Environmental Assessment concerning Environmental Load Reduction at Highway Service Areas in Japan by Introducing Low Environmental Load Toilets

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ABSTRACT

In this study, the reduction on the environmental load by the replacement of conventional toilets with low environmental load toilets such as water recycling urine-diverting toilets newly developed at highway service areas in Japan was quantified and a cost-benefit analysis concerning introducing low environmental load toilets were performed. The Moriya service area, which is one of the large–scale service areas and the Minori service area, which is middle–scale, were selected for the case study. As for the results, the water use and energy consumption, cost, and pollution load, especially, total nitrogen and phosphorous were expected to be reduced greatly as black water was removed by the water recycling urinals and urine-diverting toilets. Concerning the cost, a reduction of 247 and 25 thousand dollars, respectively, in the Moriya and Minori service areas was estimated by reducing the amount of water use. These results of the estimation are valuable for considering the cost of treatment for the removed urine in this system.

INTRODUCTION

Japanese highway service areas that have the basic facilities, such as car service lots, toilets, and restaurants are required to be comfortable, clean, safe, and environmentally friendly. The Japanese highway management and maintenance company, NEXCO, owns about 300 of these service areas, where, on average a total of 50-80 toilets are present. They are considering replacing some of these conventional toilets with low environmental load ones in the near future not only to contribute to ecological conservation but also to save on water usage costs.

Flush toilets have been widely accepted by the public including the highway service because of their comfort and good sanitation. That being said, they have the following drawbacks (Nakagawa *et. al.*, 2001):

1. They consume a large share of water resources. Water consumed by flush toilets equals between 20 and 25% of domestic water use per person per day.
2. Substances discharged from flush toilets cause the eutrophication of rivers, seas, and lakes. It is said that the 80% of nitrogen and 60% of phosphorus contained in domestic sewage come from flush toilets.

Therefore the newly low environmental load toilets have been developed toilets instead of the pre-existing toilets. The aim of this paper is to explain how the reduction on the environmental load by the replacement of conventional toilets with low environmental load toilets at highway service areas in Japan was quantified and to provide a cost-benefit analysis concerning the introduction of low environmental load toilets such as water recycling urinals and urine diversion toilets. The Moriya service area, which is one of the large–scale service areas, and the Minori service area, which is one of the middle–scale ones in Ibaraki prefecture, were selected for the case study.

MATERIALS AND METHODS

Low environmental load toilets

Low environmental load toilets to be installed in the highway service area require the following conditions:

1. Having no unpleasant smells
2. Comfortable
3. Easy to maintain

Therefore, we developed the following low environmental load toilets that can save water significantly with minimal energy consumption as candidates to be installed in the highway service area.

Figure 1 shows a water recycling urinal. The disposed flushing water was reduced up to 0.25 L per use by the sensitive electromagnet switch, which controls the flushing water for the urine or for washing the toilet bowl. The 1.7 L of the flushing water isn't mixed with the urine and recycled many times. The electricity is 3.3 W at standby and 10 W at flushing. Figure 3 shows the schematic of it. Figure 2 shows the newly developed water recycling urine-diverting toilet, which was created in 2010 by combining the pre-existing urine-diverting toilets with the water recycling toilets (Nakagawa *et. al.*, 2009). The exterior view is the same as the pre-existing water recycling toilet but it has a newly added function of urine diversion. Figure 4 shows the schematic of it. Urine can be trapped under the toilet bowl by a weight and time sensitive switch. The disposed flushing water was reduced up to 0.6 L per use by the sensitive switch made of electromagnet which controls the flushing water for the black water or for washing the toilet bowl. The 2.2 L of the flushing water for the toilet bowl isn't mixed with the black water and it is recycled many times. The electricity is 3.3 W at standby and 45.3 W at flushing. The captured urine is sent down a separate pipe into a container where it can be collected and stored for further use. As long as it is not contaminated with feces, it can serve as an excellent fertilizer after a simple dilution treatment.

Feature of the Moriya and Minori Service Area in Ibaraki prefecture

The feature of the Moriya and Minori service areas are shown in Table 1. The Moriya service area (Figure 5) is located about 30 km northeast of Tokyo, Japan and is one of the large–scale service areas. The effluent from this service area is treated

by the sewage treatment system. Figure 6 shows the restroom at the Moriya Service Area. The toilets are 8 L-type flush toilets with a bidet and a fountain of warm water.

The Minori service area (Figure 7) is located about 100 km northeast of Tokyo, Japan and is one of the middle–scale service areas. The effluent from this service area is treated by the domestic wastewater treatment system (Figure 8). The average water quality of the domestic wastewater treatment facility in the Minori service area is shown in Table 2. Figure 9 shows the restroom for women at the Minori Service Area. The toilets shown are 10 L-type flush toilets with a bidet and a warm water fountain.

