Assessment: Sustainable Projects for the Ouderkerkerplas - Water

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Transdisciplinary Case Study (GEO4-2302)
Sustainable Development & Water Science and Management

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Group 8

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FOREWORD

We would like to thank all the people that replied to our interviews and explained the technologies involved. Furthermore, we would like to thank our client Anne Stijkel for her enthusiastic guidance during the project. Lastly, we would like to thank Paul Schot, Frank van Learhoven and Wina Graus for their helpful comments on our writing.

For our report we have chosen to divide the work per project and per social and natural science specialization. We would like to be graded separately according to table 1. For example, Björn Bolhuis (natural science student) would like to be graded for:
- Methodological framework of environment (written with 3 other natural science students)
- Introduction and conclusion of the wetlands projects (written with Caspar van Deursen)
- Environmental section of the wetlands project

We divided our word limit accordingly. Björn Bolhuis' word count consists of 1/4 of words of methodological framework, 1/2 of words of introduction and conclusion wetlands, all words of environmental section. Considering the structure of our paper we concluded this was the best way of dividing the tasks involved.

Name	**Number**	**Methodological framework**	**Project - disciplinarily section & introduction and conclusion**
Björn Bolhuis	4188918	Environment	Wetlands - Environment
Evan Bruner	3931129	Stakeholders	Microalgae cultivation - Social, Economic, Institutional
Caspar van Deursen	3343596	Institutional	Wetlands - Social, Economic, Institutional
Gea van der Lee	3634787	Environment	Aquaponics - Environment
Giorgos Panis	4113977	Environment	Water power and microalgae cultivation - Environment
Diana Perez	4046978	Economic Recreation/education	Aquaponics and nanotechnology - Social, Economic, Institutional
Maik van der Wolf	3960668	Environment	Nanotechnology - Environment

Table 1: Work division of individual parts

SUMMARY

In 2013, Groenegebied Amstelland (GGA), the governmental organization who manages the Ouderkerkerplas to the south of Amsterdam, decided that they wanted to make the area more sustainable. After a co-creation process with respective institutions and stakeholders of the Ouderkerkerplas, four potential projects were proposed, which would address both the sustainable development of the area and our client's desire for water quality improvement: experimenting with the potentials of algae, building a floating greenhouse with an aquaponics system inside, a constructed wetland, and introducing nanotechnology.

The aim of this research was to gain insight into how each of these potential projects could contribute to the sustainable development of the Ouderkerkerplas. Sustainability is defined according to three pillars: the environment, economy and society. Additionally, we have taken the institutional setting, which is comprised of the rules and regulations, of the Ouderkerkerplas into consideration. The environmental pillar encompasses the impact on water quality, energy and food production, and ecology/biodiversity. The social pillar categorizes the stakeholders, and maps the stakeholders into a matrix regarding their potential threat and cooperation levels. The social pillar also gauges the recreational and/or educational possibilities of each project. A rough idea of the potential costs of project implementation was included for the economic pillar. The integrated assessment of the sustainability of the potential solutions using the three pillars gave the following results.

- Micro algae have a high return of investment and potentially produce energy. This makes it a very attractive solution. When implementing such a project a careful approach to stakeholders is advised, as not everyone might be on board with such a project from the start.
- Nanotechnology is not yet applicable since there is no exploitable nanotechnology developed yet with the aim of specifically decomposing compounds such as phosphates and phosphorus. Furthermore, due the size of the Ouderkerkerplas the technology would not be effective in terms of time and money.
- A floating greenhouse with aquaponics system has high potential for food production, and can increase recreational and educational value of the area. However, it seems the water quality problems cannot be solved. Furthermore, bird populations might be negatively affected by increased human activity. The economic costs are largely dependent on the size of the greenhouse chosen.
- Constructed wetlands have the potential to both reduce phosphorous-levels in surface water and to enhance the biodiversity, but that the case of the Ouderkerkerplas is not ideal for a constructed wetland. The phosphorous concentration in the lake is not high enough for a CWTS to function in an optimal manner, and the necessary space that is required to properly process all the water used for cooling purposes is simply too big. Stakeholders generally show a positive attitude towards constructed wetlands, although some pose a threat to the implementation.

These four projects, and their potential effect on the three pillars of sustainability, were integrated to form our results, and a clear recommendation for our client. Based on our analysis, the micro algae and aquaponics system were the most feasible projects for the area. Both show more potential strengths in regards to our client's goals than the others, and could have a higher return on investment. The financial prospects of these projects could make them more attractive to investors. However, all stakeholders will have to be integrated into the project from the start, otherwise some of them could pose a threat to its final implementation.

SAMENVATTING

In 2013 heeft Groengebied Amstelland (GGA), de overheidsinstantie die verantwoordelijk is voor het beheer van de Ouderkerkerplas, gelegen ten zuiden van Amsterdam, besloten dat ze het gebied op een meer duurzame manier willen ontwikkelen. Na een co-creatie proces met de alle betrokken partijen werden er vier potentiële projecten voorgesteld: experimenteren met het kweken van algen, een drijvende kas met een aquaponics systeem, een helofytenfilter (een kunstmatig aangelegd wetland), en Nano- technologie.

Het doel van dit onderzoek was om beter in te kunnen schatten hoe deze projecten kunnen bijdragen aan het duurzaam ontwikkelen van de Ouderkerkerplas. Duurzaamheid is gedefinieerd op basis van drie pijlers: het milieu, economie en de maatschappij. Daarnaast hebben we rekening gehouden met de institutionele setting van de Ouderkerkerplas. Voor dit onderzoek is de pijler milieu opgedeeld in waterkwaliteit, energie en voedselproductie, en ecologie/biodiversiteit. De sociale pijler classificeert de belanghebbende en brengt ze in kaart naar mate hoe betrokken ze zouden zijn bij de respectievelijke projecten. Ook de potentie voor recreatieve en educatieve mogelijkheden worden voor elk project meegenomen in de sociale pijler. Een ruwe schatting van de benodigde investeringen en eventuele opbrengsten vormt de economische pijler. Door deze pijlers te integreren kunnen we per project inschatten in hoeverre ze zouden kunnen bijdragen aan een duurzame ontwikkeling van de Ouderkerkerplas.

- Een investering in de productie van algen lijkt zich snel terug te betalen, en kan bijdragen aan het opwekken van energie. Dit maakt het een erg aantrekkelijke oplossing. Wanneer dit project geïmplementeerd zou worden is het belangrijk de betrokken partijen voorzichtig te benaderen, want wellicht staat niet iedereen er direct voor open.
- Nano- technologie is op dit moment nog niet toepasbaar op deze schaal, aangezien er nog geen rendabele Nano- technologie is ontwikkeld voor het verwijderen van fosfor en fosfaten uit oppervlaktewater. Deze technologie financieel gezien en qua benodigde tijd niet erg effectief zijn vanwege de grootte van het meer.
- Een drijvende kas met een aquaponics systeem lijkt veelbelovend voor lokale voedselproductie, en kan de recreatie en educatieve waarde van het gebied vergroten. Echter, het is geen effectieve methode om de waterkwaliteit te verbeteren, en de vogelpopulatie kan eventueel negatief worden beïnvloed door de toename in menselijke activiteit. De benodigde investering hangt sterk af van de grootte van de kas.
- Een helofytenfilter, of kunstmatig aangelegde wetland, kan zowel de fosforconcentraties in het oppervlaktewater verlagen als de biodiversiteit in het gebied vergroten. De situatie bij de Ouderkerkerplas is echter niet ideaal voor een helofytenfilter omdat de fosfor concentratie niet hoog genoeg is om het optimaal te laten functioneren, en de benodigde oppervlakte om al het koelwater van Nuon te verwerken te groot is. Belanghebbenden staan over het algemeen positief tegenover een dergelijk project, al kunnen sommige een bedreiging vormen voor de uitvoering ervan.

Deze vier projecten, en hun effecten op de drie pijlers van duurzame ontwikkeling, zijn geïntegreerd in een overzicht. Uit dit overzicht komt duidelijk naar voren dat de productie van algen en de drijvende kas het meest haalbaar lijken in de situatie van de Ouderkerkerplas. Beiden bieden meer voordelen dan de andere twee projecten, en genereren een omzet waardoor de investering terug verdient kan worden. De financiële voordelen van deze projecten zou het aantrekken van investeerders relatief gemakkelijk moeten maken. Echter, sommige betrokken partijen zouden bezwaar kunnen hebben tegen deze projecten, en moeten er vanaf het begin goed bij betrokken worden.

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1 INTRODUCTION

1.1 BACKGROUND

In 1969, a lake, the Ouderkerkerplas, was excavated for the construction of the highway A9 situated south of Amsterdam. In the 80's the northern side of the lake was redeveloped, a shallow zone was added with ecological value, footpaths and a swimming zone. Over the years, the water quality of the lake has been declining due to excess phosphate coming from the soil, inlet water, and large bird populations (Stroom et al., 2010). The excessive nutrient levels are the cause of cyanobacteria, often called blue-green algae, which bloom in the summer months (Lurling et al., 2006). The blue-green algae can pose a considerable threat to the flora and fauna, and the health of human beings (Gągała et al., 2010). In the past, the potential threats of blue-green algae have led to the closure of the recreational waters of Ouderkerkerplas (Gerritsen, 2014). Since 2009, NUON, a utility company, began using the Ouderkerkerplas as a source for cold water mining. NUON has been legally required to maintain phosphate levels so as not to further disturb the ecosystem. Through the use of an oxygenation system, phosphate is bound to reduced iron and gets deposited on the bottom of the lake. NUON has managed to consistently lower the phosphate levels, however the algae is still visible on the surface of the lake. Also, this system is not a sustainable solution, as phosphate levels will increase if NUON ceases oxygenation (Waternet, 2014). Additionally, there is a lack of interest in the area from the local community, in terms of recreational activity (Stijkel, 2014).

1.2 PROBLEM DESCRIPTION

In 2013, Groenegebied Amstelland (GGA), the organization who manages the Ouderkerkerplas, decided that they want to make the area more sustainable in terms of the environmental aspects water, energy (food), and biodiversity, while taking into account social aspects such as recreation, education and stakeholder engagement, and considering the economic viability (Stijkel, 2014). Earlier this year, GGA started a co-creation process with local institutions and stakeholders of the Ouderkerkerplas, the co-creation was led by consultant, Anne Stijkel. The first step in this process was a brainstorming session in which five possible sustainable projects were initially proposed that could affect the Ouderkerkerplas positively in terms of its social, economic and environmental value. The potential projects proposed were: eexperimenting with the potentials of microalgae cultivation, investigating hydro-power[1], building a floating greenhouse with an aquaponics system inside, creating wetlands, and introducing nanotechnologies. These projects are shortly described in table 2.

Our client Dr. Anne Stijkel (Foundation Triple-S International Institute for Inclusive Science) has been hired by GGA to guide the process of developing the Ouderkerkerplas to showcase sustainability (Stijkel, 2014). Our assignment is to gain insight into how each of the potential projects might contribute to the sustainable development of the Ouderkerkerplas. Sustainability is defined according to the three pillars: the environment, economy and society (Giddings et al., 2002). Additionally, during our assessment of the projects, we take into consideration the institutional setting of the Ouderkerkerplas, which is comprised of the rules and regulations which must be obeyed (Kemp et al., 2005). The environmental pillar encompasses the impact on water quality, energy and food production, and biodiversity/ecology of each project. The social pillar is comprised of a stakeholder analysis to determine who the stakeholders of each project are, assesses their cooperative and threatening potential, and provides recommendations for stakeholder engagement strategies. Furthermore, where applicable, the social pillar gauges the

[1] This project was only shortly assessed, as it was deemed unsuitable early in the process.

recreational/educational possibilities of each project. A rough idea of the potential costs of project implementation is included for the economic pillar. Figure 1 provides an overview of the sustainability pillars and each of the aspects discussed.

Algae Applications	Before the 'hot' water, which came out from the heat exchanger of cool water mining industry, is poured back into the lake, a biorefinery could be constructed that could take advantage of the nutrients already existing in the water for microalgae cultivation.
Hydro-power (n.a.)	The solution involves the connection of Amstel river to the Ouderkerkerplas. Then, the mechanical energy created through water flows would be converted into electricity using micro-hydro power plants.
Nanotechnology	A sunlight activated technology. Five photochemical processes work together synergistically to break down or remove contaminants from water. This process actually destroys contaminants, rather than capturing them and creating a hazardous waste disposal problem. The technology is possibly applicable for contaminant mitigation of natural water catchments.
Constructed Wetlands	Constructed wetlands are artificially built wetlands with the purpose of treating wastewater. It is a low costing technology with aesthetically pleasing results.
Floating greenhouse with aquaponics system	Aquaponics is a food production system that integrates fish and soilless plant culture in a re-circulating system. People in the nearby communities of the Ouderkerkerplas could consume the fish and crops produced within the floating greenhouse.

Table 2: Short description of proposed sustainable solutions for the Ouderkerkerplas (more detail in disciplinary chapters)

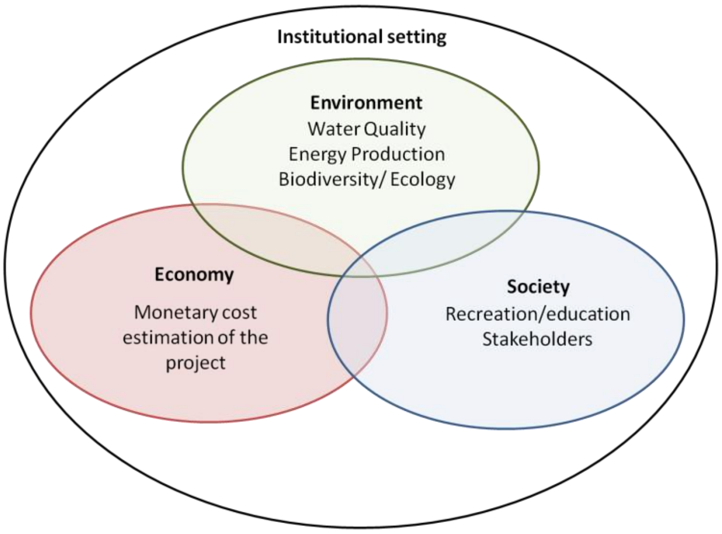

Figure 1*: Overview of sustainability pillars (environment, society, and economy) within institutional setting*

1.3 OBJECTIVES

The objective of this research is to provide recommendations to our client, Anne Stijkel, regarding the potential contribution of each project to the sustainable development of the Ouderkerkerplas. This is done after holistically investigating each project- describing the social, economic, environmental aspects while taking into consideration their institutional setting. The potentials and limitations of each project will be pictured in an integrated chart, through which it will be easier to assess each project. A short point of discussion will be the ways in which some of the projects can function together. We aim to provide a recommendation on which solution we have found to be the best suited for the area, which may provide insight for the GGA into which project may be the best to implement. However, we understand the subjectivity of what sustainability is and as such our analysis is also intended to allow our client to ultimately decide what they believe is best and if they so desire, make an alternative choice. The processes by which these objectives should be met are shown in the flow diagram in figure 2.

1.4 RESEARCH QUESTION

The problem description and described objectives results in the following central research question:

How can the potential solutions contribute to the sustainable development of the Ouderkerkerplas?

Each project will be looked at individually, with environmental, social, economic and institutional aspects analyzed. Therefore, there will be a subdivision of the research question, in terms of each project:

How can "solution X" contribute to the sustainable development of the Ouderkerkerplas, in "terms of Y" ?

- Solution X: Wetlands, Nanotechnology, algae applications, floating greenhouse with aquaponics system
- Terms of Y1: Environmental aspects
  Terms of Y2: Institutional setting, social and economical aspects

1.5 READING GUIDE

The following chapter (2) will discuss the methodological framework for the assessments of the projects. Chapter 3 - 6 will describe each solution in regards to the various disciplinary subjects. For each solution the environmental aspects will first be elaborated on, followed by societal and economic aspects, and institutional requirements. The responsible persons in each disciplinary chapter can be found in figure 2. Thereafter, the disciplinary subjects will be integrated in a chart showing the overall assessment of each project. The pro's and con's are of each solution will be visible, and a short description will be given on which solutions can be implemented together. With this information, a recommendation will be given in chapter 7, and a conclusion is drawn (8). The closing chapter (9) shortly reflects on the research done for this paper.

