ITS FOR INTEGRATED MANAGEMENT OF HIGHWAY STORWATER RUNOFF: THE TREATMENT OF CHRONIC EFFECTS AND THE PROTECTION FROM ACUTE EFFECTS ON THE ENVIRONMENT CAUSED BY LIQUID SPILLS: THE CONCESSIONARIA AUTOSTRADALE VENETA (CAV) AND THE SUPERSTRADA PEDEMONTANA VENETA (SPV) EXPERIENCES

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ABSTRACT

The environmental impact of highways stormwater runoff represents a growing interest that nevertheless it's often not properly studied and managed. The present paper presents the matured experience in stormwater runoff management through a process of several years in big infrastructure civil works in Veneto Region, an area deeply urbanized and industrialized and with a very rich artistic and environmental heritage. That needs lead to the creation of a centralized integrated system, inserted in the ITS capable to manage all the environmental aspects tied to highways runoff, from the ordinary management and control of the chronic impacts to the extraordinary emergencies issues due to accidental spills, including also the management of the maintenance scheduling and interventions.

KEYWORDS

Environment protection, liquid spills into the environment, information technology, reduction of highways environmental impact.

INTRODUCTION

In 2007, the *Passante di Mestre*, a new 32 km length highway have been realized and equipped by CAV, the Authority in charge of the infrastructure management with 55 plants dislocated along the highway in order to continuously treat the roads runoff through a system of passive filtration, an innovative BMP capable to almost fully treat the water and protect the environment from the chronic effect of runoff.

The *Pedemontana Veneta* project (SPV), a new 90 km length highway, added to the stormwater filtration system a new automated emergencies management system, the Swerm03®, capable to prevent in less than a second any liquid spill diffusion in the surrounding environment ensuring the 100% protection of the water bodies.

The control of the Swerm03® is provided by an integrated management system supplied with patented software capable to continuously analyze and verify the acquired data from the treatment plants and the emergencies management system in order to optimise the operations through the planning and scheduling of maintenance activities. A further development leaded by SWI, CAV and SPV consisted in the implementation of a specific SCADA where several single plants were managed together in the ITS pack together with maintenance activities and telemetries of pumping stations. The management of the processes linked to runoff via an unitary

system represents a reduction of environmental effects caused by roads, risks and costs being that thanks to the ITS systems processes are paperless.

OVERVIEW OF THE SPECIFICITY OF VENETO REGION

Veneto Region is one of the cores of the Italian economy, populated by 6.000.000 inhabitants, 10% of the country total population, produces around 20 % of the Italian gross domestic product with a low unemployment rate of 5.7% if compared with the national average rate that is 12%. Venezia, Cortina and Dolomiti are some example of the great cultural, artistic and naturalistic heritage of this Region, hosted in a very small territory which covers around 18.399 km^2. This scenario is a paradigmatic example which reflects the complexity of the highway network system and the environmental related issues.

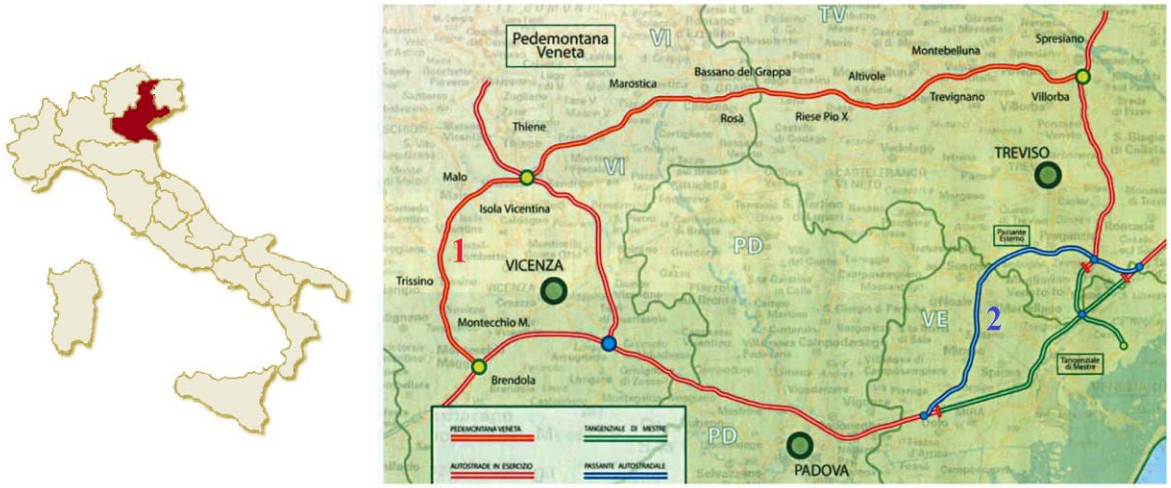

FIGURE 1 Location of Veneto Region in the Italian territory (left) and track of the main infrastructures (right): Pedemontana Veneta, 2. Passante di Mestre

