Governance of Phosphate Recovery from Wastewater in Amsterdam

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Governance of Phosphate Recovery from Wastewater in Amsterdam
Understanding Waternet's practices regarding phosphate recovery from wastewater and the circular goals of the municipality of Amsterdam through an Adaptive Management approach.

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Summary

This research deals with governance of phosphate recovery from wastewater in Amsterdam. Worldwide phosphate is becoming scarce. Therefore, reusing and recovering phosphate is becoming attractive and important. Waternet is responsible for the water management in and around Amsterdam, and recovers phosphate from wastewater. Waternet plays a role in realizing the goal of the Municipality of Amsterdam to transit to a Circular Economy, which includes recovering resources from wastewater. However, Waternet's decisions about recovering measures are made as technical opportunities arise, which makes it uncertain if Waternet's measures, such as phosphate recovery, are the most beneficial in terms of the transition to a Circular Economy. Adaptive Management is a management framework, which can help to understand the context and uncertainties involved in finding the most sustainable solution in a given context through continuously learning and adjusting decision-making, and will therefore be applied to the governance of phosphate recovery from wastewater in Amsterdam.

1. Introduction

Worldwide phosphate is becoming scarce (Steen, 1998). Research shows that the stocks of mineral phosphorus will be depleted in 50 to 100 years. Phosphate is an essential and irreplaceable nutrient in the agricultural sector (Egle et al, 2016). Therefore, reusing and recovering phosphate is becoming attractive and important. Phosphate recovery from municipal wastewater at wastewater treatment plans (WWTPs) is an alternative (Bradford-Hartke et al, 2015).

The Municipality of Amsterdam has the ambition to transit to a Circular Economy (CE) (City of Amsterdam, 2015). Recovering phosphate from wastewater is part of this ambition. Several stakeholders play a role in realizing the ambition of the municipality (Van der Hoek et al, 2016). Waternet is responsible for the water management in and around Amsterdam, and is one of those stakeholders. Waternet sees wastewater no longer as a waste product, but as a source of sustainable energy, resources and clean water (Van der Hoek et al, 2015). Through this, Waternet hopes to become more resilient against possible future resource scarcities. However, according to van der Hoek et al (2016) there is a lack of adaptive planning with regard to the treatment of wastewater in the context of sustainability. Decisions about recovering measures are made as technical opportunities arise, also regarding phosphate recovery from wastewater, which make it uncertain if Waternet's measures are the most sustainable (according to the municipal ambitions). Moreover, according to the organizational structure in which Waternet operates, the municipality is not allowed to determine Waternet's wastewater measures (see figure 1). Waternet is the executive body of water management in Amsterdam, halfly coordinated by the Municipality of Amsterdam; halfly coordinated by the Waterboard of Amstel, Gooi and Vecht (AGV) (Waternet, 2013). The Waterboard AGV coordinates Waternet's practices regarding wastewater recovery. Yet, circular goals of wastewater treatment have been set on a municipal level, but have to be implemented by Waternet, which may have other priorities or ambitions.

Therefore, it is uncertain how stakeholders' goals –in this case Waternet's practice regarding phosphate recovery from wastewater and municipal circular goals– relate and/or are aligned. Also, it is unclear how the (uncertainties involved in this) relation should be understood to optimize management actions. Adaptive Management (AM) can help to understand the uncertainties involved in finding the most sustainable technical solution in a given context (Van der Hoek et al, 2016; Guest et al, 2009). Therefore, filling the knowledge gaps through AM is the objective of this research.

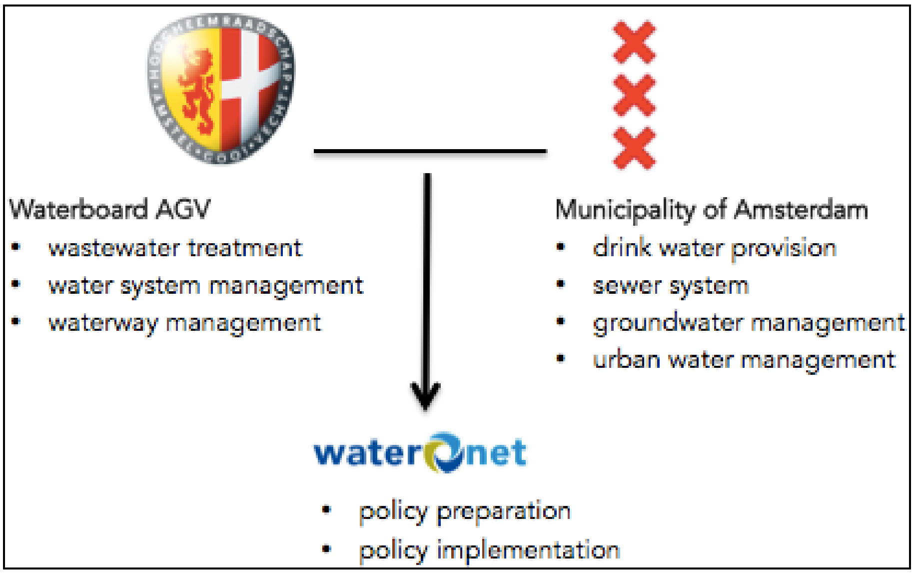

Figure 1. The organizational structure of Waternet (Waternet, 2013: I-platform online).

There is a lack of AM regarding governance of phosphate recovery from wastewater in Amsterdam (Van der Hoek et al, 2016). The research question is therefore:

How can an Adaptive Management approach contribute to a systematic analysis of the relationship between Waternet's practices of phosphate recovery from wastewater and Amsterdam's municipal goals of a Circular Economy?

Two sub-questions will contribute to answering the research question.

- Firstly, how do Waternet's practices of phosphate recovery from wastewater relate to Amsterdam's municipal goals of a Circular Economy?
- Secondly, how can governance of phosphate recovery from wastewater in Amsterdam be understood through Adaptive Management?

2. Theoretical Framework

It is widely accepted that resource management should reflect the complexities, variations and uncertainties in socio-natural systems to foster sustainability (Medema et al., 2008). AM provides guidelines on how to make sustainable decisions in an uncertain and changing context. Recovering phosphate from wastewater as part of a transition towards a Circular Economy (CE), being a complex process involving many uncertainties, could make use of AM. In this section there will be a theoretical description of 'Circular Economy' and 'Adaptive Management' to clarify the definition of the concepts for this research.

2.1 Circular Economy

''A Circular Economy is an industrial system that is restorative or regenerative by intention and design'' (Ellen Macarthur Foundation, 2013; p.7). It is an industrial system, because the linear model of resource consumption ('take-make-dispose') is replaced by an industrial model eliminating waste from the industrial chain by reusing materials to the maximum extent (Ellen Macarthur Foundation, 2013). There are two cycles in a CE: a bio-cycle, which regenerates materials without human intervention and a technical cycle, which recovers materials through human intervention. In a CE natural capital is enhanced and preserved through renewable resource flows. Renewable resource flows include circulation of all products and materials. Through circulation resources are used maximally, which is called optimized resource yield. In this way, negative externalities can be reduced and system effectiveness is fostered.

The city of Amsterdam is planning to become more sustainable through focusing on five transition pathways: renewable energy, clean air, a Circular Economy, a climate-resilient city and a sustainable municpality (City of Amsterdam, 2015). Regarding CE, the city of aims to [1] recover more resources and materials and [2] stimulate innovation, research and circular business activities. There are seven principles to realize the transition (City of Amsterdam, 2015: p.27).

- At its core, a circular economy aims to 'design out' waste. Waste does not exist when products are designed to fit within a cycle.
- All energy comes from renewable sources.
- Resources will be used to create (monetary) value.
- Products and cycles will be designed flexibly, which will allow changes.
- New business models should stimulate use of services rather than possession.
- Services should be managed on a regional level.
- Human activities should stimulate a sustainable existence of natural capital in ecosystems.

Thinking in terms of cycles, circularity, is essential in using raw materials and resources effectively to combat growing demand for resources and scarcities (City of Amsterdam, 2012).

2.2 Adaptive Management

With Holling's publication in 1978 '*Adaptive Environmental Assessment and Management*' AM received wide attention (Stankey et al., 2005). The potential of AM as a framework for managing complex environmental situations began to be recognized. Nowadays, AM has been identified as a management framework that addresses uncertainty in policymaking (Medema et al., 2008). Uncertainty is often a consequence of stakeholders who have differing views about appropriate management actions. Uncertainty can be reduced through learning. The feedback between learning and decision-making is a defining feature of AM (Dedick et al, 2012). There are two types of learning in AM, active and passive (Walters, 1986). Passive learning means that learning from management actions is only valued as it improves decision outcomes. Active means that learning is explicitely incorporated in management actions to improve decision-making.

AM is a process consisting of a deliberative and iterative phase (Williams, 2010). The key components of AM are put in place in the deliberative phase, and the components are combined in a sequential decision process in the iterative phase, see figure 2. The key components of the deliberative phase are the following.

