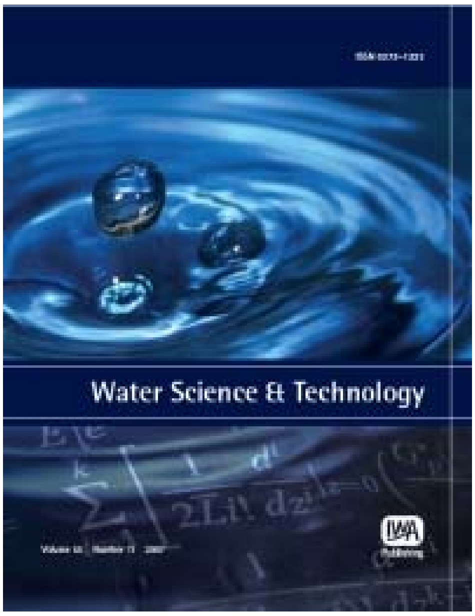

Beneficial effects on water management of simple hydraulic structures in wetland systems: the Vallevecchia case study, Italy

G. M. Carrer, M. Bonato, D. Smania, A. Barausse, C. Comis and L. Palmeri

ABSTRACT

Conflicting water uses in coastal zones demand integrated approaches to achieve sustainable water resources management, protecting water quality while allowing those human activities which rely upon aquatic ecosystem services to thrive. This case study shows that the creation and simple management of hydraulic structures within constructed wetlands can markedly reduce the non-point pollution from agriculture and, simultaneously, benefit agricultural activities, particularly during hot and dry periods. The Vallevecchia wetland system is based on a reclaimed 900 ha-large drainage basin in Northern Italy, where droughts recently impacted agriculture causing water scarcity and saltwater intrusion. Rainwater and drained water are recirculated inside the system to limit saltwater intrusion, provide irrigation water during dry periods and reduce the agricultural nutrient loads discharged into the bordering, eutrophic Adriatic Sea. Monitoring (2003–2009) of water quality and flows highlights that the construction (ended in 2005) of a gated spillway to control the outflow, and of a 200,000 m^3 basin for water storage, dramatically increased the removal of nutrients within the system. Strikingly, this improvement was achieved with a minimal management effort, e.g. each year the storage basin was filled once: a simple management of the hydraulic structures would greatly enhance the system efficiency, and store more water to irrigate and limit saltwater intrusion.

Key words | climate change, drought, multipurpose constructed wetland, non-point pollution, saltwater intrusion, treatment wetland

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INTRODUCTION

A sustainable management of water resources, as envisaged for example in the EU Water Framework Directive (EU 2000) can be a challenging task to achieve in coastal zones. A large fraction of the world population lives there (Cohen *et al.* 1997), so that many human activities and conflicting water uses are often present, resulting in multiple pressures and strong impacts on coastal aquatic ecosystems (Novotny 2003; Vermaat *et al.* 2005; Lotze *et al.* 2006; Airoldi & Beck 2007). To meet this challenge, integrated approaches to water resource management are needed (EEA 2010): the protection of the quality and ecological status of waters must be ensured, while allowing socio-economic activities, relying upon the management of water use or aquatic ecosystem services, to thrive. Optimal solutions should improve water quality and ecological status and, at the same time, prove useful for managing water use (EEA 2010). This study shows that the construction of simple hydraulic structures and the subsequent implementation of simple hydraulic management measures within constructed wetlands (Kadlec & Knight 1996) are one of those optimal solutions, especially in coastlands, characterized by hot and dry periods, where agricultural activities could cause non-point pollution (Novotny 2003).

Here the case study of a multipurpose reconstructed wetland system located in Northern Italy, named Vallevecchia, is reported. This region has recently been impacted by several droughts which have negatively affected the agricultural activities on the Padana plain, and caused scarcity of irrigation water and both extended (up to tens of kilometres) and prolonged saltwater intrusion. High nutrient loads are originated within the densely inhabited catchment basins of the plain, where about a half of the agricultural and livestock production of Italy takes place. Over the past

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decades, nutrients discharged by rivers and channels into the Adriatic Sea have led to eutrophication which caused, mainly in the 1980s, anoxic episodes and fish kills (Justic *et al.* 1987, Degobbis *et al.* 2000; Artioli *et al.* 2008). For this reason, the control of non-point pollution originated from agriculture is particularly important in the plain.

