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Implementation, management, and cost of the clean water act and storm water pollution prevention plan

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Abstract

This research is a retrospective case study designed to document the implementation, and management decisions made about a Storm Water Pollution Prevention Plan (SWPPP) for a wastewater project in California. For this study, the project manager and qualified storm water pollution prevention practitioner (QSP) agreed to extensive interviews about the decisions made and associated costs. Through laws and regulations, constructors are required to take precautionary measures to ensure pollutants stay on jobsites as opposed to running into the storm water system. Moreover, from a practical standpoint, such research might be particularly useful for addressing the challenges constructors are having with the more stringent sustainability regulations. This study used a retrospective case study as part of an exploratory qualitative research strategy for examining the costs associated with storm water pollution prevention on a twenty acre, $48,000,000 wastewater project that had a construction schedule of two years. Cost analysis was taken from historical data and was applied in a quantity takeoff. This study was aimed at documenting some practical features of the actual implementation, management, and cost in this particular case. Results indicate the primary roles of the QSP for this project and the SWPPP cost for this project was 0.46% of the total project cost.

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Keywords: Construction Management; Costing; Storm Water Pollution Prevention Plan (SWPPP); Clean Water Act (CWA); Qualified SWPPP Practitioner (QSP)

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1. Introduction

Urbanization has caused the natural environment to be uprooted all around the world. When soil is disturbed, rain and snow melt events pick up pollutants and distribute them into our waters. The flowing water from these occasions are known as stormwater. Flowing stormwater can pick up trash, sediment, oil, and toxins such as pesticides. Once larger bodies of water are polluted, serious effects can take place on aquatic life, habitats, and even human health. Today, one of the leading causes of pollution to our nation's waters is because of stormwater [2].

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Construction disturbs soil due to the clearing of natural vegetation, and once an area is developed, impervious pavements are created, such as parking lots and sidewalks. Due to this, the natural hydrology of the land is affected. In the natural environment, rain and snowmelt are filtered and absorbed by soil, as well as vegetation such as grasses, brush, and trees. As runoff flows, pollutants are captured by vegetation, and erosive processes are mitigated to an extent. Vegetated areas also provide a buffer against extreme inflow to bodies of water, slowing down and dissipating incoming water. When a naturally vegetated site is stripped for construction, soils are disturbed, stripped of their top soil, and left bare. Therefore, when it rains, there is no longer any vegetation to slow and filter the runoff, as it rushes down the bare landscape [3].

Sediment is the main pollutant of construction. According to the American Society of Civil Engineers (ASCE) and Water Environment Federation (WEF), stormwater runoff from an unstabilized construction site can cause anywhere from 35-45 tons of loss sediment per acre per year, an amount that doesn’t occur naturally. The excess sediment blocks the sunlight, reducing the amount of dissolved oxygen in the water, which the aquatic environment depends on to thrive. In addition, fish gills can become clogged, aquatic habitats can be buried, and spawning areas can be ruined [1]. Along with sediment, grease, oil, and any other toxins from trucks and various types of equipment can also be picked up by stormwater. As a result, water quality and aquatic life can be affected, along with the potential of groundwater becoming contaminated.

1.1 History of Clean Water Act

In 1972, the Clean Water Act (CWA) was implemented by the Environmental Protection Agency (EPA) in order to regulate stormwater. However, this act did not focus on construction but instead large industries and wastewater treatment plants. According to Susan M. Franzetti of the Franzetti Law Firm, “…the Clean Water Act generally prohibited the discharge of any pollutant to navigable waters from a point source unless the discharge was authorized by a National Pollution Discharge Elimination System (“NPDES”) permit.” As a result, the majority of pollution entering U.S. waterways was not being regulated.

However in 1987, the EPA decided to amend the Clean Water Act and focus on construction activities that disturbed more than five acres of land. This was also known as Phase I of the National Pollution Discharge Elimination System (NPDES) and any construction site larger than five acres had to obtain a permit. A few years later, in 1999, the EPA established a Phase II to NPDES. This required construction activities that affect one acre or more of land, along with smaller sites in a larger common plan of development of sale, to obtain a permit along with an approved Storm Water Pollution Prevention Plan (SWPPP) [2]. As a result under the current Clean Water Act, builders are required to apply for coverage under a Construction General Permit (CGP) and to submit and comply with a SWPPP to prevent stormwater pollution.

A SWPPP plan is designed and submitted prior to development, and is implemented at the start of construction until final stabilization is complete. It is a plan that describes the measures a builder will take on the jobsite to control stormwater pollution. SWPPP should include a site map showing the perimeter of the project site, stormwater collection and discharge points, stormwater flow direction, current and proposed topography of the construction area, along with any existing buildings, lots and/or roadways. It also has to describe in writing and in drawing how the project team plans to control polluted stormwater from exiting the site. This is known as Best Management Practices (BMP) [6].

Once construction starts, the builder is required to document any maintenance work, along with reports on how well the in place SWPPP performed during a rain event. If changes are required to the implemented SWPPP because of performance issues, then these changes must also be documented. All of these documents must be up to date and accurate because compliance inspectors visit construction sites to make sure the project follows the Clean Water Act. As a result, many constructors designate a member of their staff to become a Qualified SWPPP Practitioner (QSP) rather than hiring a consultant for the role. The QSP certification allows this designated person to be the lead team member, ensuring that the construction site adheres to SWPPP policies and regulations.