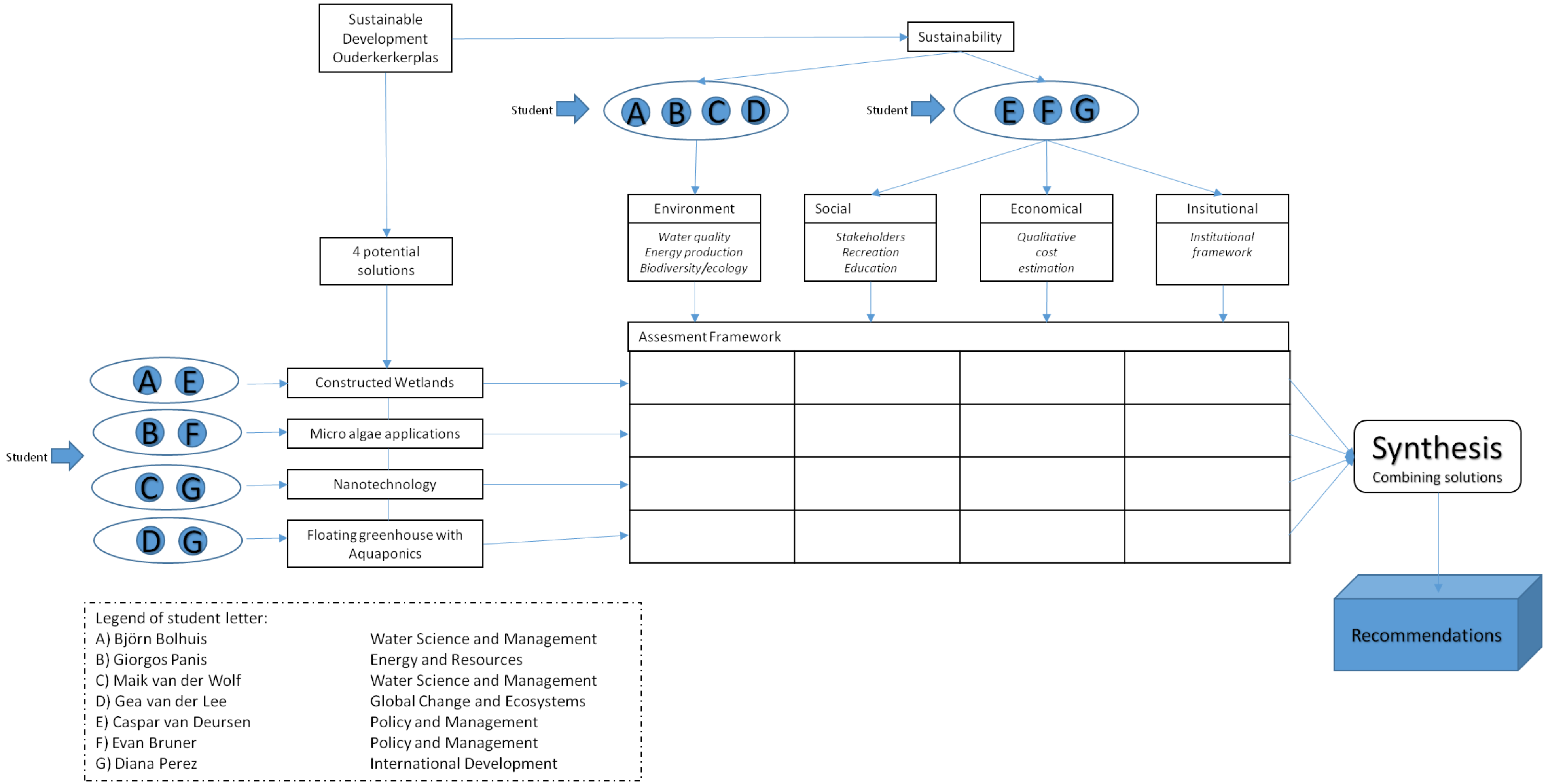

Figure 2: *Flow diagram of process done to meet objectives*

2 METHODOLOGICAL FRAMEWORK

2.1 ENVIRONMENTAL ASPECTS

Each of the proposed solutions was assessed on its environmental impacts. This analysis consists of three different aspects: water quality, energy or food production, and biodiversity/ecology. If one of these aspects was not relevant for a certain solution, it was not addressed in the analysis. The assessment was foremost based on a literature review of international scientific publications and data provided by the stakeholders. The stakeholders Waternet and Nuon provided us with insights and ideas, and the latest research data of the Ouderkerkerplas. Furthermore, research facilities of the Wageningen University and Utrecht University were visited to get insight in the latest developments in the field of respectively algae production and nano-technology. For all projects, a field visit was made to get a better impression of the research area.

To assess the impact on water quality, it was calculated what the potential phosphorous uptake could be based on research results of comparable case studies, combined with the latest measurements made in the Ouderkerkerplas. This was compared to the current phosphorous retention through the adding of oxygen by NUON (wetlands and floating greenhouse with aquaponics system). Or it was assessed how much area (and time) would be needed to retain all phosphorous in the lake (nanotechnology and microalgae applications). Further, if relevant, a rough estimation was made on what the potential food or energy production of a project could be, based on comparable studies or concepts. The impacts on the biodiversity/ecology was deemed very site specific and could not be quantified. Therefore, only expected positive or negative impacts were mentioned. Based on the above, a conclusion was reached about each of the solutions deeming how applicable they could be for the Ouderkerkerplas, and to what extent they could contribute to a sustainable development of the area.

2.2 INSTITUTIONAL SETTING

To analyze the stakeholders and their potential actions, we will also have to look at the setting in which they are allowed to act. For each project, certain rules and regulations apply which all stakeholders have to abide by. They decide which actions can be taken, and which cannot. These sets of rules and regulations are called institutions, which are defined as "the prescriptions that humans use to organize all forms of repetitive and structured interactions (…)" (Ostrom, 2005, p.3). This includes behavior in markets, businesses, families and so on, but for this research we restrict it to behavior within a potential project. The institutional aspects will include all the rules actors within a project have to follow. The project therefore is seen as the basis for an institution that gives certain options for human behavior as well as constraints. It is important to include this factor into this research as these constraints could severely limit the options available within and between projects. We chose to operationalize institution simply as the formal laws applying to each actor within a project, and which procedures they have to go through in order to realize it. These could result in restrictions to a project, conditions that have to be met before a project can be realized or, in the absence of strict regulations that prohibit the actors from doing the project, no institutional barriers.

2.3 SOCIAL ASPECTS

2.3.1 STAKEHOLDERS

2.3.1.1 Stakeholder ontological position

"Stakeholder identification, management, and engagement are recognized as key project management skills"(Walker et al. 2007). Stakeholder literature is rife with evidence of the importance of engaging stakeholders effectively in project management (Walker et al. 2007; Polonksy 1996; Polonsky & Scott 2005; Freeman 1984; Kimery & Rinehart 1998). This phenomenon is equally present within the context of natural resource management (Maarleveld & Dangbegnon 1998; Grimble & Wellard 1997; Reed et al. 2009), much of which is directed at the importance of engaging and managing stakeholders in order to ensure both successful project outcomes (Reed et al. 2009; Polonsky 1996). Various methods for identifying stakeholders, engaging them, and managing them throughout the course of project development and implementation have been developed in the literature (Grimble & Wellard 1997; Polonsky & Scott 2005; Mathur et al. 2008; Walker et al. 2007). Due to the limited scope of this paper, here we omit a review of these various methods. Instead, we describe the methods which we have chosen to employ in this paper and the justification for these choices.

Before describing the analytical tools employed in this case study, it is, first, important to describe our underlying assumptions about stakeholders, who they are, how they should be treated, and how we define them within this case study. Adapting the approach taken by Walker et al. (2007), in figure 3 we map the positions we have adopted which can summarize our ontology of stakeholders and our assumptions regarding their influence on the project management process. On the square illustrated in the figure below we have placed black dots to represent our ontology in conceptualizing stakeholder management. The figure originally had five dimensions along which positions should be determined, however, for the purpose of this case study we have eliminated the dimension of *political perspectives of stakeholders* due to our inability to assess this dimension accurately and its lack of relevance to this particular project.

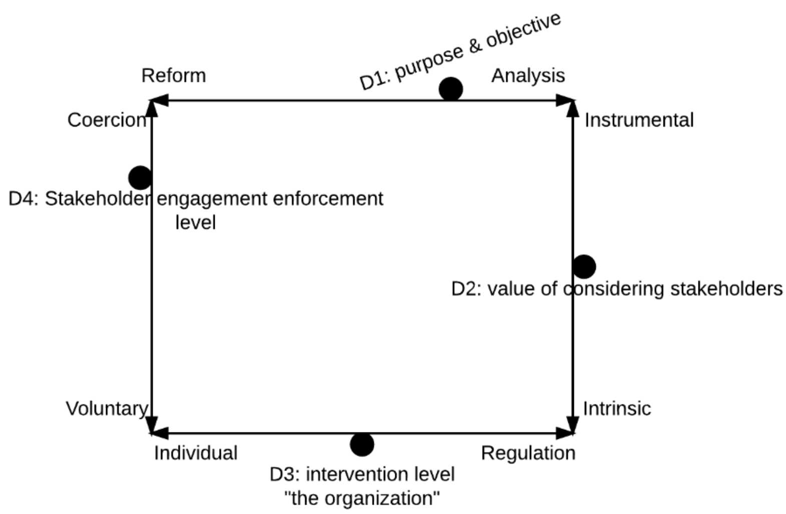

Figure 3: ***Stakeholder ontological positions (adapted from Walker et al., 2007)***

From the positions which have been established in the figure above[2], it is then possible to summarize our ontology of stakeholders and their level of influence in the project development

[2] See Appendix for descriptions on how and why were determined our position along each dimension.

process. Thus, consistent with Walker et al. (2007), we define stakeholders as "individuals or groups who have an interest or some aspect of rights or ownership in the project, and can contribute to, or be impacted by, [or threaten,] either the work or the outcomes of the project"(Walker et al. 2007).

2.3.1.2 Stakeholder types

Based on our ontological position, we adopt two tools for our stakeholder analysis. The first is adopted from Walker et al. (2007) and consists of mapping stakeholder types (see figure 4). Walker et al. (2007) have developed 4 typologies of stakeholder groups: *upstream stakeholders* are categorized as paying customers and end user of the product/service; *downstream supply chain* includes suppliers and subcontractors as stakeholders; *external stakeholders* are often ignored in project development and generally comprise of the community and individuals who feel that they will be affected by the project and its outcomes; lastly, there is the *project stakeholder group* which is comprised of the project sponsor/champion and the project delivery team. Identification is the first step in understanding who stakeholders are and how their role may impact project outcomes (Walker et al. 2007; Frooman 1999).

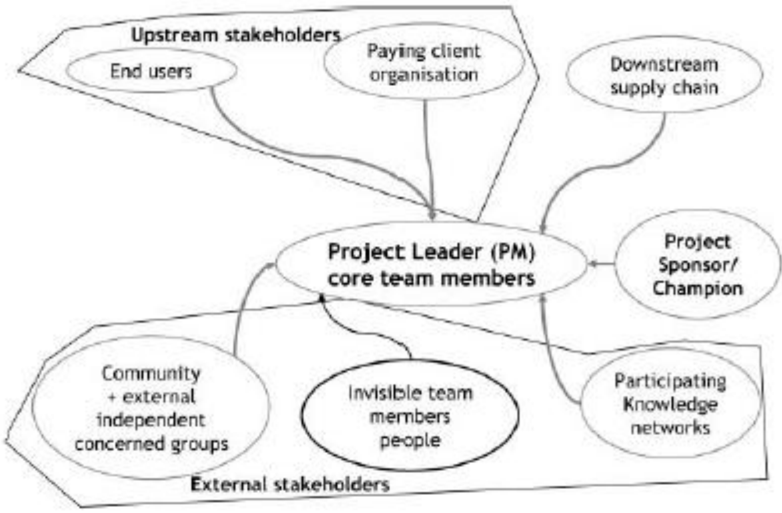

Figure 4: *Stakeholder types (adapted from Walker, 2003, p. 261)*

2.3.1.3 Stakeholder strategy matrix

Having identified stakeholder types, the following step is to determine the influencing ability of the stakeholder groups (Walker et al. 2007; Polonksy & Scott 2005; Freeman 1984; Kimery & Rinehart 1998; Savage et al. 1991). Influencing ability can be visualized in a variety of methods, due to the limited scope of this paper we omit a review of the various methods, instead we explain our choice of the stakeholder strategy matrix adapted from Polonksy & Scott (2005), which can be seen below in Figure 5.

The various locations of groups within this matrix means different things to different authors, for the purpose of this paper, we adapt the definitions which have been developed by both Savage et al. (1991) and Polonksy & Scott (2007). Beginning with the group in the upper left hand, the stakeholders placed here are considered to have a high threatening potential and a high cooperative potential, Savage et al. (1991) defines this group as the "mixed blessing" group and suggests that organizations should make efforts to collaborate with this group in order to maximize their positive influencing ability and reduce their threatening potential (Polonksy & Scott 2005). Both Polonksy (1996) as well as Kimery & Rinehart (1998) agree with Savage's definition and approach towards this group.

		Relative Threatening Potential	
		High	Low
Relative Cooperative Potential	High	Friedman - SWING Group Strategy - Change the Rules Savage- MIXED BLESSING Group Strategy - Collaborate	Friedman- OFFENSIVE Group Strategy – Exploit Savage – SUPPORTIVE Group Strategy - Involve
	Low	Friedman- DEFENSIVE Group Strategy- Defend Savage– NON SUPPORTIVE Group Strategy - Defend	Friedman- HOLD group Strategy - Hold Current Position Savage - MARGINAL Group Strategy - Monitor

Figure 5: ***Stakeholder strategy matrix (adopted from Polonsky & Scott 2005)***

Stakeholders who possess a low threatening potential couple with a high cooperative potential have been categorized by Savage et al. (1991) as "supportive" stakeholders, suggesting that by engaging this group of stakeholders in project development could help to leverage support. Other authors (Freeman 1984; Kimery & Rinehart 1998) suggest that this group should be exploited, but we place ourselves nearer the interpretation of Savage et al. (1991).

Stakeholders that have a low cooperative potential and a high threatening potential have been categorized by Savage et al. (1991) as non-supportive. Both Savage et al. (1991) and Kimery & Rinehart (1998) suggest that this group should be defended against. However, Polonksy (1996) suggests that involving these non-supportive stakeholders might be a better approach to managing the relationship and thus attempting to minimize the potential of negative outcomes.

Finally, the group of stakeholders which have both low cooperative and threatening potential have been defined by Savage et al. (1991) and Kimery &Rinehart (1998) as marginal stakeholders who should be monitored, but aren't necessarily needed to have deeply involved. However, Polonksy (1996) suggests that these stakeholders might be important in their indirect influencing abilities on project outcomes, whether they might be positive or negative. As such, in agreement with Polonksy (1996), we believe that monitoring this group is important, but other strategies might be employed to build support from these stakeholders in order to ensure that, if any changes occur, they are more likely to have a positive effect.

Consistent with Polonksy's (1996) view, we believe that all stakeholder positions within the matrix are equally important and suggest that there should be no significant difference in how these stakeholder groups are viewed. This matrix serves to guide project managers, in this case our client, Anne Stijkel, in making effective strategic decisions during project development. Depending on where a stakeholder group lies, the following applicable generic strategies identified by Freeman (1984) and Savage et al. (1991). For each project analyzed in the following case study, we will make recommendations on how relevant stakeholder groups should be engaged during the project development process in order to increase the likelihood of project success.

To summarize, first we established our ontology of stakeholders, allowing our client to understand the basis with which we have conceptualized stakeholders within this case study. This was followed by a description of mapping stakeholder types as an important first step in stakeholder identification. And, finally, we provided our approach to assessing stakeholders' influencing ability using the stakeholder strategy matrix developed by Polonsky & Scott (2005) which will be used to provide recommendations on how stakeholder groups should be engaged for project development.