In this study a long-term monitoring dataset of water flows, nutrient concentrations and environmental data collected in Vallevecchia is analysed, to evaluate how well the system removes nutrient loads under two different hydraulic configurations. The configuration leading to a higher removal of pollutants is identified as the one also providing agricultural activities with more water for irrigation and to protect themselves from saltwater. This conclusion is particularly important from the perspective of climate change, which is expected to worsen the issue of water scarcity due to droughts, already affecting several areas of the world, including Europe, and to change the way that water resources are managed (Kashyap 2004; EEA 2010).

MATERIALS AND METHODS

The wetland system

The wetland system of Vallevecchia is based on a drainage basin located on reclaimed land along the coast of the North-Western Adriatic Sea, in the municipality of Caorle (near Venice, Italy). Before the land reclamation, which started during the 1960's and finished at the beginning of the 1970s, the area used to be a lagoon surrounded by the Adriatic sea (as shown by the aerial photo on Figure 1, courtesy of Veneto Agricoltura) and without freshwater sources besides two little pits.

Figure 1 | Vallevecchia before the land reclamation.

Now, Vallevecchia has become a multipurpose, experimental system with the pioneering goal of allowing agricultural practices close to the sea. There are several small and large wetlands in the area, which can be defined as a 'wetland system' well integrated with the many human activities found there. For example, agricultural activities take place within an integrated water resources management framework, and the nutrient loads, caused by the non-point pollution from agriculture which affects the bordering eutrophic Adriatic Sea (Artioli *et al.* 2008), are removed within the wetland system through self-purification processes. Other activities within this area included shrimp aquaculture, livestock farming and tourism (e.g. along the sand littoral). Vallevecchia hosts several natural habitats including a rare sand dune system, and is a Natura 2000 site. The system has a surface of 900 ha (Figure 2), with nearly 600 ha (the study area) devoted to agriculture. There are two main wetlands, Falconera and Canadare, completely separated from the main hydraulic network and therefore not included in this study. A long beach (the white stripe on the bottom of Figure 1) and a small wooded buffer zone border the sea.

Two freshwater sources are present in Vallevecchia, but they are negligible with respect to the overall water mass balance. In general, the groundwater table is saline and about 1 m deep, but sometimes it can even reach the ground surface (LASA 2010), where salt crusts can occasionally be noticed. Conductivity measurements show that saltwater intrusion is highest along the Vallo channel, particularly where the sand littoral, south of the pine forest, is thinner (about in the middle, Figure 2), and also along the Baseleghe channel (LASA 2010). These findings are confirmed by aerial photos (not shown) which highlight burnt vegetation due to excessive salinity along these channels, causing damage to agriculture.

In the present configuration of the system, several hydraulic structures allow the recirculation of rainwater and drained water within Vallevecchia. The hydraulic network of the agricultural area is made up of a main channel (Sbregavalle) and five secondary channels running through the fields (NNW direction), each about 1 km long and spaced 0.5 km apart. There are two hydraulic pathways in the system (Figure 2). The main one runs across the Sbregavalle channel: water flows from the secondary channels, which run across the fields and collect their surface runoff (e.g. due to rain), into the Sbregavalle channel, then to a gated spillway, and finally to a pumping station which pumps water out from the system. Regulating gates are found at the beginning and at the end of the secondary

