsenic, fluoride, carbonate, pesticide, nitrates and iron will be required for checking the quality of the source groundwater.

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## 3.5.2 Installation

A LOTUS sensor integrated with the electro-chlorinator will be deployed in one of the borewell station and one tanker, whereas, LOTUS sensor alone will be installed in additional 9 more tankers.

An Onsite Chlorine Generation (OCG) system will be installed at an existing borewell/water filling station. The chlorine will be dosed together with the pumped water into the intermediate storage tank. A LOTUS sensor will be integrated into the intermediate storge tank to check on chlorine concentration during filling. The storage tank will additionally be equipped with a level indicator. The signal will be used to  adjust the dosing rate to meet the respective requirements on residual chlorine.

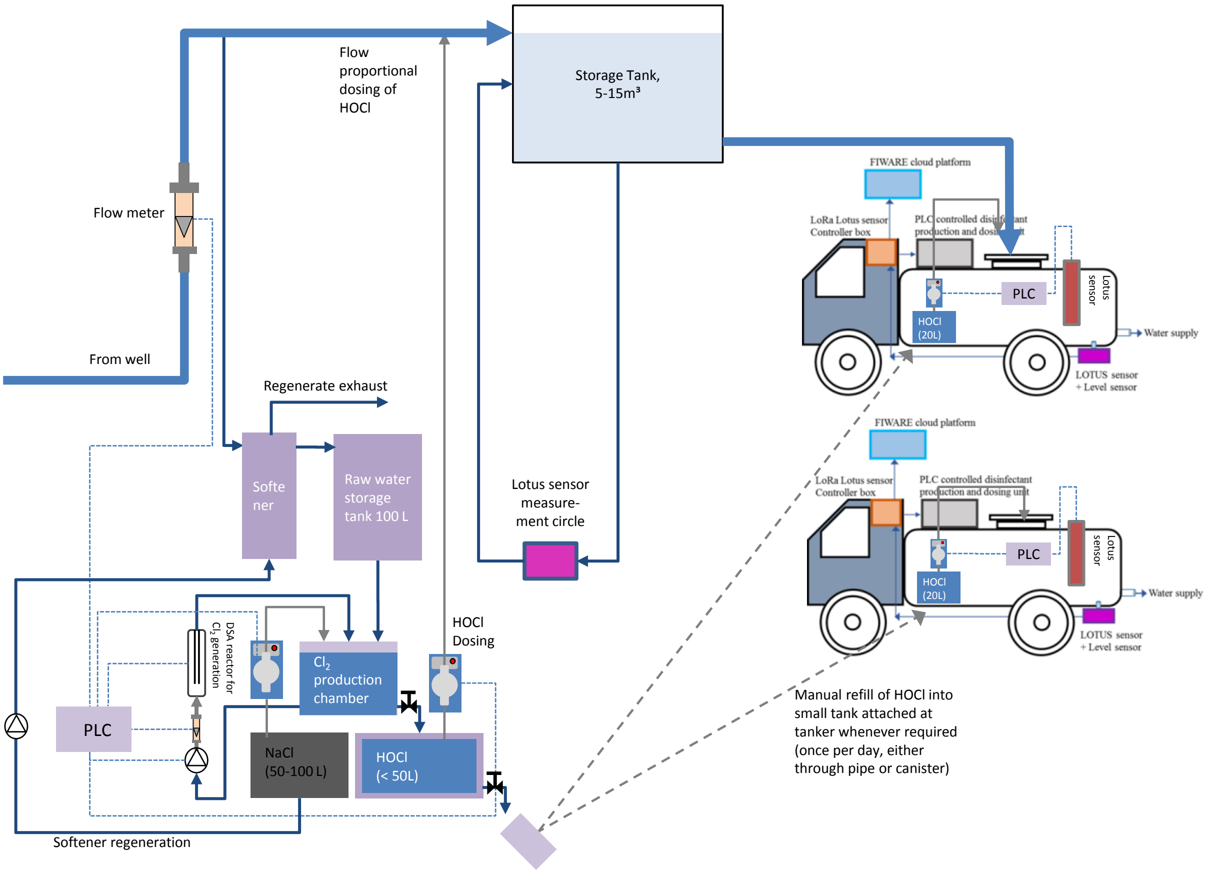


**Figure 7 Scheme for tanker based water quality assurance**

Additional Lotus sensors installed at the truck will allow to monitor the residual disinfectant inside the truck after filling and during the transport to the consumer. The Sensors will be linked to an automatic chlorine dosing system attached to the tanker, which will reassure pathogen free water conditions, as soon as the required residual chlorine level in the water is not met anymore. This can e.g. occur when the transport to the site of interest takes very long. It will also assure that sufficient residual disinfectant is present in the water before it goes into the end users storage tanks.

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Sensors will be installed at the bottom of the tanker as shown in figure 6. The sensor tip will be submerged in drinking water/RO water throughout its lifetime. The estimated power demand of about 10 Wfor LOTUS sensor, level sensors, and disinfectant dosing system will be supplied by the Tankers 24 VDC on board power supply. Alternatively, an additional backup battery will be installed which can be charged either by the power supply of the truck or an attached solar PV panel.

The wireless connection between the LOTUS box, cloud system, and data storage system will be based on the SIM (3G/4G) network. The disinfectant system will be operated based on the results from the LOTUS sensor by a PLC controller placed in the tanker.

### 3.5.3 Environment

In this use case, the fresh potable water or RO treated water will be exposed to the LOTUS sensor. However, depending upon the groundwater source the scale formation on the LOTUS sensor chip may be possible and it has to be taken care while designing the sensor chip and membrane cap.

### 3.5.4 Sampling rates and speed of response

The sensor should provide the quality parameters at every 1-minute interval, i.e. sampling, analyzing and transmitting data should be completed within 1 min. And it is required to control the chlorine dosage in real time.

### 3.5.5 Long-term stability, maintenance intervals

**Table 6 Expected sensor life and maintenance requirement of LOTUS sensor**

| Components/activities | Lifespan/time period |
|---|---|
| LOTUS sensor | 10 years |
| LOTUS sensor maintenance | Every 3 months |
| LOTUS sensor calibration | Every 6 months |
| Membrane cap filter | Replaced every 6 months |

### 3.5.6 Mechanical conditions

During transit, the movement of water might exert pressure up to 1 bar on the sensor module and the disinfection system. Continuous vibrations are expected during delivery operations. The LOTUS box will be placed outside the tanker always exposed to the weather. The temperature in the Bengaluru city varies from 15 C to 35 C with yearly average humidity 65% (min: 25% and max: 80%). Maximum precipitation of about 180 mm is observed in September.

## 3.6 Sensor Integration

The level of the water available in the tanker will be monitored using a level sensor. The output from the level sensor should be concatenated with LOTUS sensor output.

## 3.7 Available actuation or outlets for info collected

The output data from the LOTUS sensor should be transmitted to the controller and cloud. The controller will actuate the disinfectant system whereas the cloud data will be available for the administrator to run various online tools. The dashboard will be updated based on the data received by the administrator. Water quality parameters will be communicated to the end user.

## 3.8 Required components

The function of the tanker based water network solution has the following requirements:

1) Power supply unit for the LOTUS sensor, level sensor, and disinfection system.
2) A disinfection system installed in the tanker for chlorine dosage.
3) Connectivity solution either through LoRa, GSM, Wifi.

## 3.9 Dashboards and interfaces

1) The LOTUS Platform in this use case should offer three different views based on the interacting user: end-user (general public), vendor (tanker distributor) and admin (WDN operator).
2) The end-user requirements include the water quality, availability, pricing and ETA of the tanker.
3) The vendor's platform should include quality, tanker current capacity, and end-user demand.
4) The admin's platform should include the following:
   I. Display of all the available tankers and demand points in a map.
   II. An alarm system to notify the problems in the system like quality deterioration, inadequate water in the tanker, etc.
   III. DSS system to match vendor and end-user, ensure optimum water refilling in the tanker and activation of the disinfection system.

# 4 Use case 3: Irrigation water distribution network

## 4.1 Scope of the use case

The scope of the use case is to implement the LOTUS sensor in manually operated and automated irrigation systems to improve the current practice of fertilization and irrigation. Drip and sprinkler irrigation systems are used for a variety of crops such as banana, cotton, mango and pomegranate. Depending on the availability, surface water (rivers, lakes, dams, channels, storage ponds) and ground water from borewells is used for irrigation.