In Veneto Region the need for a more efficient and faster transportation system for traffic decongestion of town and cities has become a requirement that cannot be postponed and collide with a high urbanized and fragile contest.
In the beginning of the 80's the first projects were developed and discussed but only after 2000 the first solutions were realized. The main highway projects where the system presented in this paper has been implemented are briefly described and resumed below:

- **Pedemontana Veneta**: this infrastructure, 90 km total length, is actually under construction and its function is to improve the connection between the West and East parts of Veneto and reduce the pressure of the heavy traffic generated by the industrial core of the region, located between the cities of Vicenza, Padova and Treviso that actually is collapsing under an actual average daily traffic of 25.000 vehicles/day (mainly heavy traffic). The highway system has 250 stormwater outfalls which require water quality treatment and spill containment. The authority in charge of the management of the highway is SPV;
- **Passante di Mestre highway**: the first project was developed in 1990 but the infrastructure, a 32 km 3 lanes for each direction designed for transfer from the Venezia Freeway the traffic coming from the strategic East-West Italian corridor (A4 highway),

was realized and opened in 2009 with an actual average daily traffic of 72.000 vehicles/day. The authority in charge of the management of the highway is CAV.

For both this infrastructure projects, the need of a centralized management system has emerged. This leads to the development of the Swerm-3S® software that permits a remarkable improvement of the global environmental performances of the treatment network overtime, thanks also to the maintenance scheduling features.

CHRONIC AND ACUTE STORMWATER RUNOFF ENVIRONMENTAL IMPACTS

Pollutants that settle on the impermeable surfaces during dry periods are washed together with the atmospheric pollutants during rain events. Potential environmental impacts due to that consist of pollution in the receiving water body and drinking water reservoirs, shallow waters pollution, toxicity effects and ground and sediment contaminations.
The solution for the management of chronic impacts in Veneto Region had to face the issue of the lack of available spaces that has prevented the development of low impact solutions. For this reason the solutions were oriented toward artificial treatment systems, for first traditional hydrodynamic separators and subsequently continuous high performance filtration solutions like Stormfilter® system that offer a high removal of heavy metals and solids and easy maintenance operations.

The acute impact is generated from accidental or arson spills or leakages. These events are not predictable in terms of quality and quantity of the pollutants and as a consequence of that, they are not easily manageable with traditional methods and plants designed for chronic impacts.

These issues are evaluated only in big civil and infrastructure works like highways and airports. Proper solutions were applied and adopted in last years even in lack of any applicable technical and legal standard. Despite these solutions, some issues remained:

- Actuation systems require staff intervention and this is not suitable in an emergency contest;
- The activation time of electric/manual systems, even if quickly operated, are not suitable to stop the propagation of the leakage;
- The detention tank if not checked regularly may be full or not usable;
- Multiparametric probes often give unreliable data if not properly configured;

To satisfy environmental impact concern, data were collected by monitoring stormwater runoff and other site parameters in order to establish the correlation between the different physical parameters involved (rain, temperature, traffic conditions). Only in this way it has been possible to build a model using these correlations that can determine a curve of acceptance and a range of normality.

Normally, management systems for avoiding acute impacts present long times of reaction, and often precise human interventions. Several procedures include human presence and the manual control of mechanical devices like valves and gates.

The complexity of the management of acute impact events in highways is due to the fact that is not possible to predict the type of the polluting substance and also the quantities and the moment when the accidental event occurs. This leads to a substantial inefficiency of the traditional systems realized until today.

For this reasons the working group develop in cooperation with CAV a completely new product that will be described in this paper, starting from the issues that nowadays are still not solved.

AN INTEGRATED SYSTEM FOR HIGHWAY STORMWATER MANAGEMENT

The Swerm03® (acronym of StormWater Environmental Risk Management) is an active stormwater management system composed by a stormwater filtration system coupled to spill containment facilities to manage water quality, accidental spills, and maintenance operations in the context of large infrastructure projects. The web based system provided has added to the stormwater filtration system a new automated emergencies management system which can operate in less than a second and provide the containment of liquid spills of all dimensions and nature, thus avoiding the dispersion in the surrounding environment with a 100% protection of the water bodies.