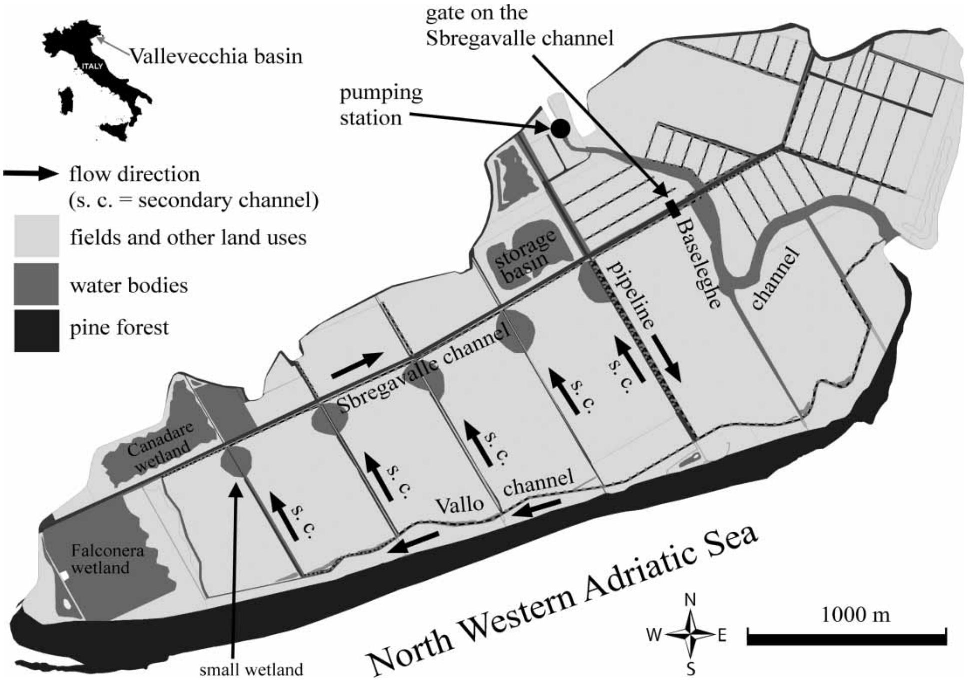

Figure 2 | Outline of the hydraulic functioning of the system, from 2006 onwards, and land use.

channels, and when they are closed the water level inside these channels increases and consequently water is distributed in the fields. In this manner the groundwater table in the area is raised up uniformly, thus benefiting agricultural activities and possibly reducing saltwater intrusion.

In the second pathway, water from the Sbregavalle channel is pumped into a storage basin, from which a gravity flow goes through a pipeline to the Vallo channel and then back inside the system. Before flowing into the Sbregavalle channel, every secondary channel enters a small (about 2.5 ha) surface-flow wetland for water treatment (Kadlec & Knight 1996) containing common reed (*Phragmites australis*). Also, there are reed beds on the sides of all channels, therefore they can be thought of as 'plug-flow wetlands'.

In this study, two system configurations are compared, before and after the construction (ended in 2005) of two hydraulic structures, a gated spillway (henceforth referred to as the 'gate') and a storage basin. The former was built near the end of the Sbregavalle channel to reduce the outflow speed and to increase water retention inside the system. Its gate can be lifted one metre above the channel level and, also, a small adjustable orifice on the bottom allows slightly salty water to flow outside. The storage basin (11 ha) was built with the main goal of reducing the discharged water volume, and was filled once per year after its construction. The usable volume for irrigation purposes is around 150,000 m^3, out of a total capacity of 200,000 m^3. The hydraulic configuration of the system before 2006 did not differ substantially from the present one except for the construction of the gate, the storage basin and the pipeline.

The monitoring dataset

The Environmental Systems Analysis Lab (LASA) has started monitoring the water quality of Vallevecchia in 2003, through sampling and laboratory chemical analysis. Water quality monitoring inside the area has been performed in three locations, i.e. the pumping station, the gate and the storage basin, but only data from the pumping station are reported because water flows (needed to calculate pollutant loads) have only been measured there. Water has been sampled twice per week, and analysed in a chemical laboratory to find pollutant concentrations following standard methodologies (APAT/IRSA-CNR 2003; APHA/AWWA/WEF 2005). Concentrations have been determined for ammonia nitrogen ($N\text{-}NH_4$), oxidized nitrogen ($N\text{-}NO_X$), dissolved organic nitrogen (DON), particulate nitrogen (PN), total nitrogen (TN), orthophosphate phosphorus ($P\text{-}PO_4$), soluble unreactive phosphorus (SUP), particulate phosphorus (PP), total phosphorus (TP) and total suspended solids (TSS). The outflow volume from the pumping station has been recorded daily. The analysed dataset covers the period 2003–2009.