- Stakeholders. Stakeholders should assess the resource problem cooperatively, and reach an agreement about its scope, objectives, and potential management actions.
- Objectives. Objectives should be clear and measurable, to guide decision-making and determine progress in achieving management success.
- Alternatives. Stakeholders have the responsibility of identifying potential management actions (alternatives), and determining a useful selection out of these potential actions. The selection determines the flexibility of the project, and can cange over time as new information becomes available.
- Models. Models should be used to compare management alternatives in terms of their costs, benefits, and resource consequences to be able to make informed decisions. Models play a key role in representing uncertainty, because they determine what environmental factors are managed and what is known about the system being management.
- Monitoring. Monitoring should ensure that resources are adequately measured based on relevant performance indicators. During monitoring, predictions are compared to observed responses, to learn about the most appropriate measures and reduce the uncertainty.

The key components are put into a sequential process of decision-making and learning in the iterative phase. At the moment there is sufficient knowledge regarding management actions, an action is chosen from the available management alternatives (Williams, 2010). This is called decision-making. The action is continuously monitored, producing data to evaluate management interventions, and update and prioritize management options (Dedick et al, 2012; Williams, 2010; Stankey et al, 2005). During assessment alternatives (management actions) can be adjusted to enhance effectiveness. AM therefore includes flexible measures, which can be adjusted when consequences of management actions are understood sufficiently (Swanson et al., 2010). Adjustments can be made within the iterative phase, which is illustrated through the arrow to decision-making, or in the deliberative phase, which is illustrated through the big arrow (figure 2). If the iterative phase is successfully conducted, learning and decision-making have been encouraged through which the uncertainty related to management actions has been reduced (Williams & Brown, 2012).

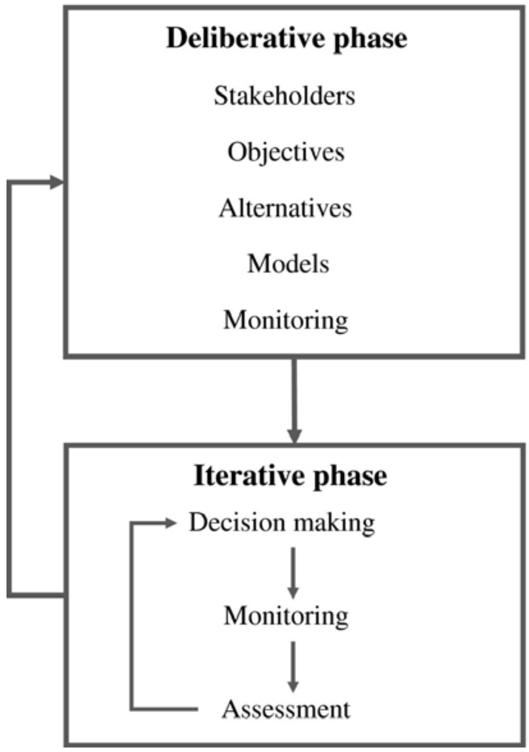

Figure 2. The deliberative and iterative phase in AM (Williams and Brown, 2014; p. 467).

To conclude, AM is a framework that allows continuously learning to improve management. It is useful when there is uncertainty regarding the impact of management actions, but an ability to diminish uncertainty through learning and adjusting (Allen et al., 2011). The challenge in using AM lies in finding a balance between gaining knowledge to improve future management and achieving the best short-term outcome based on current knowledge (Allan & Stankey, 2009).

3. Methodology

In this section the methodology of the research will be discussed. Firstly, the main concept will be defined. Secondly, the case studies will be introduced. Thirdly, the way of data gathering will be explained. And last, qualitative research criteria will be discussed.

3.1 Concepts

Conceptualisation can be understood as an operationalization to make concepts measurable (Bryman, 2012). The main concept in this research is 'governance of phosphate recovery from wastewater'. ''Governance is seen as a set of diverse practices that people are constantly creating and recreating through their concrete activity'' (Bevir, 2013: p.1). In this research, governance of phosphate recovery from wastewater in Amsterdam will be examined through the practices of two main actors, Waternet and the Municipality of Amsterdam, and their mutual relation. Specifically these two stakeholders are chosen, because their relationship regarding phosphate recovery cannot be explained according to the organizational structure shown in figure 1, yet, both are highly influential in the practice.

Neither of the stakeholders defined concrete, measurable indicators for governance of phosphate recovery, which will be explained in section 4.2.1 'Objectives'. Many quantitative and qualitative goals and indicators regarding the transition to a CE have been published by the Municipality of Amsterdam (City of Amsterdam, 2012; City of Amsterdam, 2015), but regarding phosphate recovery concrete practical targets have not been identified. Therefore, municipal governance is more broadly defined, as mentioned in the City of Amsterdam (2015): the ambition to recover more resources and materials from wastewater and to stimulate innovation, research and circular business activities. Waternet neither defined their governance of phosphate recovery specifically (de Danschutter, 2017). Broadly, Waternet aims to optimize phosphate recovery from wastewater in the long term to become more circular, through stimulating research regarding alternative sanitation (Waternet, 2016a).

To systematically analyse governance of phosphate recovery from the perspective of both actors, AM – a management framework consisting of a deliberative and iterative phase – will be applied. In figure 3 a schematic drawing is presented. In the first subquestion (SQ1, marked red) the relationship between the municipality and Waternet concerning phosphate recovery will be clarified. In the second subquestion (SQ2, marked green) AM will be applied to understand governance of phosphate recovery.

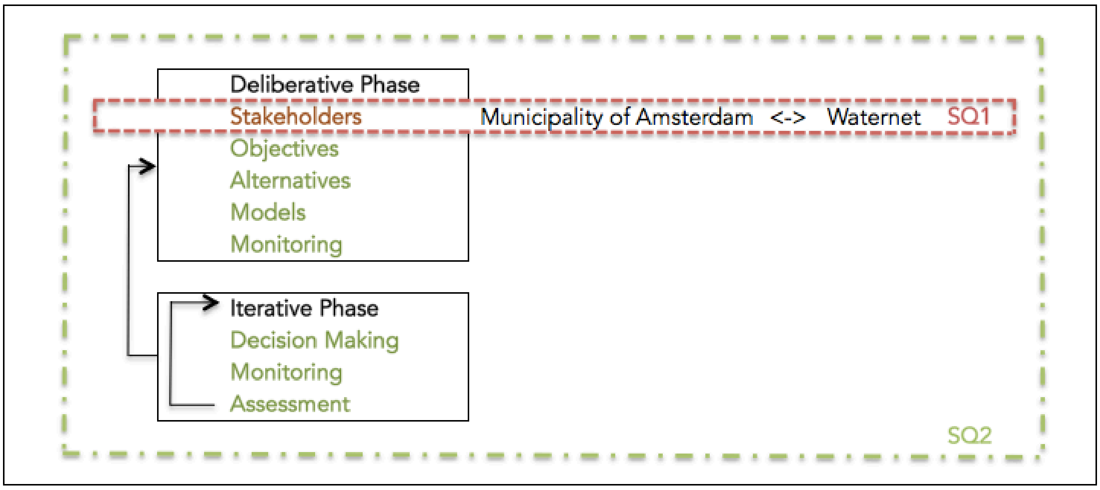

Figure 3.A schematic drawing of the components of AM that will be covered in the first subquestion (SQ1) and second subquestion (SQ2), see text for explanation (De Jong, 2017).

3.2 Cases

This research is based on qualitative data. Qualitative research is useful to acquire depth information and understand complexity in a phenomenon (Lazaraton, 2009). A small amount of units is used to obtain a deeper meaning (Bryman, 2012). Two case studies in Amsterdam have been selected in this research. Case studies are useful to acquire in-depth information on people, events or relationships bounded by a unifying factor, in this case the two actors that are both involved in governance of phosphate recovery, in a specific context. The first case is Fosfaatje at the *centralized* WWTP in Amsterdam West. In Fosfaatje phosphate is recovered as struvite (a mineralization of magnesium, ammonium and phosphate) to resolve an infrastructural problem, which has the unintentional benefit of being sustainable. The second case is New Sanitation in Buiksloterham. In Buiksloterham phosphate is intentionally recovered on a *decentralized* scale to understand how this process can be optimalized. The exact locations of the case studies is shown in figure 4a, b and c.