Today in California, constructors have to apply for the new CGP that was implemented July 1st, 2010, where SWPPP has become even more stringent. Some of the changes to this permit include: determining the site risk level, generating a rain event action plan (REAP), implementing more specific construction best management practices (BMPs), monitoring for pH and turbidity, receiving water bio-assessments, and annual reporting [6].

1.2 Violations

Besides environmental consequences, any violations of the Clean Water Act may result in legal actions and fines placed on the contractor responsible for improper storm water management [5]. These fines can result in extraordinary amounts of money that may not only ruin the constructor's profit margins for the particular project but also cause financial problem for the company as a whole. The EPA can issue administrative penalties along with criminal and civil penalties. According to the Clean Water Act Section 404 Settlement Penalty Policy, "…the Agency is authorized to issue an administrative compliance order (AO) requiring a violator to cease an ongoing unauthorized discharge, to refrain from future illegal discharge activity, and to remove unauthorized fill and/or otherwise restore the site." They may also enact a fine amount depending on the severity of the penalty. A Class I penalty can result in a maximum fine amount of $27,500 while a Class II penalty can produce a fine up to $137,500. On top of this, the EPA may seek criminal and/or civil penalties resulting in fines up to $27,500 per day of violation and imprisonment. As one can see, these fines can add up and result in a detrimental situation [4].

2. Methodology

Based on Freedman and Kelting's recommendation for future research in "Case Study: Cost Analysis For The Implementation Of The Clean Water Act And Storm Water Pollution Prevention Plan," this case study follows the same steps. The author worked with a large contractor and gained access to their database containing SWPPP prices and line items. The contractor collected these costs over a period of many years in order to have accurate prices. Once the costs and line items were found, the author conducted a takeoff to determine the actual costs of materials, man hours, etc. Additionally, an interview along with a shadowed QSP inspection walk was conducted at the project site to determine the roles of a QSP [3].

2.1 Project Specifics

Following are key details of the project as they relate to this case study:

- Project Scope: Construct a waste water treatment facility
- Project Location: California
- Projected Cost: $48 million
- Projected Timeline: 24 months
- Project Site Size: 20 acres
- Site Risk Level: 2

2.2 Research Questions

The Clean Water Act has changed the way contractors develop their estimates for projects due to the increase costs to build. As a result general constructors are continually refining their estimates to cover the costs. Based off historical data and project specifics, constructors are trying to accurately predict costs to cover SWPPP. However, every project is different considering the type, size, location, and length of the project. Also, as SWPPP is becoming stricter, it is inevitable that costs go up to. The answers to these research questions might be particularly useful for addressing the challenges constructors are having with the more stringent sustainability regulations. To answer these questions, this study described the estimated SWPPP costs of a $48 million sewer treatment facility that took place on a 20-acre site.

This study attempted to answer the following questions:

- Approximately, how much will SWPPP materials and labor cost?
- What is the cost difference of having an internal QSP verses hiring a third party consultant?
- What is the primary role of a QSP and how has that role evolved over time?
- With more stringent sustainability regulations, what are the differences of implementing SWPPP on a project site compared to Eric Freedman's and Scott Kelting's research three years ago?

3. Results

For this project, the designated QSP was an internal employee who had a job title of Project Manager. He had the traditional Project Manager responsibilities along with his QSP responsibilities. The QSP's responsibilities varied between various inspections and filling out a variety of reports. Some of the inspections that the QSP described included inspecting roads and access to make sure they were up to standard when it comes to keeping dirt and other various materials on-site. He also talked about inspecting the fiber roles, silt fences, and erosion control blankets for deterioration. These various materials are put in place at the beginning of a project so naturally after being in the natural environment for an extensive time along with animals picking at them, they tend to fall apart. As a result, these materials need to be replaced from time to time. Along with inspecting the SWPPP materials, he had to make sure that all the equipment was not leaking and all kinds of buckets filled with hazardous materials were covered so if a rain event did happen, these toxins would not wash off the site. If anything was out of place or needed to be repaired, he would task it to a crew that was already on site. Besides inspections, the QSP has to fill out multiple reports. One of the reports needs to be filled out weekly to describe how the implemented SWPPP is performing. There are also other reports that must be filled out in the event of a rainstorm. These reports include a Rain Event Action Plan (REAP), pre-storm report, a mid-storm report, and follows with a post storm report. All of these reports have different variables attached to them, so if some rainstorms do not meet certain requirements, then the report does not need to be filled out. For example, if a rain storm does not occur for a straight 24 hours, then a mid-storm report does not have to be filled out. One of the tasks for the reports includes taking water samples at pre-determined spots to test the quality of the water running off-site. If the water quality was not up to par, then actions are taken to better the implemented SWPPP. Below, Table 1 goes into a detailed take-off to determine costs associated with the implemented SWPPP.

Table 1. Quantity take-off material and labor costs of SWPPP

Item	Quantity	Unit	Unit Cost	Total
1. Periodic maintenance of BMPs	104	Crew Hour	$ 360.00	$ 37,440.00
2. Dust Control	520	Crew Hour	$ 140.00	$ 72,800.00
3. Gravel Yard Areas/Roads (incl material)	365	Ton	$ 34.00	$ 12,410.00
4. Install Silt Fence (incl material)	3,000	LF	$ 3.00	$ 9,000.00
5. Install Fiber Rolls (incl material)	5,750	LF	$ 4.00	$ 23,000.00
6. Install Erosion Control Blanket (incl material)	48,555	SF	$ .30	$ 14,567.00
7. Wheel Wash System	12	Month	$ 3,000.00	$ 36,000.00
8. Sweep Roads	104	Crew Hour	$ 150.00	$ 15,600.00
Total w/ In-House QSP				**$ 220,817.00**
9. Third Party QSP	24	Month	$ 1,000.00	$ 24,000.00
Total w/ Third Party QSP				**$ 244,817.00**

In the quantity take-off above, there is a $24,000 difference between having an in-house QSP and hiring a third party QSP. This difference was generated based off the duration of the entire project. If the general contractor for this project didn't have an already qualified QSP, then they would need to hire a third party QSP to come weekly to conduct inspections, test water samples, and prepare reports for them.

