STORMWATER RUNOFF: IMPACT, RISK ANALYSIS AND EMERGENCY MANAGEMENTON AN ITALIAN HIGHWAY

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ABSTRACT

The aim of this study is to address the issue of rainwater runoff from highways, through quality characterization of runoff and the analysis of its environmental impact. Being linear pollution sources, highways determine a chronic impact on stormwater, due to continuous leaching from atmosphere and pavement surface to receiving water bodies or groundwater. Not normally provided with a drainage network, stormwater from highways are often discharged without any kind of treatment. Acute impacts due to accident-related spills and leakages exert a negative environmental effect, which was not considered in the past, and are also difficult to predict, manage and control. A deep investigation was conducted to become aware of treatment options applied worldwide. As a result of the research activity on the problem and its possible solutions, an innovative approach designed for the 95-km-long Italian highway 'Superstrada Pedemontana Veneta' will be discussed. The system consists of a combination of a treatment system and an emergency system to manage contemporarily acute and chronic impacts. The treatment facility exploits a continuous filtration process, while the emergency device consists of a monitoring system to detect exceptional loads and a storage basin. The system allows managing up to 94% of accidental events.

KEYWORDS

Spill emergency management solution, stormwater treatment from highways, stand-alone treatment plants, low energy consumption, acute and chronic impacts

PRESENTER PROFILE

Stefano Biondi is the chief executive officer of Stormwater Italia, an environmental consultancy company working in the field of stormwater treatment, with a significant expertise in transportation infrastructures also cooperating with the Italian transportation ministry.

With over 25 years of professional experience, he has been a speaker in different international conferences.

1 INTRODUCTION

This article aims at illustrating some innovative solutions for the treatment of stormwater from highways and for the management of spills of hazardous substances within big infrastructures.

This study arises from the awareness of the negative environmental impact exerted by the discharge of highly contaminated stormwater, causing water quality worsening and water biota threatening. Important literature studies have already investigated the issue of chronic pollution due to stormwater: it is due to the many types of pollutants that settle on impervious surfaces and are washed by stormwater. Stormwater pollution rate is a function of a number of parameters (traffic volumes, dry period lifespan before the event, etc.) that make it highly variable in time and space and thus difficult to manage. Traditional treatment options, originally designed for wastewater treatment, are not efficient towards stormwater streams, that are not continuous, have a variable flow, carry different types of pollutants and are produced often far from energy supply points or centralized facilities.

Figure 1: accident resulting in a spill

In addition to chronic pollution, the environmental impact related with accidental events, such as spills or losses, has never been taken into consideration in the design phase of such infrastructures. Post-event countermeasures requires time and dedicated resources, that are anyway not suitable to guarantee receiving water body protection.

In this framework, the article aims at presenting the designed solution for stormwater treatment from an under construction, 95 km highway in Italy. A special focus will concern an innovative, automatic and patent pending solution for the management of acute impacts due to spills or accidental events (named after Swerm).

In the following sections a description of this new emergency management device will be furnished. An account of two applications of stormwater treatment and spill management solutions for two Italian highways will follow. Finally the ongoing research activity to improve Swerm features and extend its application field will be discussed.

2 STORMWATER ENVIRONMENTAL RISK MANAGEMENT

Swerm in an innovative device that has been conceived and realized to manage and control spill related emergencies. Fundamentally, it should be integrated in a drainage systems or be installed near its points of discharge.

The Swerm key component is a sluice-valve, installed along the drainage pipe, closed if an emergency situation is observed. In this way, the potentially harmful load resulted from a spill or another emergency situation is prevented from reaching receiving water bodies and can be stored either in the drainage network itself or in an exclusive container.

The crucial feature of determining an emergency situation, in the framework of drainage network standard operating, is performed by the monitoring system, made up of different sensors and water quality meters.

An intelligent control unit (PLC) manages data acquired from Swerm different components, supervises the behavior of the entire device and stores probes data and information on each component functioning.

The intelligent unit is also equipped with a GPRS transmission device: it allows monitored data transmission to an operation center, from where Swerm remote control and operation are also possible.

The innovative aspect of Swerm is its logic that commands the system operating in any meteoric condition. To better understand Swerm functioning, its components will be described in detail in the following sections.

2.1 MONITORING SYSTEM

The monitoring system has the important function of continuously checking water quality and detecting the occurrence of a spill.

This purpose is achieved through comparison and processing of data collected by two sensor groups: the first include two sensors that are used to establish actual meteorological conditions: a rain sensor to be installed outdoors and a flow switch, to be installed along the drainage pipe. Comparing the signals coming from these two sensors it will be possible to establish in which of the following situations we are:

- Dry weather: dry signal both inside and outside the pipe
- Wet weather: wet signal both inside and outside the tank
- An unexpected load is passing through the pipe: wet signal inside the tank and dry signal from outside

Depending on the result of this first assessment, the control unit takes a consistent action, as described in the following section 2.2. Specifically, the occurring of the second situation involves the activation of a second group of sensors: depending on the chosen configuration, it may include one or more of the following:

- pH meter
- conductivity sensor
- turbidity meter

Probes are guarded in a waterproof housing provided with a collision protection system and the monitoring station as a whole is waterproof (IP 68).