The solution developed is extremely compact and easy to operate through automatic pneumatic valves that permit to react to the accidental spill in less than a second. Thanks to the control of a Programmable Logic Controller, the system is standalone and it is supplied by probes and sensors that continuously monitor the meteoric conditions and the water quality.

The system is installed in line with the drainage network or in proximity of a discharge point in order to prevent the pollution of the receiving water bodies and supplied with an intelligent unit provided with a software that operates according to a dual logic capable to discriminate between "dry" and "wet" weather conditions thanks to the historical water quality data collected by the monitoring system and combined with physical and meteorological parameters. The core of the solution consists in a dual continuous monitoring system implementation, composed of two logic for *Dry Condition* and for *Wet Condition*, each of them based not only on qualitative data of the analyzed water but also on quantitative data linked to the physical and meteorological parameters.

When a certain number of plants it's installed, to grant an adequate level of operative efficiency, it becomes necessary to connect the single units to a centralized system through a dedicated SCADA, a software specifically developed for the supervision and the remote control of the single treatment plants. The main parameters that can be remotely set, visualized and managed for each plant includes the system general logic values, the manual opening of the emergency deviation valve, the water quality data flow acquired from the probes, the scheduling of the maintenance interventions, the emergency alarm states.

Description and working logic

The aim of the system is deviate a potentially contaminated flux to a detention tank, avoiding flux arrives to the treatment system. The system acts opening/closing two valves depending of the incoming flux. All the processes, commanded by a programmable logic controller, have a dual logic:

- *Dry condition logic:* each liquid presence inside inlet pipes is detected as abnormal so the system starts the emergency phase with the opening of the detention tank valve for the storage of all contaminated liquid. Contemporaneously an alarm to the central control room is sent;

FIGURE 2 Normal operation in dry conditions

- *Wet condition logic:* when the rain sensor notices than an event rain is started, the presence of liquid in the inlet pipe becomes a normal condition so the monitoring system, integrated by two probes (pH and conductivity), determines if the incoming liquid is accomplishing the normal value range. In case of an anormal range, out of the established thresholds, the system opens the detention tank valve, storaging all the contaminated liquid and sending the alarm to the central control room.

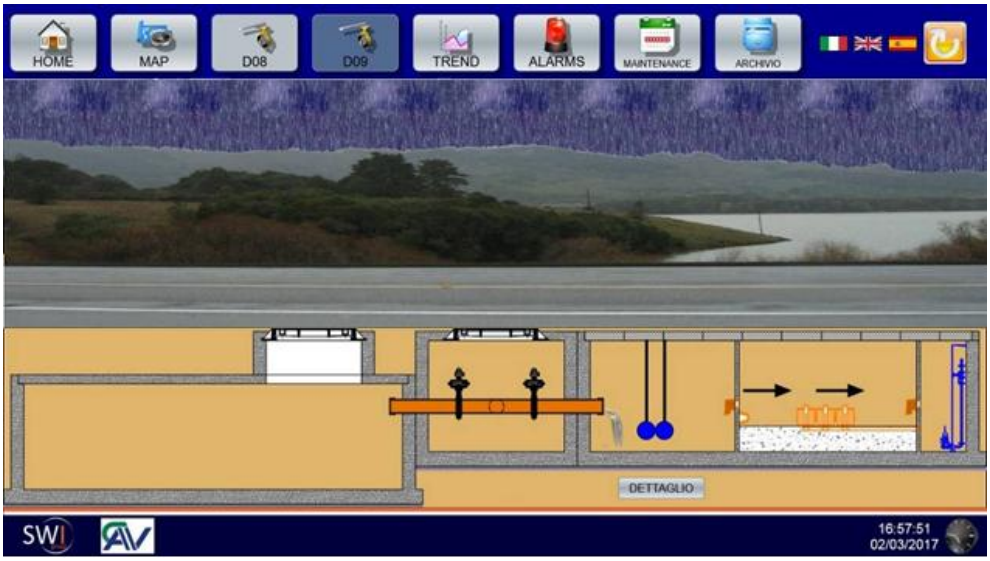

FIGURE 3 Normal operation in wet conditions

Two years of experimentation with a pilot plant monitoring system have permitted to define the behavior of the runoff in many different conditions that are implemented in the software:

- It is possible to detect an infiltration from groundwater into the treatment vault by the placement of flux sensors. The plant PLC is programmed to take in consideration this aspect, so it is capable to act and to send an alarm to the control central room;
- In winter, after a snow event, there is a runoff which goes into the drainage system. This situation also happens when no rain is detected, so it can't be considered a case of spill.