Not every line item above had a physical quantity take-off and as a result, some quantities were best estimated based off what the contractor told the author in the conducted interview. These line items include: (1) periodic maintenance of BMPs, (2) dust control, (7) wheel wash system, and (8) sweep roads. Both line items 1 and 8 were based off an hour a week for the duration of the project (104 weeks). This is adequate time allotted to conduct maintenance work along with street sweeping.

To determine dust control, a little more consideration went into defining the quantity. The majority of dust control on a project occurs during the earthwork phase due to big machines disturbing the soil. For this waste water treatment plant, the majority of the project duration includes earthwork. The Project Manager/QSP for the project explained how they controlled the dust during this time by having a water truck extensively spray down the site. Based off what the Project Manager/QSP described, the quantity for dust control was determined off spraying down the site two hours a day, five days a week for half the project duration (52 weeks). The quantity was then multiplied by the unit price given by the contractor.

Another item that needed a quantity based off time was the wheel washing system. A wheel washing system is implemented so dirt and mud is not tracked off-site by trucks. These are required when pavement is not in place around a site. For this project, pavement was not laid down till later in the project so it was determined that the wheel wash system was in place for about 12 months. The 12 months started after earthwork had already begun due to not many trucks entering and exiting the project in the beginning.

Below in Table 2, a summary of total construction costs verses estimated costs of SWPPP is provided. As one can see, the total of implementing SWPPP is less than half a percentage of the total project costs. However, in the construction world this small percentage can result in a lot of money, especially when the typical profit for a contractor is within 2%-5%.

Table 2. Percentage costs of SWPPP/total construction costs

Total Costs w/ In-House QSP	$ 220,817.00
Total Cost of Construction	$ 48,000,000.00
% cost of SWPPP/Total Construction Costs	0.46%

4. Discussion

The results of this research were based off of one case study for a $48,000,000 waste water treatment construction project that lasted two years. This research has resulted in a similar outcome as did Freedman and Kelting's research two years ago; however a few aspects are different. The cost of implementing SWPPP is still less than one percent of the total project cost, yet in this case study, the percentage was higher at .46% compared to Freedman and Kelting's .25%. The higher costs can be a result of more stringent SWPPP practices, new materials used, and/or the differences between the two projects. The point of this research was not to compare Freedman and Kelting's project to this waste water treatment project directly, but instead as a whole to show that the costs of implementing SWPPP is a significant amount of money. In this case, if the contractor failed to include SWPPP in their initial bid, they would have lost roughly $221,000 before the project even began.

Another result of this research is how the role of the QSP has developed. In Freedman and Kelting's research two years ago, the QSP's main role was to take dust readings three times a week while also managing a labor foreman to maintain best management practices. Today, the role of the QSP has developed even further and requires more actions to be taken. Along with the responsibilities they previously had, the QSP has to conduct weekly inspections and report changes to their BMPs. They are also required to fill out a variety of reports in the event of a rain storm and take water runoff samples. Some of these reports and inspections can feel repetitive and excessive but it is what is required in order to follow the Clean Water Act.

The development of the QSP's role is not the only difference between this research and Freedman and Kelting's research. Materials used when implementing a Storm Water Pollution Prevention Plan have also changed compared to two years ago, causing a more expensive product. For this case study, the constructor did not use the traditional straw waddle and matting due to the industry standard shifting to bio-degradable products. The main materials used on site (fiber roles and erosion control blankets) were coconut based. These are considered to be permanent install items, unless they need to be replaced, because they are landscaped over during the finishing stages of the project.

When preparing a budget for the construction of a project, different factors need to be considered when determining the actual costs of implementing a Storm Water Pollution Prevention Plan. Every project is different considering the type, size, location, and length of the project. This case study produced an accurate cost of SWPPP for one specific project. This does not mean that the result can be applied to each and every project in the future.

5. Conclusion

This case study was designed to document the implementation and management decisions made about a Storm Water Pollution Prevention Plan (SWPPP) for a wastewater project in California. It followed similar steps that Freedman and Kelting used in “Case Study: Cost Analysis For The Implementation Of The Clean Water Act And Storm Water Pollution Prevention Plan.” The results found were similar overall in which the cost to implement SWPPP is still under one percent of total construction costs, and having an internal trained employee is cheaper than hiring a consultant. However, when analyzing further details of the results, things have changed compared to the research two years ago.

The project analyzed in this case study was a waste water treatment plant located on a 20 acre site. Based off historical data from the constructor of the project and a take-off by the author, it cost roughly .45% of total construction costs to implement SWPPP. It was also confirmed that constructors can save money by having an internal QSP as opposed to hiring a third party consultant. Materials used in SWPPP along with the duties of a QSP have also developed further with more stringent sustainability regulations.