Figure 2: probes housing with a collision protection system

If the turbidity meter is included, a pneumatic cleaning system is also added, to avoid biofilm formation and dirt deposit on the sensor (this would affect data soundness).

pH, turbidity and conductivity have been chosen as "synthetic" parameters, useful for the detection of liquid spills. In fact, a change in their value can be brought back to the presence of a number of pollutants (acids, basis, salts, etc.) that can be the result of a spill. The choice of these parameters was also made to balance cost, maintenance requirements and energy consumption.

The probes continuously communicate with the PLC, where data are stored, processed and remotely forwarded.

2.1.1 MONITORING SYSTEM CONFIGURATIONS

The monitoring system exists in two different configurations, for inside and outside installations, respectively.

Figure 3: view of an inside configuration

As for inside installation, the control unit and the datalogger/remote control system are put together in a very compact unit that can be located inside a manhole or a basin. In this way, less room and construction works are required for its installation and there are not outside components. The aerial is especially suitable for confined spaces installations.

Figure 4: view of the control panel in an outside configuration

In the outside configuration the probes, the pertinent processing unit and the datalogger are installed separately: while sensors are plunged into the liquid that needs to be monitored, the intelligent unit, the aerial for GPRS communications and the datalogger are installed aboveground, in a suitable panel.

2.2 CONTROL UNIT AND INTERNAL LOGIC

Figure 5: Swerm intelligent control unit

Swerm 'brain' is the intelligent control unit (PLC) , that runs the system in all its functions: it fundamentally instantly and continuously stores and manages data from the monitoring system and, if a risk of pollution is estimated, it automatically activates the emergency pneumatic system, that closes the discharge pipe. The PLC also keeps all the components status under control, manages alarms and communicates remotely with the operations center.

In section 2.1 we have seen that three different situations could happen: in the first one (dry weather) no action is undertaken and PLC just stores probes data.

The third situation is linked with the passage of a load that should be confined (a liquid is passing through the pipe but it is not raining outside); in this case the control unit commands the closure of the sluice-valve.

During wet weather the second group of sensors is questioned: the PLC software is programmed with an acceptable range (for each parameter)in which measured values should stay. If this doesn't happen, the intelligent unit infers that an abnormal event is occurring and sends the input signal to the sluice valve that closes the discharge pipe. When an emergency situation is set, an alarm signal (provided with a siren and a high visibility flashing light) is switched on.

The acceptable range has been defined after a preliminary campaign to monitor 'usual' stormwater quality. Continuously acquired data are also processed and used to update acceptable limits for each parameter.

Due to the control unit, the action of opening the emergency tank in the case of an incident is automatic and thus very quick, preventing pollution widespread in the environment. The same result will be impossible with traditional man-actuated systems.

Thanks to its logic, the system is able to detect and manage any highly polluted load, either in dry or wet weather, with a completely automatic system that does not require human presence and is very quick to actuate.

The control unit finally manages and displays alarms related to each component malfunction or crash.

2.3 EMERGENCY CLOSURE PNEUMATIC SYSTEM

This is the component that fundamentally discharges Swerm function: the emergency closure system consists in a sluice-valve, to be installed along or at the end of the drainage pipe. When closed, the valve prevents the discharge of the flow passing through the pipe, avoiding its delivery to the receiving (natural) water body and thus protecting it from contamination.

Highly polluted loads contained by the valve can be diverted to an emergency detection basin or stored in the drainage network itself.

The sluice-valve activation is driven by the PLC unit when an emergency situation is detected according to its logic, as described in section number 2.2.

The valve closure is pneumatic actuated: that means that its motion comes from the expansion of a compressed gas. In the system described, neutral gas, namely nitrogen, is stored at a constant pressure in a 25 liters cylinder. This amount is chosen to assure two complete opening/closing cycles. A pneumatic circuit links the cylinder to the valve, so that the valve is actuated as soon as the cylinder is opened, commanded by the central unit, as it receives an alarm signal.

In this way, actuation time can be very low, below 1 second, much less compared to the time that will be required with a traditional electric actuator valve. This feature is particularly notable when dealing with spills: any delay in the containment of a highly polluted load can result in an environmental contamination.

A manometer and a pressure switch constantly monitor the tank pressure and, if this last reaches the lowest acceptable level, an alarm is sent to the control unit.

2.4 EMERGENCY TANK

Once the emergency closure system has been activated, the liquid spilt can be either confined in the drainage network or diverted to an emergency detection basin, where it is kept safely until an emergency team will be able to take proper actions to deal with the material. The tank is made of concrete or any other suitable material and its volume is chosen to contain the highest spill volume expected (typically the volume of a tanker).

2.5 COMMUNICATION, DATA TRASMISSION AND REMOTE CONTROL

The PLC is provided with an aerial that sends all the data stored to an operation center, via GSM or MODBUS. Beyond probes data, that is sent once a day, the PLC communicates alarms real-time, so that the operation center staff can check the situation and keep it under control.

