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Wetland Purification Pattern for Surface Runoff Pollution of Coastal Highway in Liaoning Province

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Abstract Taking surface runoff of Coastal Highway in Liaoning Province as research object, this paper analyzed water quality characteristics of runoff and flow rules of pollutants. It proposed using constructed wetland treatment technique in the drainage system from the perspective of effectively removing major pollutants. Using the constructed wetland k – C * model and relevant experience, parameters of constructed wetland can be obtained. The basic model is as follows: constructed wetland lies in two sides of the road, and surface runoff sewage is collected and treated separately with 1 km road section as the collection unit. The wetland area in one side is 191.6 m^2, average water depth is 0.5 m, wetland width is 8 m, and wetland length is 24 m.

Key words Surface runoff, Runoff pollution, Constructed wetland, Sewage purification, Coastal Highway

With development of the domestic traffic undertaking and constant increase in the mileage open to traffic, frequent traffic activities lead to worse and worse surface runoff pollution. Rain water on road surface contains dust and trace foreign matters of air. It washes road surface after becoming runoff. It takes away much metal, hydrocarbon, rubber, and fuel and other pollutants generated from vehicle wearing. Besides, harmful substances generated from vehicle transportation will be discharged to farmland or receiving body of water in the action of water drip washing, consequently leading to degradation of ecological environmental quality [1]. In this study, we take Coastal Highway of Liaoning Province as study object, analyze characteristics of surface runoff pollution, and consider the constructed wetland treatment technique in the drainage system. The constructed wetland not only can clean up surface runoff, but also can provide habitat for wetland living things, and restore ecological functions of the road area to the maximum extent.

1 Overview of the study area

The Coastal Highway of Liaoning Province is a strategic line in "five points and one line" of Liaoning Province, is a traffic hub driving development of coastal economic belt of Liaoning Province, and also reputed as the longest coastal highway in China [2]. It starts Suizhong County of Hulu Island in the west and ends Donggang City of Dandong City, connecting 6 municipalities and 7 county level cities in coastal regions, crossing 2 latitudes and 5 longitude, having a total length of 1 443 km [3].

Along the highway, the altitude is 2 – 485 m, the extreme lowest temperature is –27.3 ℃, the highest temperature is 37.4 ℃[4], the average annual precipitation is 623.4 m, and average annual precipitation intensity is about 7.8 mm/d. From the spatial distribution of annual precipitation, influenced by sea and land position and terrain, the annual precipitation takes on decreasing from southeast to northwest; the precipitation is highest in summer, accounting for more than 65%, and average intensity of summer rainstorm is 77.2 mm/d [5].

The coastal highway generally adopts minor highway standard with width of road bed mainly 10 m, 12 m, and 15 m [3]. Through preliminary survey, the Coastal Highway of Liaoning Province has 306 km long cultivated land, accounting for 26.6% of the total length (1153 km, excluding detour section and the unbuilt section); the whole line crosses 30 rivers, which are major receiving body of surface runoff. The surface rainwater runoff aggravates pollution of nearshore regions of Liaoning Province.

2 Materials and methods

2.1 Survey on surface runoff pollution of road In June to August, 2012, we made sample survey of surface runoff of the whole Coastal Highway. We set 1 sampling point every 50 km. In total 20 sampling points were set, as shown in Fig. 1. Since the surface drainage adopts decentralized sheet flow and centralized interception, we collected samples of rainwater runoff intercepted inside the curb, roadbed slope or drainage ditches.

Specific methods of sample collection: within 0 – 60 min of runoff generation, collect water sample one time using polyethylene bottle (1L) every 10 min. At the same time of sampling, use JS – 2 siphon hyetometer to make record of rainfall characteristics. We analyzed water quality in laboratory using indicators including solid suspension (SS), chemical oxygen demand (COD), 5 day biochemical oxygen demand (BOD5), total phosphorus (TP), to-

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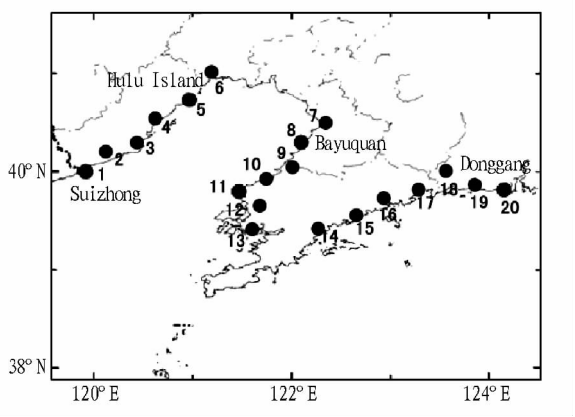

Fig. 1 Map of sample points

tal nitrogen (TN), Plumbum (Pb), Zinc (Zn), and oils. The measurement methods [6] are listed in Table 1.