Dependent variable	Matrix position Threatening ability Cooperative ability	Swing-change rules High High	Defensive – defend High Low	Offensive – exploit Low High	Hold – hold current position Low Low
(1) Modify the circumstances in which the firm and this stakeholder interact		× ×			
(2) Change the formal or informal rules under which this stakeholder operates		× ×			
(3) Refocus this stakeholder's objectives		× ×	× ×		
(4) Informally collaborate with this stakeholder when establishing policy		× ×			
(5) Reinforce this stakeholder's beliefs about the firm		× ×		× ×	× ×
(6) Include this stakeholder when developing strategy			× ×	× ×	× ×
(7) Modify this stakeholder's beliefs about the firm			× ×		
(8) Change organisational behaviour to address this stakeholder's concerns			× ×	× ×	
(9) Continue with existing activities (i.e. ignore this group)				× ×	
(10) Reduce reliance on this stakeholder				× ×	
(11) Monitor this stakeholder for change in their beliefs/behaviour/attitudes					× ×
(12) Minimise the possibility of this stakeholder-firm relationship changing in any way					× ×
(13) Link this stakeholder to the firm's wider objectives			× ×	× ×	

Source: Adapted from Polonsky (1996)

Table 3: *Applicable generic strategies identified by Freeman (1984) and Savage et al. (1991)*

2.3.2 RECREATIONAL AND EDUCATIONAL POTENTIAL

The recreational and educational potential of the proposed projects was an important aspect to consider, as it was one of the criteria the client was very interested in knowing more about. Unfortunately, it is impossible to know the real outcomes of any possible project until it is actually realized, however, we have tried to assess the recreational and educational potential of each project using two methods: through interviews held with the affiliated stakeholders, and through the use of literature reviews. The stakeholders offered their input on what potential projects could look like and what would entice visitors. The literature review showed the recreational and educational activities that similar existing projects were already engaged in, and how they contributed to attracting visitors.

2.4 ECONOMIC ASPECTS

The financial costs of each project were estimated through interviews, in which project specific experts were asked about the costs. In addition to this, a literature review about already existing projects revealed further cost estimations, which were also taken into account, where applicable. Because the costs of each project vary over a wide range, we have devised a strategy of comparison in which three categories were created. € means the project will cost < €500.000; €€ represents a cost between €500.000 and 1.000.000; and €€€ indicates that its implementation will cost >€1.000.000. Thus, within the report the projects are marked with their corresponding value in terms of one to three euro signs.

3 WATERPOWER AND MICROALGAE CULTIVATION

3.1 INTRODUCTION

In this chapter, two project solutions that were developed during the co-creation process, micro-hydro power and a micro-algae cultivation system will be assessed in terms of their potential contribution to the sustainable development of the Ouderkerkerplas. First, the inapplicability of the micro-hydro power is shortly discussed and, ultimately, is omitted from the report. Second, the analysis of the microalgae cultivation system begins. The initial part of this analysis, consistent with the evaluation of the other solutions, describes the microalgae cultivation systems, specifically, the required inputs for operation, the potential contribution to improving the environment (i.e. water quality), the limitations of this solution in regards to the Ouderkerkerplas, and the different applications of the end product.

Following the environmental analysis, we then look at the institutional setting of the Ouderkerkerplas, including the rules and regulations which govern the area and their relevance to this solution. Next, we discuss the results of a stakeholder analysis which was conducted to gain insight into who the stakeholders are, what their relative cooperative and threatening potential might be for this project, and, then, provide some recommendations for stakeholder engagement. Briefly, the added value of this project in terms of education is illustrated along with a very rough estimate of what the initial costs of the project might be in conjunction with approximations of potential revenues.

The chapter is concluded with a brief summary of how a microalgae cultivation system might contribute to the sustainable development of the Ouderkerkerplas and its feasibility in terms of the institutional context, stakeholder acceptance, and financial investments and returns.

The main research question regarding sustainable energy and materials production in Ouderkerkerplas *Water Area* is:
How can microalgae cultivation outside the lake contribute to the sustainable development of the Ouderkerkerplas?

Environmental aspects

- How can the environment of the Ouderkerkerplas be improved by constructing a microalgae cultivation system outside the lake?
- What are the requirements for an appropriate culture system in Ouderkerkerplas?
- What is the theoretical biomass yield exploiting the nutrients and water pumped from Nuon?
- What are the limitations?
- What are the different applications of dry biomass?

Social, economic aspects and institutional requirements:

- How does the institutional setting of the Ouderkerkerplas effect the implementation of a microalgae cultivation system?
- Who are the stakeholders?
- What is the relative cooperative and threatening potential of the stakeholders?
- How might these stakeholders be engaged during project implementation to increase the chance of project success?
- What are the estimated costs and returns for a microalgae cultivation system on the Ouderkerkerplas?

3.2 MICRO-HYDRO POWER

Cool water mining is a process that requires some specific conditions in order for it to be a cost efficient solution for 'thermal energy' generation. The most important of these conditions is the thermal stability of the water in the pond (Raymond van Bulderen, personal communication, October 2, 2014). More specifically, in the summer season, in the depths of the Ouderkerkerplas (-40 meters) a so-called "lid" is formed 14-24 meters below, which is called the thermocline. The thermocline is a transition layer, which divides the 'hotter' volume of water from the 'colder' one (Gorham & Boyce, 1989). To harness the usefulness of this temperature variance, NUON is pumping water from the deeper layers of the lake taking advantage of the thermal stability of the waters and the absence of circulation patterns. This is the process of how NUON provides cooling to local businesses. The company claims that the great productivity of 'thermal energy' that is extracted is due to the isolation of the Ouderkerkerplas (Raymond van Bulderen, personal communication, October 2, 2014). In order to construct a micro-hydro power plant, a connection with an outer source of mechanical energy, which would be converted into electricity, is essential; connection with Amstel river, for instance. Nevertheless, a potential connection would bring 'fresh' water into the lake, which would then trigger circulation patterns in the formerly isolated water system, which would subsequently affect the thermal stability (the 'hot' water will be mixed with the 'cold'). Because a stable water temperature is a fundamental factor for NUON's cold water mining activity, the cool water mining would subsequently be negatively affected by the potential mixing of the waters (Raymond van Bulderen, personal communication, October 2, 2014). Furthermore, a vented water system would need to be constructed to handle the excessive water induced in the lake and to avoid potential floods around the area. This indicates a significant increase in the costs (initial investments, O&M costs) of implementation. Taking this into consideration, while recognizing the additional impact on the cool water mining, the idea of implementing hydro power can be said to have no potential and further investigation is omitted from this report.

3.3 ENVIRONMENTAL ASPECTS: MICROALGAE CULTIVATION

3.3.1 INTRODUCTION

Taking into account that one of the main aspects of this case is the improvement of the water quality in the lake, microalgae cultivation is an option that can potentially contribute to the purification of the water from the overly abundant nutrients; mainly Phosphorus and Nitrogen. This option would require the construction of a culture system outside the lake exploiting the Phosphorus and Nitrogen, which are present in the water pumped for cool water mining. In addition, the culture system should be constructed just before the water used for the cool water mining is returned to the lake. The purpose of this is to take advantage of the heat exchanger's return temperature (see Temperature section). Besides water purification there is another major advantage of this project. The end product (i.e. dry biomass) has an abundance of applications in the field of energy, food and chemical industry stimulating that way sustainable development and economic growth. In other words, the main problem in Ouderkerkerplas can be transformed into a promising chance outside the lake. There are two requirements to realize this option:

1. Design of the system for cultivation and harvesting in Ouderkerkerplas.
2. Determination of the theoretical biomass yield in order to illustrate potential for investors.

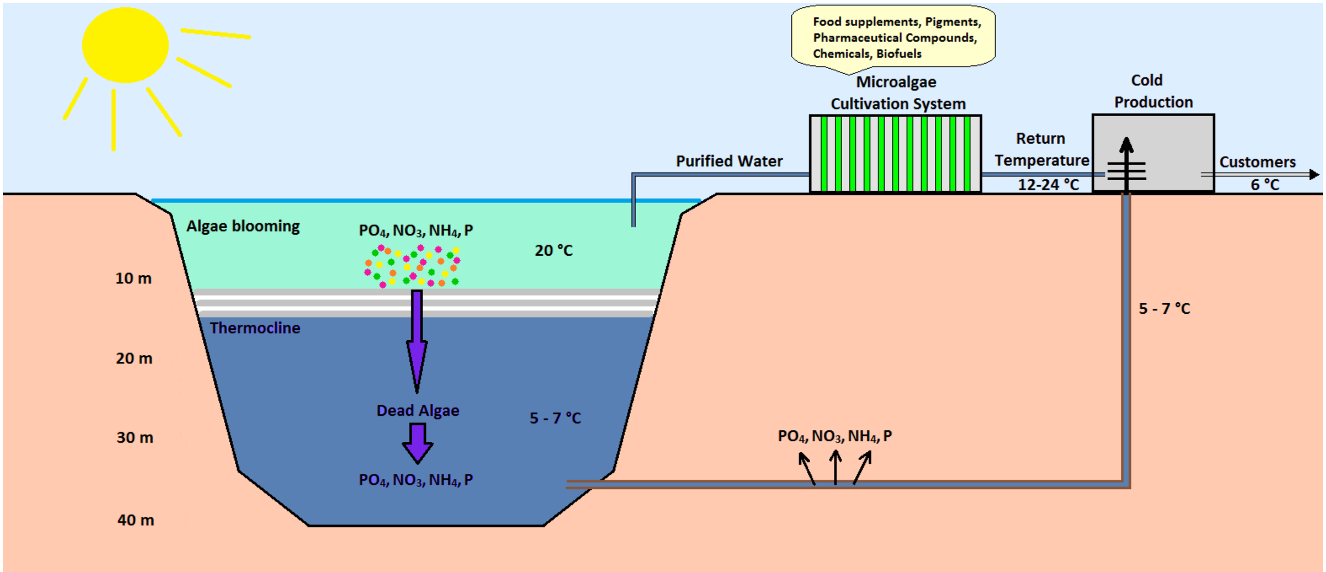

Figure 6: *Schematic view of a microalgae cultivation system in Ouderkerkerplas*

3.3.2 SYSTEM DESIGN

3.3.2.1 Cultivation Inputs

For the implementation of an algae cultivation unit, a site selection and a resource evaluation have to be performed considering several criteria: (i) the water supply; (ii) the land topography; (iii) the climatic conditions, temperature, insulation, evaporation, precipitation; (iv) access to nutrients and carbon supply sources (Mata et al., 2010). The most important of them are presented and connected with the regime in Ouderkerkerplas.

Sunlight

Sunlight availability is the most important factor determining micro-algae growth (Jonker & Faaij, 2013). To achieve high levels of production in an annual basis it is desirable that there is little seasonal variation (Slade & Bauen, 2013). The Netherlands is not characterized by seasonal stability meaning that control of light intensity will require artificial light for successful cultivation in Ouderkerkerplas.

CO_2

Based on the average chemical composition of algal biomass, approximately 1.8 tons of CO_2 are needed to grow 1 ton of biomass (Iersel et al., 2009). Furthermore, microalgae have the functional ability to fix CO_2 from the atmosphere as well as flue gases from a power plant (Venkata Subhash et al., 2013). However, due to the following limitations, the use of flue gases is not a feasible option for a CO_2 input in the environment of Ouderkerkerplas: (i) the production site would need to be in reasonably close proximity to a power station or other large point source of CO_2; (ii) it may not be permissible to emit CO_2 in large amounts at ground level (Slade & Bauen, 2013). Thus, for application in the Ouderkerkerplas, CO_2 input from the atmosphere would be required.

Nutrients

Microalgae need nutrients as fertilizers in order to grow with Nitrogen and Phosphorus being the most important. The Algae Production and Research Center (AlgaePARC) in Wageningen University, the Netherlands, has calculated the volume of these two nutrients needed in order to produce 1 ton of dry algal biomass. This amounts to 0.09 tons for Nitrogen and 0.01 tons of Phosphorus (Kleinegris et al., n.d.).

Water

Algae require considerable amounts of water in order to grow and thrive. The organisms themselves are 80-85% water (i.e. cellular water) (Murphy & Allen, 2011). Other than cellular water, for the production of 1 ton of dry biomass, 200 m^3 (in photobioreactors) to 5000 m^3 (in open ponds) of non-cellular water is needed (Iersel et al., 2009). Nevertheless, taking into account that NUON extracted last year 2.880.889(m^3/y)[3] (Waternet, Maandrapportage NUOAM0100 Mei-Oktober, 2013), water supply in the case of Ouderkekerplas doesn't constitute a problem[4]. In fact, it contributes to a high biomass yield (see Theretical biomass yield section).

Temperature

Most species of microalgae are photosynthetically active at 10°C, but the optimum temperature for photosynthesis varies from 15°C to 35°C (Arnold, 2013). After exploitation of the cool water inside the heat exchanger, "hot" water with a return temperature of 12°C - 24°C is poured back into the lake (Bakker, 2014). This temperature is very close to the optimum and in conjunction with the heat provided by the sun and artificial lights no extra energy for water heating will be needed. This will decrease the operational costs significantly.

3.3.2.2 Nutritional Modes of Microalgae

Microalgae may assume many types of metabolisms and are capable of a metabolic shift as a response to changes in the environmental conditions. There are four types of nutritional modes. These nutritional modes will be investigated in order to determine which one would be the most suitable for microalgae cultivation in Ouderkerkerplas.

1. **Photoautotrophic Metabolism**

   It is the most common procedure to cultivate microalgae and it involves the use of sunlight as energy source and inorganic carbon (CO_2) as the carbon source for the formation of biochemical energy through photosynthesis (Huang et al., 2010). The main advantage of this mode is the fewer contamination problems compared to other modes (Chiu et al., 2008).
2. **Heterotrophic Metabolism**

   It is the mode of nutrition, where microalgae utilize solely organic carbon or substrates (a carbon source such as sugars, proteins and fats) as primary energy and carbon source for their growth (Mata et al., 2010). Unlike photoautotrophic metabolism, heterotrophic metabolism takes place in absence of light, since the growth of the microalgae in the dark heterotrophic operation is enhanced by a carbon source, which replaces light energy (Perez-Garcia et al., 2011). The two major advantages of this mode are the possibility to obtain extreme lipid productivity and the facilitation of wastewater as a base environment for cultivation (Perez-Garcia et al., 2011).
3. **Mixotrophic Metabolism**

   It is a variant of the heterotrophic metabolism and constitutes the combination of photoautotrophic and heterotrophic metabolisms, where photosynthesis is the main energy source but organic micronutrients from the growing environment are essential as well (Chang et al., 2011). This technique takes advantage of an attribute that microalgae possess, which is their flexibility to switch their nutritional mode based on substrate availability and light conditions (Mohan et al., 2014).

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[3] The unit '*year*' doesn't refer to a period of 12 months, but to the period of water extraction when the thermocline is active.

[4] The culture system is going to be a flat-plate bioreactor (see Species section). Taking into account that in a photbioreactor generally 200 m^3 of water is needed for the production of 1 ton of dry biomass a yield of approximately 14.400 tons could be harvested.

4. **Photoheterotrophic Metabolism**
   In this mode the microalgae require light as energy source, while using organic compounds as the carbon source (Chen et al., 2011). The difference between mixotrophic and photoheterotrophic cultivation is that the latter requires light as the energy source, while mixotrophic cultivation can use either light or organic compounds to serve this purpose.

To date, there is little information on the commercial potential of mixotrophic and photoheterotrophic cultivation (Mata et al., 2010). On the other hand, a heterotrophic system seems to be promising for massive microalgae growth combined with biological cleaning. Nonetheless, there are two major limitations. Heterotrophic culture can get contaminated very easily causing problems in large-scale production (Olguin et al., 2012) and the cost of an organic carbon source is also a major concern from the commercial aspect (Chen et al., 2011). In photoautotrophic cultivation, even though the biomass productivity is the lowest among the different nutritional modes, lower costs for scaling up, potential uptake of CO_2 from flue gases even if this is not applicable to Ouderkerkerplas and fewer contamination problems make this mode the most preferable. Table 4 (Chen et al., 2011) illustrates the abovementioned findings cumulatively.

Cultivation condition	Energy source	Carbon source	Cell density	Reactor scale-up	Costs	Issues associated with scale-up
Photoautotrophic	Light	Inorganic	Low	Open pond or photobioreactor	Low	Low Cell density High condensation cost
Heterotrophic	Organic	Organic	High	Conventional fermentor	Medium	Contamination High substrate cost
Mixotrophic	Light and Organic	Inorganic and organic	Medium	Closed photobioreactor	High	Contamination High equipment cost High substrate cost
Photoheterotrophic	Light	Organic	Medium	Closed photobioreactor	High	Contamination High equipment cost High substrate cost

Table 4: *Overview of the different types of nutritional modes for microalgae cultivation*

3.3.2.3 Culture System

There are two main alternatives for cultivating photoautotrophic algae: open pond systems and photobioreactors (PBRs) (Robert et al., 2012).