RESULTS AND DISCUSSION

Nutrient removal

Table 1 summarizes both the annual pollutant loads and the annual water outflow volume discharged by the pumping station, before and after the hydraulic structures were constructed, calculated following Bendoricchio *et al.* (1995). In particular, nutrient concentrations determined from water samples have been integrated with daily water outflow to obtain loads. Table 1 also reports the annual water input to the system due to precipitation, which was calculated by multiplying the rain millimetres by the study-area surface (592 ha). Figure 3 shows the inter-annual variations of water flows, and pollutant loads discharged from the pumping station during 2003–2009. Figure 3(a) reports the outflow discharged from the pumping station and the rain inputs to the system. Figures 3(b) and (c) report, respectively, the discharged loads of total nitrogen (including the fraction due to oxidized nitrogen) and total phosphorus (including the fraction due to orthophosphate phosphorus). Figure 3(d) reports the discharged loads of total suspended solids. Both flows and loads display some variability.

Table 1 | Annual water flows and discharged loads of nutrients from the pumping station

	Before the hydraulic structures were built			**After the hydraulic structures were built**			
Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Water outflow (10^6 m^3)	1.5	4.1	3.4	1.2	1.0	3.2	3.1
Rain input (10^6 m^3)	4.1	6.6	5.7	3.8	4.6	8.6	6.7
N-NH_4 (t)	1.1	2.5	0.7	0.3	0.4	1.5	0.4
N-NO_X (t)	3.3	16.2	5.5	1.0	1.6	4.6	2.4
DON (t)	2.0	6.9	4.3	2.9	1.4	2.9	4.0
PN (t)	1.5	2.6	0.7	0.6	0.4	1.2	1.5
TN (t)	8.0	27.9	11.1	4.8	3.7	10.2	8.3
P-PO_4 (kg)	323	537	80	72	34	210	217
SUP (kg)	87	145	85	46	72	307	228
PP (kg)	113	253	119	115	90	304	287
TP (kg)	523	935	284	233	195	822	732
TSS (t)	28	110	92	52	34	159	89

To evaluate how the gate and the storage basin influence the system functioning, the periods before (2003–2005) and after (2006–2009) their construction are analysed separately. Table 2 reports the annual average discharged loads of several pollutants, and the average volume of rain input and of water outflow. Indeed, to investigate if the new hydraulic structures affect the nutrient loads leaving the system, loads must be analysed together with flows. The reason is that inter-annual changes of the nutrient loads could be only or partly due to water flow variations, and not to concentration changes due to self-purification processes within the wetland system, i.e. to 'real' pollution removal (Kadlec & Knight 1996). For example, the decrease of the discharged load of a pollutant could simply result from a decreased outflow from the system, even if the pollutant concentration in the outflow remains constant.

Interestingly, Table 2 shows a strong reduction of the oxidised nitrogen after 2005, much higher than the reduction of the water outflow. This improved system performance was probably caused by the construction of the gate, which reduced the outflow speed (in spite of the 11% rainfall increase) and thus permitted a greater and longer storage of water within the channels and wetlands. Then, the consequent increase of the system hydraulic retention time should have led to remarkably more efficient self-purification wetland processes (e.g. Kadlec & Knight 1996; Novotny 2003). Similar considerations apply to the marked reduction, higher than the reduction of outflow, for total nitrogen and reactive phosphorus.

Indeed, also filling the basin has led, similarly to the gate, to an increased residence time within the wetland system (because of a greater storage) and thus to a higher removal rate for, at least, some pollutants. Therefore, the storage basin also appears to have enhanced the wetland efficiency, even if much less with respect to the gate, because the basin was filled only once per year and relatively low flows (and loads) were involved.

