*DOI: 10.4408/IJEGE.2020-01.S-02*

# COASTAL EROSION MITIGATION THROUGH EJECTOR DEVICES APPLICATION

Augusto BIANCHINI(*), Alessandro GUZZINI(**), Marco PELLEGRINI(*)
Cesare SACCANI(**), Maria Gabriella GAETA(***) & Renata ARCHETTI(***)

*(*)University of Bologna - Department of Industrial Engineering - Via Fontanelle, 40 - 47121 Forlì, Italy*
*(**)University of Bologna - Department of Industrial Engineering - Viale del Risorgimento, 2 - 40136 Bologna, Italy*
*(***)University of Bologna - Department of Civil, Chemical, Environmental, and Materials Engineering - Viale del Risorgimento, 2 - 40136 Bologna, Italy*
*Corresponding author: marco.pellegrini3@unibo.it*

## EXTENDED ABSTRACT

L'erosione costiera e l'insabbiamento dei fondali rappresentano i due fenomeni che mettono maggiormente a rischio la conservazione della condizione naturale delle migliaia di chilometri di costa presenti nel mondo. Conseguentemente nel corso degli anni sono state sviluppate diverse strategie e tecnologie finalizzate al contrasto dei fenomeni di erosione e insabbiamento. In particolare, nel caso dell'insabbiamento dei fondali, il dragaggio risulta la soluzione tradizionalmente applicata dalle autorità locali anche se numerosi compromessi economici, ambientali e sociali devono essere accettati per la sua applicazione. Per questo motivo una nuova tecnologia è stata sviluppata, testata e implementata in applicazioni reali dall'Università di Bologna in collaborazione con partner industriali locali.

La soluzione tecnologica, chiamata eiettore, si basa sul principio fisico di trasferimento di quantità di moto da un flusso primario ad un flusso secondario che consente di trasportare il sedimento depositato in un'area circostante alla posizione dell'eiettore evitando la presenza di parti in movimento ed alimentazione elettrica. In virtù del tratto convergente nella parte iniziale dell'eiettore, infatti, l'aumento di velocità del flusso primario, i.e. acqua marina, crea una depressione per effetto Venturi nella parte centrale del dispositivo in grado di estrarre la miscela di acqua e sedimento presente. La miscela rimossa viene così trasportata a distanza dalla zona di possibile insabbiamento mantenendo la profondità del fondale desiderata. Numerosi sono i vantaggi ottenibili dall'implementazione della tecnologia in sostituzione del dragaggio tradizionale, specialmente nel caso di porti di dimensioni ridotte, quali quelli turistici. Fra questi i più importanti risultano: i) la garanzia poter operare in continuo per tutto l'arco dell'anno e senza creare ostacoli per la navigazione di qualunque tipo, quale per esempio quella turistica e/o commerciale; ii) l'assenza di impatto ambientale in quanto, operando continuamente, la movimentazione dei sedimenti avviene secondo un bilancio di massa nulla in cui tutto ciò che esce dal sistema è uguale a quello che è entrato; iii) l'assenza di impatto su flora e fauna marina come invece accede nel caso del dragaggio tradizionale; iv) bassi costi operativi necessari per il successo del business plan della tecnologia; v) la possibilità di mantenere la navigabilità del porto per tutto l'arco dell'anno.

Tuttavia, nonostante i vantaggi vi sono numerosi ostacoli che ne impediscono l'applicazione su larga scala come, per esempio, il ridotto numero di installazioni industriali che rendono la tecnologia poco attrattiva per i possibili investitori. Per superare queste criticità, nell'articolo sono riportati i risultati ottenuti nel corso degli anni durante le attività sperimentali in laboratorio ed in campo. Al termine, infine, sarà riportato il caso studio di Cervia: saranno mostrate le motivazioni e le considerazioni effettuate per il dimensionamento dell'impianto, i risultati ottenuti durante le prime attività sperimentali e un modello per la simulazione delle aree locali maggiormente soggette a fenomeni di insabbiamento e per l'ottimizzazione del controllo dell'impianto.

## ABSTRACT

To mitigate coastal erosion and harbors siltation, new strategies are required in the immediate term. In fact, even if many traditional solutions are available, their application is usually limited due to economic, environmental and social reasons. This situation is particularly evident in the case of small marinas or in those areas where the local economy is strongly affected by harbor operation such as in the case of the port of the municipality of Cervia (Italy). To solve the problem occurred in this specific case, an innovative device, called the "ejector", is proposed and implemented in a dedicated experimental plant characterized by low operative costs and no environmental impact. Starting from the description of the technology, the paper aims to show the ejector's potentials with respect to siltation and erosion problems. For the purpose the first results derived from the application in the case study at the municipality of Cervia are reported.

***Keywords***: *coastal engineering, coastal erosion, harbor siltation, coast management, ejectors.*

## INTRODUCTION

It is neither simple nor trivial to identify the best strategy to preserve coasts areas. In fact, there are many different factors that must be taken into consideration such as environmental, social and economic ones. In addition, due to the local specificity of coastal environment, the adopted solution cannot be simply replicated to other coastal areas. Furthermore, different phenomena can occur along the coasts proving to be very difficult to select the best strategy without compromises. Therefore, coasts management requires many efforts even if the reachable results are not always positive as expected. Despite the difficulties, however, an effective and long-term strategy to maintain the world 356.000 km of coasts is required avoiding, instead, temporary countermeasures. For the purpose, destructive phenomena affecting coasts must be clearly understood.

