Evaluating Natural Self-Sanitation Capability of Arid Creeks in Puglia Region (South-East Italy)

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Abstract

Wetland hydrologic and water-quality functions are the roles that wetlands play in modifying or controlling the quantity or quality of water moving through a wetland. Wetland plants remove nutrients, trace metals, and other compounds from the soil water and incorporate them into the plant tissue which may later be recycled in the wetland through decomposition, stored as peat, or transported from the wetland as a particular matter.

Wetlands have a very effective role for pollutant removal, for flood control, for biodiversity increase and they offer aesthetic value and wildlife habitat. An understanding of wetland functions and the underlying chemical, physical, and biological processes supporting these functions facilitates the management and protection of wetlands and their associated basins. Each wetland is unique but those with similar hydrologic settings generally perform similar functions.

This paper proposes a method to assess those areas which are suitable to develop inlet wetland of a creek (Lama S. Giorgio) typical of a semi-arid climate. The method consists of the analysis of the creek channel morphology by the use of GIS and a detailed digital soil model. It allows to identify a fundamental landscape functionality such as water self-sanitation capacity.

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1. Introduction

After a long period when landscape components have been considered separately, today there is a growing awareness among land managers that there is a need to take into account multifunctional landscape aspects. In other words, different goods and services can be provided at a single location (Willemen et al., 2010). As a result, the best possible integration between environmental (ecological) and socio-economic functions is needed.

One of the most important landscape functionalities is the landscape's role in controlling water quality (Haycock and Muscutt, 1995) and preventing pollution, thanks to landscape structures such as wetlands and riparian buffer zones (Novotny, 2004). Wetlands are areas that are inundated or saturated by surface or ground water at a sufficient frequency and duration in order to support vegetation typically adapted to saturated soil conditions (U.S. Army Corps of Engineers, 1995). Riparian buffers are strips of trees or grass and other adjunctive vegetation such as cropland and streams up to gradient from surface water bodies.

Wetlands (both inlet channels and riparian) and vegetation riparian strips are buffers areas (BAs) being able to intercept or influence (quantity and quality) surface runoff, wastewater, subsurface flow and deeper ground water flows from upland sources. Therefore, intercepting runoff of sediment and chemicals from fields will thus reduce the movement of associated nutrients, sediments, organic matter, pesticides and other pollutants into surface water and ground water recharge areas (Welsch, 1991; Dosskey et al., 1997, Postel and Carpenter 1997, Field, et al., 2006).

Furthermore, BAs are thought to promote bank stability and provide shading and habitat for aquatic life while yielding a range of ecosystem and human services, including those with use values (such as withdrawal for drinking and irrigation water; flood mitigation; enhanced aesthetics; bird watching) as well as others with non-use values, such as climate mitigation, future benefits (bequest value) and intrinsic values such as scientific, educational opportunities (USDA-NRCS 1999) and knowledge about the existence of a healthy ecosystem. (Holmes et al., 2004).

For these reasons, BAs are considered to be amongst the most important factors affecting the chemical and biological indicators of stream quality, such as soil drainage properties and stream hydrology (Solano, Soriano and Ciria, 2004). As a consequence, worldwide environment managers and agencies, including the Italian Government (see Italian "Environment Bills", since 1999, until the present Decree n. 4/2008), are to encourage the maintenance of riparian buffer zones as the best management practice in water quality preservation.

Various studies, carried out over a number of years, have stated that wetlands and riparian buffers located down slope from agricultural fields can significantly reduce the amount of pollutants entering streams, above all agricultural non-point sources (Peterjohn et al., 1984; Lowrance et al., 1985; Lowrance et al., 1985; Jacobs and Gilliam, 1985; Schultz et al., 1995). As a consequence, it can be said that the quality of water flow crossing through the watershed ecosystem reflects the integrated effects of many processes along water pathways (Wang, Yin and Shan, 2005).