The plant PLC reacts adequately by the temperature monitoring so it is capable to differentiate this situation from a typical spill;

- Conductivity trend is very different depending on the period so the system is capable to adapt the thresholds to this behavior and also to establish a percentage increment in the maximum threshold to avoid the big conductivity peak in the first flux of runoff after a long dry period.

The system offers these features:

- Continuous monitoring of pH, conductivity, Redox Potential, temperature;
- Potential anomalies of the probe operations and hysteresis phenomena detection;
- Definition of different acceptability curves for each plant;
- Alarm signal generation and sending in case of emergencies;
- Detection of the maximum level inside the spill detention tank;
- Detection of the minimum pressure level on the pneumatic actuation system;
- Detection of the power supply failure;
- Acquisition of all monitoring data and daily transfer to recipient at your choice;
- External communication with Modbus TCP/IP module.

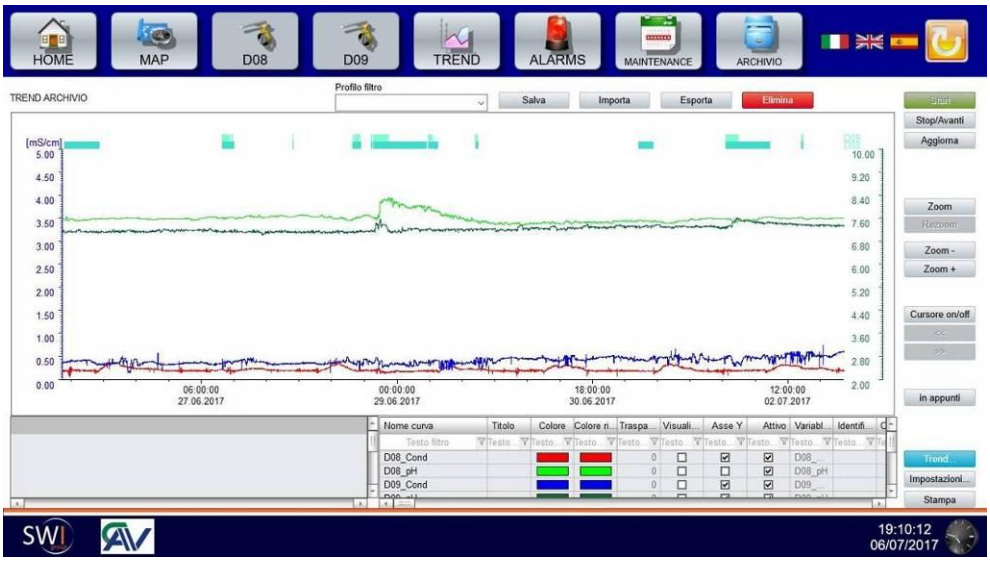

FIGURE 4 Trend of conductivity (red and dark blue), pH (green and dark green) and presence of rain (blue) of two different plants.

The SCADA besides the command and control of a network of the single treatment units permits through a simple interface the operations described below:

- Manage acceptability thresholds for monitoring (pH, electric conductivity, Oxidation Reduction Potential);
- Definition of the seasonal thresholds and for the snowmelt phenomena;
- Storage of all the operating acquired data;
- Create graphs and post process the data acquired for a correct interpretation;
- Create an active alarm list;
- Create synthetic reports related to system/units;
- Store a time history of events, alarms and activities;
- Create a maintenance schedule and reports.

The image below describes the general ITS architecture of the designed system that offer the possibility of manage different type of plants.