It seems unlikely that the water input due to precipitation could be related to the differences between the two analysed periods, and not only because it increased just slightly. Even if the increase of the rain volume (600,000 m^3) is comparable to the change of the water outflow and to the volume of the storage basin, the water volume stored in the whole area is certainly much bigger, and moreover a large fraction of the rain seems to infiltrate the soil (as suggested by the difference between outflow and rain input in Figure 3(a)), so that dilution effects seem doubtful.

Instead, total phosphorus seems to have responded differently from the other nutrients to the construction of the

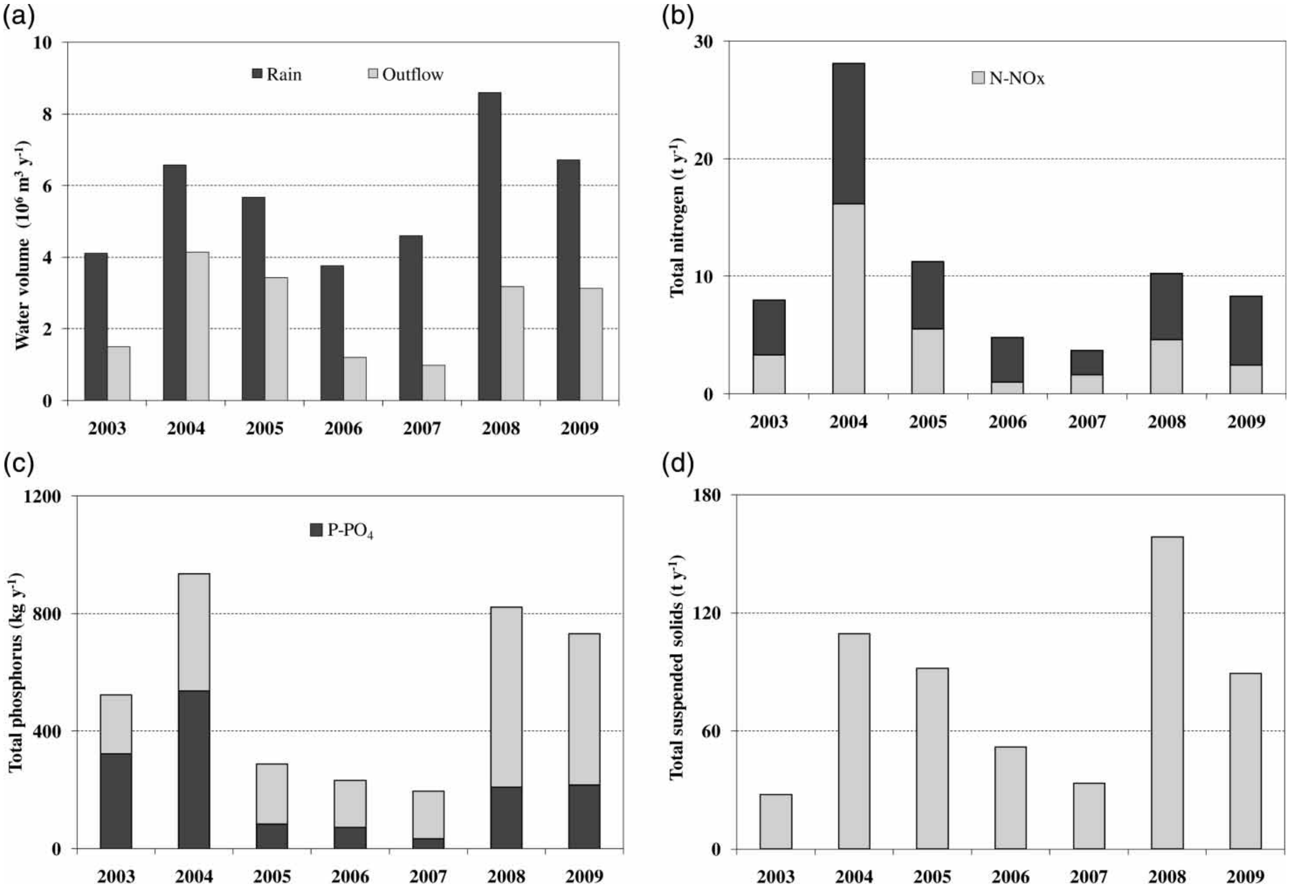

Figure 3 | Annual water flows and pollutant loads discharged by the pumping station during 2003–2009. (a) Water flows; (b) total nitrogen load, and the contribution due to oxidized nitrogen; (c) total phosphorus load, and the contribution due to orthophosphate phosphorus; (d) total suspended solid load.

hydraulic structures (Table 2). Its weak reduction, as compared to the great reduction of reactive phosphorus loads (which represent a fraction of total phosphorus) appears however to be linked again to the increased water retention time: the presence of the gate has also fostered the primary (i.e. algal) production, so that oxidized phosphorus has been uptaken by phytoplankton, but total phosphorus also (including phosphorus within plankton cells) has not changed much. This hypothesis is confirmed by the total suspended solid, which could possibly reflect the water concentration of micro-algae: the average discharged load of TSS has even increased, slightly, after the gate construction.

Table 2 | Annual averages of the water flows and nutrient loads discharged before (2003–2005) and after (2006–2009) the construction of the hydraulic structures

Year	N-NO$_X$ t	TN t	P-PO$_4$ kg	TP kg	TSS t	Water outflow 10^6 m^3	Rain input 10^6 m^3
2003–2005	8.3	15.6	313	581	76	3.0	5.3
2006–2009	2.4	7.0	133	496	83	2.1	5.9
Change (%) between periods	−71	−55	−57	−15	+9	−30	+11

Could the conclusions about the effects of the gate on nutrient removal be biased by the infiltration and evapotranspiration taking place within the system? The few evapotranspiration estimates available suggest that this process is negligible compared to the system water balance at the year timescale. For example in the storage basin, where the most intense evapotranspiration should take place, the sum of evapotranspiration and infiltration