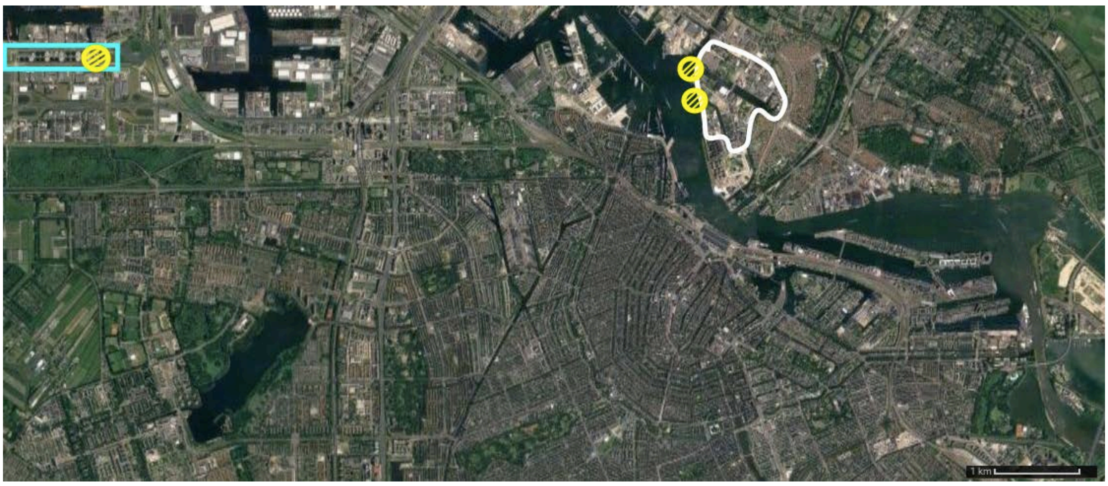

Figure 4a. A map of Amsterdam with the centralized WWTP and Fosfaatje (left), and Buiksloterham and the two possible locations for decentralized sanitation (right) (De Jong, 2017).

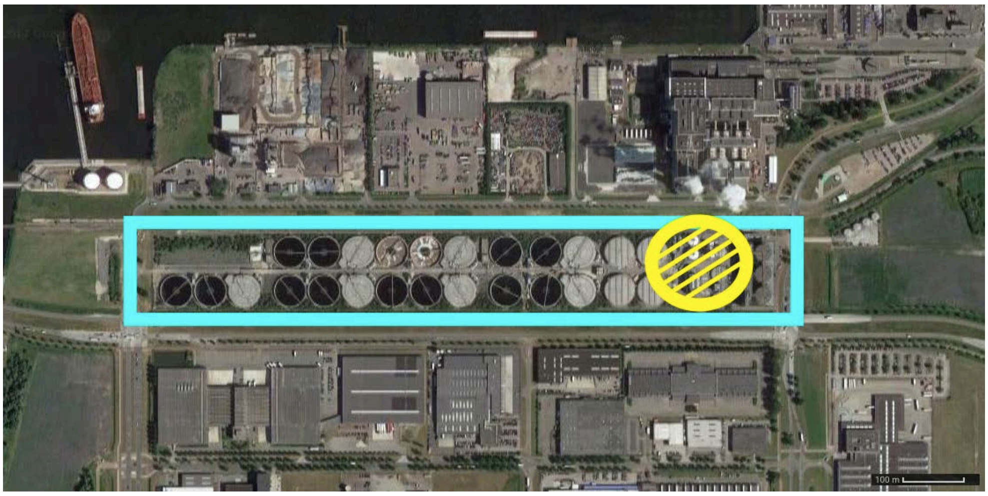

Figure 4b. A zoom in on the location of the centralized WWTP with Fosfaatje (De Jong, 2017).

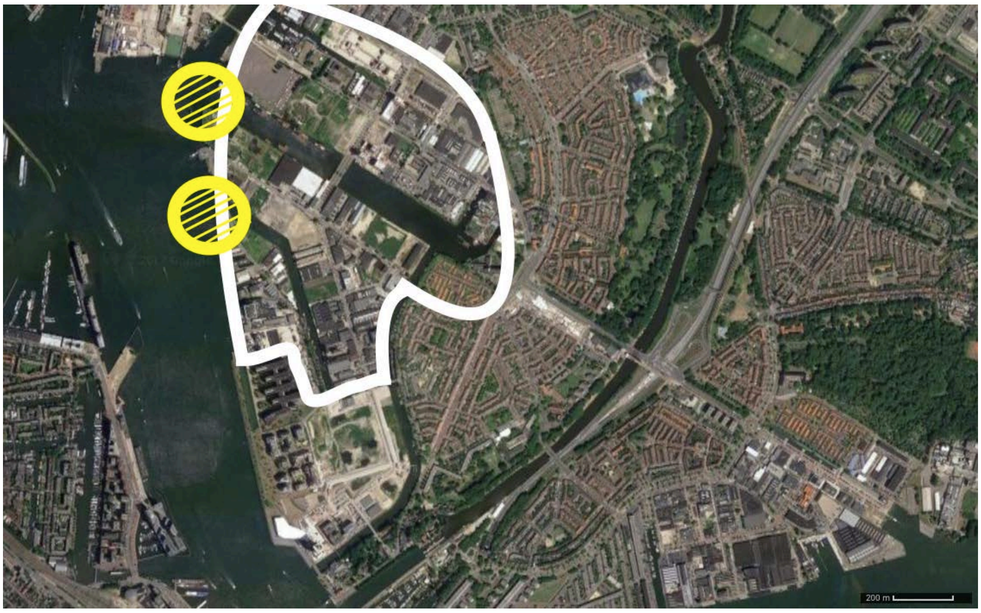

Figure 4c. A zoom in on the location of decentralized WWTPs in Buiksloterham (De Jong, 2017).

Two case studies, centralized phosphate recovery (all wastewater treated in a conventional plant) and decentralized phosphate recovery (local streams of wastewater treated separately, closer at the source) are systematically analysed to understand governance of phosphate recovery from wastewater in Amsterdam. Analyzing two case studies, which cover an extended timeline, can provide insights on the development of governance over time, see figure 5.

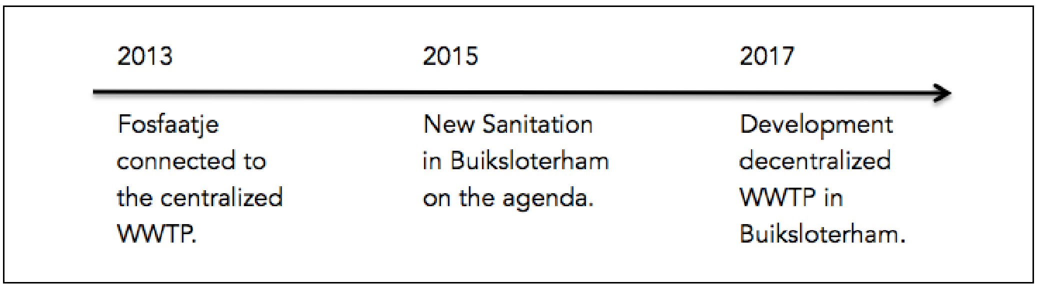

Figure 5. Timeline covered by the two case studies (De Jong, 2017).

Fosfaatje – initiative at the central Wastewater Treatment Plant
In 2006 the Waterboard AGV and the Municipality of Amsterdam established a new centralised WWTP in Amsterdam West (Van Nieuwenhuijzen et al., 2006), in which Waternet is responsible for the management of the plant (Van der Hoek et al, 2016). The WWTP has the capacity to treat urban wastewater for 1 million people and is one of the biggest sewage water purification systems in the Netherlands (Stowa, 2010; Van Roekel, 2013). Urban wastewater can be defined as household wastewater or a mixture of household water and business wastewater, rainwater, groundwater or other wastewater (Kenniscentrum Infomill, 2008). Generally, the large-scale infrastructure of the central WWTP has a long depreciation period, in theory 100 years (Gaton, 2017; De Danschutter, 2017). Flexibility is incorporated in the design, with focus on easy operations and maintenance (Van Nieuwenhuijzen et al., 2006). The WWTP is designed to be able to expand its capacity by 10%. Furter, the design of the WWTP made it possible to recover phosphate biologically. In practice, however, chemicals were added such as ferric chloride to succeed the general practice of wastewater treatment. These chemicals caused blockades of struvite formation in buffers and pipes (Klaversma et al, 2013). As a remedy, a technique was developed to recover struvite from wastewater (de Danschutter, 2017). To implement the technique, the installation 'Fosfaatje' was established (Van der Hoek et al., 2015). Fosfaatje was connected to the existing central WWTP in 2013 (de Danschutter, 2017).

New Sanitation – decentralized initiative in Buiksloterham
New Sanitation is a project to recover resources from wastewater in a decentralized system (van Duin, 2015). Decentralized WWTPs are simple, local plants, which treat separated streams of wastewater (Bradford-Hartke et al, 2015). Streams of wastewater are separated to recover resources more efficiently (STOWA, 2010). Black wastewater is toilet water, from which phosphate can be recovered. Grey water is remaining household water.
Buiksloterham is a pilot project in which decentralized sanitation will be implemented. Waternet and the municipality, together with several other stakeholders, are involved in Circular Buiksloterham to work on innovations and experiment with alternative measures and materials –that are now forbidden– to foster circularity (City of Amsterdam, 2016a; Savini et al, 2015). There is a focus on the scale of the neighbourhood – circular developments at a local scale – while at the same time taking into account the interrelationships between neighbourhoods and the wider urban area. Buiksloterham is in the process of gradually changing to a local circular economy with 3500 new houses and 200 000 square meters of working space (Circular Buiksloterham, 2014). The decentralized plant will be floating due to a lack of space (Gaton, 2017), and there are two possible locations for the installation, see figure 4 (DELVA, 2016).