Among these, coastal erosion and siltation are the most investigated in literature (Prasad *et alii*, 2014; Winterwerp & Kesteren, 2004). The first one represents a global problem due to a redistribution of sand from the beach face to offshore resulting in a loss of surface and consequently in serious economic and social damages for the local population (Zhang *et alii*, 2014). Even if coasts erosion naturally occurs, an acceleration occurred in last years. For example, more than the 20% of the European coasts, i.e. 20.000 km, are estimated to be affected by the phenomenon (Eurosion Project, 2004). A worst situation is recognized in Italy where almost the 30% of the total coasts suffers by erosion phenomena (Ispra, 2008). Despite the data are not so recent, authorities agree to the fact that dedicated countermeasures are required as soon as possible. Among those available, hard/soft protection measures, accommodation, beach nourishment, managed retreat or sacrifice areas (Lamberti *et alii*, 2005; De Jonge & Neal, 2018; Gracia *et alii*, 2018; Williams, 2018; Bonaldo *et alii*, 2019; Archetti *et alii*, 2016), all present advantages but also disadvantages that obstacle their implementation.

Concerning siltation, instead, several worries arise about coastal management and particularly about the negative effect on the human activities of the local communities such as, for example, transportation and tourism. In fact, siltation phenomenon mainly occurs where the stream is characterized by low velocities resulting in an accumulation of sediments, so at harbor entrance. For this reason, in recent years always more attention was given by the sustainable management of ports and channels. Particularly, sediments management became the most relevant topic for all the interested stakeholders. However, as for coastal erosion, many strategies were proposed and applied to avoid basins and approaches siltation even if different economic and environmental performances were obtained. Among these technologies, the most applied technology results to be dredging. Dredging is available in abroad range of applications with different production rates and working depths. Dredging technologies can be divided in mechanical and hydraulic depending on operation principle (Vlasblom, 2003).

Despite the capability, several concerns arise about the environmental impact and economic costs of traditional solutions especially in the case of small harbor and marinas. Anyway, their replacement is hindered in accordance to the fact that they are considered as well-known, reliable and widespread technologies. This condition signifies that strong arguments are required to justify the proposal of new and innovative approach. In the years, for example, always more attention was given to i) the need of more competitive approach in smaller marinas and channels, ii) the elimination of periodic interventions to restore the desired water depth with continuous and less impactful restorations, iii) the interference with other nautical activities and iv) the growing attention to the environmental impact of dredging (European Commission, 1999, 2000).

In addition to the reported limitations, it should be noted that coastal erosion and siltation are nowadays managed separately even if positive benefits could be obtained proposing a mutual approach. For this purpose, several alternative solutions were designed, realized and applied as reported by literature (Bianchini *et alii*, 2019).

Among these, an innovative device, called the "ejector", was designed and experimentally tested in laboratory and in field by the University of Bologna starting from 2002. Moving away the sediments that are depositing in the basins, the "ejector" technology aims to restore the natural flow of sediments altered by human activities and infrastructures. Furthermore, based on its working principle, the sediments can also be continuously moved in those areas affected by coastal erosion without environmental impact (Bianchini *et alii*, 2014).

Therefore, the paper aims to give evidences of the great performances achievable by the application of the technology against siltation and, possibly, erosion problem. For this purpose, the paper is structures as follow. In the first part, the main principles of the ejector technology are described. In accordance to the target, the results obtained during experimental campaigns in laboratory and on the field are reported through the first part. In the second the Life Marinaplan Plus project is described. Coordinated by Trevi S.p.A., an Italian company specialized in the field of foundation engineering located in Cesena, and involving the University of Bologna, the Municipality of Cervia and ICOMIA (International Council of Marine Industry Associations) as partners, the project aims to design, realize and manage an ejector plant in the Municipality of Cervia in order to assess plant business plan and the environmental impact. Therefore, after a preliminary description of the reasons that move the design of the plant in the specific location, the results obtained from the first two years of activities are reported. Furthermore, the STIMARE project is introduced to connect sediment siltation solution through ejector with coastal erosion countermeasures. In this framework, an integrated numerical modelling able to help in the prediction of the areas at risk of sediment accumulation and to optimize the control of the ejectors in relation to the sea conditions is briefly explained. Finally, preliminary conclusions deriving from the demo plant experience are reported.

## THE EJECTOR TECHNOLOGY

Similar to the jet pump concept, the ejector technology is based on the transfer of momentum from a high velocity primary jet flow to a secondary flow. Thanks to its simplicity, in fact, the jet pump technology was applied in sand bypassing system, since the need of limited personnel, the great portability, the reasonable manufacturing cost and the reliability as demonstrated by the first applications in coast management since 1976.

Starting from the jet pump idea, the Department of Industrial Engineering (DIN) of the University of Bologna in collaboration with two Companies, Elettromeccanica Muccioli Marco S.r.l. (Rimini, Italy) and Plant Engineering S.r.l. (Bologna, Italy) developed and tested an innovative plant for seabed maintenance, i.e. the “ejector” technology. Despite the concept, several differences are present between the classic jet pump and the ejector technology as shown in Fig. 1. From the figure, in fact, it is evident the different design between the two devices and, in particular, the converging section instead of the diffuser, the radial nozzles positioned circularly, the absence of the mixing throat substituted by an open section chamber configuration able to suck the mixture of seawater and sand.