Table 1 Pollutants and measurement methods

Pollution indicators	Measurement methods
SS	103 – 105 ℃ weighting method after dried
COD	Potassium dichromate method
BOD5	Dilution inoculation method
TP	Ammonium molybdate spectrophotometric method
TN	Ultraviolet spectrophotometric method
Pb and Zn	Atomic absorption spectrophotometric method
Oils	Infrared spectrophotometric method

2.2 Calculation of geometric parameters of constructed wetland Wetland purifies water mainly through hydrophyte absorbing, fixing and converting pollutants in water. To bring pollutant indicators of water to reach the standard, it is required to increase wetland area. The wetland area should be the maximum area required by pollutant indicators reaching the standard. Based on the constructed wetland k – C * model [7], we obtained following calculation formula:

$$As = \frac{0.0365Q}{k}\ln\frac{C_i - C^*}{C_e - C^*} \quad (1)$$

where As is the surface area of wetland (ha), Q is the average flow rate of sewage (m^3/d), k is the constant of primary reaction rate (m/year), C_i signifies water inlet concentration (mg/L), C_e is water outlet concentration (mg/L), and C^* is background value (mg/L).

Assuming all runoff sewage is generated from rainwater on road, its flow rate can be calculated through following equation [8]:

$$Q = Q\Psi F \quad (2)$$

where Q is rainwater flow rate (L/s), q is the designed rainstorm intensity [L/(s · hm^2)], Ψ is runoff coefficient, and F is catchment area (hm^2). In this study, the designed rainstorm intensity q is calculated using the rainstorm intensity formula of Yingkou City [9]: $q = \frac{1800(1 + 0.8\lg P}{(t+8)^{0.76}}$ (3)

where P is rainstorm return period (taking 1 a) and t is the designed rainfall duration (mainly referring to surface concentration time, the empiric value taking 10 min).

3 Results and analyses

3.1 Analysis on characteristics of surface runoff pollution

3.1.1 Characteristics of water quality. The most typical rainfall occurred on July 9, 2012 in Yingkou section (sample point 7). The rainfall intensity approached average intensity of summer rainstorm in Liaoning coastal region. The measured water quality changes were listed in Table 2.

Table 2 Water quality of surface runoff in Yingkou section (sample point 7) of Coastal Highway

mg/L	July 9, 2012					
	10 min	20 min	30 min	40 min	50 min	60 min
SS	221	270	193	178	197	184
COD	23	42	15	9	13	12
BOD5	2.4	7.1	1.8	0.9	1.2	0.4
TP	0.13	0.18	0.11	0.10	0.11	0.09
TN	0.012	0.015	0.01	0.006	0.008	0.008
Pb	0.009	0.062	0.008	0.007	0.006	0.005
Zn	0.008	0.090	0.007	0.005	0.006	0.005
Oils	0.9	1.1	0.9	0.6	0.6	0.5

Coastal region of Liaoning Province has large area of aquaculture, so the seawater quality should meet category II water quality specified in Seawater Quality Standard GB 3097 – 1997), and sewage discharged to category II sea area should comply with Grade I discharge standard specified in *Integrated Waste Water Discharge Standard* (GB8978 – 1996) and category III standard specified in *Standard for Environmental Quality of Surface Water* (GB 3838 – 2002). The specific target values are as follows:

From comparison between monitoring results and water quality standard, it can be seen that major pollutants of surface runoff of Coastal Highway are SS and COD, followed by oils, BOD and TP. The ratio of BOD5 to COD is 0.12, indicating poor biological degradability of runoff and not suitable for treatment by biological method. Besides, monitoring results of many times in the whole line indicated that there are great changes in the concentration of pollutants in surface runoff sewage and different monitoring time, which are related to traffic volume, number of fine days before rainfall, rainfall situation, and length of rain concentration section.

3.1.2 Flow rules of pollutants. According to data in Table 2, we can plot process curve for changes of pollutant flow and analyze flow rules of different pollutants. From Fig. 2, we can see that the concentration of pollutant is high within 30 min of the runoff generation. Later, the concentration gradually falls, indicating significant effect of surface runoff at initial stage. Therefore, treating rainwater at the initial stage can realize the purpose of purifying water.