Open Pond Systems

Open pond systems are the most commonly used for commercial microalgae production. They are relatively economical, easy to clean up after harvesting and good for mass microalgae cultivation. Nonetheless, there is lack of control of operational conditions, they are limited to few strains of algae, are easily contaminated and occupy larger land areas than photobioreactos (Arnold, 2013).

Photobioreactors (PBRs)

PBRs can be classified according to design and mode of operation. The main categories involve: (1) flat or tubular; (2) horizontal, inclined, vertical or spiral; and (3) manifold or serpentine (Mata et al., 2010). PBRs are considered to have several advantages over open ponds: PBRs facilitate better control of cultivation parameters, such as carbon dioxide and nutrients supply, water supply, optimal temperature, efficient exposure to light, culture density, pH levels and less contamination rates (Mata et al., 2010). In addition, PBRs facilitate higher volumetric productivities (Ramanathan et al., 2011). Nevertheless, they suffer from overheating, bio-fouling, difficulty in scaling up and high operational costs.

Table 5 (Mata et al., 2010) portrays a more detailed comparison of open and closed large-scale culture systems for microalgae.

Culture Parameters	Closed systems (PBRs)	Open ponds systems
Contamination control	Easy	Difficult
Contamination risk	Reduced	High
Sterility	Achievable	None
Process control	Easy	Difficult
Species control	Easy	Difficult
Mixing	Uniform	Very poor
Operation regime	Batch or semi-continuous	Batch or semi-continuous
Space required	A matter of productivity	PBRs < Ponds
Area/volume ratio	High (20–200 m^{-1})	Low (5–10 m^{-1})
Population density (algal cell)	High	Low
Investment	High	Low
Operation costs	High	Low
Capital/operating costs	High	Low (3-10 times lower)
Light utilization efficiency	High	Poor
Temperature control	More uniform temperature	Difficult
Productivity	3–5 times more productive	Low
Water losses	Depends upon cooling design	PBRs ~ Ponds
Hydrodynamic stress on algae	Low–high	Very low
Evaporation of growth medium	Low	High
	High	Low
Gas transfer control	Depends on pH, alkalinity, etc.	PBRs ~ Ponds
CO_2 losses	Greater problem in PBRs	PBRs > Ponds
O2 inhibition	3–5 times more in PBRs	PBRs > Ponds
Biomass concentration	Difficult	Easy
Scale-up		

Table 5: *Detailed comparison between PBRs and open pond systems for microalgae cultivation*

The culture system to be selected for our case goes along with the selection of species for cultivation. Different species require a different culture system in order to thrive. Therefore, it is going to be presented in the Species section.

3.3.2.4 Species

Microalgae represent a big variety of species -more than 300.000- living in a wide range of environmental conditions and carrying totally different characteristics (Alam et al., 2012). Therefore, choosing the 'perfect' species for cultivation may constitute a very complex procedure, since hundreds of parameters have to be taken into account. In our case, a species with high Phosphorus and Nitrogen removal efficiency is imperative. On the other side of the spectrum, this goal should be combined with a good biomass production in order to facilitate economic potential. The most commonly applied microalgae cultures for Phosphorus and Nitrogen removal are the *Chlorella* and *Spirulina* species (Maity et al., 2014). *Chlorella* cultivated for 14 days (i.e. one batch) in a flat plate photobioreactor, which is considered to be the best performing PBR due to large illumination surface area (Slade & Bauen, 2013), removed total Nitrogen and total Phosphorus by 89.1% and 80.9% respectively (Li et al., 2011). On the other hand, *Spirulina Platensis* cultivated in membrane photobioreactor managed to remove 49% of Nitrate (NO_3), 92% of Ammonium (NH_4) and 67% of Phosphate(PO_4) (Cheunbarn & Peerapornpisal, 2010). Along with the higher biomass productivity of Chlorella compared to

Spirulina Platensis (Maity et al., 2014) the former species cultivated in a flat plate photobioreactor is the most preferable in the case of Ouderkerkerplas.

Figure 7; ***A flat plate photobioreactor system***

3.3.3 THEORETICAL BIOMASS YIELD

The optimum exploitation of Phosphorus and Nitrogen is essential to purify the pumped water. Therefore, the amount of these nutrients should be estimated. In this way and bearing in mind the ratio (0.09 tons N and 0.01 tons P) for the production of 1 ton of dry biomass, a rough estimation of the biomass yield in an annual basis could be calculated. This will portray if there is a potential for stakeholders to invest in this project. Waternet has conducted an abundance of measurements regarding the concentration of these nutrients in different depths of the lake. According to the latest data (2013), the lid was first formed in May and lasted till October 2013 (Waternet, 2013). Table 6 illustrates the different depths of thermocline for the different months and the average nutrients concentration below this lid for 2013. The nutrients concentration above thermocline will not be taken into account, since the nutrients that are going to be used as fertilizers for the culture system exist in the water pumped for cool water mining in the summer period, which is pumped below the thermocline.

The total volume of water extracted is known and it amounts to 2.880.889 m^3 in 2013 (i.e. May-October)(Waternet, Maandrapportage NUOAM0100 Mei-Oktober, 2013). However, since the concentration of the different nutrients are determined only for one day per month according to Waternet (Waternet, Figuren rapportage, 2013), the only way to estimate adequately the total amount of different nutrients, is to determine the average value of the nutrients concentrations for the extraction period, which in turn is going to be multiplied with the total volume of water pumped.

Month	**Depth (m)**	**NO_3 (µmol/l)**	**NH_4 (µmol/l)**	**PO_4 (µmol/l)**	**P (µmol/l)**
May	14	37,15	6,24	2,81	3,48
June	16	52,56	1,62	3,62	3,93
July	18	50,93	1,83	4,16	3,98
August	22	48,60	2,55	3,68	4,98
September	24	56,89	2,08	5,04	6,03
October	24	60,55	3,20	4,94	5,69
Total average concentration		**51,11**	**2,92**	**4,04**	**4,68**

Table 6: ***Overview of the formation of the thermocline and the average concentrations of nutrients***

The species selected for cultivation (Chlorella) uses Phosphorus (P) and Nitrogen (N) as fertilizers. Thus, the amount of P and N in the molecules of Nitrate (NO_3), Ammonium (NH_4) and Phosphate (PO_4) as well the amount of the primary element P in the total extracted water for 2013 has to be determined. The different conversions are illustrated in Table 7 (ICES, 2014) and the results in Table 8.

Phosphate Phosphorus (PO_4-P)	Nitrate Nitrogen(NO_3-N)	Ammonium Nitrogen(NH_4-N)
1 μg PO_4/l = 0.011 μmol PO_4/l 1 μg PO_4/l = 0.33 μg P/l 1 μg P/l = 0.032 μmol P/l	1 μg NO_3/l = 0.016 μmol NO_3/l 1 μg NO_3/l = 0.23 μg N/l 1 μg N/l = 0.071 μmol N/l	1 μg NH_4/l = 0.055 μmol NH_4/l 1 μg NH_4/l = 0.78 μg N/l 1 μg N/l = 0.071 μmol N/l

Table 7: *Overview of conversions among the different molecules and their primary macronutrients*

	P from PO_4 (kg)	P (kg)	N from NO_3 (kg)	N from NH_4 (kg)
	349	421	2117	120
Total	**770 (kg) P**		**2237 (kg) N**	
Chlorella usage[5]	**623 (kg) P**		**1993 (kg) N**	

Table 8: *Total amount of Phosphorus and Nitrogen present in the pumped water for 2013*

The ratio of the total amount of P and N does not match with the ratio mentioned in Cultivation Inputs section (0.09 tons N and 0.01 tons P for the production of 1 ton dry biomass). Thus, an additional source of N is required to achieve a good ratio and, consequently, realize biomass production. The calculations show that 3,668 kg of N are further needed. The theoretical dry biomass yield would then amount to 62.9 tons in the period of exploitation. Nevertheless, the significant volume of water available from the cool water mining (see Water section) can result in 636 tons of dry biomass for 1 ha[6]. The abovementioned results show that there are different ways to calculate the yield. Considering water supply as a benchmark will not negatively affect the removal of Phosphorus and Nitrogen (in fact more nutrients from outer sources will be needed to satisfy the need for fertilizers) and thus we will assume that this is the most realistic biomass yield for Ouderkerkerplas.

3.3.4 LIMITATIONS

The majority of limitations involved in the construction of a culture system in Ouderkerkerplas are already mentioned throughout the text. An additional limitation involves the fossil fuel input in the form of electricity consumption during cultivation and usage of natural gas to dry the harvested biomass (Slade & Bauen, 2013). Furthermore, at certain stages of their lifecycle many algae species can produce toxins, which presence is difficult to be predicted and monitored. Thus, co-products used in the human food chain will have to show that are safe for consumption (Rellan et al., 2009).

[5] In Species section the Chlorella's nutrient removal efficiences (89.1% for Nitrogen and 80.9% for Phosphorus) were presented.

[6] The calculation sequence for determing the amount of dry biomass for 1 hectare can be found in the appendix. The reason for using 1 hectare as a parameter for the applicability on the Ouderkerkerplas is justified in the Economic costs section.

3.3.5 APPLICATIONS

Microalgae constitute very promising bio-catalysts to be implemented in the increasing field of biotechnology. This is valid for the production of food, feed, fine chemicals and biofuels (Milledge, 2012; Wijffels et al., 2013). The most valuable products involve highly - pure fine chemicals. For instance, in the pigment sector the market value for ß-carotene is estimated at 3000 US-$/kg and for astaxanthin (antioxidant supplement of the keto-carotenoids) more than 7000 US-$/kg can be appraised. The global global market volume for both products is 200 million US-$/y (Koller et al., 2014). Proteins and minerals for human nutrition have a market price of 50 US-$/kg with a global market volume of 1.25 billion US-$/y (Spolaore et al., 2006). Last but not least, for biodiesel, the general market price amounts to less than 0.5 US-$/kg with a production price of 4 US-$/kg and even more. This means that microalgae biofuels are not cost-efficient yet. However, the market volume is estimated to impressive 10^9 US-$/y (Koller et al., 2014). In retrospect, taking into account the high biomass yield that could be achieved in Ouderkerkerplas (see Theoretical biomass yield section) along with the purification of the water (see Species section), there is a high environmental and economic potential for investing in this project. A deeper elaboration on the economic potential is illustrated in the Economic costs section. A more detailed overview of the different applications of microalgae is illustrated in Figure 8 (Koller et al., 2014).

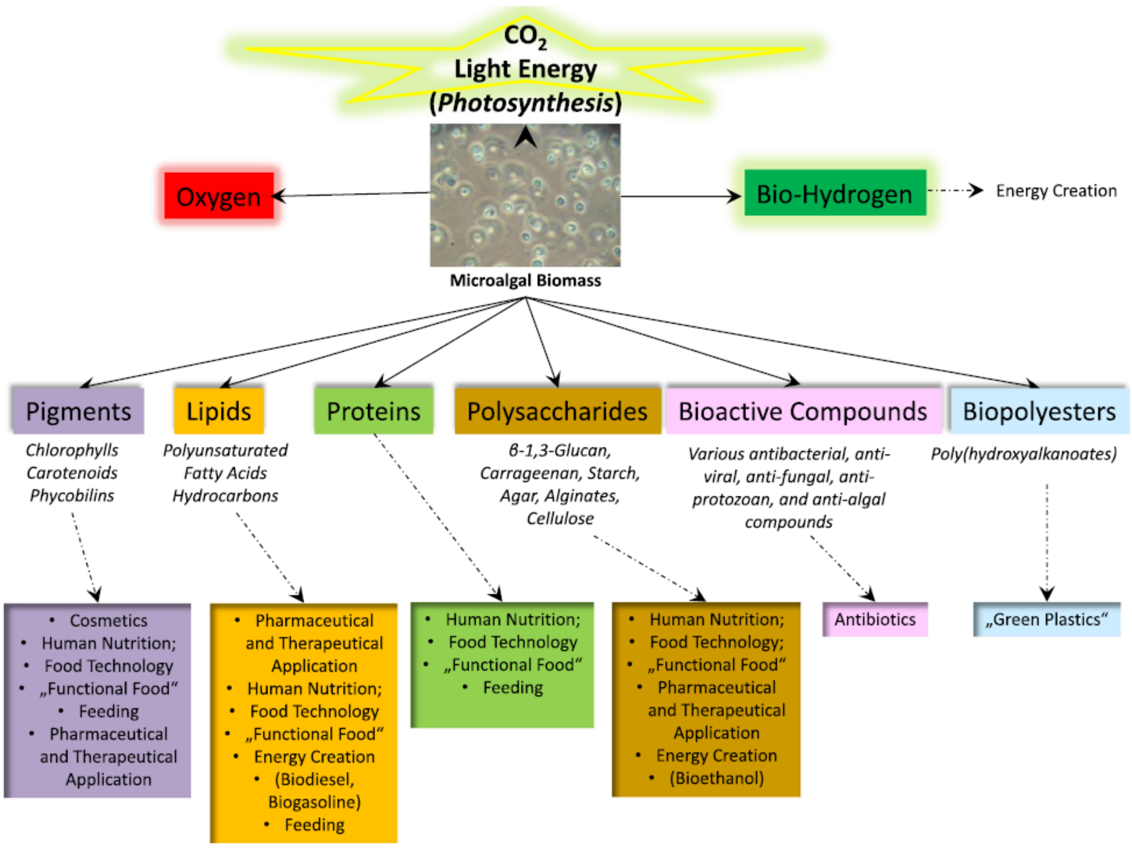

Figure 8: *Overview of products synthesized by microalgal strains and areas of application.*

3.4 INSTITUTIONAL SETTING

The implementation of a microalgae cultivation system would require several contracts with existing institutions who govern the area (Mark Schoot, personal communication, September 19, 2014). To begin with, as the system would necessarily be attached to NUON's cold water mining activity, a contract with NUON would have to be established. Additionally, given the authority of WaterNet over the quality of the lake, they would also have to be consulted with to ensure that the implementation of such a project would not in any way negative impact the water quality. GGA governs the area of the Ouderkerkerplas as a whole and as such another contract would need to be developed to permit the installation of such a system. Finally, given the amount of space required, GGA has indicated that there may also be a need for a zoning permit (Mark Schoot, personal communication, September 19, 2014). In sum, the institutional setting is not a huge barrier to implementation; however, a contract with NUON may require some negotiation to ensure that their interests are satisfied and they are included in the project development process (see Stakeholder section).

3.5 SOCIAL ASPECTS

3.5.1 STAKEHOLDERS

Here, first, stakeholders are segmented into their respective types (Figure 9) and, second, placed within the stakeholders matrix (Figure 10) which is used to determine the threatening and cooperative potential of each of the groups. Finally, we discuss potential strategies for engaging stakeholders based on their place within the matrix.

3.5.1.1 Stakeholder types

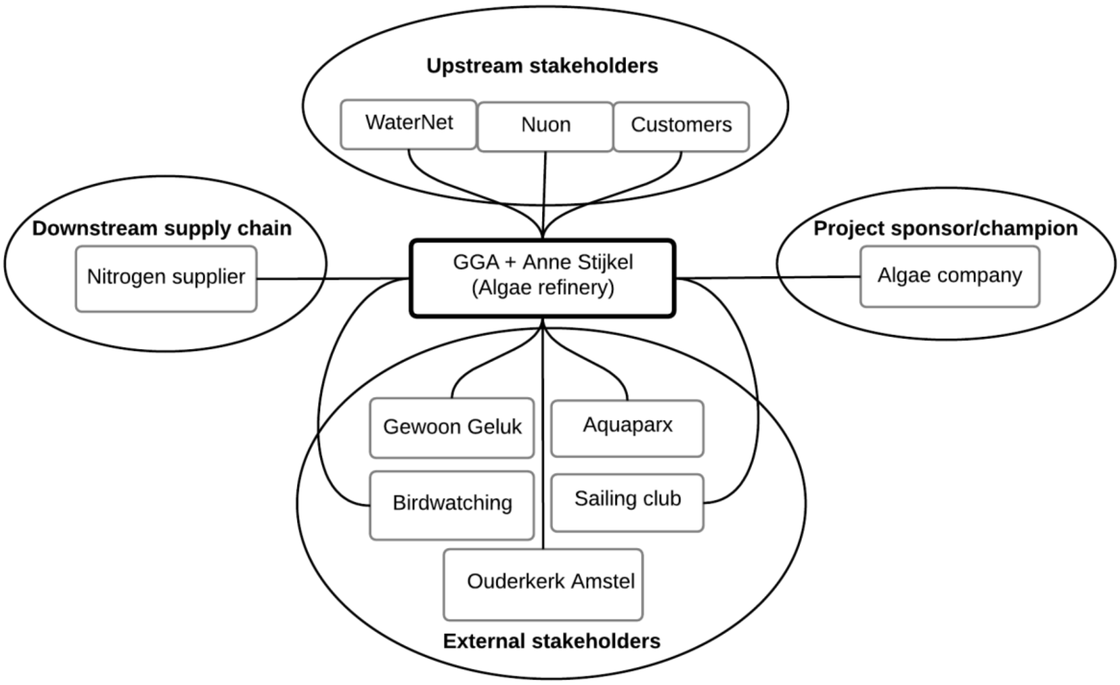

Figure 9: *Stakeholder types.*

Upstream stakeholders: NUON and WaterNet are upstream stakeholders because they both have stake in the water quality of the Ouderkerkerplas. WaterNet is ultimately responsible for the water quality of the Ouderkerkerplas and would benefit directly from any project that contributes to improved water quality. Similarly, NUON's cold water mining activity in the Ouderkerkerplas is sustained through an oxygenation system and they also would have a direct benefit from algae cultivation for the same reason as WaterNet. More specifically, because NUON is currently spending 20,000 euro per year (Raymond van Bulderen, personal communication, October 2, 2014) to maintain their oxygenation operation, if an algae cultivation system contributes to lower phosphate levels, NUON benefits[7]. Additionally, the dry biomass produced from the algae photobioreactor can be sold to upstream customers[8] for revenues.