3.3 Data Collection

Data is obtained through primary data as well as secondary data. Semi-structured interviews provide the primary data. Semi-structured interviews contain specific bullet points or questions that will be asked to all participants, but can be adjusted

throughout the interview to obtain the necessary data (Bryman, 2012). The questions are open which gives freedom to the participants to answer the question in their own way. Employees working for Waternet and the Municipality of Amsterdam have been interviewed. These employees are key figures; which means that they are able to provide meaningful insight into the governance of phosphate recovery, from either the perspective of the municipality or Waternet. Therefore, only four extensive semi-structured interviews have been conducted to gain insight into the situation. This makes the sample *purposive* (Bryman, 2012). There are two cases, and for each case two employees with relevant expertise on the case, one working for Waternet and one working for the municipality, have been interviewed. Jacqueline de Danschutter, program manager Innovation at the sustainability department of Waternet and Edgar Zonneveldt, Advisor Circular Economy and Sustainability at the Municipality of Amsterdam, provided data (mainly) concerning Fosfaatje. Marina Gaton, Project Leader at Waternet in Buiksloterham, and Sladjana Mijatovic, Program Manager Circular Economy in Buiksloterham at the Municipality of Amsterdam, provided data (mainly) concerning Buiksloterham. Also, during interviewing more respondents and sources have been identified. These respondents and sources have been used to gain background and contextual information. This is called *snowball sampling*, which means using specific participants and acquire more participants through their connections (Bryman, 2012). Additional information has been acquired through conversations with experts at meetings and conferences.
The primary data will be triangulated with secondary data. Secondary data such as policy documents and academic articles are reviewed and used as sources.

3.4 Qualitative Research Criteria

The methodology of this research affects the research criteria of qualitative research as following (Bryman, 2012).

- The reliability questions whether re-doing this research would generate the same results or not, is relatively low. Municipal policies can change every four years as a function of the election cycle; ambitions and responsibilities can change due to the political colour of the board (Mijatovic, 2017). Also, the interviews with four specific respondents are semi-structured, which means that questions changed dependent on the information provided. Re-doing this research, with other respondents, will provide different information. Further, we are in a transition towards a CE. During this transition knowledge and opinions will change due to innovation and changing circumstances. The results on governance will therefore only be useful temporarily. Nevertheless, the results on how to understand and apply AM can be useful in the long term.
- The measurement validity questions whether the measurements reflect the concept or not, is moderate. On the one hand literature does not provide concrete guidelines for measuring governance of phosphate recovery, making it uncertain if the measurement carried out will be accurate, on the other hand interviews with key figures will guarantee that concepts and data are understood correctly. Further, a case study will provide contextual and

in-depth information, which will minimize the risk of a lack of accurate measurements. Moreover, primary and secondary data are complementary; secondary data can be confirmed or contradicted through primary data and vice versa. This will make it unlikely that the measurements will be one-sided and subjective.

- The external validity questions whether the results can be generalised or not, is moderate. If AM can help to understand the relationship between two stakeholders and the uncertainties involved in resource (e.g. phosphate) recovery from wastewater in Amsterdam, the results may be applicable to other cases. Nevertheless, generalization is not a goal of this research.

4. Results

In this section the case studies will be analysed and the results will be presented. The presentation of the data is structured according to the sub-questions mentioned in the introduction. Therefore, in the first chapter (4.1) the relation between Waternet and the municipality is analysed, which is the first step in the application of AM to governance of phosphate recovery. In the second chapter (4.2) AM will be applied to the relation examined in chapter 4.1, to systematically analyse the functioning of governance of phosphate recovery.

4.1 Relation Waternet's Practices and Municipal Circular Goals

The municipality has expressed the ambition to recover phosphate from wastewater as part of the transition towards a CE, but does not carry the responsibility of determining wastewater measures taken by Waternet. Therefore, the question 'How do Waternet's practices of phosphate recovery from wastewater relate to Amsterdam's municipal goals of a Circular Economy?' arises.

4.1.1 Phosphate Recovery in Fosfaatje

Waternet has the ambition to become climate neutral in 2020 through wastewater treatment and recovering energy and raw materials from the water cycle (Waternet, 2016b). The municipality has the ambition to transit to a CE, in which resources are recovered from wastewater (City of Amsterdam, 2015). To achieve these ambitions, Amsterdam has to become a circular living lab in which (technological) innovations are developed, and a circular ecosystem in which cycles are closed and stakeholders work together (City of Amsterdam, 2016a). Phosphate recovery from wastewater corresponds with both the ambitions of Waternet and the municipality, and fits within the *technical cycle* of a CE (see section 2.1).

Two complementary studies were performed to identify the most sustainable method for phosphate recovery. De Danschutter et al (2011) used a multi-criteria analysis of costs, space-availability, performance reliability, innovation, flexibility and sustainability to evaluate the techniques of phosphate recovery. Klaversma et al (2013) used a Life Cycle Assessment (LCA) to evaluate the techniques, in which the chemicals required, used electricity for aeration, produced electricity and recovered phosphate were taken into account. Although every technique has advantages and disadvantages (Symposium Phosphate, 2017), both research showed that the most beneficial technique of phosphorus recovery –in the WWTP Amsterdam West– is extracting struvite from fermented sludge. Struvite can be extracted through the addition of magnesium chloride, instead of ferric chloride. This technique is called struvite precipitation (Van der Hoek et al, 2016) and reduces the environmental impact of phosphate recovery in three ways (Klaversma et al, 2011). First, less chemicals such as ferric chloride, iron and aluminium salts are used. Second, the dewaterability of the digested sludge increases electricity production since dry sludge can easily be burned. Third, recovered struvite becomes available for usage.

Therefore, the installation Fosfaatje has been established to implement this technique.

Not explicitly mentioned by two studies is that cost-savings were the main driver for the construction of Fosfaatje, rather than sustainability considerations only (de Danschutter, 2017; Zonneveldt, 2017). Struvite production from fermented sludge in Fosfaatje results in a reduction of maintenance costs. The installation is financed with the money saved due to a reduction of infrastructural problems (de Danschutter, 2017). The investment costs of Fosfaatje are €4 million, while the expected savings are €400,000 a year (Klaversma et al, 2013).

Fosfaatje was established to solve an infrastructural problem and has the additional benefit of fulfilling a sustainability target. Subsequently, the municipality formulated a current and future perspective on the phosphate cycle (City of Amsterdam, 2012). In the current perspective, the Netherlands import phosphate in the form of mined phosphate ore and biomass. The phosphate can enter the consumer via food chain. Thereafter, phosphate is lost via sewers. The cycle is incomplete. In the future situation, the Netherlands no longer imports phosphate ore, only biomass. Where possible this phosphate is either recovered by the food-processing industry or from wastewater at a treatment plant. Recovered phosphate can be sold on the phosphate market. Phosphate becomes trade.

An initial step towards a closed phosphate cycle was taken with the signing of the Green Deal Phosphate Recycling Chain Agreement on 4 October 2011 (City of Amsterdam, 2012). Almost twenty parties, including the national government, the City of Amsterdam, the Association of Regional Water Authorities, Wageningen University and ICL Fertilizers, expressed the ambition to bring as much secondary phosphate as possible back into the cycle within two years. The agreement aims to turn an environmental problem into an economic opportunity.

4.1.2 Phosphate Recovery in New Sanitation in Buiksloterham

The municipality also formulated a current and future vision for the water cycle, in which phosphate is mentioned (City of Amsterdam, 2012). Currently, phosphate is recovered at conventional sewage treatment plants, and in experimental projects in which urine is separated to recover phosphate more efficiently (e.g. in the Heineken Experience). In the future, streams of grey and black water are separated at the source and treated in a local (decentralized) purification facility, to optimize the process of resource recovery. Black water will be used to recover phosphate.

A better understanding on how to optimize phosphate recovery through decentralized sanitation is developed in New Sanitation in Buiksloterham, in which both Waternet and the municipality are involved. Learning, through New Sanitation in Buiksloterham, is explicitly incorporated in management actions, which is called *active learning* (see section 2.2). According to de Danschutter (2017) Waternet is involved in Buiksloterham to acquire new knowledge concerning technologies, business models and social acceptability related to measures that are currently not implemented or legally allowed (yet). Experiments with decentralized sanitation stimulate innovation, which could in turn improve the current wastewater treatment system. The municipality, on the other hand, is mainly involved to facilitate the project, in terms of knowledge, legal obstacles, finances (subsidizes), engagement of stakeholders and the allocation of land, according to Zonneveldt (2017), but also to learn and innovate regarding a CE, according to Mijatovic (2017). The Buiksloterham area is (partly) owned by the municipality, leaving the municipality the opportunity to develop the area into a circular living lab after the crisis of 2007, when there was no interests of investors (Mijatovic, 2017). The municipality finds it important to support citizens that develop circular projects.

