Nutrient Recovery Potential from Stadium Wastewater for Use as Turfgrass Fertilizer

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The current approach to wastewater treatment wastes valuable resources, such as water, nutrients, and energy. Although urine accounts for only 1% of wastewater by volume, it accounts for approximately 80% of nitrogen and 50% of phosphorus in wastewater. Source separation of urine wastewater presents the opportunity to conserve water and energy and recover nutrients for beneficial use, such as fertilizer. At a sports stadium, it is expected that the majority of wastewater is diluted urine generated by the flushing of urinals and toilets. This presents a unique opportunity for a concentrated and nutrient-rich wastewater stream with the potential for nutrient recovery for use as fertilizer. A mathematical model was created to estimate wastewater generated at Ben Hill Griffin stadium for four different scenarios, including standard and low flush toilets, waterless urinals, and no-mix toilets. The model was also used to predict water savings and potential nutrient recovery from source separated urine wastewater. A cost analysis was completed for each scenario for plumbing fixtures and storage tanks. This research confirms the high concentration of nutrients in stadium wastewater and that source separation technology could present a feasible opportunity for collection of nutrients from urine wastewater for use as fertilizer.

INTRODUCTION

The current approach to wastewater treatment wastes valuable resources, such as water, nutrients, and energy. Clean drinking water is used to dilute wastes in toilets and urinals. This diluted waste stream is carried large distances to a wastewater treatment plant. An energy intensive treatment process removes nutrients from the wastewater before it is discharged into the environment. The use of a diluted stream makes this process less efficient as more energy must be used to treat large quantities of dilute waste streams.

Gallons of water are used to flush urine in standard urinals and toilets. This is a waste of resources, as urine is 96% liquid and doesn't need additional water to wash it down the drain [1]. The use of low flow fixtures and waterless urinals can reduce the amount of water used to move urine wastewater. Although urine accounts for only 1% of wastewater by volume, it accounts for approximately 80% of nitrogen and 50% of phosphorus in wastewater [2]. Urine is nutrient rich, containing median concentrations of 8.3 g/L nitrogen, 0.8 g/L phosphorus, and 1.9 g/L potassium [3]. Using large volumes of potable water to dilute nutrient-rich waste is a poor use of water resources and is energy intensive for transport and treatment [4].

Source separation of urine wastewater presents the opportunity to conserve water and energy and recover nutrients for beneficial use. Source separation technology separates the urine wastewater stream at its source from other wastewater streams for separate treatment. This creates a concentrated, nutrient-rich urine wastewater stream with the potential for more efficient treatment. Separating human urine at the source enhances the sustainability and efficiency of wastewater management [5]. Furthermore, additional beneficial uses for the nutrients in this urine wastewater stream may be feasible. One potential use for urine wastewater could be fertilizer, since the nutrients in urine, especially nitrogen and phosphorus, are the primary nutrients in fertilizers. In fact, these nutrients are found in urine almost entirely in the mineral form readily available for plant uptake [6].

Recently, the U.S. Environmental Protection Agency (EPA) and Green Sports Alliance partnered to support issues such as water and energy conservation and sustainability at stadiums and sports venues [7]. In the specific case study of a football stadium, it is expected that the majority of wastewater is diluted urine generated by the flushing of urinals and toilets. This presents a unique opportunity for a concentrated and nutrient-rich wastewater stream with the potential for nutrient recovery for use as fertilizer on the turfgrass football field.

The specific objectives of this research were to estimate the volume and composition of wastewater produced by Ben Hill Griffin Stadium during one game for existing standard urinals and toilets, high efficiency urinals and low flush toilets, and waterless urinals and no-mix toilets and to estimate the costs for replacing urinals and toilets.

METHODS

Stadium Description

Ben Hill Griffin Stadium at the University of Florida is a large football stadium that hosts NCAA Division 1 Florida Gators football team. The stadium has a published capacity of 88,548, though average attendance per football game was over 90,000 from 2005 to 2010 [8]. The public area of Ben Hill Griffin Stadium has 29 restrooms, 13 men's and 14 women's [8]. A count was done of urinals and toilets in one publically accessible men's restroom and one publically accessible women's restroom. This count was used to estimate total number of urinal and toilet fixtures in public restrooms at Ben Hill Griffin Stadium. Men's restrooms are predicted to have a total of 368 urinals and 118 toilets. Women's restrooms are predicted to have a total of 330 toilets. The predicted total number of toilets and urinals in public areas is 448 and 368, respectively. Water is also used for sinks, water fountains, concessions, locker room showers, and in the skybox area.