Project core stakeholder group: The project core stakeholder group includes the project sponsor, *which* for this project would include an algae cultivation company as well as the project leaders, GGA and Anne Stijkel. Presently, three algae cultivation companies exist within the Netherlands that could fill this role[9].

External stakeholders: These stakeholders include the local community, which is comprised of the Ouderkerk Amstel residents, a bird watching group, the local sailing club, Aquaparx and Gewoon Geluk, all of who use the Ouderkerkerplas for various reasons.

Downstream supply chain: Due to the insufficient supply of nitrogen in the lake, a supplier of nitrogen fertilizer would be required to sustain an algae cultivation operation[10].

Each stakeholder group plays a different role. Upstream and downstream stakeholders, as well as the project champion, are all instrumental to the project, their potential to cooperate or threaten project must be understood by the project core to increase the likelihood of project success (Polonsky 1996). As mentioned, the external stakeholders have intrinsic rights and, given the aim of the GGA to promote recreation and education in the area, this group should also be understood in terms of their threatening and cooperative potential (Polonsky & Scott 2005). In the following section a stakeholder matrix is applied to understand these potentials.

3.5.1.2 Stakeholder matrix

The stakeholder matrix helps to distinguish the respective potential of stakeholder's potential to cooperate or threaten project success (Walker et al. 2007; Savage et al. 1991; Polonsky & Scott 2005). While there are several methods which can be employed to do this, we have adapted Polonsky & Scott's (2005) stakeholder strategy matrix (Figure 10).

Mixed blessing: Starting with Savage's (1991) mixed blessing group, we find 3 stakeholder groups. Beginning with GGA & Anne Stijkel. Naturally, as project leaders these stakeholders have a high interest in cooperating to ensure project success. However, more importantly, they also have a high threatening potential, arguably the highest. For example, if they do not facilitate project implementation properly, i.e. not engaging stakeholders properly, they are liable to cause any project to fail. More specifically, in regards to this solution, given NUON's expressed disinterest in new projects and, yet, the simultaneous need for their cooperation[11], unless engaged

[7] The lower the phosphate levels, the more water NUON can extract during cold water mining (Raymond van Bulderen, personal communication, October 2, 2014).
[8] Identification of potential customers has been left out of this analysis due to our inability to contact any algae cultivation companies.
[9] Unfortunately, we have been unable to successfully speak with any algae companies (Algaelink NV, Ingrepro BV, and Tomalgae) and as such have very limited data on their stakeholder interests/willingness to participate. We have attempted to contact all three algae cultivation companies within the Netherlands, to no avail.
[10] As with the algae companies, we have failed to successfully contact any commercial nitrogen suppliers.
[11] As the algae cultivation system would be attached to NUON's cold water mining operation, NUON's cooperation is fundamental to project implementation.

effectively, it is possible that if the project core fails to address NUON's interests they threaten the potential for project implementation.

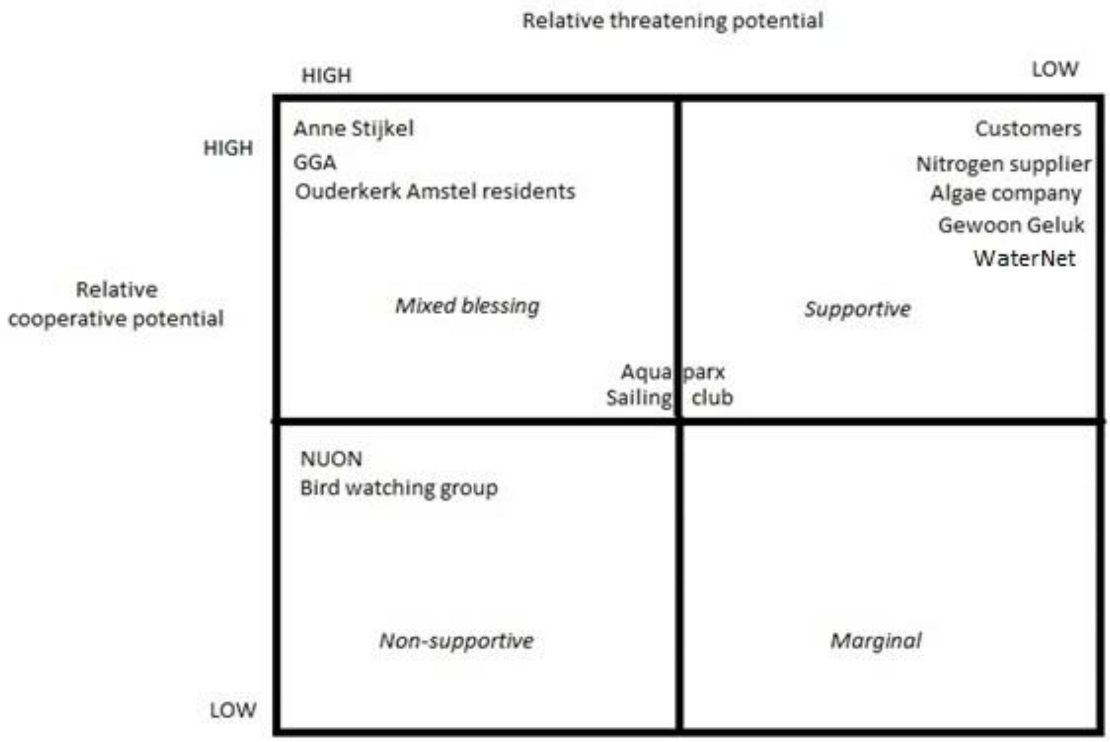

Figure 10: *Stakeholder matrix (adapted from Polonsky & Scott 2005).*

Ouderkerk Amstel residents, who we have not been able to contact, have been placed in this group based on assumption and secondary information (Mark Schoot, personal communication, September 19, 2014). According to our communication with GGA it is known that the local community is interested in improved water quality (Mark Schoot, personal communication, September 19, 2014). Additionally, it is assumed that as local residents, they harness the power to threaten project implementation through local collective action[12].

Supportive: The potential customers, a nitrogen supplier, the algae company, Gewoon Geluk, and WaterNet, are considered to be supportive, as defined by Savage (1991). Regarding the first three of these stakeholders[13], we assume they are willing to cooperate because implementing an algae cultivation system would create revenues for their businesses (or products for purchase, in the case of customers[14]). However, it is also assumed that they have low threatening potential because each of these three stakeholders can be replaced, and as such they do not hold permanent stake in the project[15]. Gewoon Geluk has expressed interest in any project which might draw more people to the area and/or improve water quality. As such, they have a high

[12] However, just to reiterate, this statement is assumptive and as such should be further investigated to determine the validity.
[13] None of whom we have been able to make contact with successfully.
[14] It's also assumed that the biomass products would be welcomed by customers because a larger supply can potentially contribute to lower long term costs for customers.
[15] For example, there are multiple nitrogen suppliers, algae cultivation companies and also potential customers.

cooperative potential. However, due to the fact that Gewoon Geluk only operates at the Ouderkerkerplas seasonally and has no legal rights or any significant amount of power[16], they are unable to threaten any project development. WaterNet has expressed interest in any project which might further contribute to improved water quality and were enthusiastic about the potential of microalgae applications (Wiebbe Baker, personal communication, October 8, 2014).
Non-supportive: NUON and the local bird watching group are non-supportive stakeholders for varying reasons. NUON is currently happy with their oxygenation system (Raymond van Bulderen, personal communication, October 2, 2014) and because they have already invested in it, the algae cultivation system threatens the usefulness of this oxygenation system, rendering their investment useless. Additionally, NUON has explicitly expressed they are not interested in participating in other projects, unless they would receive substantial economic benefits (Raymon van Bulderen, personal communication, October 2, 2014). Furthermore, in consideration of the fact that the algae cultivation system would need to be constructed as an attachment to the cold water mining system, in order to successfully implement this project, a good relationship with NUON and their agreement would be two fundamental requirements.

In regards to the bird watching group, it is quite clear that, at the moment, they are not willing to cooperate with *any* project that is being proposed (Interview 2014). Moreover, they claim that legal rights protect the area which restrict any type of development on the Ouderkerkerplas. This indicates that they are unwilling to cooperate and may potentially threaten any project development.

We have been unable to receive any input from Aquaparx and the local sailing club. They have both been placed in between mixed blessing and supportive stakeholders because we are unaware how much threatening potential they wield. We assume that they are interested in improved water quality and as such have a cooperative potential, but we have not been able to verify these assumptions. We have identified no *marginal* stakeholders for this project.

3.5.1.3 Recommendations for engagement[17]

Based on the above stakeholder types and respective places within the matrix, brief recommendations for engagement, based on literature and our ontological position, are provided for the project leaders. These strategies can be used to increase stakeholder understanding and, ultimately, foster greater levels of buy-in (Freeman 1984; Savage et al. 1991; Polonsky 1996).

Ouderkerk Amstel residents[18] have currently been entirely absent from the stakeholder process (Mark Schoot, personal communication, September 19, 2014) and as such are not aware of what is developing, we strongly recommend GGA makes strides to reach out to these residents in order to gain their support in project implementation. Particularly given the interest of GGA in increasing the attraction of the area to locals; through collaborating with these stakeholders more closely during project development, they may foster greater levels of project support. For example, more concerted efforts could have been made to include them in the co-creation process. It has been evidenced that this engagement strategy may increase project success (Freeman 1984; Savage et al. 1991; Polonksy 1996). Additionally, taking into consideration the expressed interest of WaterNet (Wiebbe Baker, personal communication, October 8, 2014)

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[16] Power in terms of their ability to collectively act against the implementation of an algae cultivation system.
[17] Due to our inability to sufficiently contact many of the key stakeholders in this research project, the following recommendations may be considered superficial. Given our inaccessibility to these stakeholders interests and views on the project under investigation, we are severely limited in our ability to provide concrete recommendations for engagement. Where possible, we have done so, but we are equally aware that many recommendations are vague and need further specification.
[18] Engagement recommendations are unnecessary to specify for GGA and Anne Stijkel, because they are project leaders and as such they are the client who this report is intended to guide.

combined with their close relationship to NUON, through working together closely with WaterNet it is possible that NUON's support might be gained.

Supportive stakeholders must be engaged by the GGA in the project development process (Polonsky 1996). Freeman (1984) and Savage et al. (1991), recommend that these stakeholders be incorporated into the planning and make effort to gain their support of the objectives of the project. Unfortunately, due to our inability to connect with three out of the four stakeholders in this group[19], we cannot provide more specific recommendations. However, Gewoon Geluk has expressed interest in any project implementation and, consistent with our recommendation, should be engaged to further catalyze project buy-in.

For the non-supportive stakeholders, NUON and the bird watching group, different strategies might be employed (Savage et al. 1991; Freeman 1984). For example, in spite of NUON's statement that they are not interested in new project developments (Raymond van Bulderen, personal communication, October 2, 2014), it is recommended that GGA engages NUON closely in project development and, specifically, makes strides to change their perception of the benefits of this project. For example, through the potential ability of algae cultivation to reduce the need (and therefore costs) of the oxygenation system. In consideration of the bird watching group's threat to litigate, GGA must incorporate them within their engagement strategy if they hope to gain project buy-in from all stakeholders.

In sum, these recommendations, which, in consideration of limited data availability are still vague, may nonetheless be seen as starting points for the GGA's stakeholder engagement strategy. Through understanding stakeholder roles, influences, and interests, and engaging them appropriately based on that information, it is then possible to incorporate them into project development and implementation (Polonksy & Scott 2005).

3.5.2 EDUCATION/RECREATION POTENTIAL[20]

This project could add educational value as it would be an experimental system which cannot be found anywhere else in the local area. Potentially, it could provide an opportunity for higher education institutes to conduct research on flat-plate photobioreactors and the cultivation of chlorella. For example, Wageningen University, who is already engaged in microalgae research, may be interested in collaborating on such a project. However, we have been unsuccessful in our attempts to verify this with Wageningen faculty. As such, although we can hypothesize this solution would have an added value in terms of education; we have been unable to confirm this.

3.6 ECONOMIC ASPECTS[21]

The following economic costs, which are intended to give insight into the investment needed for project development, should be viewed as *very* rough estimates[22]. The estimates here are based on figures provided by other studies (University of Almeria 2010; Danxiang et al. 2013; Koller et al. 2014), however, further specification will be required to determine the total costs. After determining the area required for the photobioreactor, based on the amount of water required for the cultivation of 1 batch[23], the total area required is 22.2 hectares. However, that this requires a

[19] We have been unable to contact any nitrogen supplier, algae cultivation company, or customers for this projects. Attempts have been made both via e-mail and phone.
[20] We have not found any data indicating potential added value in terms of recreation.
[21] To see how these figures were calculated, please see the appendix.
[22] Due to our inability to contact any algae cultivation companies, combined with our limited data on many of the parameters surrounding algae cultivation, we are unable to provide a highly accurate cost estimate.
[23] See Species section above.

significant amount of land space which is not available, we provide estimates for 1 hectare. The reason for this is two-fold, first, microalgae cultivation is in experimental stages and as such we would not recommend such a large system to begin with. Second, photobioreactors can be easily expanded upon (Carvalho et al. 2006) in the future, indicating that beginning with a small scale operation would be less of a risk. Taking into account, the costs of operating the photobioreactor, labor, materials, and supplemental CO_2, we estimate a total initial investment cost of 4,142,620€. However, the costs of system installation, the required artificial lighting, and the cost of supplemental nutrients (phosphorous and nitrogen) required for cultivation have not been assessed here as we haven't had sufficient access to data.

To provide stakeholders with a rough estimate of potential revenues from this system, we have calculated the potential revenues which could be generated from the sales of the highest valued product which we have found within our literature review (astaxanthin) (Koller et al. 2014). Assuming that the concentration of this supplement within the dry biomass amounts to 0.7% (Danxiang et al. 2013) and assuming that the system is capable of producing a total of 636 tons of dry biomass annually, at a price of 7,000€/kg (Koller et al. 2014), we can calculate estimated revenues of 31,164,000€.

In sum, the above figures are very rough estimates and need further investigation. However, they do provide interesting insight into the economic feasibility and the potential revenues which an algae cultivation system might potentially produce.

3.7 CONCLUSION

The application of a microalgae cultivation system as a solution for contributing to the sustainable development of the Ouderkerkerplas has many promising results. For example, from the above analysis, it is possible to ascertain that a microalgae cultivation system would contribute positively to environmental aspects in terms of permanently improving the water quality and utilizing the lake's excessive nutrient levels to produce eco-friendly algal biomass which can be used for various applications (see Applications section). However, we have not found any evidence that this solution could positively contribute to biodiversity. From the stakeholder analysis we can see that there are certain stakeholders who might initially resist this project (i.e NUON and the bird watching group). However, stakeholder support should not be an issue, if GGA engages these stakeholders effectively during project implementation.