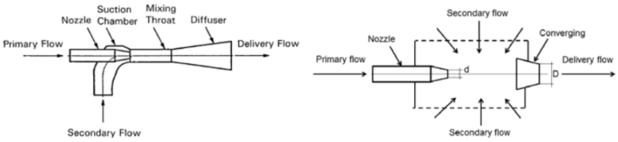


*Fig. 1 - Comparison between traditional jet pump (left) and the ejector technology (right). (Bianchini et alii, 2014).*

Based on the Venturi’s effect, an increase of the dynamic pressure and a decrease of static pressure occur along the nozzle ensuring the suction of the secondary flow that consists of a suspended mixture of seawater and sediments, i.e. the slurry, produced by the high pressure seawater jets from the radial nozzles that are clearly visible in Fig. 2, where the 3D design and the real device during some in-house tests are shown. The final converging section lastly increases dynamic pressure to discharge the material at a defined distance from the location of the ejector overcoming the exiting pressure drops. As shown, no moving parts and no electrical cables are present in the core of the technology minimizing maintenance activities and consequently operative costs.

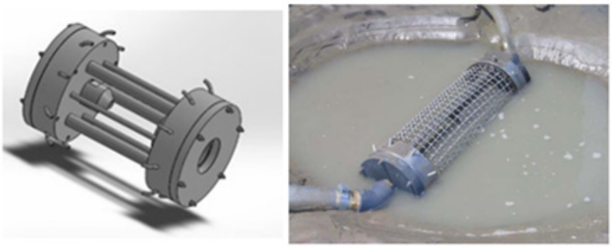


*Fig. 2 - The ejector technology (Bianchini et alii, 2014): 3D design (left) and laboratory tests (right)..*

Despite the simplicity, some auxiliaries are required for the operation of the plant such as submersible borehole pumps, that pressurize the seawater to be supplied. Mechanical filters are also suggested upstream the device to avoid the entrance of marine flora and fauna within the interstices due to the geometrical tolerances and consequently nozzles obstruction. Flow regulating and manual valves are the other noteworthy elements. In addition, a dedicated control system is also required to efficiently control the plant as in the following reported case study.

The justification to the technology is given by the several benefits achievable by the implementation with respect to traditional systems:

1. First of all, working with the sediments that naturally come to a certain area, the plant does not add or remove the sediment from that area. Therefore, since this activity cannot be classified as dredging, no authorization is required in accordance to Italian normative.
2. Secondly, placed on the seabed (as well as the pipelines), no

barrier against navigation is expected during the 24/7 continuous operation.

3. Thirdly, thanks to its design, the ejector can be used as a fixed or mobile device depending on the specific requirements of the coastal location. Focusing on the fixed configuration, as selected for the following case study, the ejector works on a limited area whose diameter depends on the sediment characteristic as, for example but not limited to, the angle of repose. Therefore, by installing several ejectors in order to create a grid in the seabed, it is possible to create a seaway for navigation.

4. Lastly but not the least, the technology is not responsible for environmental impact and turbidity as occurring during the operation of traditional technology.

*Laboratory developments and testing*

Despite the one-dimensional jet pump theory is well known and described by several models developed through the years (Bianchini *et alii*, 2019), dedicated testing activities were required to validate the results due to the complexity and uncertainty of some fundamental parameters such as, for example the friction coefficients or the convergent-divergent drag coefficient. In particular, the analyzed phenomenon was the suction effect due by the behavior of a fluid jet in free outflow from a hole, i.e. the nozzle of diameter d, towards an open environment. In fact, the high velocity of the jet exiting from the convergent nozzle creates a low pressure area leading the pumping of the second flow toward this minimum pressure point. This condition results in the exchange of momentum between the two streams that ensures the uniform mixing of the streams that flow at an intermediate velocity between the one characteristic of the primary and the secondary flows.

Starting from 2002 and up to 2013, several ejectors characterized by different geometries were tested in DIN laboratory to verify the theoretical performance in a real environment. During the tests, inlet and outlet ejector streams pressure were measured by pressure gauges, while inlet and outlet volumetric flow were measured by level variation in the water and discharge tanks, respectively as shown in Fig. 3. Experimental tests were also integrated with computer fluid-dynamic simulation.

Operational characteristics of the innovative device were described by two jet pump dimensionless ratios, i.e. the flow ratio *Q* and the head ratio *H*. These coefficients were respectively defined as:

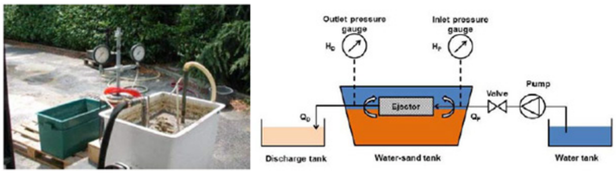


*Fig. 3 - Picture of experimental set arrangement (left); schematic of experimental set arrangement (right). (Bianchini et alii, 2014).*

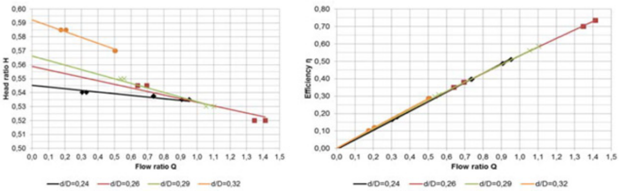


*Fig. 4 - a) H as a Q function; b) η as a Q function. The points correspond to experimental measurements, while the lines have been realized through a linear interpolation. (Bianchini et alii, 2014).*

$$Q=Q_d/Q_p \tag{1}$$

$$H=H_d/H_p \tag{2}$$

Where $Q_d$ and $Q_p$ are the delivery volumetric flow (the sum of the primary and the secondary flows as shown in Fig. 1) and the primary volumetric flow in [$m^3$/h], while $H_d$ and $H_p$ are the delivery volumetric pressure and the primary volumetric pressure in [Pa].