Figure 1. Water recycling urinal.

Figure 2. Water recycling urine-diverting toilet.

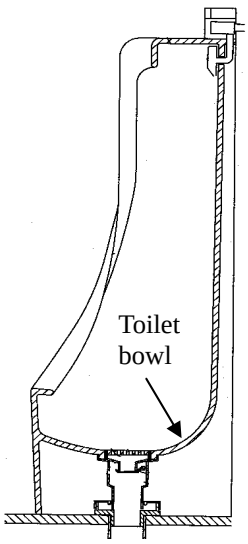

Figure 3. Schematic of water recycling urinal .

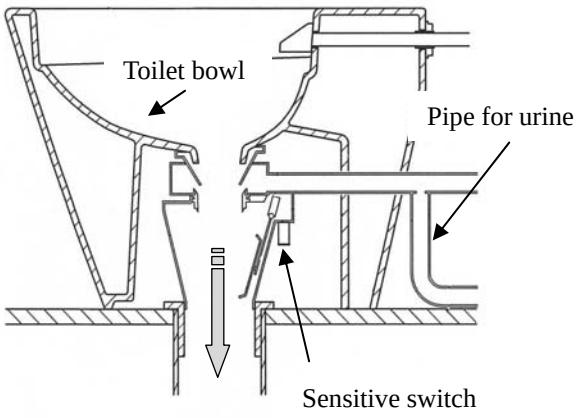

Figure 4. Schematic of water recycling urine-diverting toilet .

Figure 5. Moriya service area in Ibaraki prefecture.

Figure 6. Restroom for women at Moriya service area.

Figure 7. Minori service area in Ibaraki prefecture.

Figure 8. Domestic wastewater treatment facility in Minori service area.

Figure 9. Restroom for women at Minori service area.

Table 1. Feature of Minori and Moriya service area (SA).

Case Study			Moriya SA	Minori SA
Size of service area			Large	Medium
Wastewater treatment			Sewage	*DWTF
Number of Users		/ Year	8,080,000	560,000
	Men	/ Year	4,202,000	351,000
	Women	/ Year	3,878,000	214,000
Number of Toilets	For Men		*U 64/ R 28	U 30/ R 10
	For Women		For kids 5/ R 80	For kids 0/ R 32
	For Handicapped		2	2
Amount of Water Use	Total Amount	m^3/Year	132,670	16,138
	Total Cost	Dollar/Year	320,200	37,200
	For toilets	m^3/Year	70,794	7,063
	Cost for toilets	Dollar/Year	170,862	16,281
	Ratio of toilet water use for entire facility	%	**53.4%**	**43.8%**
Amount of Effluent		m^3/Year	134,249	16,548
Cost for sewage system		Dollar/Year	219,800	--
Electricity	Total	kWh/Year	3,250,368	233,681
	Total Cost	Dollar/Year	426,900	35,200
	For water treatment	kWh/Year	39,192	93,641
	Cost for water treatment	Dollar/Year	5,200	14,100
	Ratio of water treatment for entire facility	%	**1.2%**	**40.1%**

* DWTF : Domestic Wastewater Treatment Facility

*U 64/ R 28 : Number of Urinals is 64,Number of Regular Toilets is 28.

Table 2. Average water quality of the domestic wastewater treatment facility in Minori service area.

	Influent	Effluent
BOD (mg/L)	155	0.6
COD (mg/L)	118	4.1
T-N (mg/L)	65	8.1
T-P (mg/L)	12	0.5

As shown in Table 1, water use for the toilets occupies 53.4 % and 43.8 % of the total water used in the Moriya and Minori service area, respectively. The water used by the toilets in the Moriya service area totals to a huge amount of 70,000 m^3 per year and costs 170,862 dollars per year. As the wastewater from the Moriya service area is treated by the sewage system, the electricity for water treatment is dedicated just to the water supply, however, the cost for the sewage system is still large in the Moriya service area.

Estimation of environmental load reduction

In order to consider the advantage of introducing the low environmental load toilets, we calculated the water consumption, energy consumption, and cost from when the previous toilets were replaced with low environmental load ones. In this case, we assumed replacing all old-type toilets with the water recycling urinals and the water recycling urine-diverting toilets newly developed as written above. The basic data required for the calculation were obtained from NEXCO LTD, INAX LTD, and Reinforce LTD. The flush volumes of the toilets in the case of introducing the water recycling urinal and urine-diverting toilet are shown in Table 3.

The pollution load rates including the urine and feces excreted by one person per day were calculated from the ratio of feces and urine in the excrement (Lens P. *et al.*, 2001). Also, the pollution loads included in the urine and excrements per person per day as shown in Table 4 were calculated from the pollution load rates written above and the pollution loads including black and gray water (Matsuo *et. al.*, 1999), assuming the intervals of urination are five times per day and the excretion of feces are once per person per day. Figure 10 shows the schematic of the existing and new system at Minori service area. Following this, the amount of pollution loads that could be reduced per year was estimated at the Minori Service Area.