## 4.2 Objectives

The objective of the use case is the implementation of the LOTUS sensor in drip and sprinkler irrigation systems for decision support and long-term monitoring.

1) Integrate the LOTUS sensor with JAIN's irrigation system. Current and recent sensor data should be made available on mobile phones and long-term storage should be present to allow for long-term analytics.
2) Develop an advisory system and provide it to farmers for testing. The system should process the optimum water source, amount of water and the amount and composition of fertilizer for a specific crop, soil (out of a set of discrete classes), past weather, weather forecast and growth stage of the crop. Additionally, information on the risk of clogging and advice for cleaning should be provided.
3) Develop a concept for the integration of the advisory system with the advanced automation system.

## 4.3 KPI

**Table 7 KPI for use case 3: Irrigation water distribution network**

| KPI | Target |
|---|---|
| Functionalities implemented and tested | Sensor connected to the monitoring system and working accurately |

| | |
|---|---|
| | Alarm system operational<br>Advisory system for farmers operational |
| Dissemination of alarm or alert events to stakeholders | Sending alerts to respective mobile number / app to users based on the profile created on Lotus platform/app. |
| False alarms | < 5% |
| Reduction of the cost for pH and EC measurements | >50% |
| Dosage reduction of fertilizer | 10% |
| Reduction of clogging events | 70% if the system is cleaned according to the advice given |
| Reduction of over-irrigation | 50% |
| Time for suggestions of intervention from the moment contamination has been detected | 10 min |
| Reduction of irrigation with water of out of spec EC or pH | 20 to 30% |
| Life expectancy of membrane filter | > 6 months |
| Life expectancies of sensor | 5 years (One year without maintenance) |
| Target analytes | Mandatory: pH, EC<br>Priority: Sodium, iron,<br>Optional: N, P, K, pressure and flow |

## 4.4 Software/hardware components and connectivity

Systems for data acquisition and storage as well as local control are available at JAIN. LOTUS sensor must be integrated with an existing setup for mobile communication to send alarms and for data export.

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# 4.5 LOTUS sensor requirement

## 4.5.1 Parameters to be monitored

The following quality parameters are to be measured by the LOTUS sensor:

**Table 8 LOTUS sensor sensing parameters for use case 3: Irrigation water distribution network.**

| Parameter name | Range of measurement | Accuracy |
|---|---|---|
| pH | 4 to 9 | ±1.5% |
| EC | 0 to 2 mmhos/cm | ± 5 % |
| Flow rate | 0 to 200 $m^3/h$ | ±5 % |
| sodium | 0 to 50 ppm | ± 2 % |
| carbonate | 0 to 2000 mg/L | ±10 % |
| bi-carbonate | 0 to 2000 mg/L | ±10 % |
| iron | 0 to 5 ppm | ± 2 % |
| pesticides | 0.01 - 200µg/l | ±5% |
| total N content | 0 to 1000000 ppm | ± 10 % |
| total P content | 0 to 1000000 ppm | ±10 % |
| total K content | 0 to 1000000 ppm | ± 10 % |

+ accuracy refers to maximum relative percentage error between actual to measured value by LOTUS sensor.

Among these parameters, pH, EC, and flow rate are essential for the use case. The flow rate can be measured without the LOTUS sensor. Sodium is highly desired by end users to be added as additional parameter in the first version. Other parameters are listed as long-term goal.

*Note: Declaration of range of pesticides is difficult because it contains multiple parameters/chemicals.*

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### 4.5.2 Installation

In each water distribution network, one sensor will be mounted on the pipeline between the filter and the fertilizer dosage inlet. Optionally, a second sensor may be added behind the fertilizer dosage inlet. The sensor will be mounted with a tapping sleeve. As the filter located upstream does not remove all physical impurities, a filter cap located on the sensor is needed. During operation, power supply for the sensor is available directly at its location as it is in the direct vicinity of the electrical pumps. Power may not be available 24/7, but without power, the irrigation system is not operational, and no sensing is required.

### 4.5.3 Environment

The LOTUS sensor will be located in farming areas at the pumping stations of irrigation systems. It will be exposed to weather, i.e. radiation, rain and humidity. It will be placed in an agricultural working environment and may be exposed to hits by workers and wild animals. End users are concerned with the possibility of theft.

### 4.5.4 Sampling rate and speed of response

During irrigation events the response time needs to be fast enough to react when threshold are crossed by target parameters (EC, pH, etc) to prevent damaging soil and loss of fertilizer due to inability of plants to consume fertilizer. For long term storage and future analytics, the time resolution should be optimum enough to achieve minimal storage requirement.

### 4.5.5 Long-term stability, maintenance intervals

The sensor is expected to have a lifespan of 5 years. Maintenance intervals are requested to be as low as once per year.

### 4.5.6 Mechanical conditions

The irrigation water distribution networks are operated intermittently with pressure varying from 0.5 to 10 bar and flow rates from 5 to 200 $m^3/h$. Outside operation the pipe on which the sensor is installed may not be filled with water. A filter for removal of coarse physical impurities is located in front of the sensor location. The sensor is located in an agricultural working environment and may be exposed to hits by workers and wild animals.

## 4.6 Sensor integration

There should be the possibility to add signals from additional sensors to the LOTUS box for online computations. E.g. a flow sensor could be added if this functionality is not included the LOTUS sensor. JAIN has its own platform for data collection and storage and for localised control applications to which the LOTUS sensor can be integrated. For long term storage and linking to external data, the platform developed in WP5 can be used, which will enable advanced analytics in the future.

## 4.7 Available actuation and outlets for info collected

In case of the fully automated fertilizer dosage system, automatic valves can be operated from the LOTUS box, but most farmers use manually operated systems. JAIN has the technology for mobile connectivity, and it is available in the sensor locations.

## 4.8 Required software components

The decision support tool is supposed to give instructions to the farmers on which water to use for watering the different sections in their land with homogenous crops. The system should take into account the quality of the available water, crop type, crop age, soil type (out of a set of archetypes), past weather and weather forecast.

At each irrigation event it is critical that EC and pH stay within a certain range as they influence the availability of fertilizer to the plants and may actively damage the soil and roots at high concentrations. The soil type affects those thresholds. Both EC and pH can be influenced by the amount and composition of fertilizer added to the water. Another important role of pH is that it prevents precipitation of carbonates and bi-carbonates at low values which is important to keep the system from clogging.

Over the course of the cropping cycles, the system should ensure that each section receives an amount of water and fertilizer adjusted for optimal growth at each stage. The integration of weather data (past and forecast) prevents over-irrigation which is a potential waste of limited water capacities as well as under-irrigation which lowers the harvested amount. In the current scenario, JAIN’s customers do not use the soil moisture sensors, however, the future integration of such devices should be possible to increase the precision of the computed instructions. Adjusting the excess amount of added fertilizer over time gives farmers an economic advantage, due to reduced spendings, and protects the soil.

Automatic detection of clogging risks should be integrated to give alarms and cleaning instructions to the farmers.

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To avail this solution to a larger number of farmers, the decision support system should be independent of the fully automatic fertigation system.

## 4.9 Dashboards and interfaces

Decision support with regard to fertigation and cleaning operations should be presented to the farmers via a mobile app. Stored long-term data (e.g. in WP5 platform) should be exportable to standard formats to enable the use in external analytic software.

## 4.10 Current scenario

Currently, the vast majority of farmers uses manually operated fertigation systems. Due to fluctuations in the voltage and the source water level and due to fouling, flow rates vary, and the actual irrigated amount for each irrigation event is not known. The amount of fertilizer that is given to the system is known as it is added to a tank with known composition and volume. Guidelines on the amount of water and fertilizer depending on the crop growth stage are available from JAIN and other sources, but more precise instructions are requested. Most farmers can use multiple sources of water and switch between them based on availability. Especially in the dry season changes in bore well water level and compositions with rising bi-carbonate concentrations and EC are known to be an issue. They do have no real-time information on water quality or soil quality.

# 5 Use case 4: Groundwater and river water monitoring

## 5.1 Scope and objective of the use case

### 5.1.1 Groundwater quality monitoring for Guwahati city:

The key objectives of this use case are to assess the nature and extent of surface water pollution, understanding the environmental fate of different pollutants, evaluating the effectiveness of pollution control measures in place, evaluating water quality trend, and assessing the fitness of water for different uses.

To achieve these main objectives following sub-objective are defined:

- Develop a numerical transient state arsenic contaminant model for Guwahati city (Figure 8).