In the future, it would be beneficial for researchers to conduct similar case studies to this one, using different types of construction projects. The subsequent case study results could then be combined as one case study that analyzes the costs of implementing SWPPP on different types of construction. From there accurate percentages can be developed for constructors to use in their bids. This could be a very beneficial tool for contractors to have for the success of their future projects.

Table 1. An example of a table.

An example of a column heading	Column A (*t*)	Column B (*t*)
And an entry	1	2
And another entry	3	4
And another entry	5	6

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[1] Environmental Protection Agency. (2008). Developing Your Stormwater Pollution Prevention Plan. 2-5

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Nitrogen removal from landfill leachate via ex-situ nitrification and in-situ denitrification in laboratory scale bioreactor

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Abstract

Indonesia is a one of the emerging market economies of the world, the country not only faces increasing GDP, but also generation of solid waste. Around 16.7 tons per year of solid waste are generated which consists of around 65% organic and 35% inorganic materials, and most of the waste is disposed of in 500 landfills. Almost all of these landfills are open dumps and have no wastewater treatment for their leachate. Over the period, nitrogen from leachate is treated mostly by ex-situ nitrification-denitrification which is expensive and requires a large area. This study aims to develop landfill as a bioreactor in in-situ denitrification after ex-situ nitrification. Two columns of bioreactor landfill in a laboratory scale were used: R2 reactor with 2 year-old waste and R4 reactor filled with a 4 year-old waste. Results showed that both bioreactors are able to achieve nitrate removal through in-situ denitrification, Based on the the first order reaction, R2 has higher nitrate removal rate of 0.0302mg/L/hour compared to 0.0226 mg/L/hour of R4. No significant difference in nitrate removal ability on each samplings ports with different heights on both reactors. This may be caused by the even distribution composition of waste and leachate on both bioreactors.

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Keywords: solid waste; denitrification; bioreactor landfill; nitrate removal

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1. Introduction

In many places, municipal landfill leachate is considered as the greatest contamination source of surface and groundwater. This leachate is known to have a high organic matter content, heavy metals, inorganic salts, and nitrogen, therefore is often processed through a biological method of ex-situ nitrification, and followed by in-situ denitrification [1]. Nitrification is a two-stage aerobic process whereby nitrogen-ammonia or ammonium is converted biologically into nitrate (NO_3) or nitrite (NO_2) by aerobic, autotrophic, and chemolitotrophic microorganisms [2, 3, 4]. On the other hand, denitrification occurs through an assimilatory or dissimilatory biological process where denitrifying bacteria is a heterotrophic, facultative aerobic bacteria, which uses nitrate as an electron acceptor if there is a lack or absence of oxygen. In contrast to the denitrification process, different types of bacteria can undergo a much broader denitrification. Denitrifying bacteria tends to survive in all natural environments because it is a facultative bacterium which obtains oxygen from the dissolved oxygen in water or nitrate molecule. Denitrification takes place when dissolved oxygen concentrations in water wane, and nitrate becomes the primary source of oxygen for facultative microorganisms [4].

The disadvantage of leachate treatment with the ex-situ method is the expense, as it requires a large area and drainage system from landfill to wastewater treatment plant. In the last few years, the option to make a landfill as a bioreactor with leachate recirculation has become increasingly popular [5, 6, 7, 8, 9]. Through this leachate recirculation method, ex-situ nitrification is combined with in-situ denitrification in the landfill as a bioreactor.

Previous studies on ex-situ nitrification followed by in-situ denitrification, and denitrification capacity of waste have been extensively carried out. For example, complete denitrification occurred by injecting 500 and 1000 mg/L NO_3--N into a reactor filled with a month's worth of year-old solid waste [10]. A simulation of ex-situ nitrification which was followed by in-situ denitrification in actively-producing methane reactors showed that the reactors were able to convert nitrate into nitrogen, while methane production stopped [11]. It was also confirmed that denitrification occurs when the acidogenesis phase is dominated by heterotrophic reactions, while autotrophic reactions take place in methanogenesis and are indicated by sulfate accumulation [12].

It is also found that both fresh, young waste and old, mature waste can be used as denitrification media [13, 14, 15]. Fresh, young waste, e.g. 2-3 months old, tends to not denitrify in the acidogenesis phase because there is a tendency for nitrate to reduce to ammonium (DNRA, Dissimilatory Nitrate Reduction to Ammonium), instead of to nitrogen (N_2) [10, 16, 17]. A deeper investigation about the effect of waste age on landfill denitrification capacity was conducted using 1-, 6-, and 11-year-old waste, and comparing the waste's capacity in the denitrifying process [18]. The results showed that bioreactors with 1-, 6-, and 11-year old waste had denitrifying rates of 6.8 mg NO_3--N kg/TS waste/hour, 3.00 mg NO_3--N kg/TS waste/hour, and 1.10 mg NO_3--N kg/TS waste/hour, respectively. It was concluded that 1-year-old waste has the highest denitrification capacity, and that this capacity decreases along with the waste's age. Their research on the difference of nitrate removal ability at different depths in the bioreactor landfill showed that the highest nitrate removal was located at the deepest point of the bioreactor.