Table 3. Flush volume of the toilets.

	Existing toilets				Low environmental load toilets	
	Minori PA		Moriya SA			
L/flush	Men	Women	Men	Women	Men	Women
For feces	10	10	8	8	0.6	0.6
For Urine	6		4		0.25	

Table 4. Pollution load in black water.

	Feces	Urine
BOD (g/use)	14.4	0.7
COD (g/use)	8	0.4
T-N (g/use)	0.8	1.6
T-P (g/use)	0.3	0.1

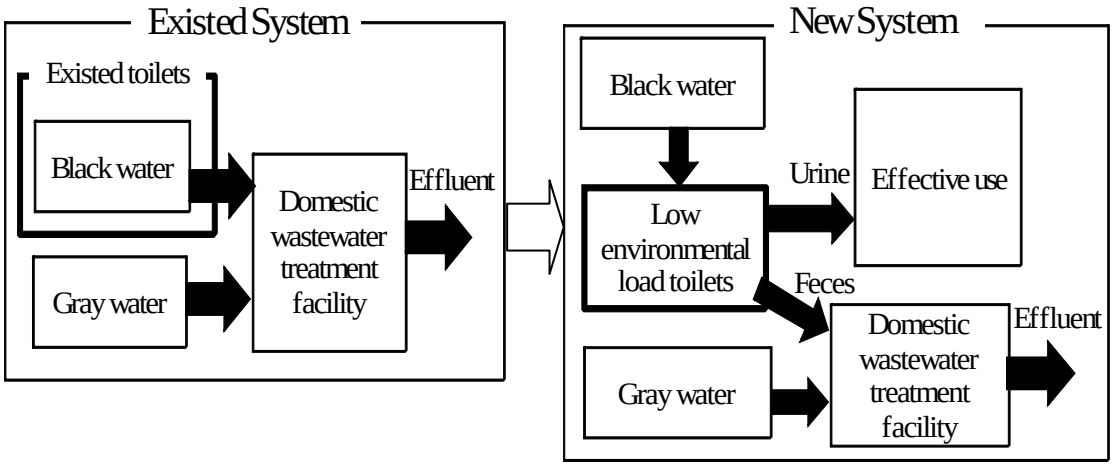

Figure 10. Schematic of the existing system and new system at Minori SA.

RESULTS AND DISCUSSION

In both cases at Minori and Moriya, the black water removed by the low environmental load toilets was assumed to be used effectively as fertilizer. The results of the estimation concerning the environmental loads by assuming the installation of water recycling urinals and water recycling urine-diverting toilets are shown in Table 5. The amount of water use was reduced by about 50 % through introducing low environmental load toilets. Especially the reduction of water consumption is significant in the Moriya service area which is a large-scale service area. The influent to the sewage pipe and domestic wastewater facility is reduced by the reduction of flush water volume, and along with it, the sewage cost and the cost of electricity concerning the domestic water treatment facility are also reduced in the Moriya and Minori service area respectively. The energy consumption in the Moriya service area wasn't reduced very much because of the electric power to make the flushing water circulate and the introduction of many water recycling toilets. Through considering the reduction of sewage costs mentioned above, the reduction of 247 thousand dollar per year was estimated in the Moriya service area. Regarding the Minori service area, a reduction of 25 thousand dollars was estimated by reducing the energy consumption at the domestic wastewater treatment.

In addition, the pollution load, especially total nitrogen and phosphorous were expected to be reduced by about 90% and 80 %, respectively, in the Minori service area as shown in Figure 11 because black water was removed by the water recycling urine-diverting toilets and the water recycling urinals. Thus, it was found that the environmental load can be reduced greatly by introducing the low environmental load toilets.

In order to consider the advantage of introducing the low environmental load toilets, a cost-benefit analysis was performed. In this analysis, all conventional toilets in the Moriya and Minori service areas were assumed to be replaced with the water recycling urinals and urine diversion toilets and the payback period was calculated. In other words, the required period for the cost generated by the

introduction of those of low environmental load toilets to be paid back, by reduction of water and energy consumption, was calculated in cost aspect. Table 6 shows the cost of introducing low environmental load toilets and cartridges, which are part of the water recycling urinals. These data were obtained from INAX LTD, Reinforce LTD.

Table 5. Result of estimation assuming the installation of water recycling urinals and urine-diverting toilets.