From the operation center, the plant manager can also remotely command the emergency opening or closing, making the system flexible and ready.

2.6 NETWORKING

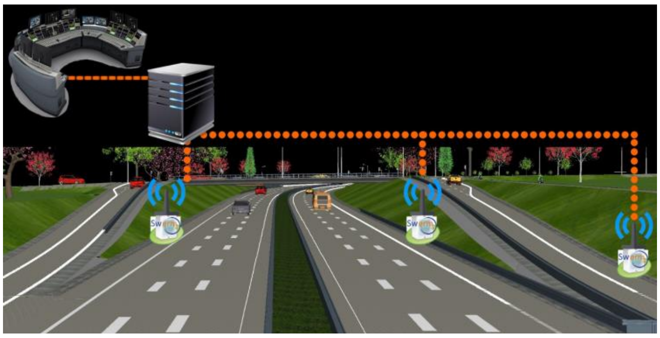


Figure 6: scheme of different devices networking and control

Different Swerm devices can be networked to a unique operation center, from where each single plant is monitored and eventually operated. In this way, alarms coming from the whole plant network and maintenance activities can be managed with a better cost/benefit balance.

2.7 ENERGY SUPPLY

Particular attention has been paid to build Swerm with low energy consumption components. As a consequence, Swerm requires a very low energy supply, with a power of 24 Watt, and is not damaged by power surges, thanks to its energetic back-up.

Either the whole system is powered from the mains, if present, or from a solar panel off-grid system, that can ensure completely autonomous functioning. The solar panelis sized to charge a battery with 5 days emergency storage.

2.8 DATA VALIDATION AND USE

Datasets collected from on-line water quality sensors are subject to noise and errors due to different causes. Thus, prior to use, time series data needs to be validated.

A first rough data analysis has been carried out through a MATLAB-based software, purpose built: first of all, the software builds an internal database, merging report files that are sent daily from the Swerm control unit.

After that, values that fall outside the physical range of each parameter are removed: for example, if pH values goes below 0, corresponding data are removed.

Finally, the software generates different graphical outputs, thanks of which a first view of each parameter trend is gained. As an example, conductivity and pH datasets, coming from a heavy traffic road in a port area are shown:

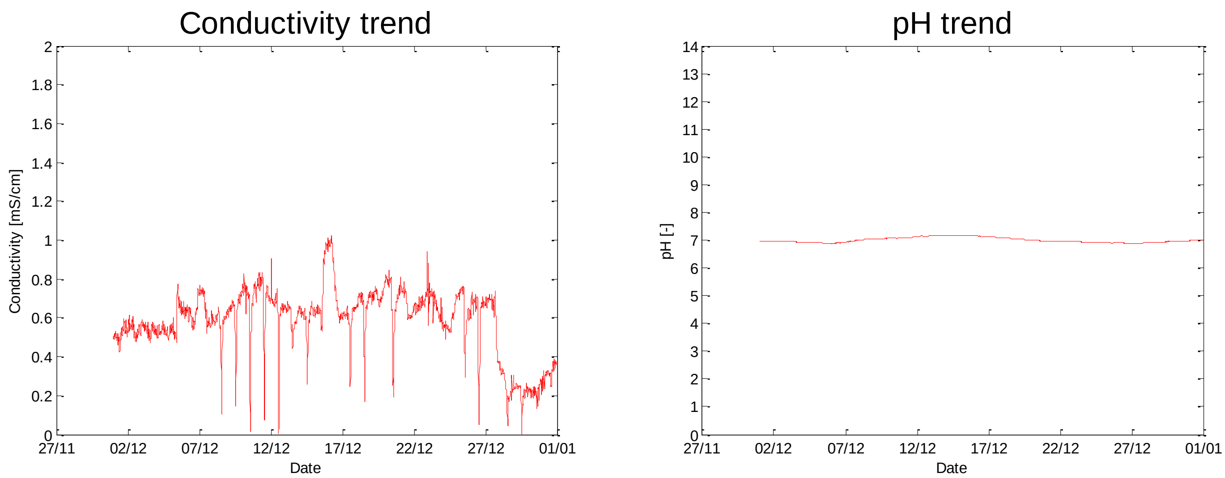


Figure 7: pH and conductivity trends along a road in a port area

The same data can be plotted togher with local precipitation to point out parameters variotions as a function of precipitation high.