Considering all the above mentioned functions, BAs should be regarded as a milestone in landscape' s functionality assessment and land management. They are of great importance, because, although treatment plants for domestic and industrial effluent have been working in Italy for a long time, quality standards are very often not satisfied. This is partly due to the widespread nature of the pollution (above all produced by nutrients coming from agricultural land) and partly due to plant mistaken performance that need, as a safety precaution, to have a natural sanitation of wastewaters coming from treatment plants. In both cases, BAs are considered a very interesting solution.

The aim of this work has been to assess inlet wetland suitable areas for ephemeral and intermittent stream channels, evaluating their self-sanitation possibilities, thanks to these landscape structures, that may be some of the most important areas for preserving water quality.

2. Materials and methods

2.1. Study area

The study area is Lama San Giorgio, an ephemeral creek, with intermittent flow, typical of the semi-arid climate of these zones (Apulia region, fig. 1). "Lame" are watercourses created, since Cretaceous age, by erosive and tectonic processes involving the carsick rocks of the Apulia Region. These creeks flow in deep narrow canyons whose outlet is in the Ionian and in the Adriatic sea. Prevalently, the creek bed has a U shaped section, but V-shaped creek beds are also possible depending on the evolution of the erosion processes. Rare, but intense flooding events can occur, as it is typical of semi-arid climates.

These physical characteristics generate a very interesting landscape with microhabitats of plant and animal species protected by the EU "Habitat" Directive (92/43/EEC), such as the *Stipa austroitalica* and many birds, reptiles and amphibians included in the Directive Red List.

Lama San Giorgio (LSG), which is about 40 km long has a basin of 238 km^2 wide. The LSG channel varies over space: sometimes it is narrow, sometimes relatively wide, in whatever case, inlet wetlands often develop there (fig. 2).

2.2. Wetland assessment

Having established the nature of the LSG creek, it is necessary to investigate whether the context is suitable to support wetlands. Some preliminary considerations are necessary, though:

- Type of soil;
- Water table: a continuous base flow or high water table is required to support wetland vegetation;
- Topographic location: a wetland site should take into account natural depressions, flood plains and undisturbed natural areas. Furthermore, it should attempt to aesthetically "fit" the facility into the landscape (native landscaping);
- Bedrock: it should be close to the surface, to prevent excavation by the stream;
- Presence or absence of natural vegetation and its type.

Among these issues, channel morphology, and in particular, natural depressions, are the main factors regulating the creek thawing suitability for an inlet wetland development. In fact, wetland is the natural land cover for this landscape component since the natural water storage allows a constant soil moisture also in dry periods while shallow water-table feeds water.
It is then necessary to investigate the landscape and topography in particular the following two aspects:

1) The actual presence of natural wetlands, by aerial photos analysis and land surveys (fig. 3).
2) Topography was analyzed by a digital terrain model (DTM) with a resolution (raster dimension) of 1 meter and GIS tools ArcGis-Arcview 9.3 (with Toll: Spatial Analyst e 3D Analyst).

In the first step of the study the relationship between the actual inlet wetland presence in the Lama San Giorgio and channel morphology was checked assessing natural depressions of the channel thanks to the use of the GIS and the DTM. In this way, it is be possible to assess, quantitatively, the LSG areas potentially suitable for the wetland development.
This allowed the LSG creek buffer capacity to be calculated relatively to the organic pollution: BOD and nutrients coming from civic sewers, for example, or nutrients (P and N) from agricultural non-point sources. In other words, a relevant landscape functionality, i.e. the creek self-sanitation capacity was evaluated. Table 1 gives the base-parameters to design a wetland, which, by an inverse process considered an inlet wetland, to evaluate its self-sanitation capacity, or, in other words, the sustainable organic pollution loads for Lama San Giorgio creek.

3. Results

In this first step of the study, LSG inlet wetlands began and the proposed method was applied to the case shown in fig. 3 where wetland was surveyed, both from the ground and from aerial photos. This is a typical case in which wetland spontaneously

develops where the thalweg is characterized by a depression allowing the accumulation of sufficient moisture for development of reed beds (*Phragmites australis*). The picture as well as the cross and longitudinal sections in fig. 4 show that reed beds do not occupy the whole channel but its morphology suggests that wetland could easily develop here.
Using the GIS and the related DTM, it is immediately possible to evaluate the channel morphology.