4.1.3 Complementarity between Waternet and the Municipality

Waternet faced high maintenance costs due to infrastructural problems with uncontrolled struvite formation (Zonneveldt, 2017; de Danschutter, 2017). Therefore, Waternet started to recover phosphate centrally from wastewater to resolve the problem. An unintentional benefit was fulfilling a sustainability target. Phosphate –a potential scarce resource– becomes available as secondary phosphate. The establishment of Fosfaatje is a solution, which is both economically and environmentally sustainable. Subsequently, the municipality incorporated phosphate into its circular goals. Waternet and the municipality are both interested in producing new knowledge upon circularity and therefore work together in Buiksloterham, to optimize the phosphate recovery process. However, their approaches and reasons for involvement differ. See figure 6 for an overview of the development of governance of phosphate recovery.

To conclude, Waternet is the operator of wastewater treatment, which is the responsibility of the Waterboard, not the municipality (figure 1). Nevertheless, the municipality included phosphate into its circular goals. Waternet's practices are an important contribution to the municipal goals (de Danschutter, 2017). The Municipality of Amsterdam has the ambition to transit to a CE, and Waternet has the ambition to become climate neutral in 2020 (City of Amsterdam, 2015; Waternet, 2016b). Both the municipality and Waternet have the ambition to recover phosphate to achieve their objectives. There is continuous collaboration between Waternet and the municipality (Mijatovic, 2017; de Danschutter, 2017). Still, this does not mean that the implementation of phosphate recovery is not uncomplicated. Therefore, the next chapter will focus on how AM can set out (un)certainties that influence the implementation of phosphate recovery.

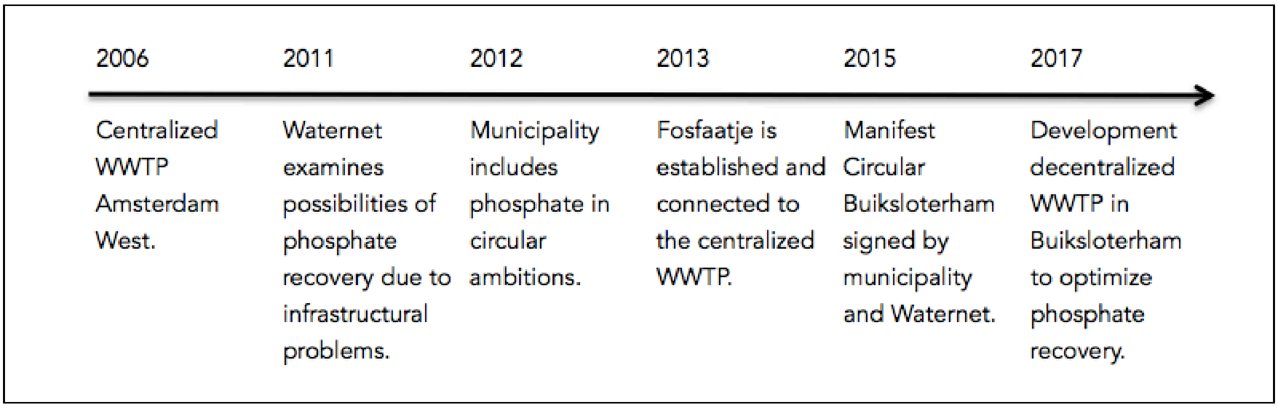

Figure 6. A timeline of the development of governance of phosphate recovery from wastewater in Amsterdam (De Jong, 2017).

4.2 Applying Adaptive Management in Phosphate Recovery

AM can help to identify the most sustainable solution in a given context (Van der Hoek et al, 2016). The framework allows managers to determine systematically whether management activities are succeeding or failing to achieve objectives (Williams & Brown, 2012). The central question in this chapter is 'How can governance of phosphate recovery from wastewater in Amsterdam be understood through AM?'. An overview of the results can be found in the end of this chapter, in figure 7.

4.2.1 Deliberative Phase

In the deliberative phase the key components of AM are put in place. The key components are stakeholders, objectives, alternatives, models and monitoring plans. In this research models and monitoring plans overlap, and are therefore combined. Important to note, AM is applied to systematically analyze governance of phosphate recovery, and not provide recommendations on how governance should function.

Stakeholder involvement

The Municipality of Amsterdam and Waternet are stakeholders in phosphate recovery from wastewater, with different responsibilities. Waternet's practices regarding phosphate recovery and the municipalities' circular goals are related in a way that Waternet's project 'Fosfaatje' stimulated the municipality to include phosphate into its circular goals, as explained in the previous chapter. Waternet and the municipality are both interested in producing new knowledge upon circularity and therefore work together in Buiksloterham, to optimize the phosphate recovery process. There is continuous collaboration between Waternet and the municipality.

Objectives

Both the municipality and Waternet have the objective to recover phosphate to become more circular, although Waternet's interest were initially economic gain. The municipality did not set concrete performance indicators for the transition to a circular economy regarding phosphate recovery from wastewater. According to Mijatovic (2017), this has to do with the fact that there is not enough knowledge about the most sustainable transition pathway for nutrient recovery, and that there is a chance of a lock-in due to interacting resource recovery measures. With regard to the former, phosphate recovery from wastewater is still in a developing phase, which makes it hard to determine concrete performance indicators for management actions. With regard to the latter, measures concerning resource recovery from wastewater can affect each other, because different measures require different interventions in the WWTP's. Implementing one intervention might affect other interventions negatively, which is a lock-in measure (see section 4.2.2 'Follow-up monitoring'). Despite these uncertainties, the municipality has expressed the ambition to reduce greenhouse gas emissions with 40% by 2025 (City of Amsterdam 2009). This implies a reduction of 3,100,000 ton CO_2-eq a year (Van der Hoek et al, 2013). Waternet has the ambition to become climate neutral in 2020 through, among other measures, wastewater treatment and recovering raw materials from the water cycle (Waternet, 2016b). Phosphate recovery in Fosfaatje is a measure to reduce CO2, due to a decrease in electricity use for wastewater treatment and an increase in electricity production from dewatered sludge in wastewater (Klaversma et al, 2013). Phosphate recovery in Fosfaatje can reduce greenhouse gas emissions with 1,120 ton CO2-eq per year. This is 3% of 33,000 ton CO2 Waternet is planning to reduce through nutrient recovery and 0,36% of 3,100,000 ton CO2 the municipality is planning to reduce a year.

The municipality and Waternet work together on new sanitation in Buiksloterham. In 2020 there should be a concrete view upon local resource recovery and usage in Buiksloterham (Circular Buiksloterham, 2014). One of the ambitions is maximum recovery of nutrients from wastewater in a decentralized sanitation system (Manifest Buiksloterham, 2015). In Buiksloterham, generic and specific lessons will be developed (Mijatovic, 2017). Generic lessons can be used and copied in another area. Specific lessons are context-dependent and cannot simply be copied. If the business case turns out positively, as a generic lesson, the objective is to implement decentralized sanitation in other areas in Amsterdam (Zonneveldt, 2017). This could be in the new build areas, given that the municipality has the ambition to build 50 000 new houses which all need to be connected to sanitation (City of Amsterdam, 2016b). In this way, Buiksloterham functions as an example for new sanitation, to prevent that new houses will be connected to conventional sanitation (Symposium Phosphate, 2017).

Generally, a more concrete objective for phosphate recovery in Amsterdam is lacking due to uncertainties about the technical process (de Danschutter, 2017), and the most promising business case for nutrient recovery (Mijatovic, 2017).

Alternatives

As already mentioned, two complementary studies were performed to identify the most sustainable method for phosphate recovery. Both research showed that the most beneficial technique of phosphate recovery is extracting struvite from fermented sludge. Struvite precipitation in Fosfaatje is a flexible measure. The installation is designed with new materials and kept its industrial look to save costs. It has a planned lifetime of 15 years, which allows alternative measures to be implemented after a relatively short period. Meanwhile, Waternet is continuously doing research to increase phosphate recovery rates in Fosfaatje in a cost-neutral way (de Danschutter, 2017). In this way, the management strategy of Waternet includes innovation. The management strategy of the municipality is similar to Waternet's. Both stakeholders stimulate innovation, research and circular activities.

An alternative measure is phosphate recovery at decentralized sanitation, e.g. in Buiksloterham. A separate sewage system will distinguish grey and black wastewater. Vacuum toilets use little water (1 liter per flush) compared to normal toilets leaving the black wastewater highly concentrated with resources (Waterboard AGV, 2016; LEAF, 2015). This makes it possible to recover more phosphate more efficiently. This measure is flexible too, because the decentralized WWTP has a modular design with four components, which can be adjusted or replaced to optimize resource recovery, if necessary (Gaton, 2017).