- Based on the observed groundwater table and arsenic concentration data, validate the numerical contaminant transport model.
- Then delineate arsenic safe aquifer or region for groundwater usage in Guwahati city.

## 5.1.2 Groundwater quality monitoring for Bangalore city:

To achieve these main objectives following sub-objective are defined:

- In Bangalore city (Figure 9), groundwater quality will be monitored from different locations (at least 20 samples daily) and it will be central data base. This data will be used for identifying appropriate water treatment technologies by public.
- Develop mitigation advice/protocol regarding household treatment based on the groundwater quality to the general public.


**Figure 8 Location map of Guwahati city.**

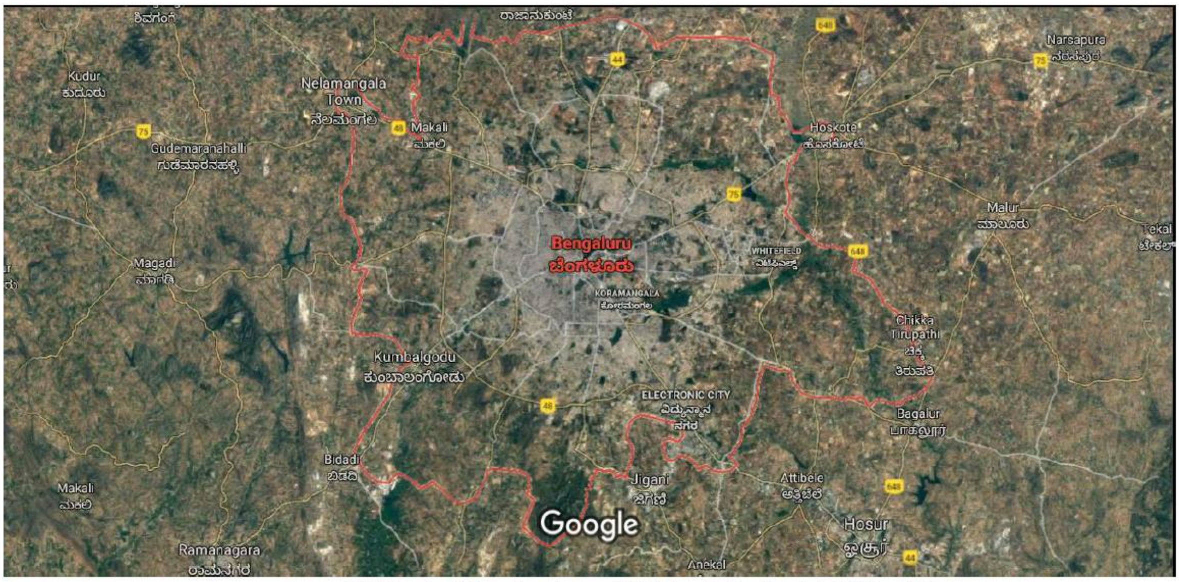


**Figure 9 Location map of Bangalore city**

## 5.1.3 River water quality monitoring for Varanasi city:

In this study, Ganga river water quality will be assessed (Figure 10), to know the extent of water pollution, and the presence of different pollutants to monitor the effectiveness of pollution control measures and assess the suitability of water for different uses.


**Figure 10 Location map of Varanasi city along with Ganga river**

## 5.2 KPI

**Table 9 Sensor performance criteria for groundwater quality monitoring at Guwahati city**

| KPI | Target |
|---|---|
| Quantification and implication | Groundwater water parameters measurement with allowable tolerance limit and identification of arsenic free aquifer for long term usage. |
| Monitor the groundwater table fluctuation | Based on the groundwater table trend, assess the suitability of shallow aquifer for long term water demand. |
| Functionalities implemented and tested | LOTUS sensor (sensor chip, support and electronic and LOTUS Box) board, cloud connectivity, data logging system, decision support system |
| Life expectance for LOTUS sensor instrument | > 3 years |

**Table 10 Sensor performance criteria for groundwater quality monitoring at Bangalore city**

| KPI | Target |
|---|---|
| Quantification and implication | Groundwater water parameters measurement with an allowable tolerance limit |
| Functionalities implemented and tested | LOTUS sensor (sensor chip, support and electronic and LOTUS Box) board, cloud connectivity, data logging system, decision support system |
| The life expectancy of LOTUS sensors assembly | > 3 years |

**Table 11 Sensor performance criteria for river water quality monitoring at Varanasi city**

| KPI | Target |
|---|---|
| Quantification and implication | Assess the river water quality parameters with an allowable tolerance limit |

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| | |
|---|---|
| Functionalities implemented and tested | LOTUS sensor (sensor chip, support and electronic and LOTUS Box) board, cloud connectivity, data logging system, decision support system |
| The life expectancy of LOTUS sensor | > 3 years |

# 5.3 Software/hardware base

Currently, no provision is available.

# 5.4 LOTUS sensor requirement

## 5.4.1 Parameters to be monitored

- **Groundwater quality monitoring for Guwahati city:**

Following are the essential groundwater quality parameters enlisted in the table 4, for monitoring and numerical contaminant transport modelling at Guwahati city.

**Table 12 Sensor requirement for groundwater quality measurements at Guwahati city**

| LOTUS sensor for groundwater quality parameters measurement | | | |
|---|---|---|---|
| **Parameter name** | **Range of measurement** | **Accuracy** | **Importance** |
| Arsenic | Arsenic = 0 to 200 µg $L^{-1}$ | ± 5 µg $L^{-1}$ | High |
| Iron | Iron = 0 to 100mg $L^{-1}$ | ± 0.01 mg $L^{-1}$ | High |
| Manganese | Manganese = 0 to 20 mg $L^{-1}$ | ± 0.01 mg $L^{-1}$ | High |
| Fluoride | Fluoride = 0 to 15 (mg $L^{-1}$) | ± 0.5 (mg $L^{-1}$) | High |
| pH | pH = 5 to 10 | ± 0.2 | High |
| Electrical Conductivity | Electrical Conductivity = 0.005 to 0.05 (S/m) | ± 0.001 (S/m) | Low |
| Ca | $Ca^{2+}$= 0 to 600 (mg $L^{-1}$) | ± 10 (mg $L^{-1}$) | Medium |

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| | | | |
|---|---|---|---|
| Turbidity | Turbidity = 0 to 500 NTU | ± 5 NTU | Medium |
| Bi- carbonate | Bi- carbonate = 0 to 1000 (mg $L^{-1}$) | ± 5 (mg $L^{-1}$) | Low |
| Nitrates | Nitrates = 0 to 500 (mg $L^{-1}$) | ± 10 (mg $L^{-1}$) | Low |
| Hardness | Hardness = 0 to 1000 (mg $L^{-1}$) | ± 10 (mg $L^{-1}$) | Low |
| Pesticide | 0.01 - 200µg/l | ± 0.1 (µg $L^{-1}$) | Low |
| Microbial content (E. coli or thermotolerant coliform bacteria) | Yes/No | Not applicable | Low |
| **Other than LOTUS sensor for groundwater table measurement** | | | |
| **Parameter name** | **Range of measurement** | **Accuracy** | **Importance** |
| Groundwater table | 2 meters to 50 meters | ± 1 meter | High |

- **Groundwater quality monitoring for Bangalore city:**

Following are the essential groundwater quality parameters enlisted in table 5, for monitoring and suggesting more suitable removal technology at Bangalore city.

**Table 13 Sensor requirement for groundwater quality measurements at Bangalore city**

| **LOTUS sensor for groundwater quality measurement** | | | |
|---|---|---|---|
| **Parameter name** | **Range of measurement** | **Accuracy** | **Importance** |
| Fluoride | Fluoride = 0 to 15 (mg $L^{-1}$) | ± 0.1 (mg $L^{-1}$) | High |
| Arsenic | Arsenic = 0 to 200 (µg $L^{-1}$) | ± 0.5 (µg $L^{-1}$) | High |
| Iron | Iron = 0 to 10 (mg $L^{-1}$) | ± 0.3 (mg $L^{-1}$) | High |
| Ca | Ca= 0 to 600 (mg $L^{-1}$) | ± 10 (mg $L^{-1}$) | High |
| Bi- carbonate ($HCO_3^-$) | Bi- carbonate = 0 to 1000 (mg $L^{-1}$) | ± 5 (mg $L^{-1}$) | Low |

| | | | |
|---|---|---|---|
| Electrical Conductivity | Electrical Conductivity = 0.005 to 0.05 (S/m) | ± 0.001(S/m) | Low |
| pH | pH = 6 to 10 | ± 0.2 | Low |
| Nitrates | Nitrates = 0 to 500 (mg $L^{-1}$) | ± 10 (mg $L^{-1}$) | Low |
| Hardness (Mg + Ca) | Hardness = 0 to 1000 (mg $L^{-1}$) | ± 10 (mg $L^{-1}$) | Low |
| Microbial content (E. coli or thermotolerant coliform bacteria) | Yes/No | Not applicable | Low |
| Pesticide | 0.01 - 200µg/l | ± 0.1 (µg $L^{-1}$) | Low |

- **River water quality monitoring for Varanasi city:**

Following are the essential river water quality parameters enlisted in table 6, for monitoring at Varanasi city.