Scenarios Considered

Four scenarios were evaluated in this study (Figure 1). The first scenario (Scenario 1) considers the collection of urine wastewater from current plumbing system of standard toilets (6 lpf) and standard urinals (3.8 lpf). Toilet wastewater is sent to a wastewater treatment plant. Diluted urine flows to a storage tank for treatment prior to being used on a sports field as fertilizer. Scenario 2 uses the same process as Scenario 1; however, standard toilets and urinals are replaced by low flow toilets and urinals. These toilets and urinals use less water per flush than standard fixtures. Scenario 3 uses the same process as Scenario 2; however, waterless urinals are used. Scenario 4 differs from the other scenarios. Urine wastewater is collected for treatment by No Mix toilets and waterless urinals. No Mix toilets separate urine and feces wastewater streams within the toilet bowl. Therefore, Scenario 4 represents maximum urine collection for treatment with minimum dilution. This scenario was also analyzed as Scenario 4b, substituting dual flush toilets for no-mix toilets.

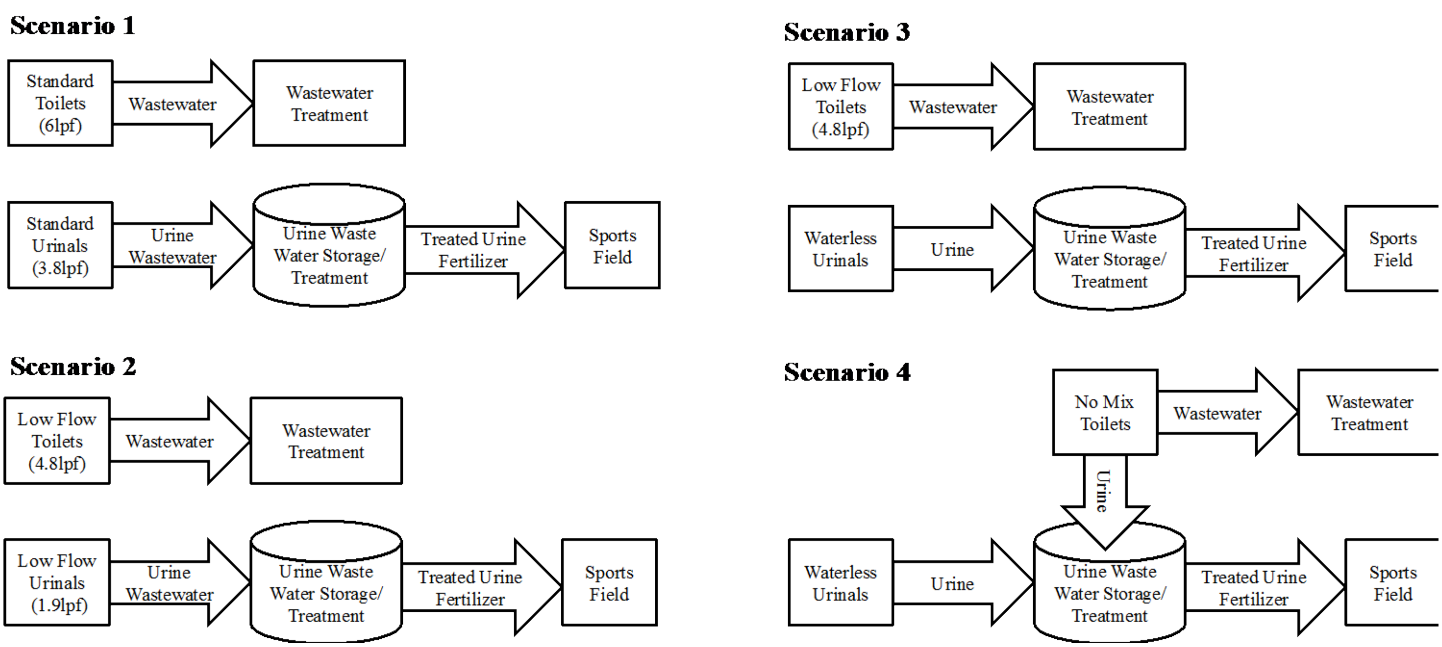

Figure 1. Four scenarios were considered and analyzed for volume of urine wastewater collected, potential water savings, potential nutrient recovery, and cost.