The ejector efficiency *η* was defined as the product between the coefficients:

$$\eta=Q\times H \tag{3}$$

Results obtained from the experimental campaign are given in Fig. 4 for different ratios between nozzle diameter d and discharge diameter *D*, the same inlet pressure and with water-water environment (no sediment). The points in Fig. 5 correspond to experimental measurements, while the lines have been realized through a linear interpolation. In particular, from the figure in the left, it is demonstrated that, being *D* a constant value, a higher d decreases the ejector suction capacity. On the contrary, a higher nozzle diameter d allows reaching higher pressure at the converging outlet, thus increasing sediment transport distance. The efficiency is reported in the right of the figure. As shown, the ratio *d/D* does not influence the ejector efficiency in accordance to existing literature.

Through the experimental research it was also found that, in the same boundary conditions, the lower is the ejector nozzle diameter, the higher is the suction efficiency, calculated as the ratio between the secondary volumetric flow $Q_S$ and the delivery volumetric flow $Q_D$.

This information results fundamental to avoid clogging risk due to the deposition of sediments along the pipe. Another important discovery is that when pressure drop increases in the discharge line suction efficiency can reduce up to 0% since

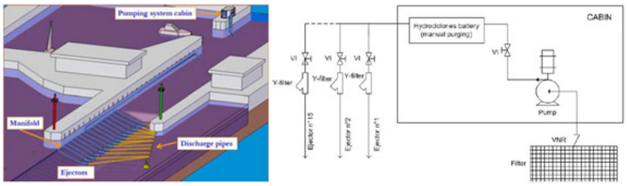


Fig. 5 - The installation in the port of Riccione. A schematic view (left) and the P&ID of the application (right).

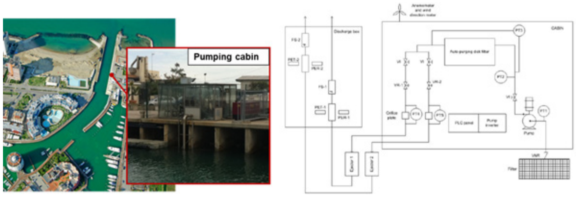


Fig. 6 - The installation in the Marina of Portoverde. A view of the marina and of the pumping cabin (left) and the P&ID (right).

the ejector is supplied at constant rate. So, when delivery flow becomes critical due to a high sediment transport, the technology decreases itself the secondary flow and convey more clean water (the primary flow), thus realizing a safe and passive self-control.

*Examples of installations*

To validate the performances measured in laboratory, several installations were realized through the years. In particular, the first full scale experimental plant was realized in the port of Riccione (Italy) in 2005. Consisting of 15 ejectors, the plant covers the 65 meters of the inlet canal as shown in Fig. 5 ensuring the maintenance of the seabed at a constant depth (over 3 m) for the entire duration of the project. A 90 kW centrifugal pump protected at the suction by a grid filter, a purging manual hydrociclones battery to avoid the clogging of the interstitial spaces in the ejectors, a manifold for feeding lines with one manual valve VI (to balance the lines) and one Y-filter were present were also present as auxiliaries. Despite the plant did not ensure continuous operation, positive results were found during the campaign both in terms of restoring of the water depth in the basins and in terms of water turbidity as described in (Bianchini *et alii*, 2014).

Following that application, the first automated plant was realized in the Portoverde Marina (Italy) in 2012. With respect to Riccione plant, the main difference consists in the fact that a fully automated and remotely accessible plant was realized. Consisting of two ejectors, the plant schematics is very similar to the previous case even if more instrumentation and control logics were implemented to improve the performances as shown in the Piping and Instrumentation Diagram (P&ID) of Fig. 6 (Bianchini *et alii*, 2014). The plant was successfully operated between the 26th April and the 19th September 2012 and between the 21st September 2013 and up to the 1th May 2014 maintaining the seabed at a depth of about 2.5 and 3.0 m during all the winter.

## THE CASE STUDY OF THE HARBOR OF CERVIA

Located in the coast of Emilia Romagna, the harbour of Cervia (Fig. 7) was firstly realized in order to convey the salt produced in the near salt flats. Designed along an artificial canal, the harbour had a very important role in the local economy interconnecting the land and the maritime markets in the past. Therefore, great attention to maintenance activities was present since the first half of the nineteenth century when docks started to be lengthened to account for coast advancement. A change of the historical use and consequently a new design of the small marina occurred during the '70s when the local Municipality decided to modernize the existing infrastructure due to the inadequacy to satisfy new users' demands. Therefore, active since 1975, the new tourist port currently extends over an area of approximately 43.000 m$^2$ with a capacity of around 300 berths.

In accordance to past interventions, a further lengthening of the docks was planned and realized in 2009 by the Municipality as a countermeasure against coast advancement. With respect to previous interventions, however, a careful analysis of the impact on the coastal areas was possible thanks to the available bathymetries near to harbor inlet. In fact, three bathymetries were realized in the following six months in order to assess the behavior of sediments.

As shown in Fig. 8a, an adequate depth was assured at harbor inlet immediately after sand removing through dredge's propellers. However, a reduction of the area characterized by an acceptable depth was found already after five months (Fig. 8b). In particular, a movement of the sediments in the South direction is recognizable in Fig. 8b following sea currents as verified by the presence a small localized area of depth deeper than 3 m in the left upper side. The direction of the sediments and the siltation phenomenon occurring at harbor inlet was more evident after seven months from the intervention as reported in the bathymetry shown in Fig. 8c.