is about 3 mm day^{-1} (measurements of water level drop, July–September 2009, unpublished data; this estimate cannot be extrapolated to the whole system, being referred to the free water surface during the warmest season). Also, evapotranspiration should not bias the estimated nutrient removal within the system because loads are considered, so that their amount within the system is not affected by evapotranspiration.

No infiltration measurements are available, but the combined loss from the system due to both infiltration and evapotranspiration can be estimated as the difference between rain and outflow in Figure 3(a). Since evapotranspiration should be negligible, infiltration represents most of such water loss. Table 2 suggests that the increased retention time in the system due to the gate construction has led also to higher infiltration (e.g. in channels and fields), since rain inputs have increased after 2005 but outflow has decreased. In addition, infiltration has indeed taken place also in the filled storage basin and has been increased by water recirculation to the Vallo channel and the agricultural fields. But, even if higher infiltration means higher nutrient loads lost into groundwater, this does not affect the conclusion that the self-purification within the system has become more efficient after the gate construction: if reduction in nutrient loads was only due to infiltration, then the reduction percentage (Table 2) would be similar to that of the water outflow. Finally, increased infiltration into groundwater could be useful to counter saltwater intrusion, as discussed in the section ‘Potential performances of the system’.

Potential performances of the system

The increased efficiency of the system after 2005 has been achieved, strikingly, with a very low management effort for the new hydraulic structures, e.g. the storage basin has been exploited only minimally, since it was only filled once per year. Consequently the potential efficiency of the system should be much higher, and such a hypothesis has been tested through a simple calculation. The whole year has been divided in two periods, as shown in Table 3: the ‘storage’ period (November–April), and the ‘irrigation’ period, when agricultural activities need water (May–October). When looking to the 2003–2009 averages, these periods are characterized by the same rain input but completely different discharged water volumes. Most of the outflow, and consequently most of the discharged pollutant loads, are concentrated during the storage period (Table 3).