3.1. Wetland self-sanitation evaluation

In order to evaluate wetland self-sanitation, it is necessary to calculate its geometry. In the study case, having assessed the presence of a natural depression, its dimensions (for the potential, complete wetland development) were calculated (fig. 4): Length: 52 m; Width: 32 m; Area 1662 m^2.

In order to evaluate the wetland volume, a *Phragmites australis* root depth of 0,50 m was considered (a safety measure, normal *Phragmites australis* root depth of about 0,70 m).
The self-sanitation has been evaluated in terms of BOD_5 reduction, BOD_5 (Biological Oxigen Demand) since it is an oxygen measure used by microorganisms apt to decompose wastewater (in five days), polluted by organic compound and coming, for example, from civic settlements.
The most diffuse relationship between BOD and wetland geometry is the following Kickuth equation (US-EPA, 2000):

$$A_{wetland} = \frac{Q * [\ln(C_0) - \ln(C_t)]}{K_{BOD_5}} \qquad [m^2]$$

where ln is the natural logarithm symbol and:
- Q = means daily wastewater flow [m^3/d];
- C_0= means BOD_5 of inlet wetland wastewater [mg/l];
- C_t= means BOD_5 of outlet wetland wastewater (being t the residence time) [mg/l];

- K_{BOD5}= de-oxygenation constant, literature (US-EPA, 2000) gives a range of 0,06-1,5 d^{-1}, prudentially, it has been considered a value of 0,08 d^{-1}.

This calculation allows for the wetland water sanitation capacity in terms of the population equivalent (PE) to be evaluated. Population equivalent (in wastewater monitoring and treatment) refers to the amount of oxygen-demanding substances whose oxygen consumption, during biodegradation, is equal to the average of the oxygen demand proper of the waste water produced pro capita. It is a measure of pollution representing the average organic biodegradable load pro capita per day.
Considered a water availability of 200 l/d (0,2 m^3/d) per person, if PE is the equivalent population number, the daily wastewater flow would be Q=0,2*PE and explained the Kickuth equation by Q=0,2*PE, it is possible to correlate PE to the wetland water self-sanitation capacity:

$$PE = \frac{1662 * 0{,}08}{0{,}2 * [\ln(C_0) - \ln(C_t)]}$$

This equation allows to correlate the anthropogenic load PE and the related pollution input ($\ln(C_0)$ in the formula) to sanitation perspectives by wetland, ($\ln(C_t)$ in the formula), as shown in the graph of the fig.5, where the following were considered:
- A sanitation goal of 20 mg/l of mean BOD_5 for outlet wetland (C_t).
- Various mean of BOD_5 of inlet wetland (C_0), plotted on the x axis of the graph.
- Consequent equivalent population (PE) whose wastewater can be treated by wetland.

4. Discussion

The results seem to confirm the hypothesis of a strict correlation between the presence of reed beds and the channel morphology.

It is necessary to embark on more studies in order to definitively confirm this assumption which tests a large number of sites and consider other limiting factors of wetland development (soil type, water-table etc.).
Having confirmed this assumption by employing the GIS software and refined digital terrain models, the proposed method allows for areas naturally suitable for reed beds and wetland development to be immediately assessed and correlated to wastewater self-sanitation polluted by organic compounds. The achievement of this goal appears to be very useful in terms of the evaluation of Lama San Giorgio's landscape functionality. Plants are to release oxygen into the generally oxygen-deficient soil environment through their roots while creating an oxidized root zone where bacterial transformations of the organic matter (measured in terms of BOD) and nitrogenous compounds can occur. Soils can safely retain or incorporate into the soil structure and/or decompose over 99% of potential pollutants such as nutrients (nitrogen and phosphorus), pesticides, and organic matter. The most effective storage is attributed to saturated soils, typical for wetlands. However, this storage capacity may be exceeded, and a change of the pollutant retention capacity can occur, causing pollutants to be released into ground or surface waters.
As a consequence, a quantitative evaluation of suitable wetland areas and of their capacity to reduce organic pollutants and nutrients is needed. PE from the Kickuth formula can be considered the LSG carrying capacity of organic pollution, that is a fundamental concept if LSG is considered, being all arid and semi-arid zones creeks which is not commonly considered to be able to self-depurate. Inlet wetlands and reed beds vegetation give a "new" functionality to creeks.
Furthermore, the presence of reed beds and inlet wetlands is important for many other services that these landscape structures assure: biodiversity development; floods control; reduction of water speed during flood events, with the consequent deposition of mineral and organic particles and constituents they include, such as phosphorus or trace metals; climate mitigation; aesthetics enhancement.