Models & Monitoring Plans

To make informed decisions, it is important to understand the consequences of management actions through models (William & Brown, 2014). The municipality is still in the process of finding the most promising model in terms of resource recovery from wastewater as part of the transition towards a CE, including phosphate recovery (Mijatovic, 2017). It tries to develop a model in which decentralized and centralized sanitation are combined to stimulate resource recovery (and circularity). Waternet models the impact of resource recoveries through a Life Cycle Assessment (LCA). LCA is a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction to materials processing, manufacture, distribution, use and disposal or recycling (Klaversma et al, 2013). One of the indicators of a LCA is the climate footprint. The climate footprint is an inventory of the greenhouse gas emissions released through using energy, resources and transport (de Danschutter, 2017). Fosfaatje will be monitored through climate footprint.

In Buiksloterham there is a plan to establish monitoring programs for environmental ánd social impacts (Gaton, 2017). It requires a clear view of the social acceptability and safety of inhabitants before implementing and/or scaling up decentralized sanitation. Providing information on the use of vacuum toilets to inhabitants is an example. The impact of information provision will be monitored through surveys.

4.2.2 Iterative Phase

In the iterative phase the key components are combined in a sequential process of decision-making and learning. Therefore, decision-making, follow-up monitoring and assessment will be applied to governance of phosphate recovery.

Decision-making

Wastewater from both businesses and households is treated in the centralized WWTP (Van der Hoek et al, 2016). After treatment, a small part of the clean water is disposed as surface water. The rest, including materials such as sludge, is transported to the sludge treatment. The fermented sludge is transported to Fosfaatje, in which the addition of magnesium chloride makes recovery of phosphate possible. This technique turned out to be the most sustainable, based on the LCA (de Danschutter, 2017), and was therefore implemented in 2013. The wastewater chain can be seen in figure 5.

Figure 7. Wastewater treatment process in centralized sanitation in Amsterdam, from the source to the resource recovery (van der Hoek et al, 2016; p. 59).

In the decentralized sanitation system in Buiksloterham black wastewater is transported to a local, floating purification plant, after it is derived from vacuum toilets (Waterboard AGV, 2016), see figure 6 (in Dutch). Due to vacuum toilets, almost 85% of the phosphate can be recovered, using less energy than is needed for phosphate recovery at centralized sanitation. In fact, energy is generated from grey wastewater at the plant (Gaton, 2017). This energy (heat) can in turn be used in the houses. In this way, the investments of a separate sewage system and vacuum toilet can be financed by [1] the cost-savings of reduced use of drinking water for flushing toilets and [2] the energy recovered from grey wastewater for heating houses.

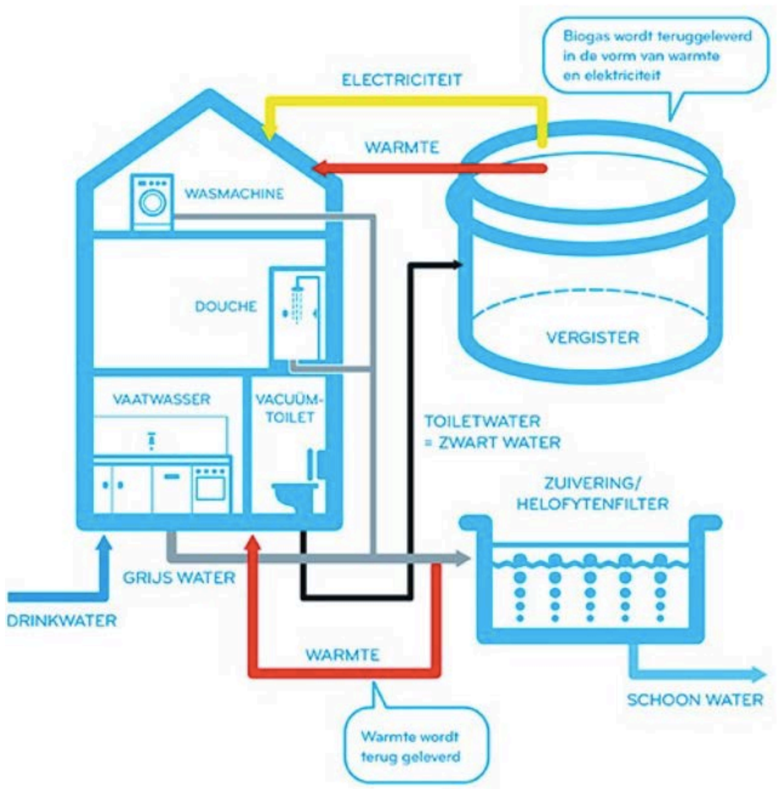

Figure 8. A schematic drawing of decentralized sanitation in Buiksloterham, in which black and grey water is separated at the source (Klaversma, 2017: online Bureau de Helling, Nieuwe Sanitatie).

Follow-up Monitoring

There is collaboration between Waternet and the municipality, they strive for the same objective, which is phosphate recovery from wastewater to become more circular, provided that the business case is positive (de Danschutter, 2017; Mijatovic, 2017). Based on both policy documents and interviews, achieving this objective is challenged by factors such as the performance of Fosfaatje; the low prices of phosphate; legal obstacles; the ambition of Amsterdam to enlarge the city; (re)arrangement of responsibilities; and other resources being recovered.

I. Currently, 95,000-ton of phosphorus flows through wastewater from both businesses and households in the Amsterdam area per year (van der Hoek et al, 2016). In Fosfaatje, only 16% of the phosphorus in sludge can be recovered as struvite, and only 75% is of useful quality (Gaton, 2017). Fosfaatje can treat 2000 m^3 sludge per day, which equals 1000-ton struvite a year (van der Hoek et al, 2016). However, Fosfaatje is not functioning as planned (de Danschutter, 2017). The installation faces technical maintenance problems. The main part of phosphate in wastewater disappears before recovery, or sticks to the sludge (Symposium Phosphate, 2017). The investments necessary to resolve these problems are higher than the returns from phosphate marketing (de Danschutter, 2017).

II. Low phosphate prices on the world market are an important factor (de Danschutter, 2017; Gaton, 2017; Zonneveldt, 2010; KAW, 2017). It is therefore neither profitable to recover secondary phosphate nor to explore for new phosphorus rock reserves (de Haes et al, 2012). Natural phosphate reserves are depleting, and the U.S. already stopped exported it to keep it for the domestic market (Zonneveldt, 2017). The depletion of phosphate is an urgent sustainability problem because it is an irreplaceable element for food production (Symposium Phosphate, 2017). However, there is rather a surplus than shortage of phosphate in the Netherlands. Phosphate is imported through biomass. After the phosphate is consumed, it either ends up as feces in our toilets or is flushed away elsewhere (Zonneveldt, 2017). The phosphate cycle is open. Producing fertilizer from struvite in wastewater (done for instance by ICL Fertilizers) and exporting this to the countries where we import our biomass from, or to European countries that demand phosphate (Mijatovic, 2017) would close the cycle. The phosphate problem should be addressed on an international scale (Symposium Phosphate, 2017). Nevertheless, once phosphate will be excessively scarce world wide, the business case will develop itself, due to rising prices (Mijatovic, 2017. Scarcity, urgency and prices of a resources are highly correlated. The market will find the solution.

III. Dutch legislations regarding the creation of a phosphate market are another factor (Savini et al, 2015). When Waternet found out that infrastructural problems in the WWTP Amsterdam West were caused by spontaneous accumulation of struvite formation (phosphate) in the pipes, the idea was raised of capturing phosphate in an installation. At that time, however, phosphate was framed as 'waste' in legislations. This disabled Waternet of capturing and selling phosphate. In January 2015 the Dutch Fertilizer Act was established (Nutrient Platform, 2015). Still, phosphate cannot be sold directly (de Danschutter, 2017).

IV. If there is no clear, legally allowed market for phosphate, the question is why 50,000 new houses built by the municipality should be connected to decentralized sanitation, which aims to increase the efficiency of phosphate recovery? There are two options of sanitation for the new houses in Amsterdam. Firstly, there is the option of improving centralized sanitation. The central WWTP is functioning well, but is almost full, and will only have the capacity to treat water for the new houses if rainwater will be separated (Gaton, 2017). Rainwater is relatively clean, and does not need the full treatment process. If rainwater is separated from the wastewater; capacity is freed up to treat wastewater for new houses. Secondly, there is the option of decentralized sanitation. Decentralized sanitation could enhance the recovery of both energy and nutrients from wastewater (Symposium Phosphate, 2017). It requires investments in terms of behavioral changes (e.g. flushing chemicals in toilets) and finances. With regard to the latter it is uncertain if the municipality is willing to reserve land for a local installation in every neighborhood, because of the drive to sell as much land (houses) as possible after the recession of 2007 (Symposium Phosphate, 2017). But, according to Enna Klaversma in a Waternet Meeting (2017) investments need to be made anyway because tipping points in centralized sanitation can be found in Amsterdam. In other words, both centralized and decentralized require investments (Gaton, 2017).