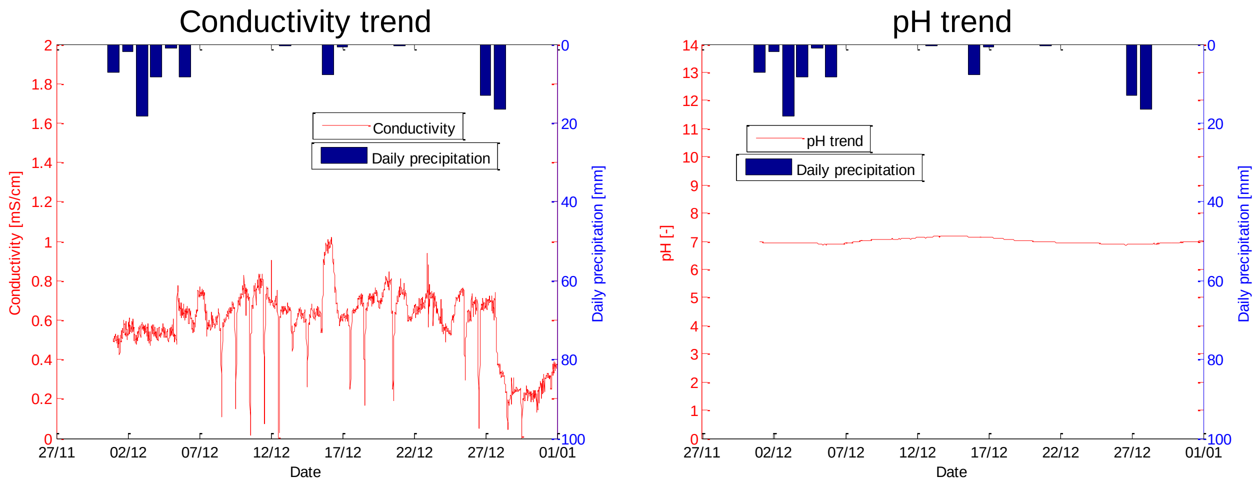


Figure 8:precipitation/pH and conductivity trends along a road in a port area

Finally, different parameters series can be plotted together to understand possible correlations between different time-series.

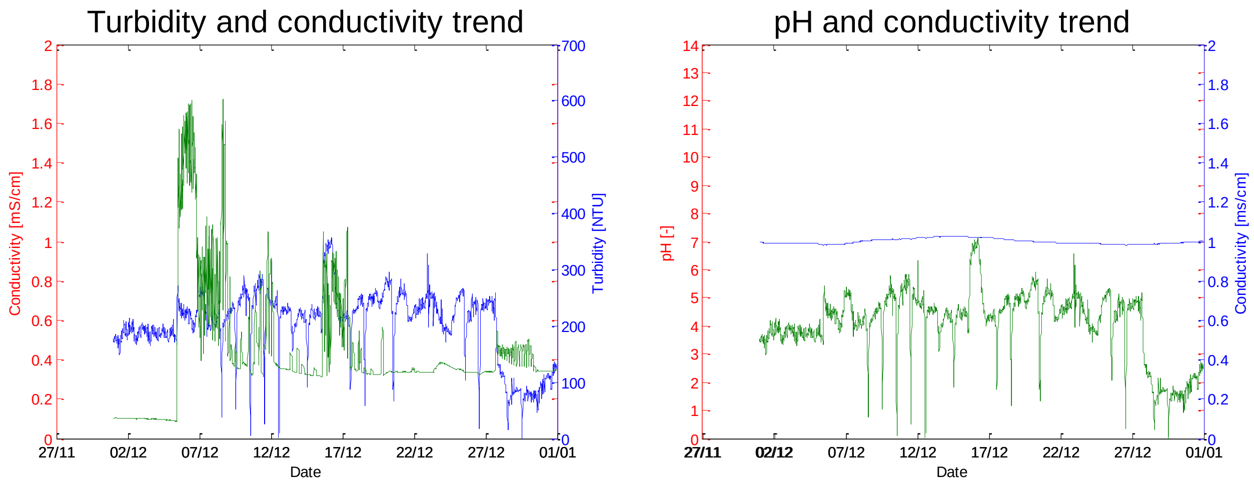
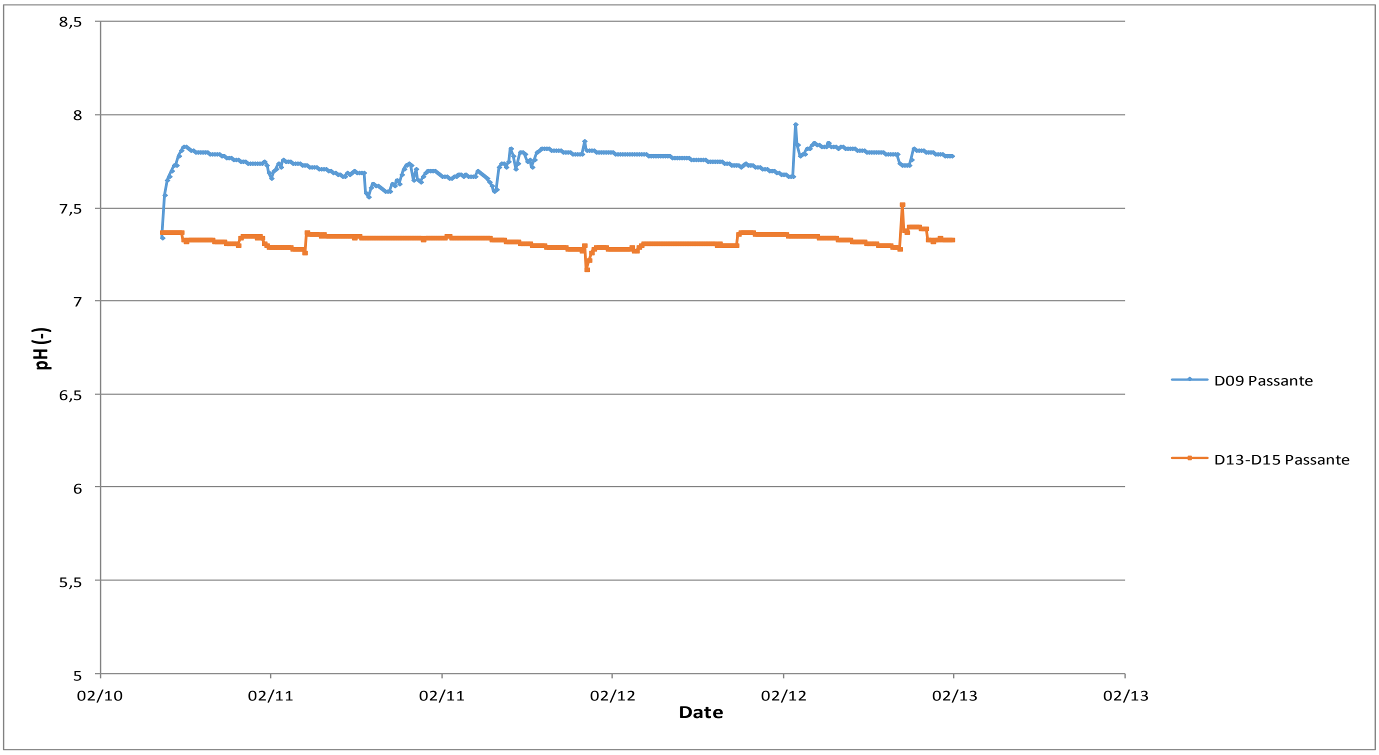