**Table 14 Sensor requirement for river water quality measurement at Varanasi city**

| LOTUS sensor for river water quality measurement at Varanasi city | | | |
|---|---|---|---|
| Sensing parameters | Range | Accuracy | |
| Carbonate ($CO_3$) | Carbonate = 0 to 1000 (mg $L^{-1}$) | ± 5 (mg $L^{-1}$) | Low |
| Electrical Conductivity | Electrical Conductivity = 0.005 to 0.05 ($Sm^{-1}$) | ± 0.001(S/m) | Low |
| pH | pH = 1 to 14 | ± 0.2 | Low |
| Iron | Iron = 1 to 10 (mg $L^{-1}$) | ± 0.3 (mg $L^{-1}$) | Low |
| Trace and toxic metal (e.g. arsenic) | Trace and toxic metal = 1 to 10 (µg $L^{-1}$) | ± 0.5 (µg $L^{-1}$) | High |
| Ca | Ca= 0 to 600 (mg $L^{-1}$) | ± 10 (mg $L^{-1}$) | High |
| Turbidity | Turbidity = 0 to 500 NTU | ± 5 NTU | Low |

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| | | | |
|---|---|---|---|
| Nitrates | Nitrates = 0 to 500 (mg $L^{-1}$) | ± 10 (mg $L^{-1}$) | Low |
| Fluoride | Fluoride = 0 to 15 (mg $L^{-1}$) | ± 0.1 (mg $L^{-1}$) | Low |
| Hardness | Hardness = 0 to 1000 (mg $L^{-1}$) | ± 10 (mg $L^{-1}$) | Low |
| Microbial Content (i.e. E. coli or thermotolerant coliform bacteria) | Yes/No | Not applicable | Low |
| Pesticide | Pesticide = 0 to 2 (mg $L^{-1}$) | ± 0.1 (µg $L^{-1}$) | Low |
| Bi-Carbonate ($HCO_3^-$) | Bi-Carbonate = 0 to 1000 (mg $L^{-1}$) | ± 5 (mg $L^{-1}$) | High |
| Free Chlorine | Free Chlorine = 0 to 500 (mg $L^{-1}$) | ± 20 (mg $L^{-1}$) | Low |
| Total K content | Total K content = 0 to 500 (mg $L^{-1}$) | ± 20 (mg $L^{-1}$) | Low |
| Total N content | Total N content = 0 to 500 (mg $L^{-1}$) | ± 20 (mg $L^{-1}$) | Low |
| Total P content | Total P content = 0 to 500 (mg $L^{-1}$) | ± 20 (mg $L^{-1}$) | Low |
| Chloride | $Cl^-$= 0.1 to 3 (mg $L^{-1}$) | ± 0.1 (mg $L^{-1}$) | Low |
| DO | DO = 0 to 15 (mg $L^{-1}$) | ± 1 (mg $L^{-1}$) | High |
| BOD | BOD = 1 to 600 (mg $L^{-1}$) | ± 1 (mg $L^{-1}$) | High |
| COD | COD = 1 to 3700(mg $L^{-1}$) | ± 10 (mg $L^{-1}$) | Medium |
| Sodium | Sodium = 0 to 500 (mg $L^{-1}$) | ± 20 (mg $L^{-1}$) | Medium |
| Magnesium | Magnesium = 0 to 500 (mg $L^{-1}$) | ± 20 (mg $L^{-1}$) | Medium |
| Sulphate | Sulphate = 0 to 500 (mg $L^{-1}$) | ± 20 (mg $L^{-1}$) | Medium |
| Boron | Boron = 0 to 500 (mg $L^{-1}$) | ± 20 (mg $L^{-1}$) | Medium |

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| | | | |
|---|---|---|---|
| Phosphate | Phosphate = 0 to 500 (mg $L^{-1}$) | ± 20 (mg $L^{-1}$) | Medium |
| Free Ammonia | Free Ammonia = 0 to 500 (mg $L^{-1}$) | ± 20 (mg $L^{-1}$) | High |
| Total dissolved solids | Total dissolved solids = 0 to 1000 (mg $L^{-1}$) | ± 50 (mg $L^{-1}$) | High |

## 5.4.2 Installation

- **Groundwater quality monitoring at Guwahati and Bangalore city:**

The portable sensor will be carried over the site, and fresh groundwater samples will be collected in a testing cell. Then the sensor will be dipped in the cell and only after stabilizing the pH and DO concentration readings need to be recorded. The battery backup for sensor must be for at least 8 hours and should be easily rechargeable on site.

For groundwater table measuring sensor (other than LOTUS sensor), it has its own battery back up system; it only requires a battery recharging electric point.

- **River water quality monitoring for Varanasi city:**

The portable LOTUS sensor will be designed for river water quality monitoring. It needs power for at least 8 hours. The river water quality can be monitored either by two methods on site. In the first method, the river water sample from approximately 3ft depth will be collected and immediately analysed on-site using LOTUS sensor. In the second method, the sensor will directly take the reading from a 3 m depth of river water.

In the second case, the sensor must be withstood to a pressure of 3 meter depth in river water. It should have fishing weight (minimum of 15kg) and need provision to attach at the bottom, for sustaining in a heavy river water current. It should have to protect cover to avoid a collision from the suspended load or debris or chunk of wood.

## 5.4.3 Sampling rates and speed of response

- **Groundwater quality monitoring at Guwahati and Bangalore city:**

The LOTUS sensor should take readings of water quality parameters once in a week for Guwahati city (at least from six monitoring sites) and daily for Bangalore city (at least 20 locations with GPS coordinates). The LOTUS sensor should be enabled to give a reading or response within 5 minutes. Since the sensor will be power by either the LOTUS BOX or mobile phone, the required power for each sample testing should not be more than 25mAh out of 5000mAh mobile battery backup. The mobile

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memory must store a minimum of 1000 water analysis reading. Along with water quality parameter, GPS (Global Positioning System) location data must be integrated to capture the location of the sampling site for strategic planning and preparation of contaminant map.

- **River water quality monitoring for Varanasi city:**

The LOTUS sensor should able to give a reading with response time less than 2 minutes. Since the sensor will be powered by either by LOTUS BOX or mobile phone, the required power for each sample testing should not be more than 25mAh out of 5000mAh mobile battery backup. The mobile memory must store a minimum of 1000 water analysis reading. Along with the water quality parameter, GPS (Global Positioning System) location data must be integrated to capture the location of the sampling site for strategic planning and preparation of contaminant map.

Long-term stability, maintenance intervals:

| **Components / activities** | **Lifespan / time period** |
|---|---|
| Life expectancy of LOTUS sensors and assembly for Guwahati city groundwater monitoring | > 3 years |
| Life expectancy of sensors assembly for Bengaluru city groundwater monitoring | > 3 years |
| Life expectancy of sensors assembly for Varanasi city river water | > 3 years |
| Maintenance and calibration for groundwater use case | Every 6 months |
| Membrane filter cap required only for river water use case | To be replaced every 3 months |
| Maintenance and calibration for river water case | Every 6 months |

### 5.4.4 Mechanical conditions (water pressure, exposure to weather)

- **Groundwater quality monitoring at Guwahati and Bangalore city:**

In Guwahati city, the portable LOTUS sensor should be lightweight and supported by plug & play sensor concept. It should have a LOTUS sensor and other accessory carrying case.

- **River water quality monitoring at Varanasi city:**

In Varanasi city, the LOTUS sensor must be designed to withstand for river water flow of 5 m/s. Therefore, for the safety purpose it is consider as 8 m/s and must withstand for river water pressure up to 1.96 bar.

# 5.5 Sensor Integration

- **Groundwater quality monitoring at Guwahati and Bangalore city:**

The groundwater quality and table will be monitored using LOTUS sensor and portable water level measuring instrument. Both level and quality will be measured onsite and data will be stored in the LOTUS box. The output from the LOTUS box has to be connected to the cloud with appropriate connecting protocol (e.g., LOTUS application (Figure 11)).