Wastewater Volume and Composition

In the specific case study of a football game, it is expected that the majority of wastewater is generated by the flushing of urinals and toilets. This presents an opportunity for a concentrated and nutrient-rich wastewater stream. Wastewater volume generated at a football game in Ben Hill Griffin Stadium was estimated using data from the UF Water Reclamation Plant. A mathematical model was also generated to estimate wastewater volume and composition from a football game at the stadium. Estimates for the concentrations of nutrients in urine wastewater were obtained through peer-reviewed literature [3].

Cost Estimation

Cost was estimated for all scenarios including manufacturer costs for various plumbing fixtures and liquid storage tanks. Cost for plumbing fixtures were estimated using the Kohler website. Cost estimate for storage tanks was provided by Florida Aquastore. Storage of human urine is a crucial step prior to its application as fertilizer [5]. Costs for construction, operation, and maintenance were not considered in this study. It is expected that these costs would be similar for each scenario and therefore were excluded. In the Ben Hill Griffin case study, standard fixtures are already in place; however, costs for Scenario 1 were still considered in order to draw comparisons between the four scenarios.

RESULTS AND DISCUSSION

Wastewater Volume and Composition

A mathematical model was generated to estimate the amount of wastewater and composition generated during game day at Ben Hill Griffin Stadium. Using this mathematical model, volume and composition of wastewater generated by Ben Hill Griffin Stadium was estimated for all scenarios (Table 1).

Table 1. Wastewater Volume, Composition, and Potential Nutrient Recovery Estimated for Ben Hill Griffin Stadium Per Game

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 4b
Urinal (lpf)	3.8	1.9	0	0	0
Toilet (lpf)	6	4.8	4.8	4.8	4.2, 6
WW (L)	621160	489308	424567	424567	430345
Water Savings (%)	--	21.23	31.65	31.65	30.72
Urine WW Collected (L)	140771	76031	11290	29819	154401
Urine Collected (L)	11290	11290	11290	29819	22580
% Urine by Volume in Urine WW	8.02	14.85	100.00	100.00	14.62
N collected (kg)	94	94	94	248	187
P collected (kg)	9.0	9.0	9.0	23.9	18.1
K collected (kg)	21.5	21.5	21.5	56.7	42.9

The mathematical model assumes all wastewater generated is due to men's and women's restrooms uses and that other water uses such as water fountains, concessions, and locker room showers are negligible. The mathematical model is given by:

$$WW = [(x/2)*m*a] + [(x/2)*n*b] + [(x/2)*b] + [x*11*c]$$

The variable x represents the number of bathroom uses; the variable m represents the ratio of urinals to men's total plumbing fixtures; the variable n represents the ratio of men's toilets to men's total plumbing fixtures; the variables a and b represent the volume per flush of urinals and toilets (Lpf), respectively; and the variable c represents the sink flow rate (L/s). In the Ben Hill Griffin Stadium case study, calculations were done using $x = 90{,}000$ people, $m = 368/486$, $n = 118/486$, and $c = 0.158$ L/s. Variables a and b (Lpf) changed based on each scenario.

Wastewater flow data was acquired from the University of Florida's Water Reclamation Plant for the 2011 football season. Accounting for average water uses on other parts of campus, it was estimated that approximately 1,725,000 L of wastewater enters the treatment plant from Ben Hill Griffin Stadium during a football game. This wastewater was estimated to be approximately 2% urine by volume, double the concentration in regular wastewater. This higher concentration of urine confirms that a large sports stadium could offer the potential to harvest nutrients from source-separated wastewater.

The amount of wastewater estimated by the flow data from the wastewater treatment plant is significantly more than that estimated by the mathematical model. One explanation could be that more bathroom uses occur than predicted. Another explanation could be that more wastewater is generated through other uses such as water fountains, showers, or the skybox than was predicted. Since the mathematical model presented a conservative estimate of the volume of wastewater generated, its results are acceptable. A conservative estimate suggests the potential for nutrient recovery could be even higher.