In terms of potential recreational/educational value, further investigation is needed, but it is likely that a microalgae cultivation system can provide educational opportunities, particularly higher education. Our estimated initial investment cost for the first year, which needs to be further verified in consideration of our limited data availability, indicates that this solution is relatively inexpensive. Moreover, the potential revenues generated seemingly make this project very attractive in terms of economic aspects. Finally, the institutional context within which this project would be implemented does not pose any major restrictions. Because the microalgae photobioreactor would need to be attached to NUON's already existing cold water mining operation, the most significant concern in this aspect is that NUON *must* be willing to cooperate.
In conclusion, from the analysis conducted above, it can be said that a microalgae cultivation system would positively contribute to environmental aspects in terms of enhanced water quality and potential food/fuel production; it does not face significant stakeholder opposition and, as such, is likely to be socially accepted; it is economically attractive; it may have added value in terms of education potential; and, there are potentially minor institutional constraints. As such, it is our recommendation that this solution is worth further investigation and offers a promising contribution to the sustainable development of the Ouderkerkerplas.

4 NANOTECHNOLOGY

4.1 INTRODUCTION

One of the potential solutions discussed during the co-creation meetings in order to improve the water quality in the Ouderkerkerplas was the introduction of nanotechnology(Stijkel, personal communication, September 9, 2014). Nanotechnology is a technique that makes it possible to work on a scale from atoms to around 100 nanometers. It can be used for various functions in diverse scientific fields, and is currently used in everyday products such as cosmetics to specific biomedical uses. In regards to water treatment possibilities, nanotechnology has been acknowledged as an "affordable, effective, efficient and durable way ...for water treatment" (Kanchi, 2014). What the nanoparticles do is convert organic compounds into inorganic compounds, making them easier to decompose naturally, through a process known as photodegradation (Wang, personal communication, October 22, 2014). Given this background, nanotechnology has the potential to be a viable solution to the high phosphate levels in the Ouderkerkerplas. Nanotechnology is already being used on an individual scale to create purified drinking water (Owen, personal communication, October 21, 2014). It is still unclear as to how this technology could be transferred into a setting like the Ouderkerkerplas, where the objective is not to reach drinking-water quality, but to improve the water quality up to the standards set by Waternet, the local water authority. New methods such as nanotechnology to improve water quality can be in the interest of Waternet, as the present oxidation practices in the lake are not really a sustainable solution to the problem considering the fact that the phosphate concentrations in the lake will rise again once the process of adding of oxygen stops (Bakker, personal communication October 8, 2014). Upscaling the use of nanotechnology will be one of the challenges for the Ouderkerkerplas, due to the size of the lake. Using this method to improve the water quality at the lake could lead to various effects, both environmental and social. On the one hand, the potential solution could impact the water quality, which as a result would influence the ecological setting and biodiversity of the lake. On the other hand, improving the water quality could lead to a vitalization of the area by the surrounding communities, as people would be able to use the lake as an educational center and for leisure activities, such as swimming, kayaking, etc. The environmental and social implication of this possible project will be elaborated on in this chapter. To understand these implications better, the following questions have been devised:
How can nanotechnology contribute to the sustainable development of the Ouderkerkerplas?

Environmental aspects

- In general, what is nanotechnology and how can the technology be used to treat water?
- In which areas/waters is nanotechnology potentially useful and are there any example cases in which nanotechnology is used effectively?
- What are the potential effects on the environment? Meaning, water quality, ecology and biodiversity?
- What is the potential and the applicability of the nanotechnology on the Ouderkerkerplas?
- Are there any negative side effects using this technology?
- In case nanotechnology is useful for the Ouderkerkerplas, what is the most effective way to integrate it in the area, technically but also spatially?

Social, economic aspects and institutional requirements:

- Who are the stakeholders involved in this project and how would they contribute to its fulfilment?
- What is the recreational potential of this project?
- What is the economic implication of this project?

4.2 ENVIRONMENTAL ASPECTS

4.2.1 NANOTECHNOLOGY AND WATER TREATMENT

In the past years, conventional biological and physical treatment methods (absorption, ultrafiltration, coagulation, etc.) have been the main-stream techniques to remove organic pollutants from various waters and wastewaters (Mao, Shen, & Guo, 2012). Nevertheless, the decontamination of many emerging anthropogenic organic pollutants requires novel and more sustainable techniques to chemically transform them into non-hazardous compounds. Nanomaterials are essential building blocks that can produce chemicals in an environmentally friendly manner, harvest light to supply energy, and help develop faster computers and better medicines. In the field of water science, nanotechnology plays an important role in terms of water treatment and fuel production as nanomaterials are being used for renewable hydrogen production, storage and utilization.

4.2.1.1 How does it work?

The approach of using nanotechnology in order to decompose organic pollutants is based on the oxidation of organic pollutants into CO2, water and other inorganic species by using molecular O2 as an oxidant (Chen et al., 2010). Chen describes the process (shown in scheme 1) as follows: "To degrade organic pollutants efficiently through oxidation under ambient conditions, the organic pollutants, O2 or both have to be activated, during which external energy and/or catalysts are usually needed. As a renewable energy source, sunlight is most attractive to supply energy for these activation processes" (Chen et al., 2010).

$$\mathrm{Org} + \mathrm{O_2} \xrightarrow[\text{or catalyst}]{\text{energy}} \mathrm{CO_2} + \mathrm{H_2O} + \text{Inorganic species}$$

Scheme 1: *Nanotechnology in order to decompose organic pollutants (schematic process description) (Chen C., 2009)*

Sunlight (energy) is used to drive the chemical transformation of organic pollutants. It requires a photochemical system into which the energy enters via the absorption of light with a certain wavelength by one of the components such as the organic pollutant and the photocatalyst. A semi-conductor is used to convert solar energy into chemical energy in order to destroy pollutants.

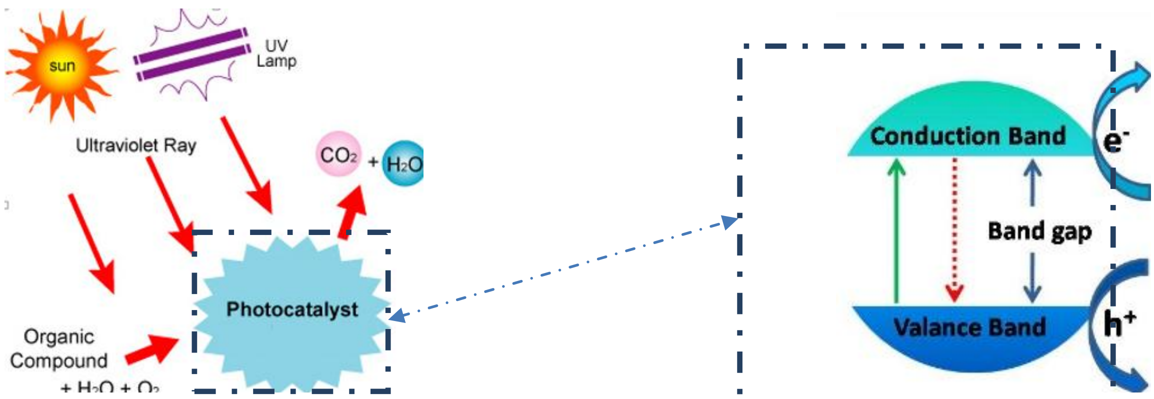


Figure 11: *One single nanoparticle functions as a semi-conductor/photocatalyst to convert solar energy in to chemical energy.*

4.2.2 CURRENT STATUS AND RESEARCH

4.2.2.1 Utrecht University

At the moment Utrecht University is investigating nanotechnology in order to further develop knowledge about it's possibilities and applicability. It is a potential useful instrument/tool in terms of energy production and water treatment (Wang, personal communication, October 22, 2014). The focus of the research currently underway is how to improve the effectiveness of the nanomaterials so as to increase the endurance of it's application. If they succeed to increase the catalyst's stability, the efficiency of the semi-conductor will increase because it will last longer. G. Wang describes 2 types of research which are being done on nanotechnology at the moment. The first one being more investigated because it generates a fuel.

1. Renewable hydrogen production: water splitting to create hydrogen and carbon dioxide. Hydrogen can be burned and used as fuel (with no pollution) (currently, Wang is working with catalysts that react with water particles in order to separate them).

2. Photo degradation: converts organic compounds into ones that are easier to decompose. Mainly into CO^2 and H_2O. This method creates a byproduct of dust/sand-like substances (the nanoparticles themselves) in the water. Decomposing organic compounds is harder than decomposing inorganic ones.

Research at Utrecht University is being done as follows: A dye, simulating a natural contaminant, is added to a water substance (photo 1). Nanoparticles are added to function as a catalyzer (photo 2), after which the complete set up is put under UV-light, which functions as an energy source to activate the photo degradation process (photo 3). By using different dye's, nanoparticles and UV-light exposures, it is possible to investigate the effectiveness of the degradation process. In order to make the decomposition of compounds specific to phosphate, you would have to design a catalyst that would react with the phosphates.(Wang, personal communication, October 22, 2014)

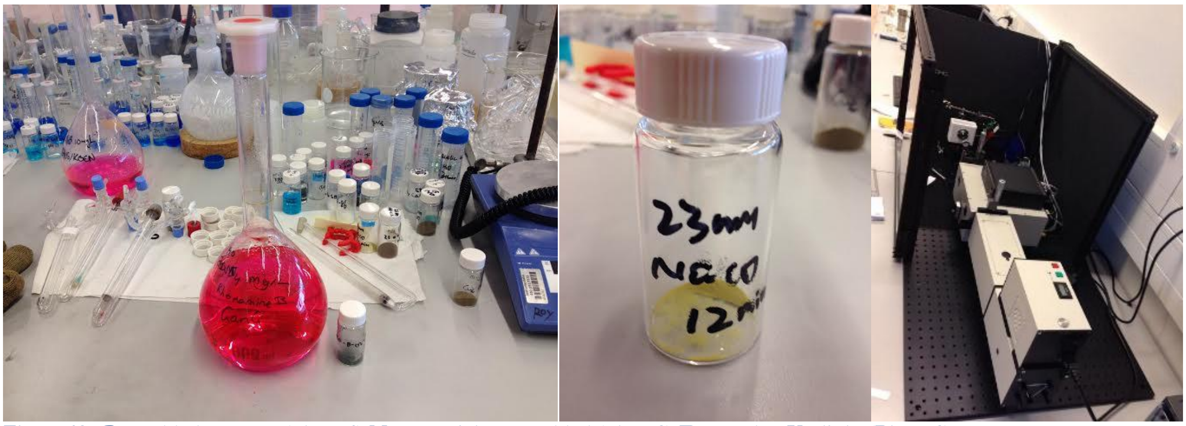
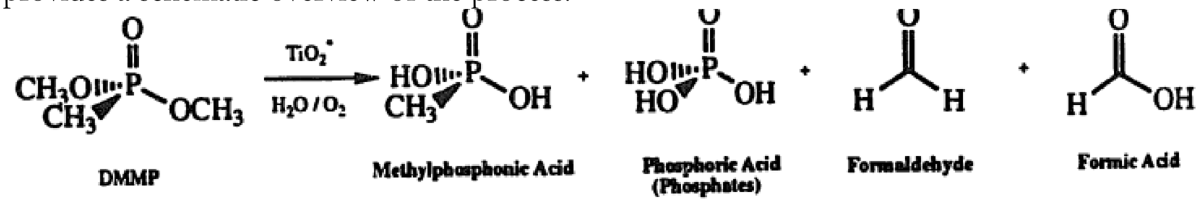


Figure 12: *Dye added to water (photo 1) Nanoparticles are added (photo2) Exposed to Uv-light (Photo 3)*

4.2.2.2 Florida International University (FIU)

FIU has already explored related photocatalytic methods breaking apart complex phosphor compounds to simpler phosphor compounds which eventually might have a different effect on the algae compounds. Their research was focused on a kinetic analyses of the TiO2-catalyzed photodegradation of two stimulants in oxygenated aqueous solutions. The first being dimethyl methylphosphonate (DMMP), chemically known as $C_3H_9O_3P$, and the second being diethyl methylphosphonate (DEMP), chemically known as $C_5H_{13}O_3P$. The effects of substrate concentration and solution pH were investigated. The major products formed by the photocatalytic decomposition of DMMP are methylphosphonic acid, phosphoric acid, formaldehyde and formic acid (Shea et al., 1997). These remaining compounds are more easily degradable in natural environments which would result in a decrease in algea growth. Scheme 2 provides a schematic overview of the process.



Scheme 2 Remaining compounds from TiOz-catalyzod photolytic degradation of DMMP in aqueous solutions(Shea et al., 1997)

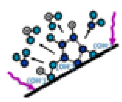
The research by FIU has shown that the phosphonates DMMP and DEMP are readily degraded by TiO2 photocatalysis over a range of concentrations and solutions pH. The saturation kinetics were observed and the final products were indicative of complete mineralization. The study suggests that TiO2 photocatalysis should be an effective technique for the destruction of organophosphorus compounds in aqueous solutions.

4.2.2.3 University Of Tabriz

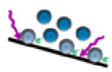
At the University of Tabriz research has been done on photocatalic degradation in water using ZnO as an alternative catylisyt to TiO2. The results show that a ZnO/UV-light process could also be effectively used to facilitate a photocalitic degradation process in water (Daneshvar et al., 2004).

4.2.3 EXAMPLE CASES OF NANOTECHNOLOGY BEING USED FOR WATER TREATMENT

Already in the USA, Puralytics, a company actively involved in water treatment projects and initiatives all over the world, is using nanotechnology to treat water effectively. Their first achievement is a 'Solarbag,' which uses nanotechnology to convert the bag into a sunlight-activated reusable water purifier. Secondly, a so called 'Lilypad' has been produced with the objective to treat storm-water runoff and natural water catchments. This sunlight-activated nanotechnology is potentially useful for water treatment purposes. The solar energy activates five photochemical processes, which work together synergistically to break down or remove contaminants from water. These processes actually destroy contaminants, rather than capturing them and creating a hazardous waste disposal problem. The method employed by Puralytics basically uses solar energy to burn the pollutants (Wang, personal communication, October 22, 2014). The technology is possibly applicable for contaminant mitigation of natural water catchments near industrial sources of waste or other sources of contamination. For the functioning of Lilypad the following 5 processes are being executed (Owen, personal communication October 21, 2014).



Photocatalytic Oxidation: sunlight activates a nanotechnology coated mesh to generate hydroxyl radicals (OH-), which break apart chemical contaminants rendering them inert.



Photocatalytic Reduction: Reduces toxic species such as mercury (Hg II), silver (Ag I), arsenic (As V, and chromium (Cr VI) into more readily adsorbed materials.

Photolysis: Direct disassociation of contaminants by high intensity UV light, including atrazine, amoxicillin, DEET and all estrogenic chemicals.

Photoadsorption: The catalyst strongly absorbs heavy metals including mercury, lead, selenium and arsenic, permanganate and other compounds.

Photo Disinfection: Multiple wavelengths and high intensity UV disinfect pathogens more effectively than standard UV germicidal lamps.

4.2.3.1 Experiments

Students of Oregon State University are currently testing the Lilypad on a small scale to determine how well it gets rid of all kinds of contaminants. Tests are being done in campus lab spaces affiliated with OSU's Institute for Water and Watersheds. The promising results have driven Oregon BEST to fund a phase II testing as well as the construction of an outdoor green storm water research lab.

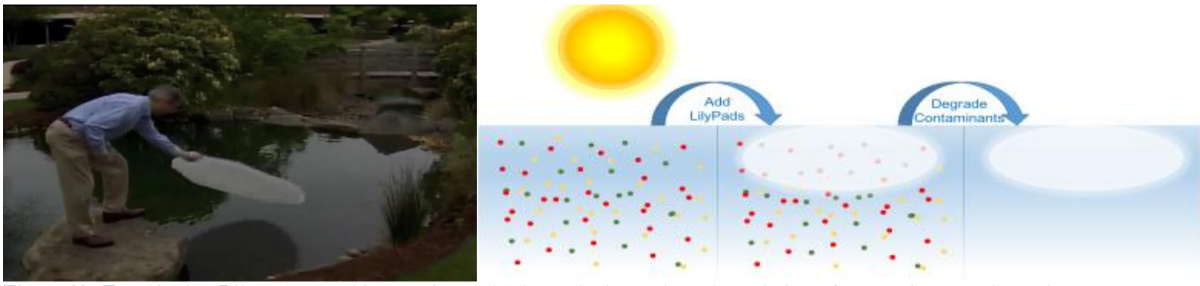


Figure 13: *Functioning Lilypads tested in practice and schematical overview: degradation of contaminants using solar energy*

A second test setting is a rain garden with a storm water treatment with rectangular Lilypads. The following picture shows the ribbon cutting ceremony for the facility, so there is no water to be seen yet in the Lilypad treatment.