3.2 Constructed wetland mode

3.2.1 Selection of wetland type. According to water distribution methods, the constructed wetland can be divided into surface flow

constructed wetland and subsurface flow constructed wetland. In the subsurface constructed wetland, sewage flows in subsurface, so it is able to take full advantage of internal fillings, plant root system and surface biomembrane combined with biological, physical and chemical actions. The merits are strong pollution load and water load bearing ability, free of strange smell, and small effect of climate [10], and the drawbacks are complex structure, high investment, and high operation and management requirement.

In the surface flow constructed wetland, sewage flows in soil surface of wetland. Organic matters of water are removed through stalk under water and biomembrane, while suspension particles are collected through interception of plant root and stalk. The distinctive merits include removing solid suspension, low investment, low operating cost, and simple management and maintenance; the drawbacks are small treatment load and attraction of mosquitoes and flies in summer [11].

Since major pollutant of surface runoff pollution of Coastal Highway is solid suspension and the overall pollution condition is relatively light; the Coastal Highway is far away from residential area, it is unnecessary to worry about mosquitoes and flies; the Coastal Highway is long and not easy to manage and maintain; the groundwater level is relatively high in coastal region, it is suitable for building the surface flow constructed wetland similar to the coastal wetland.

3.2.2 Design of geometric parameters. The constructed wetland is in two sides of the road, separately collecting and treating surface runoff sewage of each road side. Taking 1 km road section as an example, calculating at the road width of 12 m, the catchment area in single side road $F = 0.6\ hm^2$. According to equation (3), we can obtain the highest rainstorm intensity of Yingkou City $q = 200\ L/(s.hm^2)$. Substitute it to the equation (2), it is able to reach the average flow rate of surface runoff sewage $Q = 388.8\ m^3/d$.

Taking the major pollutant solid suspension as an example, at the initial stage of rainwater runoff (first 30 min of rain), the average concentration of solid suspension is 228 mg/L. According to related standard, the outlet concentration of solid suspension should reach 70 mg/L. According to equation (1), the surface area of wetland As is $191.6\ m^2$. Relevant parameters of the above calculation process are listed in Table 4.

The water depth of constructed wetland is generally lower than 0.6m. In this study, we took the average water depth $h = 0.5$ m. To effectively remove solid suspension, the linear velocity of water in surface flow wetland is generally lower than 100 m/d. Take the wetland width as W, the wetland length is L, $Q/(Wh) \leqslant 100$ m/d, then $W \geqslant 7.8$ m; take $W = 8$ m, then $L = 24$ m.