As recognized by the Municipality experts, a complete siltation of the harbor inlet occurred in less than two months requiring traditional dredging to recover previous working conditions. Additional useful information derives from the analysis of the three bathymetries. In fact, as shown in Figs. 8a, 8b and 8c, sediments are deposited at the inlet of the harbor due to the alteration of the natural marine flow conditions, i.e. velocity, caused by the change of the existing infrastructure.

Not being technically and economically possible to modify the infrastructure realized, it was decided to periodically remove the sediments in order to ensure the full operability of the harbor during the year. For the purpose, traditional dredging and sediment handling through boat propellers/dredgers were planned and periodically operated as shown in Tab. 1 where a

*Fig. 7 - Aerial and front view of the harbor of Cervia (Italy).*

list of the interventions of the dredgers from 2009 to now are reported. From the analyzed years it results that almost 17.000 m$^3$ of sediments are yearly removed from the basin being responsible for a total expenditure of about 1 million € for dredging and about 350,000 €, i.e. a weighted average cost of 9.05 € per dredged cubic meter of sediment.

As possible alternative solution of the problem, the ejector technology was proposed and applied in the LIFE MARINAPLAN PLUS project. Coordinated by Trevi S.p.A. and involving the University of Bologna, the Municipality of Cervia and ICOMIA as partners, the project started the 3 October 2016 with a total duration of 39 months, the project aims:

- To realize a preliminary on field test (completed on July 2017);
- To design, realize (completed in June 2018) and operate a sand by-passing plant at the Cervia port channel inlet;
- To assess the techno-economic and environmental impact of the technology.

For the purpose, a total budget of 2.519.245 €, of which the 57.7% financed by the European Commission, was allocated to complete the recognized activities.

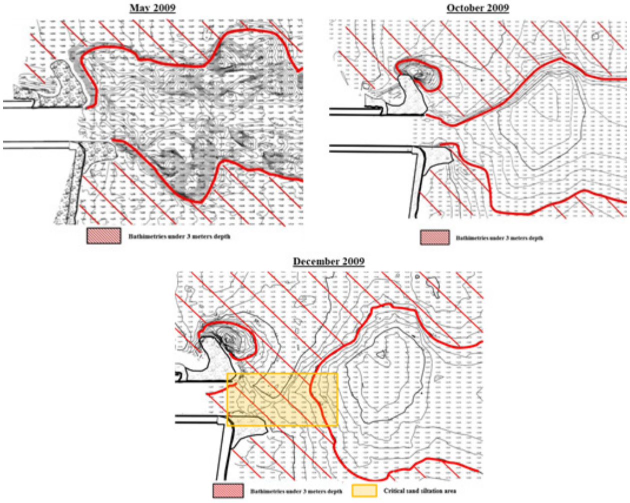


*Fig. 8 - Bathymetries surveys were performed after the lengthening of the docks: a) immediately after the intervention, b) 5 months after sand removal, c) 7 months after sand removal when a critical siltation area was identified.*

| *Year* | *Month* | *Operation* | *Quantity (m$^3$)* | *Duration (die)* | *Cost (€)* |
|---|---|---|---|---|---|
| *2009* | *Jan-Feb* | *Dredging* | *20,000* | *-* | *180,000* |
| *2009* | *May* | *Propellers* | *-* | *12* | *100,000* |
| *2010* | *Jan-Mar* | *Propellers* | *-* | *12* | *100,000* |
| *2011* | *Jan* | *Propellers* | *-* | *6* | *52,000* |
| *2011* | *Nov* | *Propellers* | *-* | *6* | *52,000* |
| *2012* | *Apr* | *Propellers* | *-* | *3* | *23,400* |
| *2013* | *May-Jun* | *Dredging* | *16,950* | *-* | *150,000* |
| *2014* | *Feb-Apr* | *Propellers* | *-* | *4* | *20,000* |
| *2014* | *Feb-Apr* | *Dredging* | *51,200* | *-* | *500,000* |
| *2015* | *Jan-Feb* | *Dredging* | *10,000* | *-* | *-* |
| *2015* | *Apr-May* | *Dredging* | *23,400* | *-* | *180,000* |

*Tab. 1 - Dredging and/or sediment handling through boat propellers or dredgers in Cervia harbor from 2009 to 2015*

### *The obtained on-field tests' results*

Before to proceed in the plant design, design data concerning the performances of the ejector in the specific locations were required. For the purpose, on-field tests were planned and performed in between June and July 2017 (Fig. 9). In particular, electrical power consumption and sand flowrate were investigated. For the purpose, a central nozzle diameter ejector with 18 radial nozzles connected to a discharge line length of 60 m was used. In this condition, a primary volumetric flowrate $Q_p$ equal to 27 m$^3$/h was measured. Considering also the supply to the tangential nozzles to improve the mixture in the secondary flow, a total supply flowrate of 43.5 m$^3$/h was measured while 34 m$^3$/h containing water and sediments were found in the discharge flowrate.

From the obtained data, it was calculated that the ejector aspires 7 m$^3$/h (= 34 - 27) of water and sand mixture. Assuming the mean value for the sand to mixture ratio equal to 0.10 kg of sand for each kg of mixture and a sand bulk density of 2.000 kg/m$^3$, it was also possible to calculate the achievable sand flowrate, i.e. the potential of the technology in comparison to traditional dredgers, equal to 2 m$^3$/h. This signifies that almost 96 tons of sand (= 2 x 2000 x 24 x 10$^{-3}$) can be daily removed thanks to the continuous operation of the technology. In a year more than 35.000 ton of sand, i.e. 17520 m$^3$ of sand, can be nominally bypassed, without environmental impact and no impact with respect to navigation.