Another important aspect of the proposed approach consists of a better management for wastewater. Plotting on a graph such as the one shown in fig.5 it allows the quantitative relationship between anthropogenic loads and environmental system to be highlighted, considering the latter as a resource, rather than as a problem. Beyond the technical approach, which is currently under refinement, the experimented method offers various advantages for optimizing management practices:

– it does not consider wastewaters eventually reaching LSG creek as a problem, a "tiresome" waste but as a resource, which create a new functional landscape, feeding fundamental ecosystems, such as wetlands;

– it allows the wastewater impact on the environment to be highlighted and, as a consequence, managers will have full awareness about all discharge scenarios, not only in the sanitation plant but throughout the whole system. This is important because sanitation plants cannot always, during the their life cycle, perfectly respect the initial design: changes in PE number very often result in the sanitation plant outlet not being able to meet quality standards. Therefore, it is strategically important to have the possibility for a further resource coming from the territory.

With regard to these aspects, there is another relevant advantage from the social and landscape point of view since to increase functionality means to give the creek a stronger liaison to the context as well as a new identity that would be able to combat illegal activities which are to damage the environment.

5. Conclusions

Landscapes are ecological meaningful units where many processes and components interact and, in consequence, optimal land organization needs the holistic consideration of watershed characteristics and related functionality. A landscape's functionality can be defined as its capacity to provide goods and services for human beings and a comfortable habitat for wildlife.

In this paper, the self-sanitation capacity of Lama San Giorgio, a typical semi-arid climate intermittent creek is investigated. In this context, the presence of inlet wetlands and reed bed vegetation development is fundamental.

This paper suggests the use of a method to quantitatively evaluate it by a morphological analysis, i.e. analyzing the natural depressions and the consequent wetland geometry. The aim is to evaluate the self-sanitation capacity of typical semi-arid climate creeks, taking into account the relationship between human loads (equivalent population producing organic pollution) and the capacity of the system to sustain these loads.

The method needs further refinement from a technical point of view but it seems very promising whereas it defines quantitatively a fundamental landscape functional aspect, such as inlet wetland and related water sanitation potentiality. Furthermore, it allows land managers to develop an awareness about discharge scenarios not only into the sanitation plant but in the whole system.

In addition, to increase LSG functionality means to give to the creek a stronger liaison to the context and to the new landscape's identity.

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Table 1: Typical Design Features for Constructed Wetlands Design Factor (*).	**Surface water flow**
Minimum surface area	- Primary treatment: > 5 m^2/PE - Secondary treatment: 5 m^2/PE - Tertiary treatment: 0,5-1 m^2/PE
Maximum water depth	Relatively shallow
Minimum hydraulic residence time	5-14 days
Maximum hydraulic loading rate	- Primary treatment: 4 cm/d - Secondary treatment: < 5 cm/d - Tertiary treatment: < 20 cm/d
Minimum pretreatment	Primary (secondary optional)
Range of organic loading as BOD	80-110 kg BOD_5/ha/d
Minimum soil depth	50 cm

(*) Source: US-EPA, Contructed *Wetland Treatment of Municipal Wastewaters*. Cincinnati, Ohio, 2000 (EPA Report No. EPA-625/R-99-010)