Figure 14: *Rain garden with storm water treatment*

4.2.4 EFFECTS ON THE ENVIRONMENT

The Lilypad technology is potentially useful for water treatment of open water catchments. It purifies up to 650 sorts of contaminants. Attachment ? provides an overview of all contaminants destroyed by a Lilypad (Owen, personal communication October 21, 2014). DMMP is included on the list, which is the same stimulant that Florida International University has been investigating with positive results. Using the Lilypad in an open water catchment, pond or lake like the Ouderkerkerplas, from an environmental point of view, would have little negative effects. Since it is a surface effect, it would remove nutrients, contaminants and sterilize water near the surface, but it will not affect fish, plants, or other organisms inhabiting the deeper lake waters. Since the Lilypad is implemented as an open loop system it would not kill any organisms nor would it create an unintended dead zone in the water.

4.2.5 APPLICABILITY ON THE OUDERKERKERPLAS

In the case of the Ouderkerkerplas where only phosphate levels cause a significant problem in terms of water quality, the Lilypad technology might be over effective as it also addresses all kinds of other contaminants. Puralytics has not studied nanomaterials that only address phosphates and phosphorus explicitly to any extent. Nevertheless studies have been done elsewhere to produce a catalyzer/nanomaterials which decomposes phosphates and phosphorus, with promising results (Shea et al., 1997). Also, according to G. Wang PhD in nanomaterials at Utrecht University it would, from a technological point of view, be possible to develop and produce a nanomaterial, which would only target phosphates and phosphorus. For now, the only existing nanotechnology that could be applicable to the Ouderkerkerplas is the Lilypad, which addresses 650 kinds of contaminants.

4.2.5.1 Hypothetical calculation

Before making any calculation it is important to notify that it is practically impossible to make a founded calculation since the effectiveness of the system is dependent on many variables including: sunlight intensity, the amount and types of contamination, the characteristics of the water (stagnant or moving water), how many, how much coverage, how the water source is filled and drained, how many contaminants (the actual P concentration), how fast you are trying to clean it, etc.. For now it can be assumed that each m^2 of Lilypad can purify 1 m^3/day for approximately a year depending on the previously mentioned variables (Owen, personal communication 21-10-2014). Within the context of uncertainties as a result of many variable factors, the following calculation might still give an indication of relation between the amount of nanomaterial in terms of surface [m^2] and the reduction of P concentrations [$mg/m^3/day$] in the Ouderkerkerplas. This calculation is based on the effectiveness of the Lilypad as it is at the moment. Future research might develop nanomaterials, which specifically address P concentrations instead of 650 kinds of contamination like the Lilypad does, and therefore be more effective.

- The surface of the lake is 0.73 km^2
- The mean P concentration of the lake is estimated at 0,11mg/L for 2013 (data Waternet)
- the volume of the lake is $12*10^9$L (Stroom et al., 2010)
- Multiplying this data provides a total P in the Ouderkerkerplas of $1.3*10^3$kg.

1 m^2 of Lilypad surface area will remove 1 LRV (ie 90%) of contaminants in 1 m^3 of water in 1 tropical solar day in well mixed water (Owen, personal communication 21-10-2014). In the Netherlands a more moderate climate is at hand, which might reduce the Lilypad's effectiveness. Since it is a lake, the water is not stationary, but also there are no high flow rates, so the extent to which the water is mixed might also be limited. For this reason, the assumption is made that for the Ouderkerkerplas a Lilypad coverage of 1m^2 would remove about 40-60%[1] of contaminants in 1 m^3 of water instead of 90%. The following table contains an overview with different hypothetical coverage areas of the Ouderkerkerplas with Lilypad technology to see whether this would have significant effects in terms of decomposing contaminants in the water. The levels of P in the lake (0,11 mg/L) will affect the efficiency of the Lilypads, but it is impossible to tell to what extent because it is just one of the many variables (e.g. sunlight, flow rates, etc.) affecting the effectiveness of a Lilypads purifying potential per square meter. For this reason, two charts have been made outlining the different efficiency potentials of the Lilypads: 40%, 60%. The 90% efficiency rate is left out because this is only reached under optimal conditions.

Surface m² covered with Lilypad in %	lake surface m²	volume purified m³/dag	efficiency %	actual purification m³/day	actual purification of P mg/m³/day	actual purification of P kg/m³/day	total volume lake m³	hypothetical time needed to purify the whole lake (days)	hypothetical time needed to purify the whole lake (years)
5	730000	36500	40	14600	1606000	1,606	1,2E+10	821918	2252
10	730000	73000	40	29200	3212000	3,212	1,2E+10	410959	1126
25	730000	182500	40	73000	8030000	8,03	1,2E+10	164384	450
50	730000	365000	40	146000	16060000	16,06	1,2E+10	82192	225
75	730000	547500	40	219000	24090000	24,09	1,2E+10	54795	150
100	730000	730000	40	292000	32120000	32,12	1,2E+10	41096	113

Table 9: *Hypothetical calculation of costs/ time needed for purifying the Ouderkerkerplas with Lilypads efficiency 40%*

Surface m² covered with Lilypad in %	lake surface m²	volume purified m³/dag	efficiency %	actual purification m³/day	actual purification of P mg/m³/day	actual purification of P kg/m³/day	total volume lake m³	hypothetical time needed to purify the whole lake (days)	hypothetical time needed to purify the whole lake (years)
5	730000	36500	60	21900	2409000	2,409	1,2E+10	547945	1501
10	730000	73000	60	43800	4818000	4,818	1,2E+10	273973	751
25	730000	182500	60	109500	12045000	12,045	1,2E+10	109589	300
50	730000	365000	60	219000	24090000	24,09	1,2E+10	54795	150
75	730000	547500	60	328500	36135000	36,135	1,2E+10	36530	100
100	730000	730000	60	438000	48180000	48,18	1,2E+10	27397	75

Table 10: *Hypothetical calculation of costs/ time needed for purifying the Ouderkerkerplas with Lilypads efficiency 60%*

Theoretically there is a linear relation between the amount of Lilypad surface and the potential amount of removed contaminants including P concentrations. In practice this would not be the case as the relation is dependent on the set of previously discussed and unknowable variables.

4.2.6 DISCUSSION

Current research and test results by universities such as FIU and UU show that nanotechnology has the potential to purify water catchments from contaminants including organophosphorus compounds. The Lilypad which uses this technology comes with pro's and con's. At first, the Lilypad is located on the surface of the water of the lake. This so called ' hypolimnion' water depth is exactly where the phosphate levels are at their highest and algae develops rapidly due to the sunlight. Also the effectiveness of the Lilypad increases with mixing of the water, bringing contaminants to the surface and making sure the water is well oxygenated. The Ouderkerkerplas is relatively well mixed, as it is not a small stagnant pond. Only surface breezes, convection and diffusion already allow treatment of stagnant sources over time. Both a pro and a con is that metals are also removed and will eventually fill up the nanotechnology mesh and reduce performance. Furthermore, the Lilypads are relatively fragile, and could be lost/damaged by vandalism. Nitrogen, Sulfur, and Phosphor compounds all convert to another compound, typically an acid, which may be undesirable in some water streams. Finally, the effects of small amounts of Lilypads would probably not be noticeable as the phosphate levels are measured over the whole lake and the water is mixed up again. More localized measurements might be able to identify the actual effects of the Lilypads if they were to be used for the Ouderkerkerplas.

4.3 INSTITUTIONAL SETTING

This project needs to ensure that the current cold water mining activities, which NUON is engaged in, will not be disturbed (Schoot, personal communication, September 19, 2014). As already mentioned, the introduction of nanotechnology would only affect the surface water, and not the water temperatures, meaning it's implementation would not affect the cold deep water mining. There have never been any nanotechnology projects of this size, and the environmental effects are not completely known yet (Handy and Shaw, 2007), so the GGA must ensure that it is legally possible to insert this kind of technology into a natural environment such as the Ouderkerkerplas. Not only this, but nanotechnology would (eventually) address the complete removal of phospohorus in the lake, which might not be in accordance with the water quality standards set by WaterNet.

4.4 SOCIAL ASPECTS

4.4.1 STAKEHOLDERS

Identifying the stakeholders of the project, via the stakeholder map introduced earlier, allows us to properly understand the role that the stakeholder groups have. The stakeholder matrix shows how GGA and Anne Stijkel should approach them, if this project were to be implemented (Polonksy and Scott, 2005).

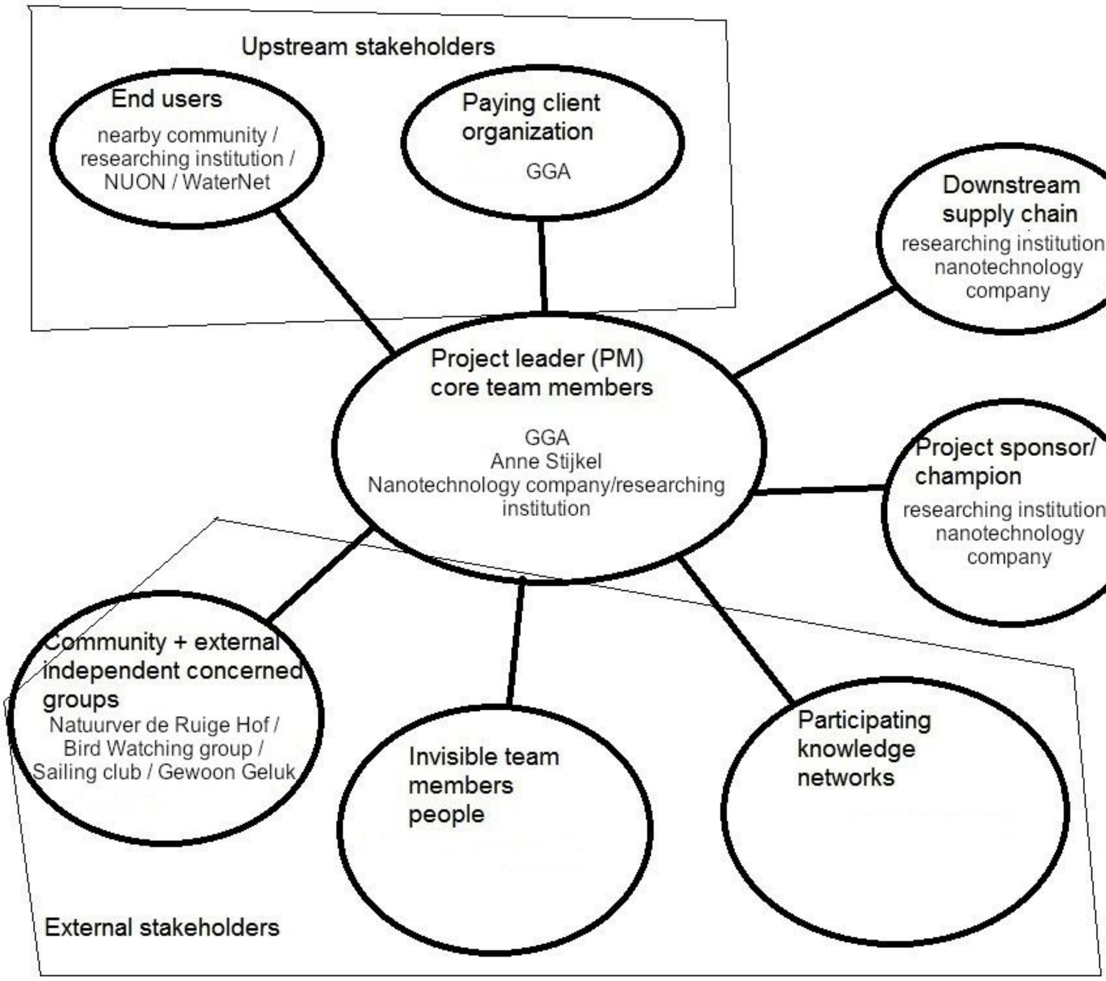


Figure 15: ***Stakeholder map for nanotechnology***

The *project leaders* for this project would be Anne Stijkel, the GGA and whichever nanotechnology or researching institution would be backing the project. Because of the scale of the project, it would be vital to find a researching institution- be it in the form of a university or a private company- to cooperate with Waternet, who can support the plan through creating a kind of research program out of it. Our contact with Puralytics did not express interest in joining this project, as their focus is more about purifying water to make it potable. A university institution might be interested in such a project, but the current research within this field is focused on splitting water molecules in order to create fuel from the hydrogen, because of its revenue potential (Wang, personal communication, October 22, 2014). Some *project leaders* are also part of the *downstream supply chain* and *project sponsors*, because they will be supporting the project monetarily and logistically. The *upstream* category of stakeholders will be the nearby communities, NUON, Waternet and the researching institution/private company sponsoring the project. Both groups are instrumental actors in the project. Waternet is responsible for the water quality at the lake (Schoot, personal communication, September 19, 2014), so it's improvement through this project would help them realize this goal. The researching institution could be fined if the project led to water quality degradation, so it is important for them to work together with Waternet. NUON would use the improved water for their continued mining activities, so they are also classified as *end users*. Improving the water quality would allow nearby communities to use this area for new recreational and educational activities (discussed later). The group of *external* stakeholders in this case includes solely the community and concerned groups. The bird watching group expressed clear disinterest in any project that would affect the lake, especially ones with "industrial" or "commercial" objectives (Litjens, personal communication, October 14, 2014). Because we were unable to specifically ask them about this project, we will assume that they would be against it. Gewoon Geluk would be not a direct *end user* of the improved water quality, but could be indirectly affected by the influx of people, and therefore potential customers brought on by the project, which is why they are classified in the group of *external* stakeholders. The stakeholders' relative threatening and cooperative potential is now elaborated on, which will be useful for building a trustworthy relationship between the stakeholders and the *project leaders*.

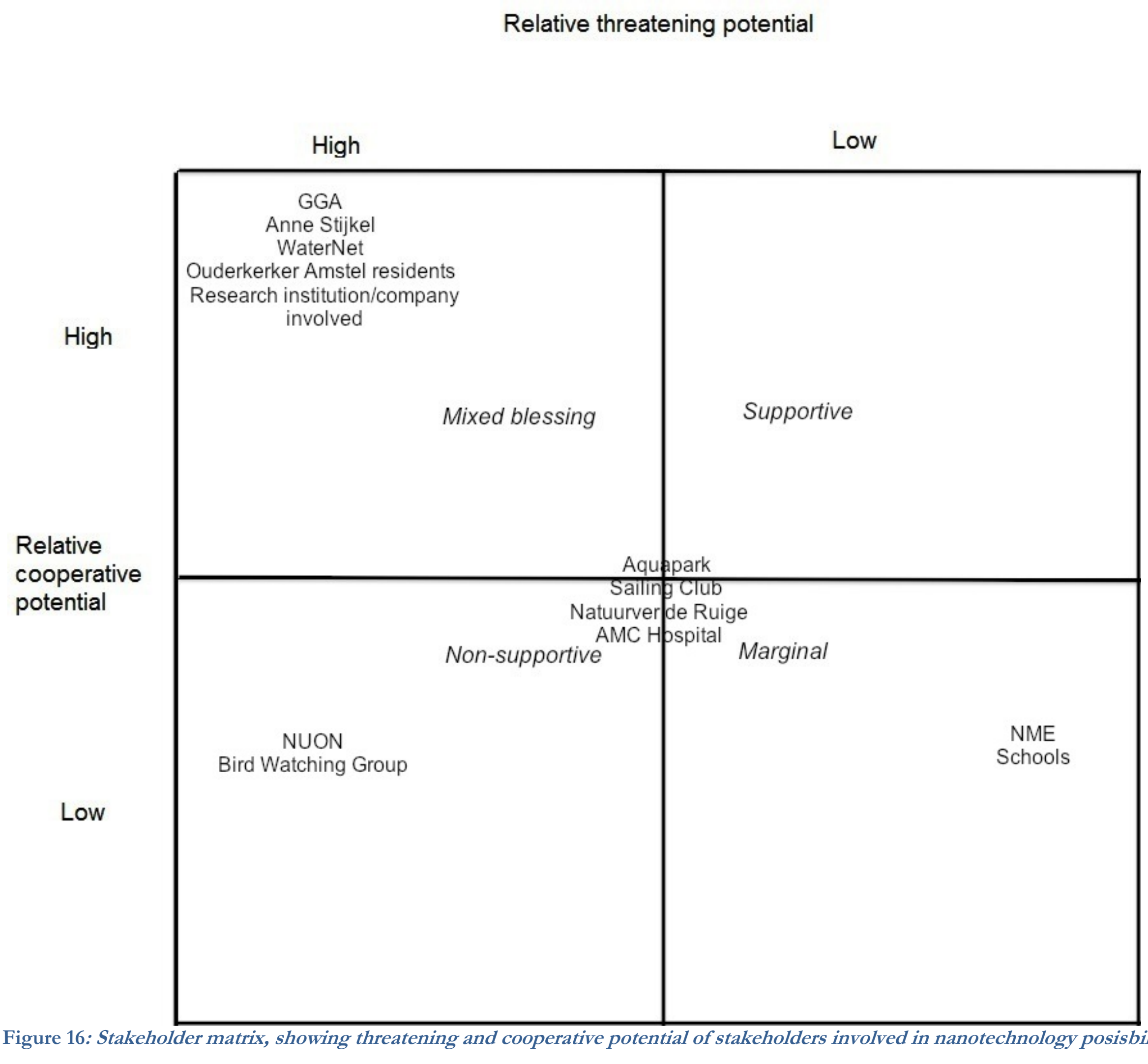


Figure 16*: Stakeholder matrix, showing threatening and cooperative potential of stakeholders involved in nanotechnology posisbility*