In this simple calculation, every rain event characterized by a precipitation equal to or >10 mm during the storage period has been considered. The resultant water outflow from the gate (such outflow is only a fraction of the volume of those rain events, calculated by comparing past precipitation events and the corresponding flows at the gate) has been calculated assuming that ideally all of this outflow could be stored in the storage basin. Results indicate that the storage basin could be filled, potentially, five times every storage semester. If for the sake of clarity the semester is divided in three bimesters, 1.3 filling cycles could take place during November–December, 1.7 during January–February, and 2.2 during March–April.

Indeed a completely, automatic system of water uptake should be implemented to be able to store this theoretical water volume. However, since the system is not automated and in order to be conservative, since infiltration was not considered, it can be realistically assumed that the basin can be filled three times every semester with an optimal routine management. The water volume corresponding to one filled basin could be stored and then used during the following irrigation period, while the volume corresponding to the other two full basins, equal to 300,000 m^3, would be available during the storage period for water recirculation and infiltration inside the area, thus countering saltwater intrusion from the bordering sea. Indeed systematic measurements are needed to test the effectiveness of the latter idea, which however seems to be realistic given the characteristics of the aquifers in the area and the damage that salt can cause to the vegetation in Vallevecchia. Therefore, agricultural activities in Vallevecchia could benefit from storing freshwater in multiple ways.

To make these calculations more accurate, evapotranspiration and infiltration should be considered. However, the conclusions seem robust with respect to the former process, which is probably unimportant, even in the storage basin (see ‘Nutrient removal’ section). Instead, further research is needed to explore the influence of infiltration on the basin management. Future experimental activities will also include the definition of a guideline set for hydraulic management (e.g. of the gate position, basin filling, water recirculation) with two goals. First, the complete automation of the storage basin filling procedure, finalized to improve water quality, and second, using the freshwater from the basin to counter saltwater intrusion.

Table 3 | Averages (2003–2009) of water flows and discharged nutrient loads during the storage (November–April) and irrigation (May–October) periods

	Rain input		**Water outflow**		**TN**		**TP**		**TSS**	
Period	**10^6 m^3**	**%**	**10^6 m^3**	**%**	**t**	**%**	**t**	**%**	**t**	**%**
November–April	1.7	51.5	1.9	76	9.3	86.1	0.4	72.4	60.7	70.2
May–October	1.6	48.5	0.6	24	1.5	13.9	0.2	27.6	25.8	29.8

Finally, it should be noticed that the gate effects are not limited to a higher removal of nutrients. An increased retention time also means that both recirculated and rain water volumes are kept within the channels for a longer time, leading to higher infiltration (Figure 3(a)) and freshwater distribution in the fields, and making it easier to fill the storage basin, since a higher water volume is available in the system. Therefore not only do both of the new hydraulic structures have enhanced self-purification processes but, at the same time, both have fostered agriculture by increasing the within-system storage of water, usable to counter saltwater intrusion or to irrigate, during dry and hot periods. Thus, similarly to the case of sewage treatment in arid areas characterized by salt build-up issues (Shuval 1967), an integrated approach to the management of water seems to be an optimal solution to control non-point pollution in the presence of seasonal droughts and saltwater intrusion negatively affecting agriculture.

CONCLUSIONS

The analysis of seven years of timeseries of water quality and flows has highlighted important differences between the performance of the wetland system before and after the construction of two hydraulic structures, i.e. a gate and a storage basin. These simple hydraulic structures have led to markedly higher reduction of pollutant loads, for example by increasing the system residence time: N-NO_X loads decreased by 71%, TN by 55%, P-PO_4 by 57%, while water outflow decreased only by 30%. Strikingly, these results have been achieved with only a minimal management effort, and probably the wetland efficiency could easily be increased even more by implementing simple hydraulic management measures. These management measures would also provide more water to protect agricultural activities from droughts and saltwater intrusion, so that they appear to be an optimal solution from both the environmental and economic points of view.