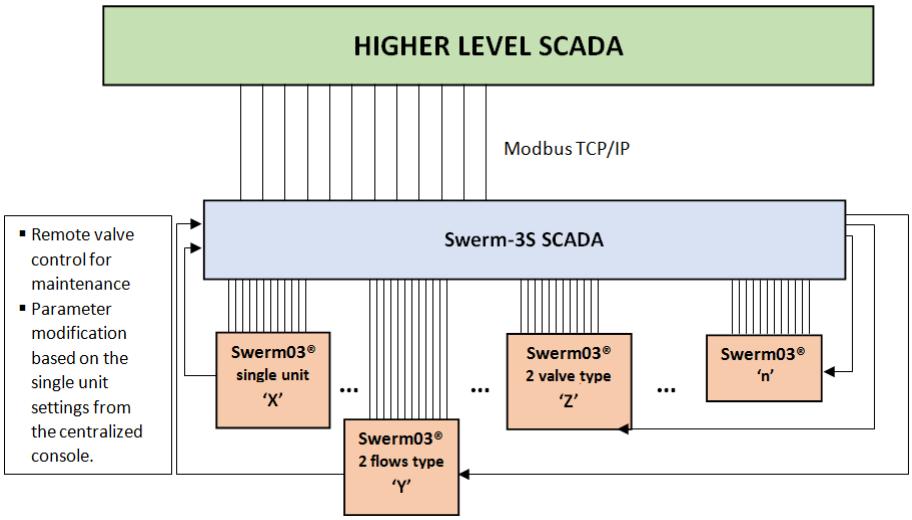

FIGURE 5 General IT structure of the system

The image below reports an example of the real time interface of the system during a rain event. The plant diagram in the lower part of the screen represents the sections and the equipment installed, that may be different depending on the type of plant installed (single, double inlet, single or double valve, etc.)

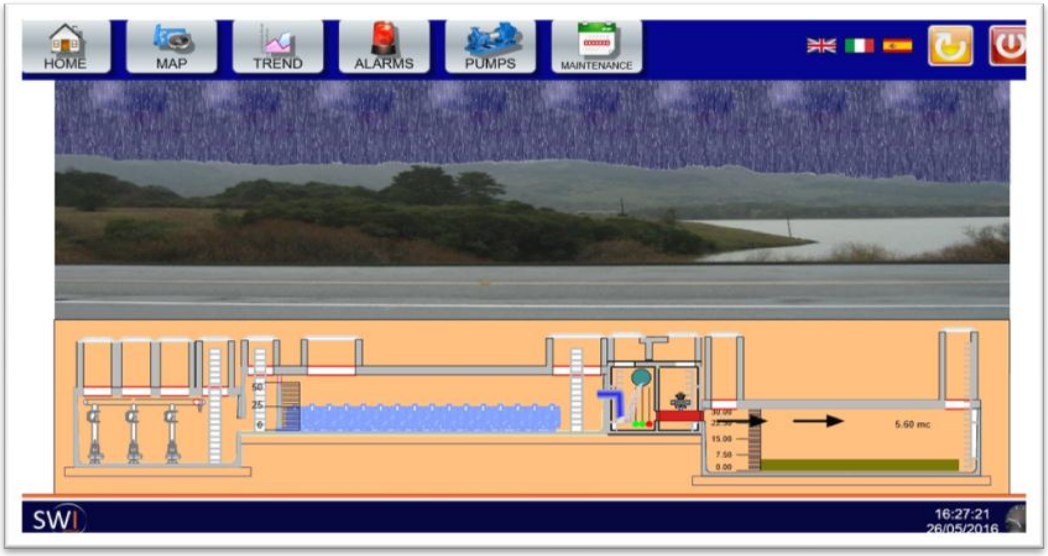

FIGURE 6 Example of a possible scenario in wet conditions

The information represented include meteorological conditions, qualitative characteristics of incoming stormwater runoff from sensors and probes, nitrogen level inside the actuation system, number of openings/closures of the valves, liquid level inside the emergency detention tank, detection of gas leaks from the nitrogen tank.