- **River water quality monitoring at Varanasi city:**

The water quality of the river water can be collected by two approach. In first approach, the water sample across the river surface is collected and the mixed water sample is used to measure the river water quality. In second approach the water is collected at the below water surface and they are mixed in a lab for further analysis. The LOTUS sensor will be used for both the approaches. For example, in first approach, the LOTUS sensor will be used at the laboratory to measure the river water quality parameter, in second approach sensor will be immersed in the river water at different depth varying from zero to three meter. Later this data will be used to calculate the average water quality of the river water. In both cases LOTUS sensor will be integrated with LOTUS box to collect the water quality parameters in real time and collected data will be stored in cloud. The energy required for the water quality measurement by sensor and data communication by LOTUS box will be supplied by the battery integrated with the LOTUS box (as shown in figure 11).

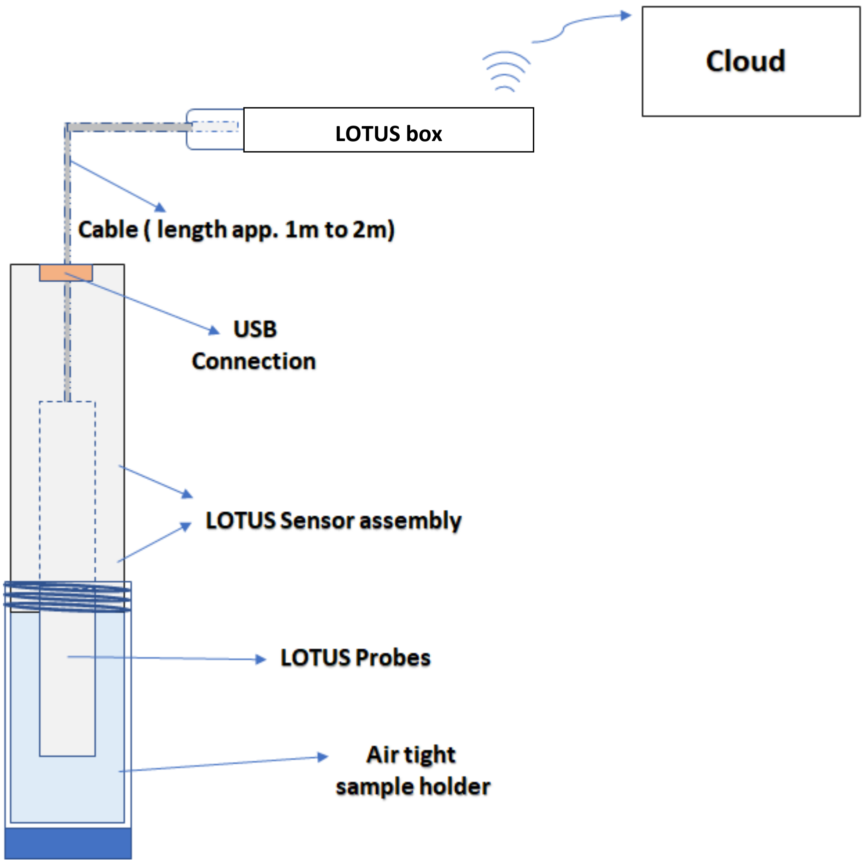


**Figure 11 schematic diagram of the groundwater analysis by portable LOTUS sensor to cloud**

# 5.6 Required components and connectivity

**Groundwater quality monitoring for Guwahati city, Bangalore city and river water quality monitoring at Varanasi city**

Cloud connectivity is required at the LOTUS sensor locations. Decision support system (DSS) will extract the data from data collection system and plan according to the contamination concentration.

- **Groundwater quality monitoring at Guwahati city and Bangalore city:**
  Dashboards should be developed for administrator user:
  - Administrator's dashboard should include the following:
    - Display different parameters concentration of groundwater and observed groundwater table,
    - DSS displaying the possible mitigation strategy for Guwahati city and removal technology for Bangalore city,
- **Groundwater quality monitoring at Varanasi city:**

Dashboards should be developed for administrator user:

- Administrator's dashboard should include the following:
    - Display of different river water quality parameters concentration,
    - DSS displaying the possible removable method or treatment.

## 5.7 Current scenario

- **Groundwater quality monitoring at Guwahati city and Bangalore city:**

At present the groundwater quality is measured by CGWB manually by collecting the water sample from dedicated monitoring wells located across Guwahti city.Following parameters are monitored on sesonal basis i.e. once in a four month: arsenic, fluoride, iron etc, ground water level. The location of monitoring wells across Guwahti city are shown in figure 12. In LOTUS project, the sensor will be used to measure the water quality parametres on daily basis wherein the LOTUS sensors will be manually handeled by LOTUS project staff to collect the water quality data from these wells.

Simillarly in Bangalore city, a LOTUS project staff will collect the groundwater quality parameters by carrying the LOTUS sensor manually to the field. In this case, the water will be collected from the house hold borewells manually and it will be mapped with GPS location by using LOTUS box.


**Figure 12 Location map of selected groundwater monitoring wells in Guwahati city**

- **River water quality monitoring at Varanasi city:**

The Varanasi river water quality at present is monitored by the Central Water Commission (CWC) for selective basic parameters. Three different locations of river water samples monthly analyzed at the laboratory. Therefore, CWC has intended to analysis the river water quality for heavy metals along with basic water parameters at site. Figure 13 shows the location of the selected site for river water quality monitoring at Varanasi city.


**Figure 13 Location map of selected river water quality monitoring at Varanasi city**

# 6 Use case 5: Wastewater treatment

## 6.1 Scope of the use case

The scope of the use case is to employ the LOTUS sensor to improve the operation of wastewater treatment plants. The following subcases will be considered:

1. Activated sludge treatment
2. Algal-based wastewater treatment

## 6.2 Objectives

Wastewater is used water that is influenced/contaminated by humans. Wastewater results from one or the combination of the following streams:

1. Industrial effluents
2. Domestic effluents
3. Agricultural effluents.

Typically, wastewater contains oil, metal, heavy metals, acids, solids, chemicals, excreta, urine, feaces, food, bath water, storm water etc. It is also a source of pathogens such as bacteria and viruses that cause severe health issues in humans and in animals. As many as 1.45 million people die every year all over the world because of diarrhoeal illness caused by pathogens present in wastewater [1]. In addition, the organic, inorganic and micropollutants in the wastewater can cause damages to the environment. If the untreated wastewater is released directly into the waterbodies, it can reduce the bio-diversity in lakes, rivers etc. This problem is faced throughout the world and is still quite pronounced in India. India accounts for 2.45% of the total land area of the world but represents 16% of the world population. In addition, India accounts for only 4% of the water resources of the world [2]. More than 70% of wastewater up to now remains untreated in India. If immediate corrective steps are not taken, the situation is expected to deteriorate in the future [1]. Treatment of wastewater from industries and domestic usage is one of the important challenges faced by the humanity in general and India in particular to reduce environmental pollution and to improve the health of the population and the quality of living.

Wastewater treatment aims to mitigate the effects of pollutants present in wastewater before releasing it to the environment. A typical wastewater conventional treatment plant is shown in Figure 6.1. It consists of four main elements:

1. Preliminary treatment (marked 1 in Figure 14): Incoming wastewater is treated in a preliminary treatment facility. Removal of large coarse solids such as rags, sticks etc. is the main purposed of the preliminary treatment facility.
2. Primary treatment (marked 2 in Figure 14): The preliminary effluent is treated in the primary treatment facility. The primary treatment facility is responsible for the removal of floating and settleable organic and inorganic waste materials from the preliminary effluent
3. Secondary treatment (marked 3 in Figure 14): The primary effluent is treated again at this facility. Removal of biodegradable organic matter using aerobic biological treatment with the help of bacteria is carried out here.
4. Tertiary treatment (marked 4 in Figure 14): Also known as advanced treatment, the effluent from the secondary treatment process is carried out in this facility. The dissolved and suspended solids that are not already treated is removed at this facility.