Indonesia is a typical developing country located in Southeast Asia. As one of the emerging market economies of the world, the country not only faces increasing GDP, but also generation of solid waste. With around 300 million inhabitants, 16.7 tons per year of solid waste are generated. The solid waste consists of around 65% organic materials and 35% inorganic materials, and most of the waste is disposed of in 500 landfills. Almost all of these landfills are open dumps and have no wastewater treatment for their leachate. Land, air, and water pollution occur in the surrounding environments, and this pollution often goes undetected for years. During the past decade, developing landfills as bioreactors has been widely studied, but there have been no such studies conducted in Indonesia. This study aims to review the potential for denitrification of organic waste of differing ages in landfill bioreactors. This study used organic waste samples aged 2 and 4 years old and was conducted in two bioreactors on a laboratory scale. With high organic contents in the solid waste, the option for developing Indonesia's landfills as bioreactors will become a sustainable choice.

2. Research Methodology

2.1. Laboratory Scale of Simulated Landfill Bioreactor

This experiment was conducted in two acrylic column bioreactors where one of the bioreactors was filled with a 2-year-old solid waste sample (R2) and the other with a 4-year-old solid waste sample (R4). Each reactor's diameter and height were 20 cm and 100 cm, respectively. At the top of the column, a lid was provided to create anaerobic conditions. A hose with a valve at the bottom of the column was attached for leachate drainage. Three valves for sample extraction (#1, #2, ottom to top) were located parallel on the side of the column (Fig 1).

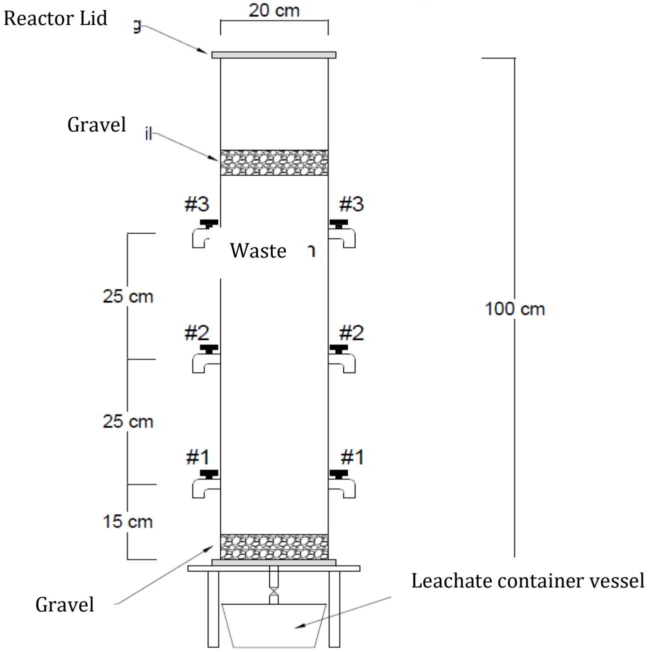

Fig 1. Schematic Model Laboratory Scale Bioreactor Landfill

2.2. Solid Waste Pretreatment

The source of the solid waste was from the Cipayung Landfill, located in Depok. The Cipayung Landfill is approximately 30 km from the Indonesian capital city of Jakarta, and receives 4200 tons per day of municipal solid waste from the city of Depok [19]. Followed by collection, waste that is difficult to degrade (plastic, metal, etc.) was removed. Initial measurements included moisture, pH, nitrite, nitrate, C/N ratio, COD, and volatile solids. All of the parameters were measured in accordance with standard methods (Table 1).

2.3. Experimental Design and Operation

Prior to the experiment, a layer of gravel 5 cm thick was placed at the bottom of the column. Next, landfill bioreactor R2 was filled with 2-year-old waste and R4 with 4-year-old waste (Table 2). An 800 kg/m3 compaction was performed for both reactors with a total waste of 18 kg for each reactor. After waste was placed inside the column reactor, 5 cm of gravel was also placed on top of the waste. The gravel layers were used to evenly distribute leachate on the waste surface, and to avoid clogging in the drainage area.

To reduce ammonia, 21.6 L of distilled water were added to both reactors to maintain an ammonia-nitrogen concentration under 150 mg/L in the leachate. Next, to simulate the denitrification process, 6.6 L of KNO_3 (1000 mg NO_3-NL-1) were added to each reactor so that the liquid height inside the columns was exactly above the waste layer and able to be drained over time. This nitrogen-ammonia removal and nitrate addition were intended to simulate the ex-situ nitrification process in landfills. In order to test nitrate content, leachate samples from each reactor were extracted every two hours on the first day, then every 24 hours on the remaining days. Measurements in each reactor were terminated when nitrate concentration in leachate was no longer detected or reached 0 mg/L.

Table 1. Measurement Parameters and Standards

Parameters	Methods
Ambient Temperature (oC)	Thermometer
pH	pH Meter
Moisture content (%wt/wt)	SNI 03-1971-1990
VS (%wt/wt)	Standard Method 2540 E
Total Nitrogen	Standard Method 4500-N org B. Macro-Kjeldahl Method
Nitrate	Spectrophotometry
Nitrite	Spectrophotometry
Total Carbon	Spectrofotometry
COD	Spectrophotometry
Dissolved Oxygen	Dissolved Oxygen Meter
Solid Waste Composition	SNI 19-3964-1994

Table 2. Solid Waste Sample Characteristics

Parameters	2-Year Old Waste	4-Year Old Waste
Ammonia	0.1025 g/kg	0.055 g/kg
Nitrate	0.1125 g/kg	0.2 g/kg
Nitrite	0.5 g/kg	0.5 g/kg
pH	10.3	10.3
Moisture	79.01%	78.88 %
Total Carbon	39.5%	15%
Total Nitrogen	4.4%	8%
C/N Ratio	8.977	1.875
Volatile Solids (VS)	76.53%	73.08%

2.4. Data Analysis

Experimental data were analyzed through descriptive statistics using Microsoft Excel.