Concerning costs, however, electrical energy was required to power supply the submersible pumps. For the purpose a nominal power supply of 3 kW was required to achieve the reported performances. In terms of energy this signifies 1.5 kWh for each m$^3$ of sand removed from the seabed. Assuming an average price for electricity price of 0.18 €/kWh typical for industrial

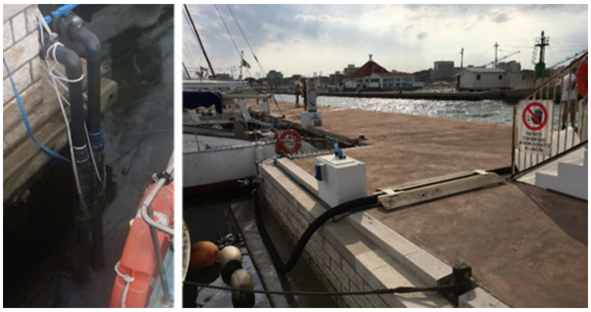


Fig. 9 - *Two pictures taken during the on-field tests. The two submersible pumps (left) and the passage of temporary supply piping.*

Fig. 11 - *Plant P&ID (left) and some pictures taken during the installation (right).*

application in Italy, a specific electricity cost equal to 0.27 € for each m$^3$ of sand results.

### *The design and realization of the ejector plant installed in Cervia*

Justified by the need to bypass the sediments in the discharge direction, the natural movement from North to South, currently impeded by the port infrastructure, can be restored by the ejector technology (Fig. 10). Consisting of two identical modules with five ejectors each one (Fig. 11), the demo plant concept is the same explained for Riccione e Portoverde cases. In particular, pressurized water is fed to each module by a dedicated submersible water pumps that are remotely controlled by inverter in order to minimize the electrical consumption. In addition, to increase motor cooling, flow sleeves fitted to the submersible motor are also implemented ensuring an improved heat removal thanks to the passage of the liquid close to the high temperature components.

High density polyethylene pipes with a nominal diameter of 250 mm and length of 6 meter are used to connect the pumps to other components. Two autopurging disk filters are installed downstream the pumps, ensuring a filtration grade over 400 microns in a protected cabin with the other mechanical and electrical auxiliaries. Finally, water supply to each ejector is conveyed through transparent plastic pipes with a nominal diameter of 80 mm and length of 30 meter connected together by wet-mate connectors.

Fig. 10 - *Aerial view of the harbor of Cervia. The project aims to evaluate the performances of the ejectors to restore the natural movement of sediments from North to South direction.*

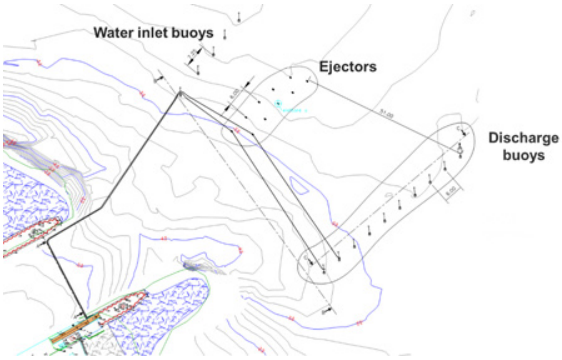


Fig. 12 - *LIFE MARINAPLAN PLUS project: ejectors positioning.*

For monitoring and control purposes, several process data, i.e. pumps outlet pressure, pressure loss on the filters, water flowrate for each ejector, and environmental data, i.e. wind velocity and direction, are continuously monitored and recorded in the dedicated PLC that is accessible from remote locations for real time operations or successive assessment. Furthermore, two cameras are also installed for the video monitoring of the harbor channel inlet and of the filtering cabin as an additional input for plant control.

The ten ejectors are positioned immediately in front of the port entrance (Fig. 12) ensuring the bypass sediments phenomenon.

Buoys, that are fixed to mooring posts, are used as a visual reference to simplify maintenance operation on inlet and discharge pipelines. The buoys are placed out of the entrance channel, and so they cannot affect navigation safety. On the other hand, any contact between a buoy and a boat would certainly damage the buoy, rather than the boat, without any particular impact on the operation of the plant.

### *The integrated numerical modelling*

The research project STIMARE (Innovative strategies, monitoring and analysis of the coastal erosion risk), financed by the Italian Ministry of the Environment and the Sea (MATTM) aims to define strategies for coastal management, based on a strong involvement of the stakeholders, and on the use of innovative or low-costs technologies for coastal monitoring and preservation (Archetti *et alii*, 2019). One of the pilot sites involved in the project is Cervia: the main activity related to that site is the evaluation of the potential application of ejectors in combination with anti-erosion infrastructure. To assess the technology potential, a model needs to be developed to locally study the seabed sediment transport in relation to weather conditions.

So, contemporary with experimental and monitoring activities carried out on the demo plant in Cervia, preliminary coupled wave - hydrodynamics simulations were elaborated aiming i) to help in the prediction of the areas at risk of sediment accumulation or erosion and ii) to optimize the control of the ejectors in relation to the sea conditions. Particularly, the scenarios' based approach by means of multiple-nesting modelling system (Samaras *et alii*, 2016; Gaeta *et alii*, 2016) aims to establish an efficient and computationally reasonable method for the operational use. For the purpose, the following methodology was developed and implemented to the specific case study:

1. Set-up of the numerical model. Detailed bathymetry of the Cervia port and navigation channel on April, 2019 were used. The unstructured mesh was implemented with two different densities for the resolution, from 5 m (close to the port) up to 200 m (offshore) as reported in Fig. 13. MIKE21 by DHI was used to implement the approach and investigate its operational use for the management of the ejectors system.
2. Scenarios definition on the basis of the meteocean climate of the study site. Collected data from buoy and gauges between 2007 and 2019 were used to define the dataset for scenarios' runs considering 5 aggregated parameters, divided in number of classes, consisting on wave height, period and direction, sea level and outlet discharge (see Tab. 2). A total of 105 resulted.