Figure 9: turbidity/conductivity and pH/conductivity coplots

In the following graphs, pH and conductivity datasets from the two Passante (D09 and D13-15) monitoring stations are plotted:



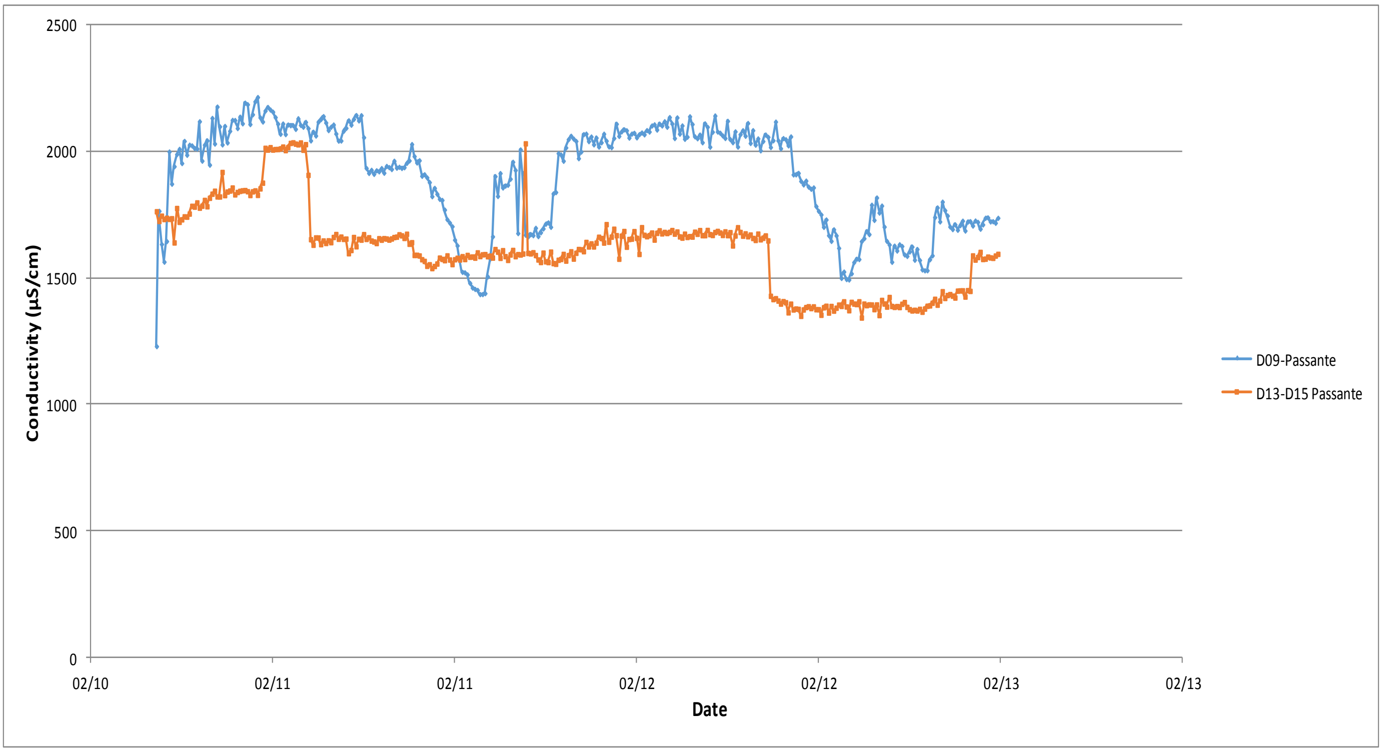


Figure 10: Passante three days pH and conductivity plots

On-line water quality data are affected by errors due to measurement errors and sensors failures.