**Figure 14 A typical wastewater treatment plant**

The operation of a wastewater treatment plant is successful if it achieves the desired goals of water purity at the effluent. This should happen most efficiently in terms of the input of energy (in particular electric power) and materials and the use of the by-products. In this project, we look at the secondary and tertiary treatment processes. In order to achieve the desired effluent quality, highly efficient day-to-day operation is necessary. In addition, the operational cost of the wastewater treatment processes should be as low as possible as the operational costs are generally passed onto the public funds. Also, it is desirable to monetize the wastewater in the form of bio-fuels and fertilizers. This will motivate more private participation and healthy competition to make our water clean and lives better. This can be achieved only if the control of such processes can handle constraints and optimize economic objectives directly. Many classical control techniques that are typically employed at these plants fail to achieve these objectives often. Model Predictive Control (MPC) is an advanced control scheme that can help in achieving these goals. In addition, the effluent qualities must also be maintained for all weather conditions for varying influent qualities. We want to apply advanced MPC schemes that can handle uncertainties in a non-conservative way to achieve the desired goals. Highly accurate feedback data in the form of measurements is very important for the successful implementation of an advanced control scheme. The low cost LOTUS sensor which is developed in the LOTUS project will be used to obtain information on critical parameters of the water at different stages of the process.

**Subcase 5.1: Activated sludge wastewater treatment**

Advanced control of activated sludge treatment plants will be studied. Activated sludge process proposed more than 100 years before, uses biological means to treat the wastewater process [3]. The technology based on activated sludge process has advanced to treat different kinds of wastewater. The LOTUS sensor and the control scheme will be tested at a lab-scale demonstrator plant.

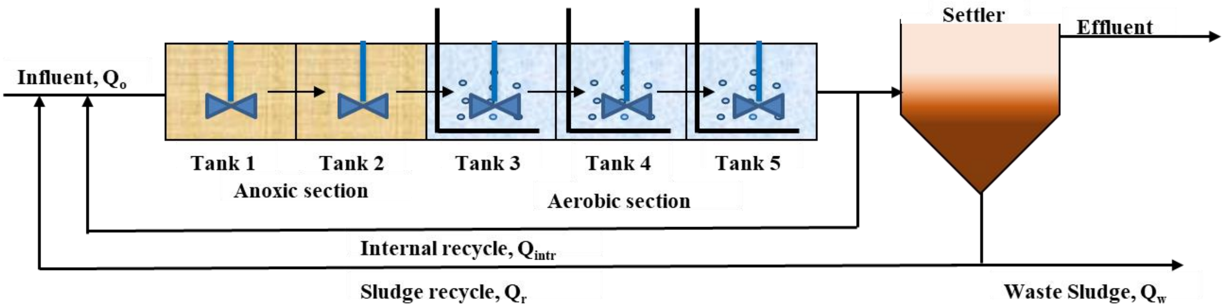


**Figure 15 Activated sludge treatment process**

Figure 15 describes the activated sludge treatment process. It consists of an anoxic section, an aerobic section, and a settler. There are two recycle flows: an internal and an external sludge recycle flow. The process can be modelled using first principles. By advanced control (described in section 6.8) two important goals will be achieved:

1. Minimize energy consumption
2. Improve the effluent quality water

Model predictive control can address the constraints and optimize over a given objective directly and thus can maintain the effluent quality at desired levels at all times while minimizing the energy consumption. The uncertainties can be handled using multi-stage Nonlinear Model Predictive Control schemes [4,5] (further details can be found in Section 6.8).

A particular challenge in this area is the measurement of the concentrations of pollutants (in particular nitrates and ammonia) in the plant because of the expected problem of fouling of the sensor. Suitable setups for intermittent measurements and cleaning will be investigated.

**Subcase 5.2: Algal-based wastewater treatment**

The second case study will be of the operation of algal-based wastewater treatment plant at ABAN Bio-tech in co-operation with NEERI, Chennai. Figure 16 shows a cultivation of algae in raceway ponds at ABAN Bio-tech, Chennai. The algal based wastewater treatment plant is advantageous because of the following:

1. It increases the amount of dissolved oxygen in the effluent water
2. It decreases the amount of dissolved nitrogen and phosphorus in the effluent
3. Bio-fuels, organic cattle feeds and fertilizers can be produced that can be monetized

**Figure 16 Algae-based wastewater treatment plant at ABAN Bio-tech, Chennai.**

The first step towards the improved operation of the algal-based wastewater treatment is the modelling of the plant and in particular of the growth of the algae. On this basis, strategies to maximize the production of bio-fuels while maintaining the effluent water quality will be studied. They will be implemented as real-time control strategies using the LOTUS sensor. The challenge of the fouling of the sensor is equally present here.

The key steps in carrying out the objectives in both the case studies are given below:

- Monitoring of waste-water treatment plants in real-time and to derive suitable corrective actions to achieve the desired water purity and maximize product yield.
- Validation of LOTUS sensor to monitor the level of contamination at different stages of the depollution process, then use of the sensor as a tool to optimize the performances of the process in terms of cost and depollution quality.
- Implementation of advanced control strategies based on the data from LOTUS sensor in an algal-based and in a conventional wastewater treatment plants using the following sequence of steps:
    - Model the wastewater treatment plants using first principles.
    - Perform parameter sensitivity analysis and model validation.

- Design and implement economics-based MPC using the software platform do-mpc.
- Formulate objectives in the controller to achieve an improved yield of bio-fertilizers, minimize energy consumption and to improve the quality of water at the outlet.
- Identify key uncertainties in the model to robustify the approach using multi-stage NMPC against the model and environmental uncertainties.
- Analyse the benefits of additional online measurements by the LOTUS sensor and decide on the best sensor locations and the required measurement frequency.
- Develop sensing concepts that are suitable for the environment in a wastewater treatment plant, e.g. periodic insertion and removal of the sensor and automatic cleaning after the measurement.
- Perform simulation studies of the controller to improve and to tune the controller.
- To implement the sensor in the lab-scale test plant at NIT, Warangal and at the algal-based treatment plant at ABAN Biotec, facilitated by NEERI
- Implement and test the controller in an algal-based wastewater treatment plant at ABAN Bio-tech, Chennai in co-operation with NEERI and at NIT Warangal.
- Further improvements of the sensor, the measurement set-up and the control algorithm.

## 6.3 KPI

**Table 15 Sensor performance criteria for wastewater treatment plant**

| KPI | Target |
|---|---|
| Number of functionalities implemented and tested | All high priority functionalities: functional, non-functional and Lotus Platform |
| Operational cost reduction (excluding pumping) | >5% |
| Improvement of the quality of the effluent water | > 10% |
| Dosage reduction of required process chemicals (disinfection, fertilizer, depollution) | > 5% |
| Tailor made dashboards with high visualisation | One fully operational dashboard |
| Life expectances of sensor | > 1 year (3 months without maintenance) |
| Target analytes | pH, DO; Nitrate, COD, BOD, TSS, phosphorous, chlorine; ammonia |
| Mandatory parameters | Nitrate, ammonia |
| Response time | < 15 minutes for stable concentration measurement |
| Number of sensors | 2 for lab scale plant at NIT Warangal, not known for algal-based process |

## 6.4 Components and connectivity

The closed loop diagram that represents the control of wastewater treatment plants is shown in Figure 17. The software program do-mpc based on Python developed at TU Dortmund will be used as the main tool to implement the advanced control solution. The sensor data will be collected and transmitted to a standard desktop computer which then runs the MPC code and provides the control inputs that are applied to the plant.

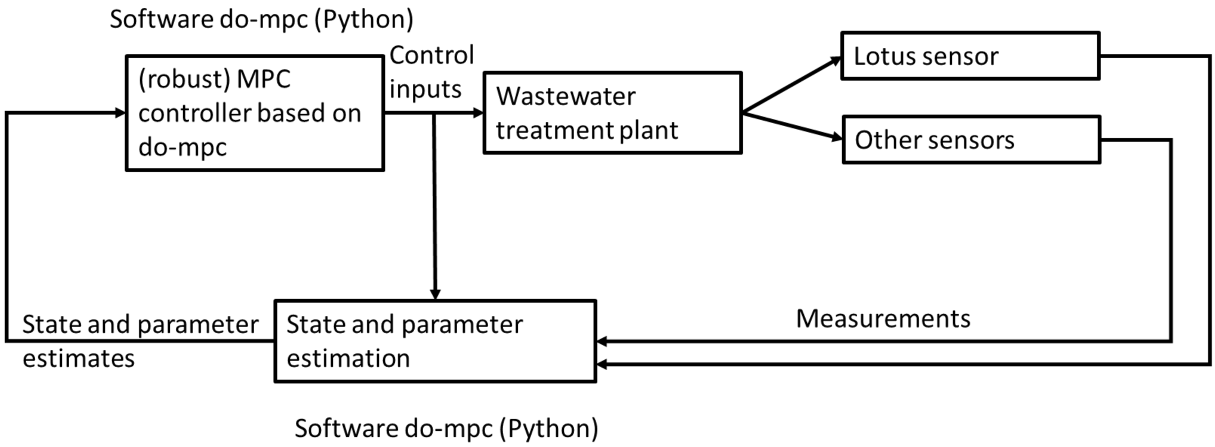


**Figure 17 Closed loop system for the control of wastewater treatment process**

## 6.5 LOTUS sensor requirements

The LOTUS Sensor requirements for wastewater treatment and monitoring are listed in Table 16. The nitrate, ammonia and DO (Dissolved Oxygen) levels need to be measured in an online fashion for feedback control. DO sensors are available on the market, so initially, this information does not have to be provided by the LOTUS sensor. The most crucial measurement for which currently no cost-efficient solutions are available is the concentration of nitrates. BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) measurement for water suggest the presence of organic matter and indirectly presence of toxic metals in the water. Other parameters such as TSS (Total Suspended Solids), phosphorous, pH indicate the quality of the treated wastewater. Measurements by the LOTUS sensor are not mandatory during the course of the project.