3. Results and Discussion

3.1. Nitrate Removal

Results showed that nitrate concentrations in both bioreactors have decreased over time. Nitrate continued to decline until it was undetectable (reached 0) in reactor R2 on the 168th hour and 216th hour on reactor R4, therefore measurements were stopped on the 216th hour (Fig 2).

The COD concentration on both leachate bioreactors showed a slight decrease which signified a denitrification process, both heterotrophic and autotrophic [18]. C/N ratio on both waste samples was low, indicating that autotrophic denitrification might dominate this nitrate removal since heterotrophic denitrification requires a higher carbon source [18, 20]. However, it is not yet certain whether this conclusion can be used or not, due to a significant decrease of COD in reactor R4, possibly indicating carbon use for heterotrophic denitrification. In order to ensure which one was the dominant reaction, it is suggested that the onset of sulfuric gas be measured.

The initial increase in pH value was affected by a high nitrate reduction rate [18]. The decreased nitrate concentration caused carboxylic acid accumulation due to the re-initiation phase of methanogenesis [15, 16]. Denitrification processes tend to occur in anaerobic conditions, which means that in order for denitrification take place, this process requires anoxic conditions with DO concentrations as low as possible. However, this study showed quite a high amount of DO concentration in leachate samples, around 1-5 mg/L, and anaerobic conditions are achieved only when DO concentrations are below 1 mg/L. There exists the possibility that denitrification may happen in an aerobic condition which produces N_2O gas rather than N_2 gas [21, 22, 23]. Unfortunately, all of these studies examined the process of aerobic denitrification in wastewater and sludge sectors, but not in leachate.

When nitrate concentrations reach zero, the nitrite concentration in leachate would not be detected anymore, hence the termination of the denitrification process. It was found in this study that nitrite concentrations in leachate reached zero in reactor R4 before they did in reactor R2. However, a high concentration of nitrite may be caused by a partial denitrification process, whereby the conversion of nitrate to nitrogen gas terminated with nitrite, an intermediate product. This termination may have been caused by the absence of anaerobic conditions which are required for an optimum denitrification process, and which were indicated by the level of DO that was still categorized as aerobic (around 1-5 mg/L). The purpose of nitrification and denitrification is to remove ammonia and convert it to N_2 gas in the atmosphere. Slightly increasing trends of ammonia occurred in the denitrified leachate in the course of the run.