These errors appear to have different causes, depending on the measurement technique and on the location of the sensors.

The noise and the errors in the collected datasets can be detected and corrected using automatic error correction tools. We are going to test the software to eliminate outliers and faulty periods.

2.9 ADVANTAGES AND INNOVATIVE ASPECTS

To sum up, Swerm is undoubtedly a unique and innovative device put together in only one compact object. There are many different positive features and outstanding functions that make it a unique solution for spill retention and management, with nothing similar in the market. The most important advantages that Swerm offers are:

- the system is completely automatic, but can be operated and constantly monitored remotely, in case of need

- short activation time (less than 1 second)

- the system works either in dry or wet weather, thanks to a binary logic system that allows its functioning in all meteoric conditions

- low energy consumption and possible stand alone installations, with solar energy supply

- each device can communicate remotely via GSM or through a fiber optic network. In this way, many Swerm devices can be kept under control and managed remotely from a single operation center.

Further research activities are ongoing to be carried out in two main branches. Because of the increasing attention to energy saving and efficiency, an important research activity will concern the possibility to feed the system with renewable energy sources. We are going to study the possible integration of photovoltaic energy sources with mini-hydro devices, to be installed along sewers and able to produce energy when water crosses them. Thanks to that, stand alone installation will be feasible and less expensive.

Within this framework, we are also looking at low energy consuming and more compact sensors and control units to build smaller devices that will be more easily integrated in treatment or emergency management plants.

Another research branch aims at studying probes reaction to the most common substances involved in accidental events along highways. Building a correlation between data patterns and substances spilt will be useful to deduce the type of pollutant involved in a spill and thus undertake the proper action to manage the situation.

2.10 CONTINUOUS STOMWATER TREATMENT DEVICES

Considering stormwater distinctive characteristics, already illustrated in section 1, an innovative treatment system is proposed, that overcomes the limitations of traditional treatment solutions, conceived for the more continuous and uniform municipal and industrial wastewater flows.

Figure 11: filtrating cartridges inside a treatment plant

The proposed solution includes a treatment system based on a filtration process, instead. Fundamentally, water crosses a filtration media that mechanically retains solid particles and removes dissolved pollutants through adsorption and ion exchange. Filtration media is filled inside plastic cartridges, easy to move and maintain, to be placed inside a concrete vault. Water enters the basin from an inlet pipe, passes through filtrating cartridges and is finally discharged through underdrain pipes, that exit the vaults leading water to the discharge pipe.

In this way, the plant does not require any energy supply, having a gravity functioning, does not contain any moving part (being less subject to malfunctions or breakages). As opposed to first flush tanks, they allow to capture 95% of rain volumes, on an annual basis. Finally, the treatment is performed in a great number of small plants along the roadway. In this way, the plants are placed under bys, making management and maintenance activities easier to carry out, without stopping the traffic flow, and the construction of a centralized treatment plant and a large drainage network is not required.

3 APPLICATIONS

Up to now there have been two main projects with Swerm devices within road infrastructures. They will be described in detail in the following sections. Other installations already exist in the framework of port infrastructures.

3.1 PASSANTE DI MESTRE-VENICE

The solutions described in the previous sections have been first put into operation along a 32,3 km highway (Passante di Mestre) that is a portion of A4 motorway.

Figure 12: Passante di Mestre building yard

Figure 13:Passante di Mestre on a heavy traffic day

62 filtration plants have been installed along the highway, to continuously treat stormwater resulting from rain events. Filtration plants contain a number of filtrating cartridges varying between 3 and 10.

Figure 14: under construction filtration plant

Together with stormwater treatment plants, two monitoring stations have been installed along the highway to carry out apreliminary monitoring campaign, to acquire information that will be useful to calibrate Swerm software and for probes data validation.

This location has been chosen for three main reasons:

- Passante di Mestre is geographically near Superstrada Pedemontana Veneta, being thus subject to similar meteoric conditions. This aspect is particularly important, since stormwater quality is site-specific: information on stormwater characteristics should come from an area with conditions similar to the ones of the place for which stormwater characterization is required.

- traffic volumes are expected to be similar

- Passante di Mestre has been built recently and its pavement wear is similar to the Superstrada Pedemontana Veneta one.

Figure 15: monitoring station along Passante di Mestre

The monitoring stations will be equipped with the same sensors contemplated for Pedemontana installations, namely pH and conductivity sensors. They will be combined with a control unit and a transmission device, stored in a panel outdoors, according to the outside configuration already described.