V. This is where another factor comes into play, because (financing) a new sewer system is the responsibility of the municipality, and treating the wastewater the responsibility of the Waterboard AGV. WWTP's and sewage systems have different depreciation periods, which make it uncertain when to invest in new sanitation, who pays what, and how to organize a transition towards new sanitation (Symposium Phosphate, 2017). With regard to the latter, it requires a clear view upon the possible areas in which centralized and decentralized sanitation can be combined, and the responsibility of stakeholders to manage these systems (Mijatovic, 2017; KAW, 2017). In fact, new sanitation may require a re-arrangement of the responsibilities. Responsibilities of all stakeholders change when transitioning to a new business model (e.g. new sanitation).

VI. The last factor is the interaction between resource recovery measures from wastewater. In general, choosing an option for recovering resources can limit the possibilities for other technical option(s) because measures interact (Van der Hoek et al, 2016). For twenty-one recovery measures it was examined how they affect the phosphorus recovery in Amsterdam:

- In most cases, eighteen out of twenty-one measures, the measures that affect phosphorus recovery positively, do not affect other resources which can be recovered from wastewater negatively. Struvite precipitation in Fosfaatje, a measure which obviously affects phosphate recovery positively, does not affect the other resources negatively, because phosphorus recovery takes place after sludge is fermented and biogas is produced. This is called a no-regret measure: a measure that can be implemented in several strategies. According to Gaton (2017) it is beneficial that biogas production is not affected through Fosfaatje, within the context of Waternet's ambition to operate climate neutral, which is a priority.

- In some cases the measures affect both phosphorus as well as another resource positively (win-win situation). Thermal Hydrolysis stimulates both phosphorus and alginic acid recovery, and is therefore a win-win measure: a measure that is beneficial for two or more goals.
- Out of twenty-one recovery measures only three have a negative impact on phosphorus recovery. For example, the measure 'cellulose recovery from primary sludge' slightly decreases phosphorus recovery. This is an important consideration for the WWTP in Amsterdam West because phosphate recovery measure requires minimum phosphate concentration to be effective. Further, the Green Deal in 2015, signed by both Waternet and the municipality, stated that there is an ambition to recover cellulose from sludge at wastewater treatment plants (City of Amsterdam, 2015). At the same time, there is the ambition to close the phosphate cycle. These measures for resource recovery interact and should be taken into account to prevent lock-ins. Lock-in measures limit the option of implementing another measure.

Assessment

Referring to the deliberative phase of AM, stakeholders such as Waternet and the municipality collaborate in centralized as well as decentralized sanitation. The organizational structure, however, does not allow the municipality to determine wastewater measures taken by Waternet (see figure 1). Neither of the stakeholders set concrete, measurable objectives for phosphate recovery in Amsterdam, due to uncertainties about the functioning process (de Danschutter, 2017; Mijatovic, 2017). The impact of phosphate recovery is modelled through a LCA and monitored in climate footprint, but de Danschutter (2017) and Zonneveldt (2017) argue that indicators should assess the scarcity of phosphate to indicate the sustainability.

Referring to the iterative phase, Waternet and the municipality both mentioned critical uncertainties. Phosphate is an essential nutrient and there is no substitute for it, but market prices of phosphate do not reflect the scarcity of the resource and remain low (Symposium Phosphate, 2017). Therefore, costs of maintenance problems in Fosfaatje outweigh the yields of phosphate marketing (de Danschutter, 2017). There is political commitment necessary to create a monetary value (Symposium Phosphate, 2017). Also, there are legal changes required to be able to close the phosphate cycle, on both a domestic and international scale. This requires a clear view on the chemical components of phosphate (to rule out the precense of micro-pollutants), and how secondary phosphate can compete with regular phosphate. Closing the phosphate cycle, through the creation of a market and removing legal barriers, is not the responsibility of the municipality, but the responsibility of the market (Mijatovic, 2017). Still, the municipality could lobby with the European Union in Brussels if asked by Waternet. Further, both Waternet and the municipality seek for a vision in which centralized and decentralized sanitation can be combined, to optimize circularity. In this regard – combining different projects including different measures – there should be a clear view upon interactions between measures, to avoid lock-in measures (van der Hoek et al, 2016). Although struvite precipitation in Fosfaatje as a measure does not limit alginic acid, bioplastic, cellulose and biogas production from wastewater, other measures do affect phosphorus recovery negatively.

Regarding Buiksloterham, Waternet and the municipality agreed upon actively experimenting with alternative measures to foster circularity. Both parties expressed the potential of decentralized sanitation to be implemented in new neighborhoods, provided that it is a proven technology and the business case is positive (Zonneveldt, 2017; Gaton, 2017; Mijatovic, 2017). Sustainability is a priority of Waternet, but it should not have an expensive price tag (de Danschutter, 2017; Mijatovic, 2017). At the moment the market prices of phosphate are low due to a surplus, which makes likely that locally recovered phosphate will be used by the local population for their gardens and rooftops (Gaton, 2017). In this way, the benefits of the increase in phosphate recovery rates through decentralized sanitation, in terms of the financial feasibility of the business case, are negotiable. Therefore, a complete transition towards a decentralized system over the coming decade would neither be desired nor cost-effective. The term 'New Sanitation' does not necessarily imply decentralized sanitation; it could be a combination of decentralized and centralized (Symposium Phosphate, 2017; Mijatovic, 2017).

To conclude, both parties mentioned factors that challenge the success of centralized and decentralized sanitation to recover phosphate from wastewater. Neither of them, however, reached the point of assessing these factors to adjust decision-making. According to Mijatovic (2017), assessing management actions is a very slow process in practice. Learning during the process of implementation is mostly not taken into account, in terms of capacity and money. Management actions can be adjusted only after innovations are fully implemented, which can take years in the case of Amsterdam. The challenge is therefore how to adjust already during the process of innovation.With regard to phosphate recovery from wastewater, decisions have been made, from which Fosfaatje and New Sanitation in Buiksloterham are results, but adjusting governance based on what is learned during the process has not yet happened (see arrows in figure 2). This can be concluded based on the uncertainties in policies, mentioned in the section 'Follow-up monitoring'. The loop of decision-making and learning, a defining feature of AM, in phosphate recovery from wastewater in Amsterdam is not yet closed.

Deliberative Phase	Fosfaatje	Buiksloterham
Stakeholders	Although Waternet and the Municipality of Amsterdam have different responsibilities, they collaborate on phosphate recovery to become more circular.	Waternet and the Municipality of Amsterdam work together in Buiksloterham to optimize phosphate recovery from wastewater.
Objectives	Waternet aims to be climate neutral in 2020, which will contribute to the municipal transition to a CE. A concrete objective for phosphate is lacking.	Waternet and the Municipality of Amsterdam both have the objective to optimize phosphate recovery from wastewater in decentralized sanitation.
Alternatives	Different techniques of phosphate recovery were examined, struvite precipitation in Fosfaatje turned out to be the most sustainable measure for the centralized WWTP.	Phosphate recovery through decentralized sanitation as an alternative measure to optimize phosphate recovery from wastewater, and to understand the chances and challenges of new sanitation.
Models & Monitoring Plans	Waternet uses LCA to model implications of management actions, and monitors phosphate recovery through climate footprint (GHG-reduction).	Waternet aims to model both technical and social implications of management actions.

Iterative Phase		
Decision-making	Fosfaatje is implemented to recover phosphate from wastewater in the Amsterdam area.	In Buiksloterham alternative measures, resource recovery through decentralized sanitation, will be tested.
Follow-up Monitoring	Fosfaatje faces uncertainties due to low recovery rates, low market prices, legal obstacles and interactions with other measures.	Not applicable yet.
Assessment	Waternet and the Municipality of Amsterdam collaborate, but did not set concrete objectives for phosphate recovery, due to uncertain factors: technical maintenance problems, low market prices, legal obstacles; expanding city; arrangement of responsibilities and interacting resource recovery measures. In pilot projects such as Buiksloterham alternative measures are tested to foster innovation, which might decrease uncertainty. However, loop of decision-making and learning is not yet closed.	

Figure 9. An overview of AM in phosphate recovery from wastewater in Amsterdam (De Jong, 2017).

5. Discussion

In this section there will be a focus on the challenges of applying AM to governance of phosphate recovery, and recommendations that might be useful for governance of phosphate recovery from wastewater in Amsterdam.