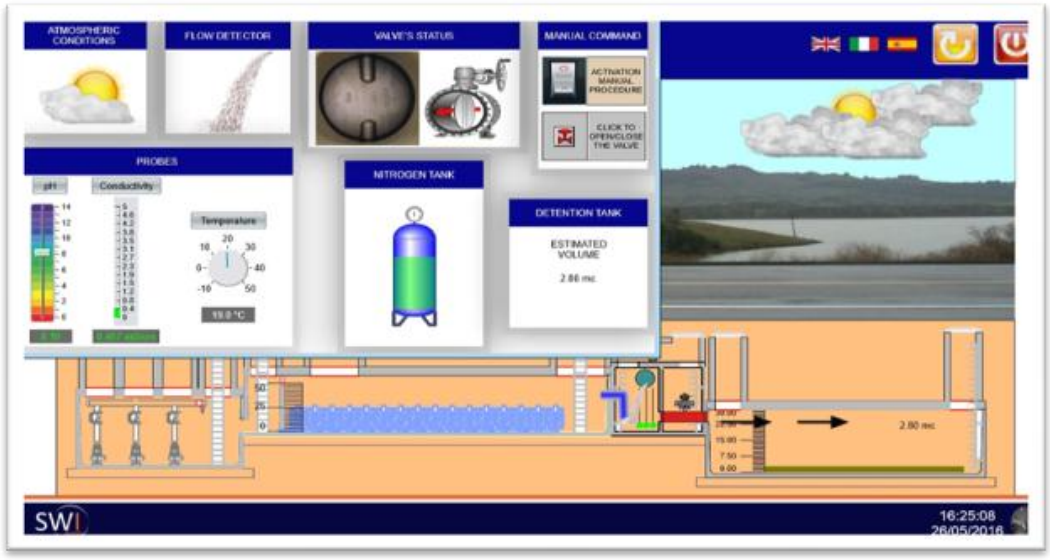

FIGURE 7 Example of different scenarios from the SCADA

Furthermore, it's possible to define different authorization levels and operability through login access to permit to end users the visualization of the data or the total command of the unit. The system is fully scalable to high/low new/existent hierarchy SCADA systems with the most diffused communication standards and interface.

The maintenance management module

Evaluating the environmental performance of highway stormwater runoff treatment plants, the need of a correct and timely maintenance has emerged as a strategic key factor.
Usually the maintenance operations are marginal because the plants are relatively small, not centralized but widespread along the infrastructure so the companies in charge of the management of the highways often are not able to evaluate the efficiency of that systems. As a result of that the poor or absent maintenance leads to a complete inefficiency of the treatment system increasing the environmental risks and erasing the investment utility.
To solve these management issues, that are usually done by general technician and not by the plant manufacturer, every single treatment plant is equipped with an "Electronic plant book" that includes the know how coming from the management experience of CAV and SPV. In this electronic interface the SCADA system stores all the maintenance interventions recordings with photographic reports. The system collects and manages the maintenance interventions calendar and deadlines of the entire network.

The maintenance module has been developed for planning, scheduling and managing in a simple and effective way the maintenance interventions and to establish the necessary operations intervals in order to ensure a full efficiency of the treatment network. Operating the maintenance interventions at the right time offers a real advantage if compared to prefixed times operations. Furthermore, the spare components supplying process will be more efficient due to a preventive maintenance.

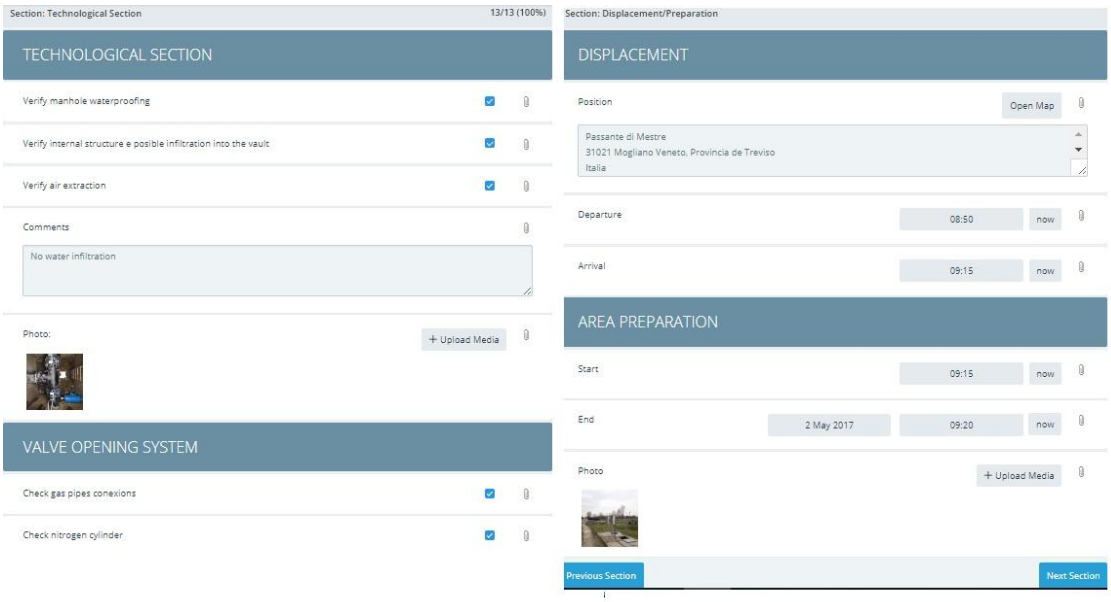

FIGURE 8 Example of a maintenance report generated

Maintainers are equipped with a smartphone APP to record every activity and phase planned ensuring the possibility to verify and control all the processes. All the data collected are statistically and functionally processed, ensuring a remarkable management and environmental efficiency.