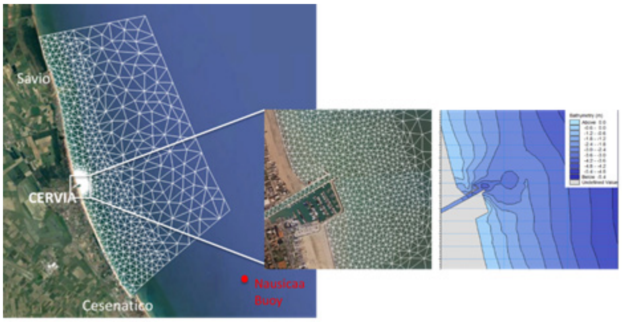


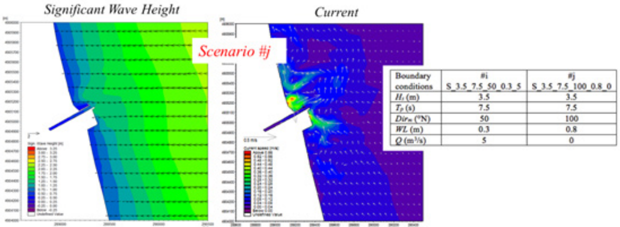
Fig. 13 - The unstructured mesh with two different densities for the resolution, from 5 m (close to the port) up to 200 m (offshore).

| *Parameter* | *Minimum* | *Maximum* | *Class step* |
|---|---|---|---|
| *Wave height - $H_s$ (m)* | *0* | *4* | *0.25* |
| *Wave period - $T_p$ (s)* | *1.5* | *8* | *0.5* |
| *Wave direction - $Dir_m$ (°N)* | *0* | *120* | *10* |
| *Sea Level - WL (m)* | *-1.0* | *1.4* | *0.2* |
| *Oultet discharge - Q (m³/s)* | *0* | *100* | *Variable* |

*Tab. 2 - Class properties applied to the data sets for scenarios' definition.*

3. Running of simulations for each scenario. The defined scenarios were used (in sequence) as boundary conditions for the model runs, resulting in an extensive data set of wave and hydro-morphodynamics features on the entire computational domain. The wave-hydrodynamics patterns of the site were numerically obtained: spectral and hydrodynamics modules were coupled to simulate all the possible scenarios as in Fig. 14.
4. Storage of the numerical results for the entire computational domain. Data are properly stored in NetCDF files.
5. Extraction of local data. Operatively, once obtained the forecast weather offshore Cervia from National or Regional Forecating system, a query algorithm implemented in Matlab will provide sea conditions at the port entrance, which can help to optimize the control of the ejectors.

In Fig. 15 a schematic representation of the model sequence is shown where at the port entrance (in $^*$), beside the estimation of the wave characteristics by the wave propagation model, also the outputs of the hydrodynamic and morphodynamics code are given: i.e., the current speed and direction ($U$ and $dir$) and the sediment transport discharge $Q_{ls}$.



| Boundary conditions | #i<br>S_3.5_7.5_50_0.3_5 | #j<br>S_3.5_7.5_100_0.8_0 |
|---|---|---|
| $H_s$ (m) | 3.5 | 3.5 |
| $T_p$ (s) | 7.5 | 7.5 |
| $Dir_m$ (°N) | 50 | 100 |
| $WL$ (m) | 0.3 | 0.8 |
| $Q$ (m³/s) | 5 | 0 |

*Fig. 14 - Results obtained for a generic scenario #j.*

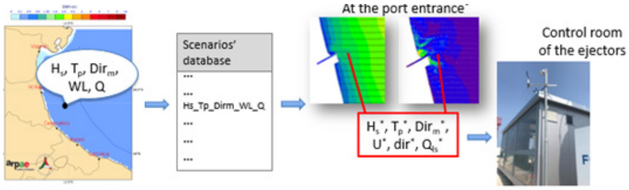


*Fig. 15 - Modelling chain for Cervia harbor.*

Once the model will be validated thanks to the ongoing monitoring activities, it will be possible to use short term sea weather forecast to optimize the control strategy of the plant. In particular, the water flow rate feeding each ejector would be optimized as a function of the expected sediment load produced by natural sediment transport. The local weather station will be used as a real-time correction element of the weather forecast. The optimization of the control strategy is fundamental to further reduce the power consumption of the plant without compromising its effectiveness, thus increasing the sustainability of the technology.

## CONCLUSION AND FUTURE OUTLOOK

The use of ejector technology for contrasting both sediment siltation and coastal erosion is under evaluation in the pilot site of Cervia. The demo plant started its operation in June 2019 and will run at least up to December 2020. Therefore, the monitoring and modeling activities are still on going in the framework of LIFE MARINAPLAN PLUS and STIMARE projects and are fundamental for the technology validation and optimization. Despite the positive results obtained during preliminary tests in terms of sediment handling capacity and power consumption, long-term monitoring is required to verify the economic sustainability of the ejectors technology with particular attention to ordinary and extraordinary maintenance activities. Also the environmental impact on the local marine flora and fauna due to the 24/7 operation will be carefully evaluated. However, the best performances of the plant should be reached by optimizing the control procedures. For the purpose, a combination of in field measurements and weather forecasting is considered essential to control operation ranges, energy consumption and the presence of trends/anomalies. The final aim is to optimize the operative costs by ensuring a defined depth at the entrance of the basin.