The aim of this activity is to define, based on solid technical-scientific fundamentals, each parameter typical range. These values will be useful to establish pH and conductivity acceptable ranges, out of which the control unit commands the activation of the emergency closure pneumatic system. The validation program also requires this information.

Traditional chemical analysis will be run in parallel, to study correlations between values measured by probes and analytical results.

3.2 SUPERSTRADA PEDEMONTANA VENETA

Superstrada Pedemontana Veneta is an under construction, 95 km long toll highway in north-east Italy. With 35000 vehicles per day expected, the work should reduce local traffic, also thanks to the connection with three others major highways in the region.

Figure 16: Pedemontana Veneta project route

Figure 17: Pedemontana Veneta building yards

Superstrada Pedemontana Veneta will cross an environmental sensitive area, rich in water-bearing stratum. In the high plains area there are a number of watertables, hydraulically connected with impermeable stratums in lowlands. There are over 100,000 wells in this area, 800 of which are public drinking water wells. They feed some of the most important aqueducts in the region and bring drinking water to about 5 million people.

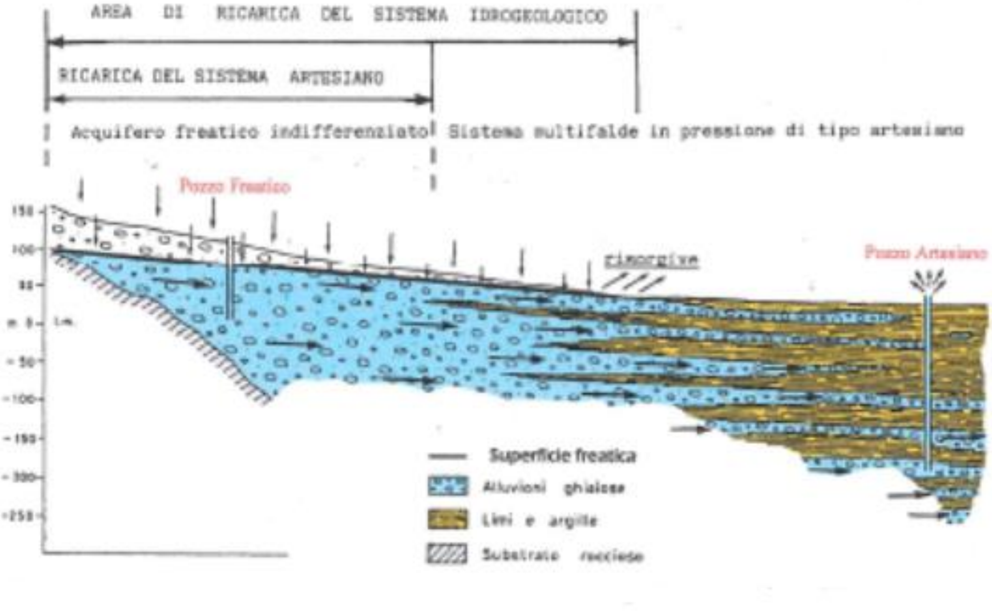


Figure 18:groundwater motion from high plains watertables to lowlands impermeable stratums

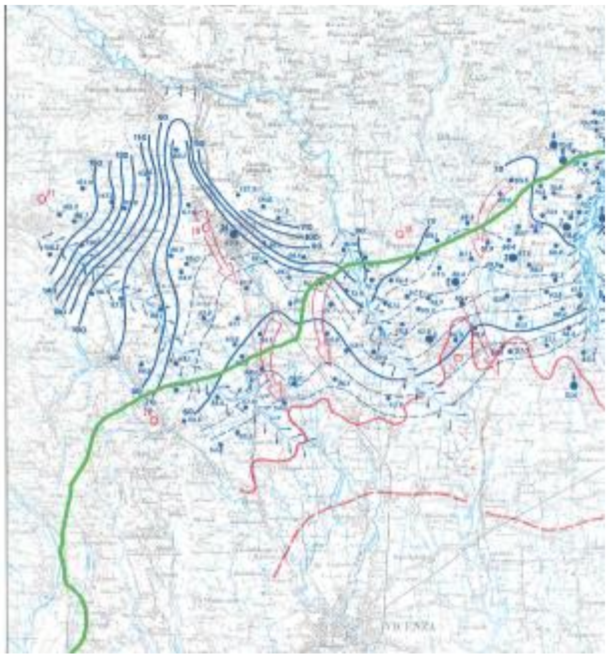


Figure 19:hydrological flows and wells location in the Pedemontana Veneta region

The extraordinary social and economical importance of this large water body implies an adequate effort to protect and preserve this invaluable resource, both quantitatively and qualitatively.

The construction of the new highway has bought up many worries about its environmental impact on local water bodies.

Actually, highways determine a chronic pollution to receiving water bodies, through stormwater contamination, due to continuous leaching from the atmosphere and the pavement wash off. If not provided with a drainage network or treatment facilities, stormwater from highways is discharged as it is. The many pollutants carried by water determine, in this way, a severe environmental contamination. Together with chronic pollution, acute impacts due to accidental spills or losses also exert a negative environmental effect, not considered in the past, and are in addition difficult to predict, manage and control. There are many case studies that witness a severe environmental contamination due to the discharge of hazardous substances.