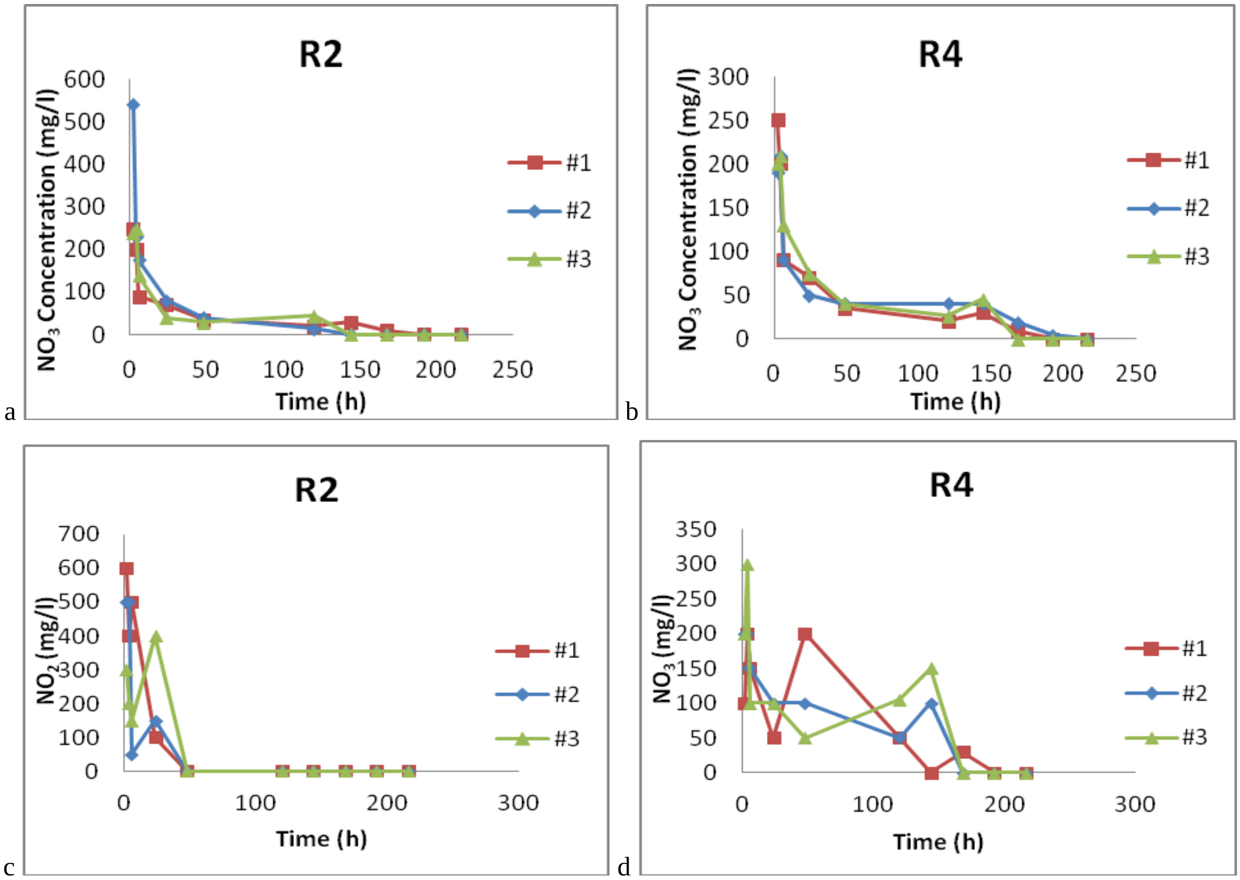

Fig 2. Nitrate (a and b) and Nitrite (c and d) Concentration Changes on Leachate Samples Graph in Both Bioreactors filled with 2-year-old waste (Left, R2) and 4-year-old waste (Right, R4)

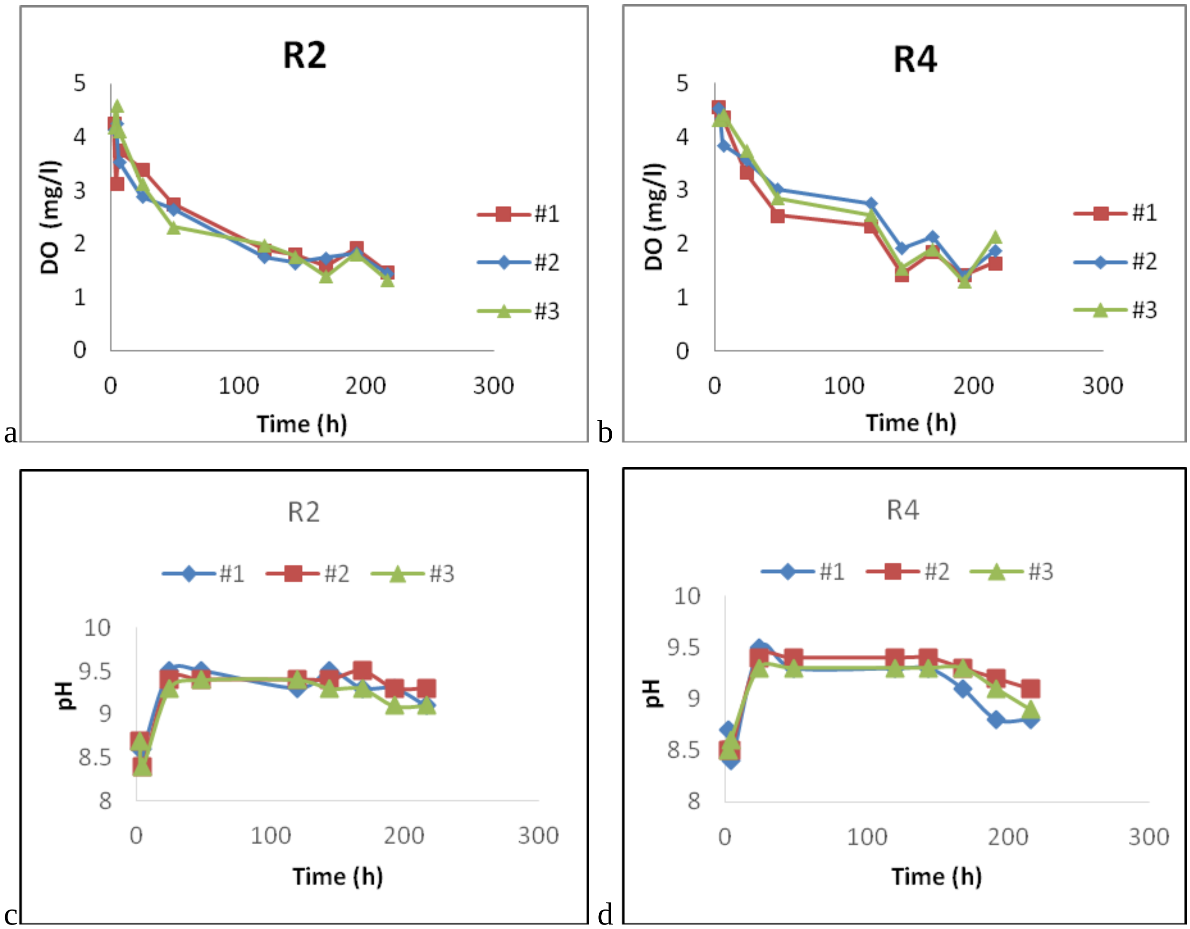

Fig 3. Dissolved Oxygen (DO, a and b) and pH (c and d) Changes on Leachate Samples Graph in Both Bioreactors filled with 2-year-old waste (Left, R2) and 4-year-old waste (Right, R4)

There are several possibilities that may account for this increase of ammonia. The first possibility is that the waste's nitrogen content in the bioreactor adsorbed and dissolved in the leachate [13]. Another possibility which may have caused the ammonia increase is that there were no air holes in the reactor for gas release. As a result, the nitrogen gas produced from the denitrification process was stuck inside a space at the top of the column, leading to nitrogen fixation by bacteria in the leachate on the column surface. Nitrogen fixation is a part of the nitrogen cycle where atmospheric nitrogen gas is fixated by bacteria into ammonia in water and/or earth environments [16, 25]. Nitrogen gas as N_2 or N_2O were fixated into ammonia in the leachate, resulting in an increase of ammonia concentration over time. It was also shown by the highest ammonia concentration in reactor #3, which was closest to the leachate's surface. In designing landfill bioreactors, it is necessary to ensure the existence of a pathway to release gas, and allow no possibility of gas retention in the landfill. Another possibility which may have caused an increase in the ammonia concentration was the process of DNRA (Dissimilatory Nitrate Reduction to Ammonium). DNRA is a biological process that reduces nitrate to ammonia [20]. However, the possibility of DNRA occurring in this study was quite small considering the high ratio of carbon and nitrogen (C/N) [17, 20]. Anaerobic bioreactor landfill conditions led to the absence of an ammonia elimination pathway; therefore, the ammonia continued to accumulate.