The modelling of sediments transportation as a function of the expected meteorological phenomena is a key element for both siltation and erosion issues analysis. The scenarios' based approach by means of coupled wave-hydrodynamics model is of the essence in the framework of an operational system – response speed. The combination of the specific interpolation method with an adequately high number of defined scenarios is deemed to deliver the best performance overall due to its simplicity. The approach could represent a valid tool in the management of the ejector system giving a possible contribution in the coastal mitigation due to their sediment movimentation at the port entrance.

Thanks to the combination of monitoring actions and implemented modelling, it will be also possible to evaluate the coastal erosion mitigation potential of the demo plant installed in Cervia.

## ACKNOWLEDGEMENTS

The research activity was funded by the Executive Agency for Small and Medium-sized Enterprises (EASME) of the European Union through the LIFE Programme funds, "Marinaplan plus" Project Life 15 ENV/IT/000391 and by the Italian Ministry of Environment through the funded project "STIMARE" (Strategie Innovative per il Monitoraggio ed Analisi del Rischio Erosione, www.progettostimare.it).

## REFERENCES

Archetti R., Damiani L., Bianchini A., Saccani C., Pellegrini M., Airoldi L., Abbiati M., Romagnoli C., Saponieri A., Bruno M. F., Tarantino E., Pratola L., Doglioni A., Barbanente A., Simeone V. & Gaeta M. G. (2019) - *Innovative strategies, monitoring and analysis of the coastal erosion risk: the STIMARE Project.* 29th International Ocean and Polar Engineering Conference (ISOPE). Honolulu, United States of America.

Archetti R., Paci A., Carniel S. & Bonaldo D. (2016) - *Optimal index related to the shoreline dynamics during a storm: The case of Jesolo beach.* Natural Hazards and Earth System Sciences, **16**: 1107 - 122.

Bianchini A., Pellegrini M. & Saccani C. (2014) - *Zero environmental impact plant for seabed maintenance.* 4th International Symposium on Sediment Management (I2SM). Ferrara, Italy.

Bianchini A., Cento F., Guzzini A., Pellegrini M. & Saccani C. (2019) - *Sediment management in coastal infrastructures: Techno-economic and environmental impact assessment of alternative technologies to dredging.* Journal of Environmental Management, **248**: 1 - 17.

Bonaldo D., Antonioli F., Archetti R., Bezzi A., Correggiari A., Davolio S., De Falco G., Fantoni M., Fontolan G., Furlani S., Gaeta M. G., Leoni G., Lo Presti V., Mastronuzzi G., Pillon S., Ricchia A., Stocchi P., Samaras A. G., Scicchitano G. & Carniel S. (2019) - *Integrating multidisciplinary instruments for assessing coastal vulnerability to erosion and sea level rise: lessons and challenges from the Adriatic Sea*, *Italy* - Journal Of Coastal Conservation, **23**: 1 - 19.

De Jonge V. N. & Neal W. (2018) - *How to make Integrated Coastal Erosion Management a reality.* Ocean & Coastal Management, **156**: 290 - 299.

European Commission (1999) - *Directive 1999/31/EC*.

European Commission (2000) - *Directive 2000/60/EC*.

Eurosion Project (2004) - *Living with coastal erosion in Europe: Sediment and Space for Sustainability*.

Gaeta M. G., Samaras A., Federico I., Archetti R., Maicu, F. & Lorenzetti G. (2016) - *A coupled wave-3-D hydrodynamics model of the Taranto Sea (Italy): A multiple-nesting approach* - Natural Hazards and Earth System Sciences, **16**: 2071 - 2083.

Gracia A., Rangel-Buitrago N., Oakley J. A. & Williams A. T. (2018) - *Use of ecosystems in coastal erosion management*. Ocean & Coastal Management, **156**: 277 - 289.

Ispra (2008) - *Coastal areas* - Annuario 2008, 257 - 292.

Lamberti A., Archetti R., Kramer M., Paphitis D., Mosso C. & Di Risio M. (2005) - *European experience of low crested structures for coastal management* - Coastal Engineering, **52**: 841 - 866.

Prasad D.H. & Kumar N.D. (2014) - *Coastal Erosion Studies - A Review* - International Journal of Geosciences, **5**: 341 - 345.

Samaras A., Gaeta M. G., Moreno Miquel A. & Archetti R. (2016) - *High-resolution wave and hydrodynamics modelling in coastal areas: Operational applications for coastal planning, decision support and assessment* - Natural Hazards and Earth System Sciences, **16**: 1499 - 1518.

Vlasblom W. (2003) - *Dredging equipment and technology. University lecture notes* - Delft University of Technology.

Williams A. T. (2018) - *The management of coastal erosion* - Ocean & Coastal Management, **156**: 4 - 20.

Winterwerp J. C. & Van Kesteren W. G. M. (2004, E D S.) - *Introduction to the Physics of Cohesive Sediment in the Marine Environment* - Developments in Sedimentology, **56**: 1 - 466.

Zhang K. Leatherman S. P. & Douglas B .C. (2014) - *Global Warming and Coastal Erosion* - Climatic Change, **64**: 41 - 58.

*Received September 2019 - Accepted January 2020*