Thanks to that system, the stormwater runoff are managed like an industrial process, from chronic impacts treatment to acute impact treatment. The constant verification and checking of all the information from the field presents an affordable infrastructural investment cost with low operational cost.

Stormwater runoff treatment plants actually have a marginal significance but the real importance of their function unfortunately too often is understood only when it's too late.

THE PASSANTE DI MESTRE PROJECT

The Passante di Mestre was realized between 2006 and 2008 with the aim of bypassing the crossing traffic to Venice avoiding the congestion of urban roads with high environmental and economical costs. The design of the Passante di Mestre takes into consideration the environmental peculiarity of the local contest, the total length of the track is 32 km with 9 trenches section, 8 tunnels, 4 viaducts and many environmental mitigation interventions designed and partially realized. 64 plants were realized for the chronic impact treatment, providing a first flush detention section and a subsequent water treatment with Stormfilter® filtration system.

To solve the issues of the acute impact management, a 2 years experimental project was developed in two existing plants along that highway in cooperation with CAV, the company in charge of the management of the highway network. Subsequently, the existing plants were revamped in order to perform the conversion to a Swerm03® system through the implementation of a specific SCADA for a centralized control of all the functions and the management of emergencies deriving from accidental spills.

Part of the intervention consists in connecting the inlet pipe through a T junction and two valves that permit the diversion of the flow to the filtration treatment in "ordinary" rain conditions or

alternatively to the spill detention tank, in emergency conditions. The valves are actuated via a pneumatic system loaded with nitrogen or compressed air.

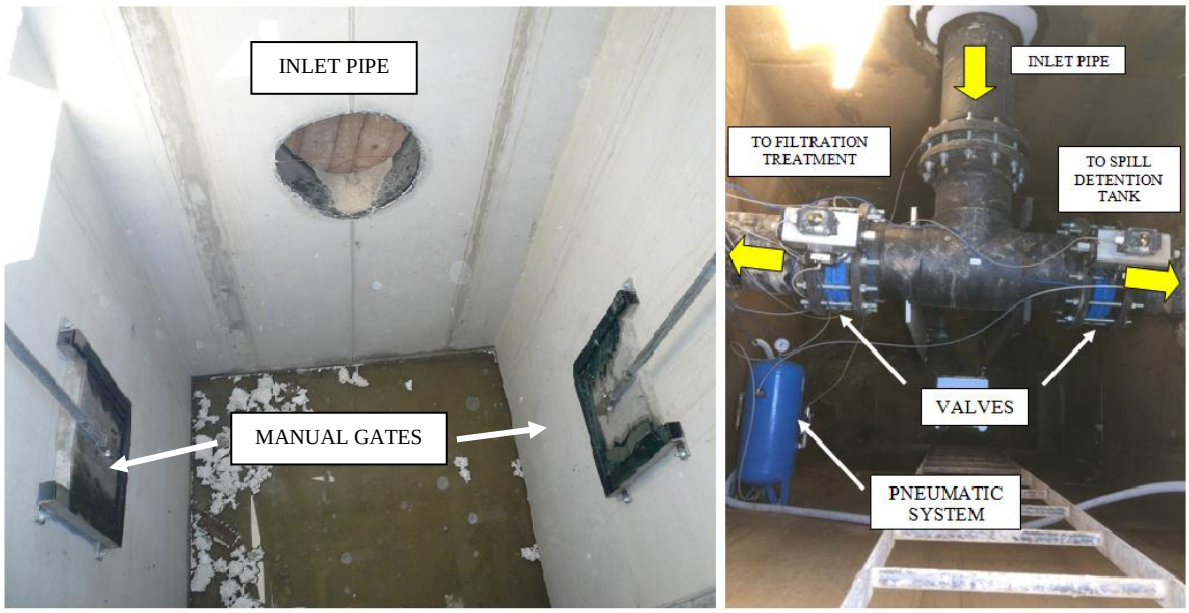

FIGURE 9 Status of the filtration inlet before revamping interventions (left) and after (right) with the installation of the connection pipe, valves and pneumatic system

The other main intervention consists in the positioning, in a proper location, of the multiparametric probes for measuring the water quality values analyzed by the software to define the acceptance of the inlet flow thanks to a specifically developed software.
All devices are connected to a local control panel installed near the tanks for visualization and control the water quality parameters, probes calibration and system settings. The control panel contains also the modules for the data transmission to the centralized SCADA remote system.