**Required online measurements:**

1. Continuous sampled data of nitrate, ammonia and DO
2. Periodic measurements of COD, BOD, TSS, pH, TSS, total nitrogen and phosphorous

**Table 16 Sensor requirement for wastewater treatment and monitoring**

| Sensing parameters | Range | Accuracy | Importance |
|---|---|---|---|
| Nitrates | Nitrates = 0.5 to 50 (mg $l^{-1}$) | ± 5% | Very high |
| Free ammonia | Free Ammonia= 0.5 to 50 ($g/m^3$) | ± 5 % | Very high |
| Phosphate | Phosphate= 0.5 to 5 ($g/m^3$) | ± 5 % | Very high |
| pH | pH = 2 to 14 | ± 0.2 | High |
| DO | DO = 0 to 5 ($g/m^3$) | ± 5 % | High |
| Total dissolved solids | Total dissolved solids = 10 to 1000 (mg $L^{-1}$) | ± 10 % | High |
| Total N content | Total N content = 3 to 50 ($g/m^3$) | ± 10% | Medium |
| BOD | BOD = 1 to 400 ($g/m^3$) | ± 5 % | Medium |
| COD | BOD = 1 to 1000 ($g/m^3$) | ± 5 % | Medium |
| Turbidity | 0-200 NTU | ± 5 % | Medium |
| Total P content | Total P content = 0 to 50 ($g/m^3$) | ± 10% | Medium |
| Flow rate | 10-1000 $m^3$/hr | ± 3% | Other sensors avaiable |
| Temperature | 0-80 °C | ± 0.5 °C | Standard sensors available |

The LOTUS sensors should, in particular, provide measurements of the concentration of the following in the order of priority:

1. **Nitrate -** top most priority
2. **Ammonia -** second priority
3. **Phosphate -** third priority

**Non-functional Requirements:**

1. The interface between the data collection system and online control strategies.
2. User interface for the engineers/operators to interact with the system including real time data and alarms, future strategies.

**LOTUS Platform requirements:**

1. The end user requirements include monitoring of the treated wastewater quality parameters.
2. The engineer's platform must include tools to determine the operating expenditure.

**Validation criteria:**

**Sensor:**

1. Validating the sensor for the known contamination levels, analysing the wastewater samples with other methods.

**Online performance**

1. Stable closed-loop operation of the advanced control schemes for the two plants.
2. Reduction of power consumption compared to conventional instrumentation by at least 5%
3. Significant improvement of the effluent quality.
4. Robustness against varying inflows and long-term changes of the biomass.

**LOTUS Platform:**

1. LOTUS platform clearance test for users and admins during the monitoring and pilot test time.
2. Display of the required parameters and features (treated wastewater quality parameters) for the end user requirements.

## 6.6 Sensor Integration

Sensor integration is a key factor in the control of the wastewater treatment plant. The sensors provide the feedback critical to efficient control. A representation of the sensor locations is shown in Figure 18. Sensors will also be used for periodic measurement of the effluent quality.

LOTUS is co-funded by the European Commission under the Horizon 2020 research and innovation programme under Grant Agreement N° 820881 and by the Indian Government, Ministry of Science and Technology.

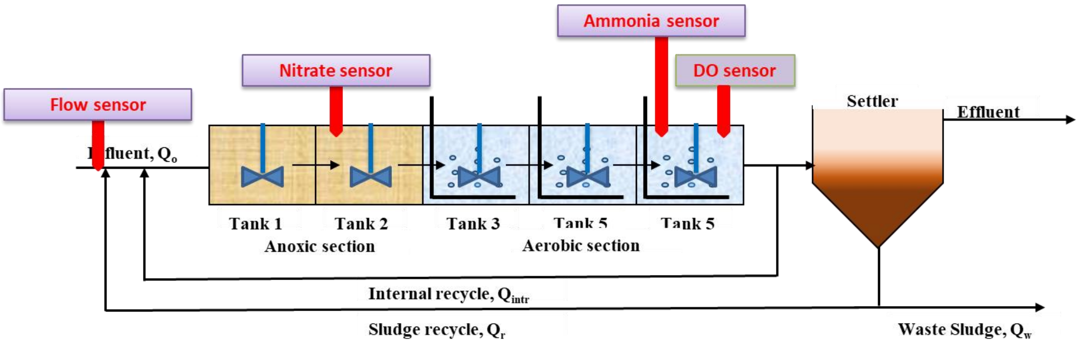


**Figure 18 Depiction of important sensors integrated in the wastewater treatment plant**

## 6.7 Available actuation and outlets for info collected

The effluent quality in terms of COD, BOD, TSS, nitrogen, phosphorous, ammonia and the operational cost information will be recorded periodically, and this data will be shared.

The internal flow rate and the oxygen transfer rate in the aerobic section will be manipulated. The schematic diagram of the controlled actuations are shown in Figure 19.

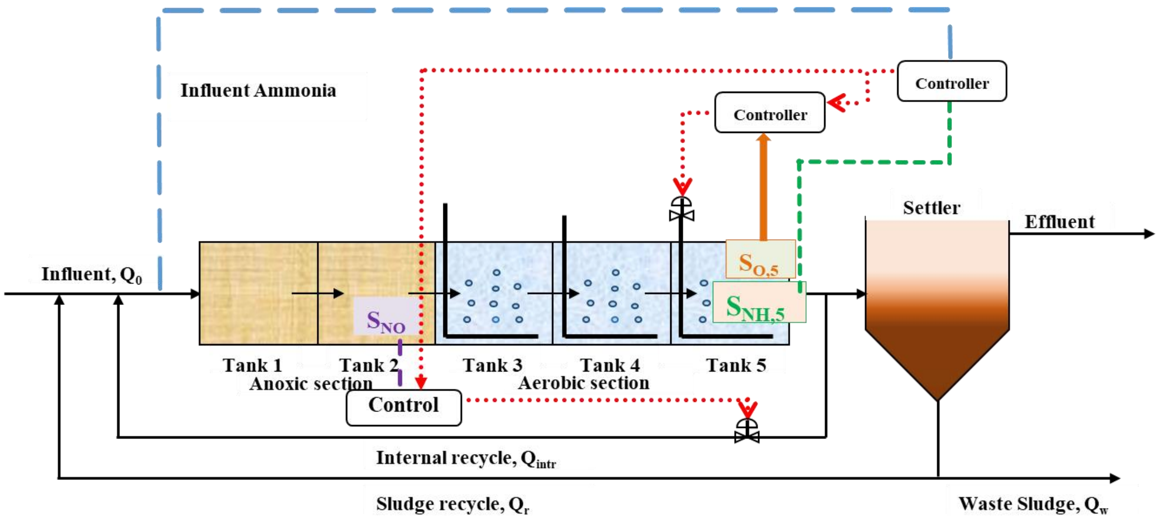


**Figure 19 Actuation and control of the activated sludge treatment process**

For the algal based plant, currently pH levels are controlled in the plant. As a part of this project, further actuation mechanisms to meet the desired goals will be studied.