3.3 STORMWATER TREATMENT SOLUTION

The area environmental sensitivity is the main reason why the commissioning board decided to look for an innovative approach for stormwater treatment and management. The proposed solution allowed to deal at the same time with acute and chronic impacts having contemporarily a positive cost/benefit balances, low energy consumption and maintenance requirements.

Stormwater resulting from Superstrada Pedemontana Veneta in ‘normal’ conditions will be treated with a number of small treatment plants to be installed along the highway. Furnished with special filtration cartridges, they act both as mechanical filters and adsorbents, removing suspended solids and heavy metals, frequently found in stormwater coming from road infrastructures. The device works continuously, to treat not only the first flush precipitation (but up to 95% of annual precipitation), does not require any energy supply or specialized maintenance. Being small, plants can be located under bys, making management and maintenance activities easier to carry out, without stopping the traffic flow. In addition, a number of detention basins will be built to laminate peak flows.

Figure 20: under construction detention basin

Treated water will be finally infiltrated into the soil through nearly 200 absorbing wells.

Treatment plants will also be coupled with 185 Swerm devices: each of them can be kept under control and operated from a single control room, where alarms and maintenance activities are managed as well.

3.4 RISK ANALYSIS FOR ACUTE IMPACTS MANAGEMENT

Beside chronic pollution, acute environmental impacts will be managed thanks to Swerm devices, to be installed along the highway. Their design was based on an accurate risk analysis, that has taken into consideration the many aspects related with an accidental event happening. The following probabilities should be considered:

- The probability of an accidental events (from historical data on road accidents)
- The probability the accidental event involves trucks loading hazardous substances
- The probability the accident occurs during a rainfall event

According to Swerm logic, already described, we can consider the system able to prevent any spill happening during dry weather. As for rainy periods, we can consider the system efficiency equal to 80%: that means that 80% of accidental events happening during wet weather are detected by the monitoring system and correctly managed. Finally,considering that 40% of accidents happen during wet weather and that rainy days are about the 30% of one year days, we can infer that the system is able to manage 92% of the spills, as shown in the following figure.

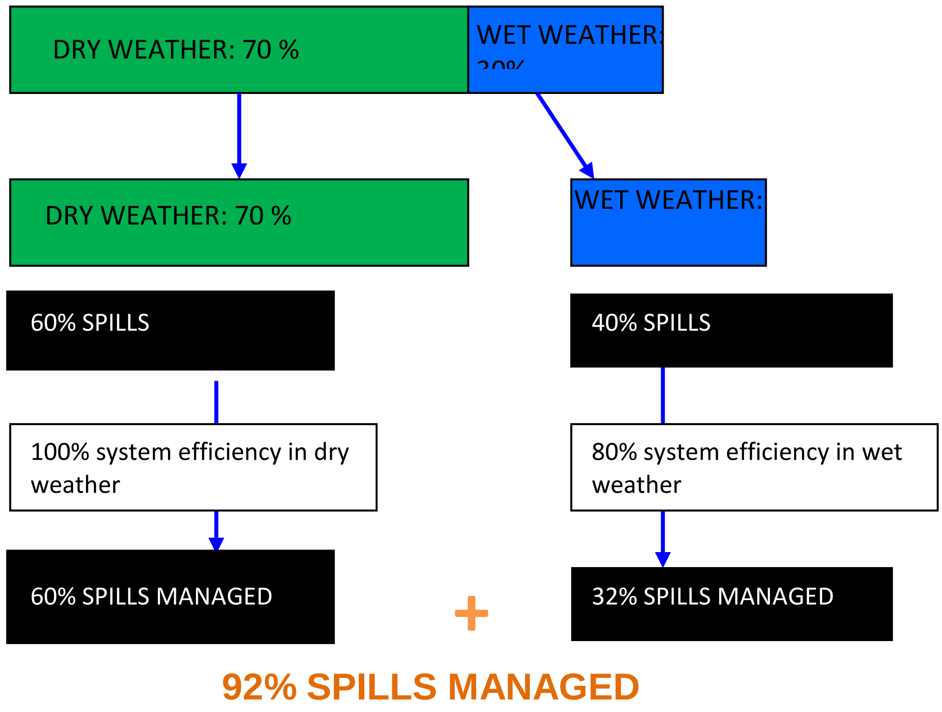


Figure 21: risk analysis probability scheme

4 CONCLUSIONS

This study aimed at illustrating an innovative, patent pending solution for spills related emergencies management. Its components and, most of all, its functioning that allows a safe control of any emergency situation resulted from a spill or any other accidental events is described. Together with stormwater treatment devices, they act as a unique solution for all-round management of stormwater from highways.

An important application of these solutions is described and consists in a network of stormwater treatment and spills management plants, along a 95 km under construction highway in Italy. This will probably be the first example of integrated management for the whole amount of stormwater that originates from an highway. At the same time, this will be the first large-scale installation of a completely automatic network of devices for spill related emergencies.

ACKNOWLEDGEMENTS

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