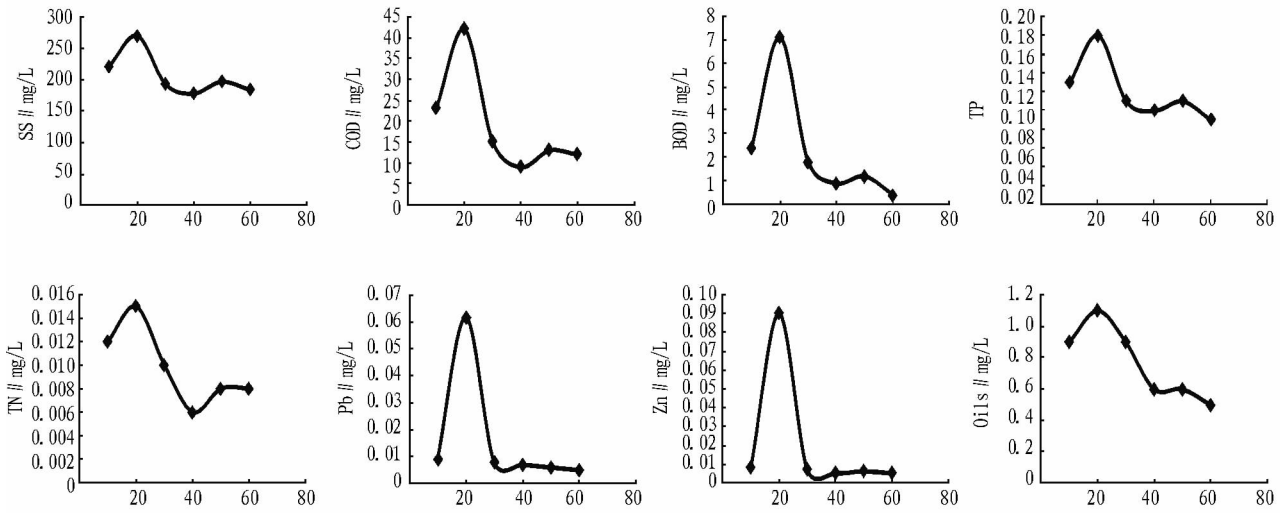

Fig. 2 Curves for changes of water quality parameters with runoff time

Table 3 Comparison table of water quality standard mg/L

	SS	COD	BOD5	TP	TN	Pb	Zn	Oils
Grade I of integrated waste water discharge standard	70	100	30	0.1		1.0	2.0	10
Category III of surface water environmental standard		20	4	0.2	1.0	0.05	1.0	0.05

Table 4 Parameters of constructed wetland

Designed parameters	Value	Designed parameters	Value
Rainstorm return period // a	1	SS inlet concentration // mg/L	228
Designed rainstorm intensity // [$L/(s.hm^2)$]	200	SS outlet concentration // mg/L	70
Runoff coefficient	0.9	Background value // mg/L	14.7
Average flow rate of sewage // m^3/d	388.8	Velocity constant // m/year	1000

3.2.3 Selection of plants. The constructed wetland is preferred to combine with road green projects, to reduce damage of road traffic to environment through surface absorption and degradation of surface rainwater pollution [12]. At the same time of satisfying cleaning ability, selection of wetland plants should be mainly local plants. Therefore, in the design, it is preferred to select reed, cattail, calamus, Eichhornia crassipes, and Indian shot, *etc.* Besides, it is feasible to simulate community types of local wetland and shallow water area according to natural conditions of the road sections (the plants are listed in Table 5), to establish a constructed wetland system with emergent plants, floating plants, and submersed plants in picturesque disorder.

Table 5 Major community types of wetland and shallow water area

Plant types	Major community types
Swamp vegetation	Reed swamp and cattail swamp
Emergent plants	Cattail – water fennel – Alisma orientalis community, carex – barnyard grass – Scirpus community – reed – wild rice – cattail community
Floating plants	Duckweed – Spirodela polyrrhiza community and Gorgon Euryale – Trapa Comm and pondweed communities
Submersed plants	Potamogeton crispus – Najas marina community and snapdragons – Potarmogeton pusillus L – Hydrilla verticillata community and Potamogeton malaianus Miq – Myriophyllum spicatum community

4 Conclusions and discussions

From the water quality characteristics of surface runoff and management and maintenance of Coastal Highway, the surface flow constructed wetland is an effective and relatively reasonable selection. According to flow rules of pollutants, as long as cleaning the pollutants at the initial period (30 min), it is able to purify the water body. On this basis, using the constructed wetland k – C * model, it is able to calculate the required wetland area. In addition, on the basis of the related parameters of the Coastal Highway constructed wetland obtained through relevant experience, the basic model is as follows:

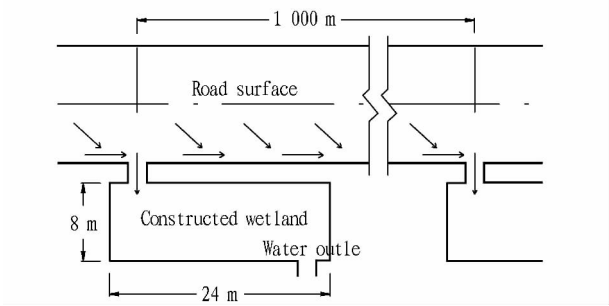

Fig. 3 Plane of wetland for purifying surface runoff sewage

Since this project does not need power, this mode is not provided with rainwater regulation tank. The collected rainwater directly enters the constructed wetland system only relying on gravity. Different soil filtration media have no significant difference in effect of removing solid suspension [13]. Generally, it is feasible to adopt natural soil combined with gravel, coarse sand or ash slag as matrix. To ensure smooth inlet and outlet water, the bed is provided with 1% slope.

Because the Coastal Highway crosses different geographical regions, the wetland mode used in respective regions should be adjusted in accordance with local situations. Except difference in major pollutants in runoff rainwater, the main point lies in changes of runoff sewage flow rate resulted from precipitation. On the basis of complying with the above design ideas, it is recommended to adjust the distance between each wetland to adjust the wetland area in combination with utilization of land surrounding the Coastal Highway.

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