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## 6.8 Engineering tools and their functions

The implementation of the model predictive control scheme will be carried out using the do-mpc platform developed at Process Dynamics and Operations Group, TU Dortmund. It has a modular design consisting of four modules:

1. Model
2. Simulator
3. Optimizer
4. Estimator

The structure of the tool is shown in Figure 20. The tool provides an efficient way to implement MPC algorithm minimizing the time required for implementation. Many simulation studies and practical implementations have been carried out using this tool and hence, it is highly reliable. Complete MPC setup together with estimation algorithms are available. In addition, robust uncertainty handling available leading to a practical implementation approach.

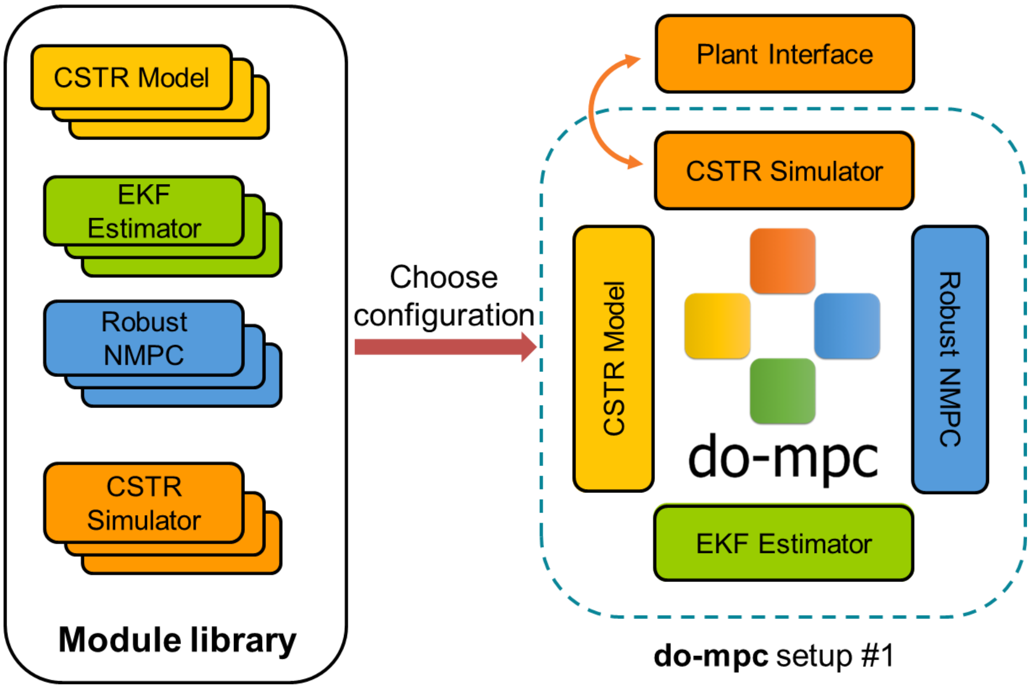


**Figure 20 Modular Structure of do-mpc platform**

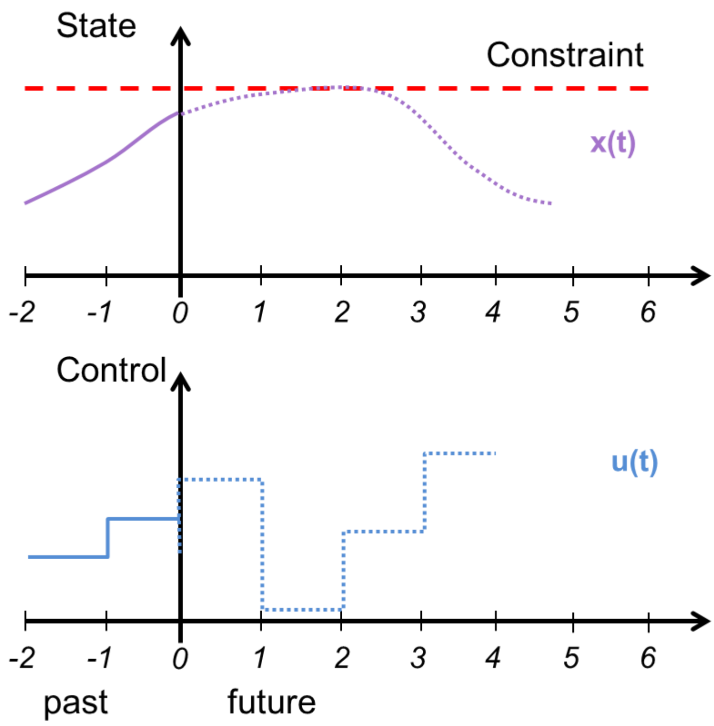


**Figure 21 Description of Model Predictive Control scheme**

Model Predictive Control is an advanced control scheme that obtains a sequence of control inputs by forecasting the system behaviour in the future for finite steps. It has the ability to handle constraints directly and can optimize over given objectives to find the control inputs that must be applied to the plant. The basic idea of the scheme is shown in Figure 21. In the figure, the current time step is t=0. The dotted lines show the predicted control and state trajectories. This trajectory is obtained by solving an optimization problem such that is optimal for a given objective such that the constraints are satisfied. From the obtained sequence of control inputs, only the input from the first step is applied to the plant and a new measurement is obtained at the next time step. The optimization problem is solved at the next time step and the optimal control inputs are obtained in a receding horizon fashion.

The advantages of the scheme can be clearly seen in the context of wastewater treatment. Energy minimization can be the objective of the optimization problem and the effluent water quality parameters can be constraints in the problem formulation. Thus, the control inputs obtained for the objective and constraints will result in an improved performance when compared to a classical control scheme, where only reference is tracked.

If the uncertainties are present, there exists certain inherent robustness in the standard MPC scheme against sufficiently small disturbances. However significant disturbances can lead to performance loss and constraint violations. To handle significant uncertainties, multi-stage NMPC can be employed. Multi-stage NMPC is a robust NMPC scheme that predicts different state trajectories for different realizations of the uncertainties, as shown in Figure 22. The method is non-conservative because of

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the presence of feedback information is formulated explicitly in the predictions. Both standard MPC and robust multi-stage MPC can be implemented using the software tool do-mpc.

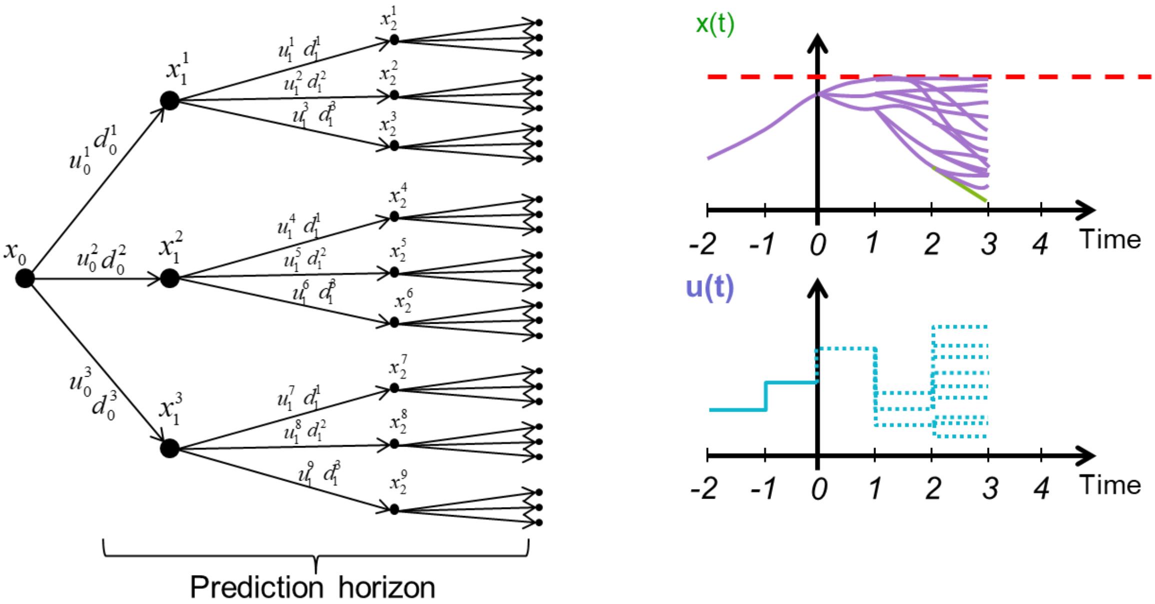


**Figure 22 Description of robust multi-stage Model Predictive Control scheme**

# 6.9 Dashboards and interfaces

Currently not planned. Interfaces to the SCADA systems at the plants possible using OPC (Open platform communication).

# 6.10 References


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