Case Study			Moriya SA	Minori SA
Amount of Water Use	Total amount (m^3/Year)	After introducing	66,832	8,258
		Amount of reduction	65,838	7,880
	Total cost (dollar/Year)	After introducing	168,115	18,998
		Amount of reduction	152,085	18,202
	For toilets (m^3/Year)	After introducing	3,340	323
	Reduction rate for toilet use (for total amount)		95% (50%)	95 % (49%)
Waste water treatment	Amount of removed urine（m^3/Year）		1,616	112
	Amount of wastewater （m3/Year）	After introducing	65,782	8,605
		Amount of reduction	68,467	7,943
	Cost for sewage system (Dollar/Year)	After introducing	107,702	--
		Amount of reduction	112,098	--
	Reduction rate of wastewater		51%	48%
Electricity	Total amount (kWh/Year)	After introducing	3,220,264	188,594
		Amount of reduction	30,104	45,087
	Total cost (dollar/Year)	After introducing	423,724	28,381
		Amount of reduction	3,176	6,819
	For water treatment (dollar/Year)	After introducing	9,088	48,554
		Amount of reduction	30,104	45,087
	Reduction rate for total amount		1%	19%

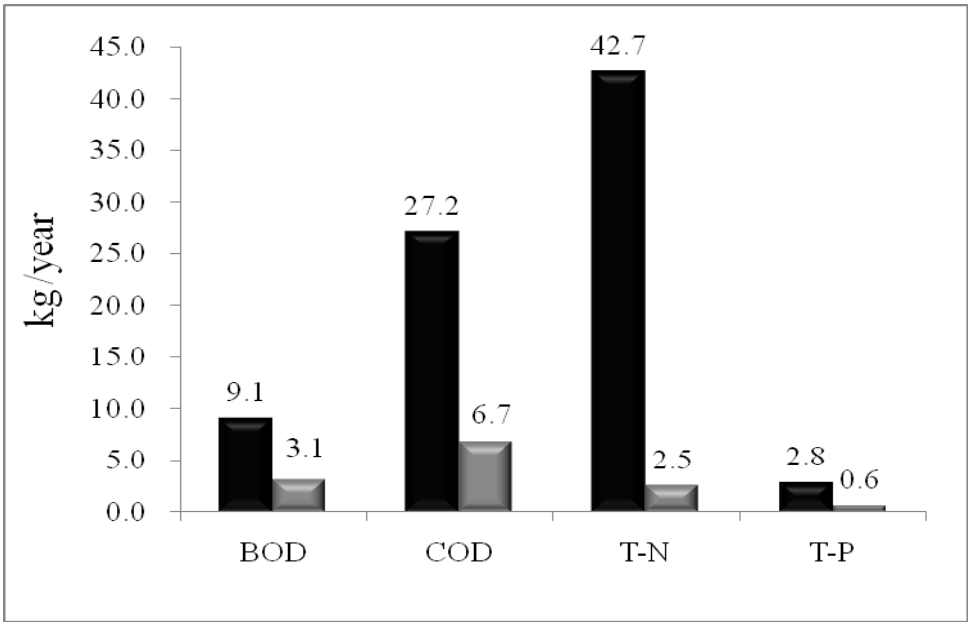

Figure 11. Amount of pollution load from Minori SA(service area).

Table 6. Cost for introducing the low environmental toilets.

Case Study		Moriya SA	Minori SA
Cost for introducing the low environmental toilets (dollar/Year)	Water recycling Urinals	276,500 (64 units)	107,500 (30 units)
	Water recycling urine-diversion toilets	106,200 (108 units)	49,800 (42 units)
	Urine storage tanks	7,000 (21 units)	6,600 (20 units)
Amount of cost reduction by introducing the low environmental toilets (dollar/Year)		247,434	25,021

Consequently, it was demonstrated that the payback period of the introduction of low environmental load toilets was 4 and 13 years in the case of the Moriya and Minori service areas respectively, in terms of cost. This result of the estimation is valuable for considering the cost of treatment for the removed urine in this system. Concerning the treatment for removed urine, so far, using it as a fertilizer in the rape blossoms field in the vicinity is considered, without neither the cost nor energy as possible, for recycling nutrients back into the environment.

CONCLUSIONS

In this study, the reduction on the environmental load by the replacement of conventional toilets with low environmental load toilets at highway service areas in Japan was quantified and a cost-benefit analysis concerning introducing low environmental load toilets such as water recycling urinals and urine diversion toilets were performed. The Moriya service area, which is one of the large–scale service areas and the Minori service area, which is one of the middle–scale areas, were selected for the case study. As for the results, the pollution load, especially, total nitrogen and phosphorous were expected to be reduced by about 90% and 80 %, respectively, in the Minori service area by introducing water recycling urinals and urine-diverting toilets as urine was removed and water use was reduced. Concerning the cost, the reduction of 274 and 25 thousand dollars, respectively, in the Moriya and Minori service area was estimated by reducing the amount of water use. In addition, it was demonstrated that the payback period of the low environmental load toilet introduction was 4 and 13 years in the case of the Moriya and Minori service areas respectively.

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