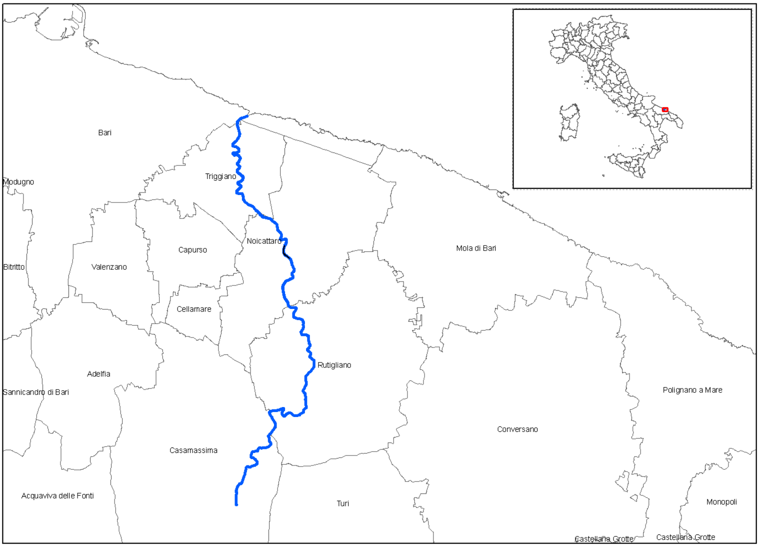

Fig. 1: Study area

Fig. 2: Lama San Giorgio morphologies, land use (vineyard) and wetlands

Fig. 3: Site were the method has been applied.
Red lines indicate longitudinal (thalweg) and cross sections

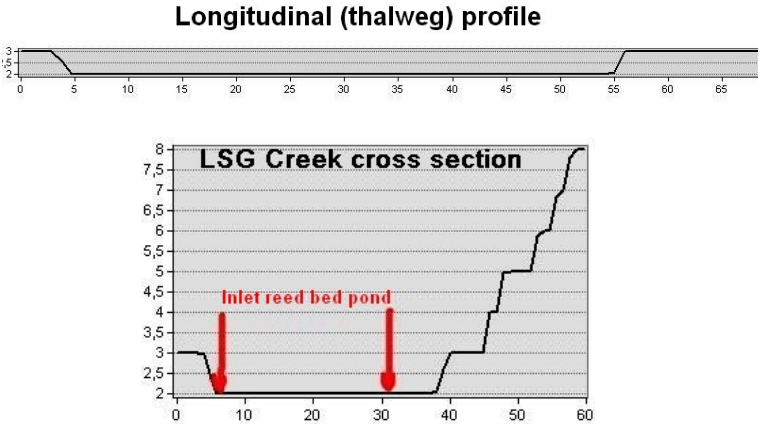

Fig. 4: Cross and longitudinal section

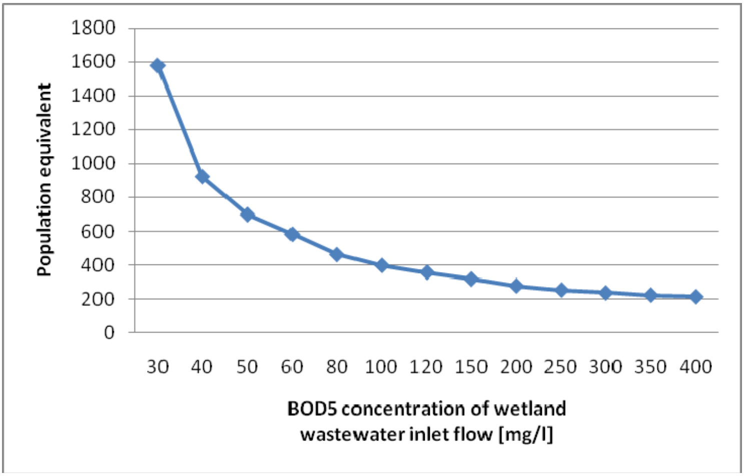

Fig. 5: Relationship between population equivalent and BOD_5 content of wetland inlet flow, in the case of a [BOD_5] goal for wetland outlet flow of 20 mg/l