3.2. Comparison of Nitrate Removal Ability between R2 and R4

To make a comparison between both bioreactors, rates of nitrate removal abilities were analyzed based on two assumptions: (1) a zero order reaction, or (2) a first order reaction. Several references have showed that denitrification kinetics may be a zero order or first order reaction [18, 20, 26, 27]. Zero order reaction is a reaction whereby the reaction's rate is independent from the concentration of the reactant; in other words, the reaction rate is constant all the time. To calculate the nitrate removal rate from each bioreactor, we must first calculate the average nitrate concentration variables for ports #1, #2, and #3. This study did not measure the zero hour to produce an intact regression; therefore, it was more representative to assume that nitrate concentration at the zero hour was the same as it was at the addition of 1000 mg/L of KNO_3. The slope value which resulted from the average nitrate concentration linear regression was the bioreactors' nitrate removal rates with zero order assumption in mg/L/hour units.

First order reaction is where reaction rate is dependent on the reactant's concentration, which means that the reaction rate is only linearly dependent on the reactant's concentration. The slope value, resulting from the linear regression of average nitrate concentration, is the reactor's nitrate removal rate with first order assumption in units of hour-1. The descriptive statistics and several other parameters are presented in Table 3.

Table 3. Descriptive Statistics Linear Regression Analysis on Both Assumptions

	Zero Order		First Order	
	R2	R4	R2	R4
Linear Equations	y=(-2.743x)+372.41	y=(-1.7605x)+302.82	y=(-0.0302x)+5.7838	y=(-0.0226x)+5.4969
Slope	-2.743	-1.7605	-0.0302	-0.0226
Standard Deviation	319.51	290.33	2.17	2.11
Mean Standard Error	106.50	87.54	0.72	0.63

In the zero order reaction, the slope values of R2 and R4 were -2.743 and -1.7605, respectively, which indicate that both R2 and R4 reactors had nitrate removal rates of 2.743 mg/L/hour and 1.7605 mg/L/hour, respectively. However, in the first order reaction assumption, the slope values of R2 and R4 were -0.0302 and -0.0226, respectively. The result indicates that the R2 reactor with 2-year old waste had a higher nitrate removal than the R4 reactor with 4-year old waste. The organic matter and carbon-to-nitrogen ratio were found to be higher in the 2-year old waste sample than in the 4-year old waste sample. This organic matter was in the form of volatile solids (VS) which act as electron donors and have an important role in the nitrate removal process. The higher amount of degradable organic carbon may increase the denitrification process, hence reduce nitrate faster [17, 28, 29].

Standard deviation and mean standard error from zero order assumption was 319.51 and 106.50 for R2, and 290.33 and 87.54 for R4, respectively. The standard deviation and mean standard error from the first order assumption was 2.17 and 0.72 for R2, and 2.11 and 0.63 for R4, respectively. In the first order assumption, standard deviation and mean standard error values were smaller than the zero order assumption. This indicates that first order assumption is more valid in concluding the nitrate removal ability of each bioreactor.

3.3. Comparison of Nitrate Removal Ability with Height Difference in Bioreactors

Variation in nitrate concentration between port #1, port #2, and port #3 on reactors R2 and R4 (Fig 2) tended to show a similarity over time. The slope of linear regression was shown to have a slight difference. Likewise, the Pearson correlation functions indicated the absence of a significant difference between nitrate removal ability at different depths.

The absence of a significant difference of nitrate removal ability at different depths may be explained by the evenly-distributed waste composition at each layer of both reactors, which could have caused the nitrate removal ability to be similar. Chen, et al. (2009), who also studied the influence of depth differences on nitrate removal ability in three reactors filled with 1-, 6-, and 11-year old waste, showed that there was a difference in nitrate removal ability at different depths only within the reactor containing 1-year old waste, while the other reactors did not show any significant difference, similar to this study. Inside their reactor with 1-year old waste, the highest nitrate removal ability was found at the middle and lower layer, while the upper layer showed a slower nitrate removal. This difference was caused by gas accumulation in the upper layer which happened on leachate recirculation, thereby inhibiting the contact between leachate and waste. Furthermore, they stated that the difference might have been caused by the uneven distribution of waste inside the reactor, because the waste was still partially degrading and causing a difference in nitrate removal ability between layers, in contrast to the results obtained in the R2 and R4 reactors used in this study.

4. Conclusions

Landfill bioreactors are quite effective to remove nitrate and therefore decomposed solid waste may be used as an effective media of in-situ denitrification after the in-situ nitrification. The R2 reactor with a 2-year old waste has a higher nitrate removal than R4 reactor with a 4-year old waste due to the higher amount of organic matter in form of volatile solids (VS). No significant difference in nitrate removal ability on each sampling ports with different heights on both reactors. This may be caused by the even distribution composition of waste and leachate on both bioreactors.

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