Urine volume was estimated using another mathematical model:

$$U = y*1.33*0.25$$

The variable y represents the amount of bathroom uses in which urine will be collected; the factor 1.33 L/person/day represents the average urine volume in liters produced per person per day; the factor 0.25 represents the ratio of 4 hours spent at the football game to 16 hours awake. The potential amount of nutrients collected was calculated using peer-reviewed literature accepted median values of 8.3 g/L nitrogen, 0.8 g/L phosphorous, and 1.9 g/L potassium in urine [3]. Source separation of urine wastewater during game days at Ben Hill Griffin Stadium could result in both water savings and significant nutrient recovery (Figure 2).

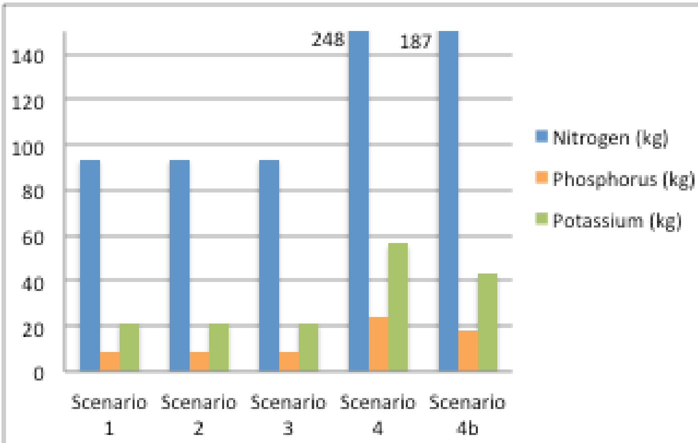

Figure 2. Potential nutrients collected (kg) from wastewater per game day for each scenario.

Cost Estimation

Costs were estimated for the four scenarios. Initial manufacturing costs were considered, including toilet and urinal fixtures, flushometers, and storage tanks (Table 2). Estimates for bathroom fixtures and flushometers were obtained from Kohler. Estimates for storage tanks were acquired from Florida Aquastore. Storage tanks were large enough to hold at least twice the volume of wastewater collected per game day. Other costs including construction, installation, and maintenance were not considered and were expected to be similar for each scenario.

Table 2. Initial Costs for Toilet and Urinal Fixtures, Flushometers, and Storage Tanks for Each Scenario

Scenario	Urinal Cost	Toilet Cost	Storage Tank Cost	Total Cost
1	$147,568	$163,968	$120,000	$431,536
2	$147,568	$163,968	$70,000	$381,536
3	$238,832	$163,968	$50,000	$452,800
4	$238,832	$448,000	$50,000	$736,832
4b	$238,832	$158,592	$120,000	$517,424

CONCLUSION

Source separation of urine wastewater presents the opportunity to conserve water and energy and recover nutrients for beneficial use. Results of the mathematical model demonstrate that source separation at a large sports stadium could result in significant water savings, reducing operating costs and environmental impact, as well as increasing sustainability. In addition, source separation of stadium wastewater can lead to the recovery of nutrients such as nitrogen, phosphorus, and potassium. Nutrients recovered could potentially be used as fertilizer on the turfgrass field. The results of this study suggest the feasibility of water savings and nutrient recovery from source separated wastewater and could lead to more sustainable operations of large sports venues.

Comparison of several scenarios suggests that collecting source separated urine wastewater from waterless urinals (Scenario 3) would be most beneficial. This scenario is cost effective and results in high nutrient collection and high water savings. As source separation technology improves and the cost of no-mix toilets becomes comparable to standard toilets, a scenario involving no-mix toilets for nutrient recovery may become more feasible.

The assessment of various treatments of collected urine wastewater for use as fertilizer was beyond the scope of this study. Further research is needed to confirm the feasibility of various treatments of collected source separated urine wastewater. In addition, more work must be done to assess the performance of treated urine wastewater as fertilizer. This study concludes that there are enough nutrients available in urine wastewater from a large sports stadium that source separation for beneficial reuse is vital to explore in order to make stadiums more sustainable.

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