Challenges of Applying AM

AM has been used in this research to systematically analyze governance of phosphate recovery from wastewater in Amsterdam. Applying AM has been a challenge due to three reasons. First, AM is not (yet) explicitly used by neither of the stakeholders, although they implicitly have a lot of similarities with AM in their approaches. The theoretical components of AM that are conducted in this research, are not necessarily the components that are conducted in practice, which made it uncertain under which theoretical component information from practice had to be designated. In this way, it is acknowledged that information of practices that did not fit within the framework of AM are left unappointed. Second, governance of phosphate recovery from wastewater is in a relatively early phase. As Zonneveldt (2017) argued, there is an ongoing transition towards a CE, in which the most sustainable approach might still have to be developed. For example, several times during the interviews it was mentioned that current phosphate recovery is not a game changer in circularity in the Netherlands. In a meeting at Waternet (2017) it was said that recovering phosphate is ''peanuts'' in terms of circularity compared to recovering thermal energy. Recovering thermal energy would contribute significantly in terms of a reduction of greenhouse gas emissions ánd a positive business case, because there is a clear price for heat. Also with regard to Buiksloterham, it is a project in development, which makes it hard to determine problems and chances in this early phase (Mijatovic, 2017). Third, AM was applied to two stakeholders that are highly influential in governance of phosphate recovery from wastewater in Amsterdam, yet, not the only stakeholders involved in the practice. Therefore, the way in which governance of phosphate recover was measured is not comprehensive, and in all probability leaves a lot to be desired. It is therefore acknowledged that this research might leave information unnoticed.

Recommendations

In this research a systematic overview of governance regarding phosphate recovery from wastewater has been set forth, rather than recommendations are being made. Nevertheless, the Waterboard Vallei and Veluwe – which treats wastewater for the Amersfoort area in their WWTP– are in a far developed stage of recovering phosphate from wastewater to become more sustainable and circular. In fact, the Waterboard has a closed business case regarding phosphate recovery from wastewater, which was explained and illustrated during the guided tour at the WWTP (Symposium Phoshate, 2017).Therefore, based on a success story of the Waterboard Vallei and Veluwe, and the concrete recommendations suggested at the Symposium Phosphate (2017) for Waterboards to close the phosphate cycle, some statements might be useful for governance of phosphate recovery in Amsterdam.

1. The goal for phosphate recovery should be clear. If phosphate is recovered from wastewater to combat scarcity, it is useful to have a concrete market. In Vallei and Veluwe the recovered phosphate will be transported to England, to be used in the potato industry for the coming 10 years. This ensures security of the business model. See figure 8a for the product.
2. In Vallei and Veluwe there is a major focus on the chemical structure of phosphate, which makes it legally allowed to sell the product. It is assured that phosphate does not contain micro-pollutants such as medical remnants. The structure of the granules can be seen in figure 8b.

Figure 10. Phosphate 'Crystal Green' on the right (10a) and the structure of the phosphate on the left (10b) (De Jong, 2017).

3. Wastewater should not be framed as ''waste'' anymore. Waste implies an end stage, whether it should be seen as a starting point for generating resources. Renaming the WWTP in Amsterdam West as a ''Factory for Energy and Resources'', which is already the case, creates an attractive label for marketing purposes.
4. Although there is a surplus of phosphate in the Netherlands and thus no economic driver, geopolitics (U.S. politics, see section 'Follow-up Monitoring') may become a major threat to our phosphate security, which could be a reason to become more independent through recovering secondary phosphate.
5. Before thinking in terms of decentralized sanitation, there is an agreement on the necessity to create a more coherent vision for the circular city (Mijatovic, 2017; KAW, 2017; Gaton, 2017) in which both the organizational and political challenges of New Sanitation are addressed. The underground of Amsterdam is filled with sewage pipes and other transport systems. Is it physically and organizationally possible to lay new (extra) pipes for decentralized sanitation? In this way, it is not a matter of techniques; it is

about how to understand governance concerning the techniques (Zonneveldt, 2017; de Danschutter, 2017; Mijatovic, 2017). Another challenge, as already mentioned, is that responsibilities of stakeholders may change during the transition towards new sanitation (KAW, 2017). According to Mijatovic (2017) it could be useful to develop a clear vision for new sanitation, before determining responsibilities. After this, responsibilities and risks can be divided. A last challenge is to convince civil servants of alternative developments (Symposium Phosphate, 2017). The political color of the municipal board determines the position the municipality takes in the transition towards a CE (Mijatovic, 2017). Politics will determine the amount of money available for (projects related to) wastewater treatment measures (de Danschutter, 2017; Zonneveldt, 2017). Alternative measures need to pass a certain legal and political stage, but once the measure has passed, it is easier for other measures to get through too. Through pilot projects the success of alternatives may be proved.

6. Legislations should adapt to New Sanitation. For example, as mentioned before, decentralized sanitation, in which phosphate is recovered, can become financially beneficial when thermal energy is recovered from grey wastewater. However, there is a legally obligation to connect new houses to the urban heat network (*stadswarmte* in Dutch), which enables Waternet to recover energy from grey wastewater. This poses a problem in Buiksloterham. Another example is that it is currently not mandatory to build new houses more sustainable, because it is not a requirement in the Building Act *(bouwbesluit* in Dutch) in Amsterdam. A difficulty in this regard is the tension between the need to redefine legislation to foster innovation and the purpose of legislations to protect the environment.

Through AM these recommendations could be useful to enhance management effectiveness, because there is continuously interaction between learning and decision-making.

6. Conclusion

Waternet's practices regarding phosphate recovery from wastewater are aligned with municipal circular goals. Whereas the Municipality of Amsterdam formulated circular goals related to phosphate recovery, it does not have direct influence on wastewater measures taken by the executive body Waternet. The two stakeholders do, indeed, relate. The plan of phosphate recovery from wastewater arose when Waternet experienced expensive infrastructural problems due to uncontrolled struvite formation. After evaluating different techniques, Fosfaatje was established to recover phosphate as struvite. Struvite was the problem and is the solution. The phosphate recovered by Fosfaatje suited both Waternet and the municipal circular goals, resulting in cooperation in decentralized sanitation in Buiksloterham to (possibly) optimize the process. Waternet wants to become climate neutral in 2020 by, among other things, recovering resources from wastewater. The municipality has the ambition to transit to a circular economy, in which materials are reused and circular activities are stimulated.

AM was applied to Waternet's practices of phosphate recovery and municipal circular goals to systematically determine whether management activities are succeeding or failing to achieve objectives. With help of AM uncertainties regarding phosphate recovery from wastewater have been identified. Fosfaatje is not functioning as planned and has a relatively small contribution to CO_2-reduction. Also, prices of phosphate are low, because there is no scarcity-indicator to assess the sustainability of phosphate recovery yet. Further, there is no clear and legally allowed market to close the phosphate cycle. All of this together could have been the reason for a negative business case, but Fosfaatje resolves a highly expensive infrastructural problem, which was the main reason behind the establishment of the installation, leaving Fosfaatje a cost-neutral investment within 10 years.

In the case of Buiksloterham, it has been a challenge to apply AM, because the project is still in a developing phase. What can be said, though, is that both Waternet and the municipality work together in Buiksloterham to deliberately test alternative measures for phosphate recovery to foster innovation and explore new opportunities (*active learning*). Phosphate is recovered from highly concentrated black wastewater, increasing the recovery rates from 15% to 85%. However, if the prices of phosphate remain low, the local population will use the secondary phosphate. In this way, the benefits of increased phosphate recovery rates through decentralized sanitation are negotiable. On the other hand, looking at all the possibilities of decentralized sanitation, the business case might be positive anyway due to thermal energy recovery. Pilot studies explore new business models and should stay priority.

The central question '*How can an Adaptive Management approach contribute to a systematic analysis of the relationship between Waternet's practices of phosphate recovery from wastewater and Amsterdam's municipal goals of a Circular Economy?*' can be answered as AM has helped to systematically operate governance of phosphate recovery from wastewater in a way that the relationship between the municipality and Waternet has been clarified and uncertainties that challenge successfull implementation of phosphate recovery have been identified. Also, AM provides a framework through which learning from these uncertainties could enhance management efficiency, because new opportunities can be seized and threats can be spotted early. In the case of Amsterdam, Waternet and the municipality are in the process of assessing management actions (adjusting based on what is learned). Management actions can be adjusted only after innovations are fully implemented, which can take years in the case of Amsterdam. The challenge is therefore how to adjust already during the process of innovation. Therefore, it can be considered, for both Waternet and the Municipality of Amsterdam, to explicitely use AM.

To conclude, there is an agreement on the necessity to create a more coherent vision for the circular city in which both technical and socio-political uncertainties of New Sanitation are addressed. The term 'New Sanitation' does not necessarily imply decentralized sanitation; it could be a combination of decentralized and centralized. In what way phosphate will be part of new sanitation is dependent on multiple uncertain factors, but in the end, the business case should be positive.

The following is recommended for future research.

- How can the sustainability of phosphate recovery be measured?
- What is an appropriate scale for secondary phosphate marketing, to close the phosphate cycle with regard to circularity?
- What legislative changes are required before secondary phosphate can be sold on the domestic as well as international market? According to Mijatovic (2017) the University of Wageningen is doing research upon this.
- How can phosphate recovery be optimized while taking into account the interaction between measures?
- Waternet is responsible for treating wastewater, not for producing resources. Who carries responsibility for producing and selling secondary phosphate?
- Who can use recovered phosphate on a local scale, and how? Currently, this is examined at Wageningen University (Symposium Phosphate, 2017).
- In which neighborhoods in Amsterdam could decentralized sanitation be possible (socially, physically, organizationally and financially)?

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