FIGURE 10 View from CAV SCADA of two plants installed along the Passante di Mestre

PEDEMONTANA VENETA HIGHWAY PROJECT

The Pedemontana Veneta Highway is the biggest Italian new toll highway project, designed for an average daily traffic of 27.000 vehicles/day to solve the mobility requests of a fragile area with very high light and heavy traffic congestion due to high saturation of the existing network.
The design of this infrastructure includes management solutions for collection, control and treatment for highway stormwater runoff. Along the infrastructure are expected and partially realized 189 stormwater continuous treatment plants based on Stormfilter® filtration systems able to treat all the stormwater runoff ensuring the management of the chronic impacts.

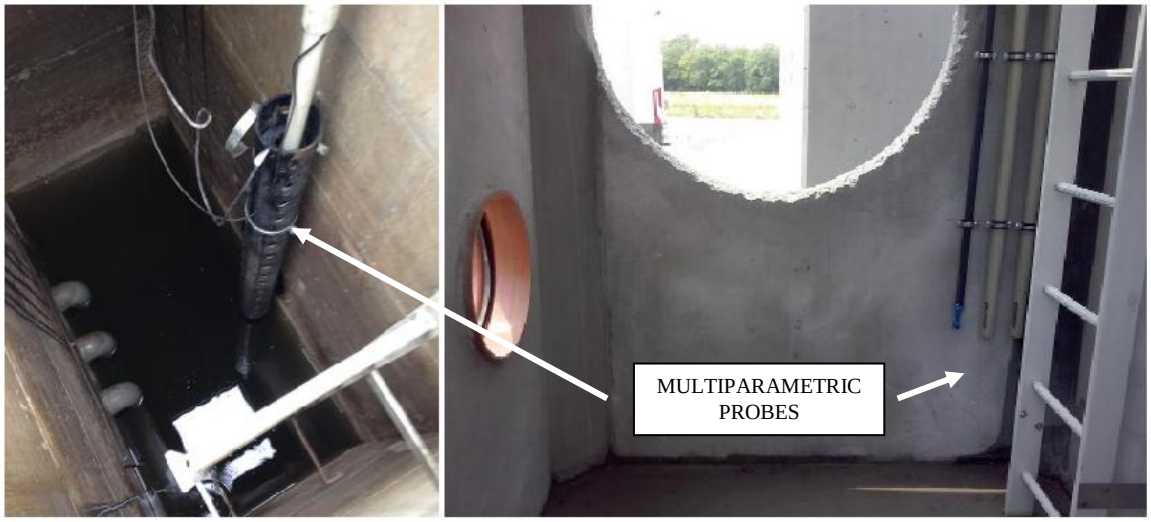

FIGURE 11 Details of different multiparametric probes installation

Along the infrastructure different type of stormwater runoff treatment plants have been designed: in line filtration plants, highway tollbooth plants, pumping stations, detention and retarding basins. Each of this plant will be coupled with a Swerm03® system for the management of the acute impacts, which goes to form an extensive network of 189 continuous stormwater runoff monitoring stations, interconnected through a centralized SCADA.

FIGURE 12 Example of local control panel with transmission module

Thanks to its automation and smart logic, the system offers a continuous global protection and a timeliness via the sending of alarms and messages to the end users (environmental protection Authorities, highway operation managers, etc.).

SUMMARY AND CONCLUSIONS

The need of a centralized system for stormwater runoff management in large infrastructure has become a strategic issue for environment protection. Through a several years process of research and experimentation in Veneto Region, a complete and integrated system was developed in cooperation with CAV and SPV.

The capabilities of the implemented system permits the local highway Authority to manage in an innovative way, like an industrial process, all the environmental aspects tied to highways runoff, from the ordinary control of the chronic impacts to the extraordinary accidental spills scenarios.

The maintenance scheduling and managing module represents a significant innovation that permits a real time monitoring of the efficiency of the network, an extensive information gathering related to the durability of the components leading to a remarkable reduction of the staff costs.

The core of the structure is a SCADA system accessible by insiders and public and the final result is a functional network that offers a high environmental protection grade, data availability, fully scalable and responding to the requests of an Intelligent Transportation System.

Further improvements of the implemented system are under development thanks to the availability of data and to the IT architecture that may be included in other ITS networks for different purposes.