These kinds of integrated wetland systems and management measures could be exported to similar geographical areas that suffer salt water infiltration, or in places where big rain events concentrated in short periods take place, such as tropical regions. Global climate change is expected to exacerbate the issue of water scarcity, so that the multipurpose approach exemplified by Vallevecchia appears even more important in a future perspective.

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REFERENCES

Airoldi, L. & Beck, M. W. 2007 Loss, status and trends for coastal marine habitats of Europe. *Oceanography and Marine Biology: An Annual Review* **45**, 345–405.

APAT/IRSA-CNR 2003 *Metodi Analitici per le Acque (Water Analysis Methods)*. APAT Manuali e linee guida 29/2003, Rome, Italy.

APHA/AWWA/WEF 2005 *Standard Methods for the Examination of Water and Wastewater*, 21st edition. APHA/AWWA/WEF, Washington, DC, USA.

Artioli, Y., Friedrich, J., Gilbert, A. J., McQuatters-Gollop, A., Mee, L. D., Vermaat, J. E., Wulff, F., Humborg, C., Palmeri, L. & Pollehne, F. 2008 Nutrient budgets for European seas: a measure of the effectiveness of nutrient reduction policies. *Marine Pollution Bulletin* **56** (9), 1609–1617.

Bendoricchio, G., Comis, C. & Carrer, G. M. 1995 Metodologia per il controllo della qualità dei corpi idrici (Methodologies for the control of the quality of water bodies). In: *3 Convegno di Terra d'Otranto: L'Acqua Fattore di Crescita del Territorio 25–26 maggio, Lecce, Italy*, pp. 489–505.

Cohen, J. E., Small, C., Mellinger, A., Gallup, J. & Sachs, J. 1997 Estimates of coastal populations. *Science* **278** (5341), 1209–1213.

Degobbis, D., Precali, R., Ivancic, I., Smodlaka, N., Fuks, D. & Kveder, S. 2000 Long-term changes in the northern Adriatic ecosystem related to anthropogenic eutrophication. *International Journal of Environment and Pollution* **13** (1–6), 495–533.

EEA 2010 *The European Environment – State and Outlook 2010. Water Resources: Quantity and Flows*. European Environment Agency, Copenhagen, Denmark.

EU 2000 EU Water Framework Directive, 2000/60/EC. *Official Journal* (OJ L 327), European Parliament, Bruxelles, Belgium.

Justic, D., Legovic, T. & Rottini-Sandrini, L. 1987 Trends in oxygen content 1911–1984 and occurrence of benthic mortality in the northern Adriatic Sea. *Estuarine, Coastal and Shelf Science* **25** (4), 435–445.

Kadlec, R. H. & Knight, R. L. 1996 *Treatment Wetlands*. CRC Press, Boca Raton, USA.

Kashyap, A. 2004 Water governance: learning by developing adaptive capacity to incorporate climate variability and change. *Water Science and Technology* **49** (7), 141–146.

LASA 2010 *Il Monitoraggio e Gestione delle Acque Aziendali a Valle Vecchia di Caorle. Report of 2009 activities for Veneto Agricoltura*. Laboratorio di Analisi dei Sistemi Ambientali, University of Padova, Italy.

Lotze, H. K., Lenihan, H. S., Bourque, B. J., Bradbury, R. H., Cooke, R. G., Kay, M. C., Kidwell, S. M., Kirby, M. X., Peterson, C. H. & Jackson, J. B. C. 2006 Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science* **312** (5781), 1806–1809.

Novotny, V. 2003 *Water Quality. Diffuse Pollution and Watershed Management*, 2nd edition. John Wiley & Sons, New York, USA.

Shuval, H. I. 1967 Water pollution control in semi-arid and arid zones. *Water Research* **1** (4), 297–308.

Vermaat, J., Bouwer, L., Turner, K. & Salomons, K. (eds.) 2005 *Managing European Coasts. Past, Present and Future*. Springer-Verlag, Berlin, Germany.

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