The above matrix places the stakeholders on axes measuring their potential cooperative and threatening potentials (Polonsky and Scott, 2005). The *mixed blessing* stakeholders (GGA, Anne

Stijkel, Waternet, the residents nearby and the research company/institution) would have highest vested interests in the project, and they would therefore have both high threatening (they could sway the project in different directions) and high cooperative (their interest in the projects would entice them to make sure it goes according to plan) potentials. The GGA and Anne Stijkel would reach their goal of improving the water quality through a sustainable method, Waternet would be able to continue their cold water mining, while the research institute/company would be learning about the impacts of this technology. The nearby residents would also benefit from the project because of the recreational and educational potential that the improved water quality could result in. Because we were unable to talk to the Aquapark, sailing club, Natuurver de Ruige or the Hospital, we have been unable to assess their cooperative or threatetning potential. The bird watching group, part of the *non-supportive* category (low cooperative and high threatening potential), is interested in preserving the lake as it is (low cooperation), so as not to disturb the bird populations. They could mobilize nearby communities and other environmental organizations to try to stop a project (high threatening). For this reason, Anne and the GGA could try to engage their support by further investigating how an improved water quality could attract more species or affect the current bird populations of the area. NUON, another *non-supportive* actor, have already heavily invested in the cold water mining project with Waternet. It would also be smart to bring them into the picture, as their support would be important for a successful project implementation. The *marginal* stakeholders, NME and the schools, should be monitored and kept up to date with the project's proceedings (Savage, 1991), particularly because they could be interested in the educational and recreational potential of the finished project.

4.4.2 RECREATIONAL AND EDUCATIONAL POTENTIAL

Introducing this kind of technology would bring the Ouderkerkerplas into the spotlight, as no nanotechnology projects of this size exist. This would entice visitors to come here to learn about the potentials and processes of using nanotechnology.

As discussed earlier, there are two potential ways for the technology to be implemented at the Ouderkerkerplas. The floating filters (Lilypads, figure 17) could serve as visible representations of nanotechnology potentials, and would be useful tools during educational school trips, for example. The second method (dust particles figure 18) would not be visible, but brochures and posters can be made within the area to explain to visitors about the invisible nano-technological processes within the water. These same brochures can be made in cooperation with NME, who could use them in their school educational programs (Romijn, personal communication, September 24, 2014). Because the effects of this technology can be seen within a short time span (40 minutes for a small container (Wang, personal communication, October 22, 2014)), there could even be an experimental/ interactive station for visitors.

According to Wang, using dust particles leads to a byproduct/waste of dust, which can react with various elements and convert into other compounds (personal communication, October 22, 2014). This could lead to potential social health risks (Handy and Shaw, 2007). Because the catalysts needed for the processes are currently unstable and only last about 15 minutes, it is impossible to infer what could happen after a few years of the insertion of nanotechnology into the lake (Wang, personal communication, October 22, 2014).

The unobtrusive nature of the nanotechnology ensures that the activities the aquapark and sailing club currently engage in wouldn't be affected. The improvement in water quality could lead to a vitalization of the area by the surrounding communities, as people would be able to use the lake for leisure activities, such as swimming, kayaking, etc. This could benefit some stakeholders, as it would bring them more customers and therefore revenue.

Figure 17: *Puralytics Lilypad nanofilters*

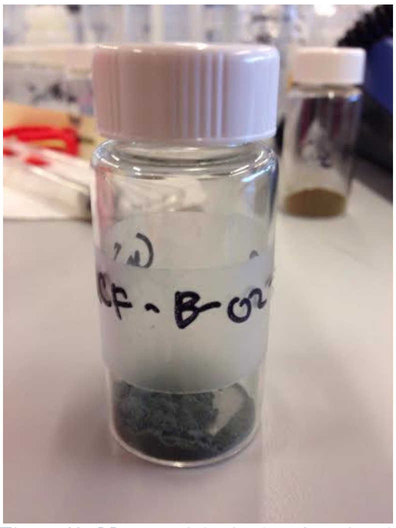


Figure 18: *Nanoparticles in dust form in a lab.*

4.5 ECONOMIC ASPECTS

The cost of the floating filters are "approximately $1/m3 including EVERYTHING- facilities, power, chemicals, consumables, etc." (Owen, personal communication, October 21, 2014). Using the current exchange rate of $1 = €0.79, and the above estimations, we can infer the possible costs of different sized Lilypad projects:

Surface m2 covered with Lilypad in %	Volume purified m3/day	Costs €/ year
5	36,500	28,767
10	73,000	57,534
25	182,500	143,835
50	365,000	287,671
75	547,500	431,506
100	730,000	575,342

Table 11: Cost estimation

Because we are unaware of the standards set by WaterNet regarding the suitable P levels in the water, we are unable to conclude which price is most likely, so the range cost of this project lies between €28,767 and €575,342 per year (€- €€), since the Lilypads need to be replaced on a yearly basis (Owen, personal communication, October 21, 2014).

To calculate how much the project would cost to fully clear the lake of P, we would have to multiply the yearly cost by the amount of time it would take the different sized projects to purify the lake:

Surface m² covered with Lilypad in %	hypothetical time needed to purify the whole lake (years)	Costs in € per year	total costs €
5	1501	28835	43287671
10	751	57670	43287671
25	300	144175	43287671
50	150	288350	43287671
75	100	432525	43287671
100	75	576700	43287671

Table 12: C*ost estimation*

The economic costs of the powder application method is completely unknown, as to create that small amount shown in figure 18 requires the costs of the researcher, the technology in the lab, and the lab materials. It is also unknown how much powder one would need to disperse in a lake the size of the Ouderkerkerplas, in order to perceive an improvement in the water quality.

4.6 CONCLUSION

From an environmental point of view, nanotechnology is not yet applicable since there is no exploitable nanotechnology developed yet with the aim of specifically decomposing compounds such as phosphates and phosphorus. The inconclusive research also expresses concern regarding the unknown social health effects that this technology could result in, in the future. The existing Lilypad nanotechnology addresses a wide range of over 650 contaminants, which is undesirable in the case of the Ouderkerkerplas. Developing a catalyst that specifically targets P would be more useful for this project, as it would address the main issue regarding water quality in the lake. Having this project at the Ouderkerkerplas would also be a chance to place Amsterdam on a level of world recognition in regards to nanotechnology, as it would be a pioneer-researching program, which would surely attract students and visitors. This potential is countered by an equally important challenge, namely, the unknown future social health effects that the implementation of such technology could result in. Another limitation of the project is that due the size of the Ouderkerkerplas the existing Lilypads would not be effective in terms of time (and money). It would cost too much time to reduce the P concentrations of the whole lake, even with a surface coverage of 75% or more. The costs of such a project would also be unfeasible as the Lilypads have to be replaced once every year due to reduced performance over time.

5 CONSTRUCTED WETLANDS

5.1 INTRODUCTION

A possible solution to deal with the high P concentration in the Ouderkerkerplas is a constructed wetland. Constructed wetlands, or 'Constructed Wetland Treatment Systems' (CWTSs) are man-made systems that are specifically engineered for water quality improvement, and offer a cheaper and low-cost alternative for conventional wastewater treatment (de Moel *et al.*, 2006; Wetlands international, 2003). Other primary purposes can be the creation of 'natural' habitats, flood control and the production of food and fiber (Wetlands international, 2003).

Looking at water quality improvement, CWTSs can be specifically designed to deal with a certain problem or pollutant (Horne, 2000). In the case of the Ouderkerkerplas this would be the removal of nutrients (and phosphates in particular) from the water (Strijkel, 2014). The potential for the enhancement of biodiversity will also be discussed in this chapter. Since energy production is not a relevant subject for constructed wetlands, this will not be included in the environmental analysis.

The potential set up of a constructed wetlands is subject to several institutional boundaries. The stakeholders can operate within these boundaries. In addition to exploring the institutional boundaries and doing a stakeholder analysis, this chapter will also have an estimation of the costs involved as well as an assessment of the recreational value. The latter was requested by the client, but could not be appropriately investigated during this research, therefore we only present a possibly biased estimation of this.

The fact that it could offer advantages for the biodiversity, recreational and educational value, besides it being a low-cost technology to remove phosphorous, gives CWTS a good potential for the sustainable development of the Ouderkerkerplas. The possibilities, limitations and feasibility of constructed wetlands will be discussed from both an environmental and a social point of view. The following research question is asked:

How can constructed wetlands contribute to the sustainable development of the Ouderkerkerplas?

Environmental aspects:
- What are the phosphorus retention/removal processes that take place in a constructed wetland?
- What is the optimal type of constructed wetland and what efficiency can be expected?
- What can constructed wetlands contribute to the biodiversity in the Ouderkerkerplas?
- Are there any comparable case studies in the Netherlands?
- How can a constructed wetland be integrated in the Ouderkerkerplas in combination with the cold water mining project of NUON?

Social, economic aspects and institutional requirements:
- Who are the stakeholders involved in this project and how would they contribute to its fulfilment?
- What is the recreational potential of this project?
- What is the economic implication of this project?
- What are the institutional limitations of implementing such a project?

5.2 ENVIRONMENTAL ASPECTS

5.2.1 PHOSPHORUS RETENTION AND REMOVAL PROCESSES

In order to determine the most suitable type of CWTS, the possible phosphorus retention and removal processes have to be investigated. In wetlands, phosphorous can occur as phosphate in organic and inorganic compounds. CWTSs can potentially create an environment that can intercept all forms of phosphorus. Following is a brief description of the most important processes as described in literature (STOWA, 2005; Vymazal, 2005).

Peat/soil accretion, **adsorption and precipitation**: The soil is considered the most important long-term phosphorous sink. Soil accretion is basically the filtering mechanism of the soil that removes undissolved particles moving through it. Soil absorption refers to the movement of soluble inorganic P from pore water to soil mineral surfaces. This can be seen as an equilibrium between the solid phase and P in pore water. The phosphate buffering capacity increases with higher clay or mineral content (Rhue and Harris, 1999). Precipitation is a chemical reaction of phosphate ions with cations such as Fe, Al, Ca or Mg. Obviously, high concentrations of P, or one or more of the cations enhance the amount of P that is precipitated. Depending on the P loading of the inflow water, up to about 75 g m^{-2} yr^{-1} can be retained in CWTSs. In natural wetlands this number is a lot lower, about 1 g m^{-2} yr^{-1}, especially due to the lower P load in the water.

Plant uptake: Plants take up phosphorus mainly through their rooting system, especially in the beginning of the growing season. But since the phosphorus is released back into the system after plants decay, it is not considered as a sustainable long term removal capacity. However, harvesting and removing the plant biomass does remove phosphorous from the system. The amount of storage in aboveground biomass, and therefore the removal efficiency of phosphorus, differs per plant species. Efficiencies of 10-20 g P m^{-2} yr^{-1} can be reached (Vymazal, 2005).

Microbiota uptake: Microbial uptake of P is very fast, but the total amount that is stored is almost negligibly small.

Other phosphorous transformations include dissolution, fragmentation, leaching and burial, but these processes are considered less important (Vymazal, 2005).

5.2.2 MOST SUITABLE TYPE OF CWTS AND THE EXPECTED EFFICIENCY

Taking the above mechanisms into account, it is possible to design a CWTS which is ideal for the removal of phosphorus from the Ouderkerkerplas. Research has shown that when looking at phosphorus removal, free water surface flow is the most effective, mainly because this is the only system in which all P retention/removal processes described above can take place (Luederitz *et al.*, 2001; Vymazal, 2005). Figure 19 gives a schematic illustration of such a system. In this subchapter, the most favorable characteristics will be described, and a rough estimation will be given of the efficiency that can be expected.

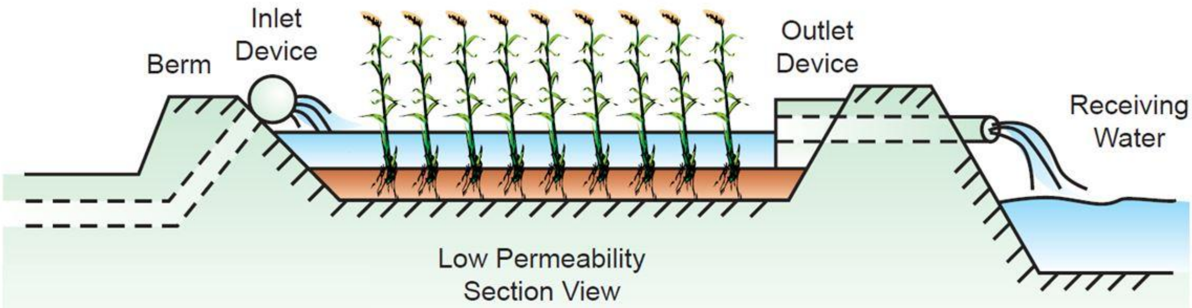


Figure 19: Typical configuration of a surface flow wetland system (Kadlec and Knight, 1996)

As stated above, the soil acts as the most important long term phosphorus sink. The upper soil layer in the area of the Ouderkerkerplas consists mainly of clay and peat (WaterNet, 2010). This soil typically has a high mineral- and organic content. Both of these characteristics increase the absorption capacity for phosphorus (Brix *et al.*, 2001) and are therefore favorable properties to use in a CWTS. Furthermore, the soil is Fe rich, a property which is also utilized with the current method of oxidation of the lake (Tomassen *et al.*, 2012). The occurrence of Fe triggers, in aerobic circumstances, a precipitation reaction which binds phosphorus in the soil. In the lower layers of the Ouderkerkerplas aerobic circumstances have to be created by human intervention, but in a wetland as described in Figure 1 only aerobic environments occur. The availability of Fe in the soil is not considered as a limitation on the phosphorus retention (WaterNet, 2014). This makes the soil very suitable for the construction of a CWTS. Because of these favorable soil characteristics, and the fact that soil properties are the most important factors that determine the functioning of a CWTS (Vymazal. 2005; Vymazal, 2007; Kazermarczyk & Renman, 2011), the assumption was made that a CWTS in the Ouderkerkerplas could potentially match the efficiency achieved in literature: A removal efficiency between 40 and 60 %, up to a removed load of 45 – 75 g m^{-2} y^{-1} depending on the P-load in the water (Vymazal, 2005).

Looking at long term efficiency, the absorption capacity of a soil will decrease over time (Karezmarczyk & Renman, 2011). Estimations on how long the initial removal efficiency can be sustained range from 1-2 years to 8 years (Karezmarczyk & Renman, 2011). Successful cases however, show that when designed properly, a stable P-removal for at least 7 or 8 years is possible (Brix *et al.*, 2001; Luederitz *et al.*, 2001). After this period, soil has to be renewed or Al or Fe can be added to increase the retention capacity of the soil (Karezmarczyk & Renman, 2011).

Another design feature is the choice of plant species. A species with a high growth rate and a relatively large above surface biomass which can be harvested is preferred. The Common Reed (*Phragmites* spp.) and the Cattail (*Typha* spp.) are good examples of emergent species that are suitable for CTWSs (Wetlands International, 2003). Their grow rates are slightly lower than of some floating and submerged plants, but unlike these, Reed and Cattail have a higher nutrient uptake from sediment sources and are easier to harvest (Wetlands international, 2003). Estimations of the efficiency of P removal due to the harvesting of biomass range from 6-20 g m^{-2} y^{-1} (Stottmeister *et al.*, 2003; Vymazal, 2005).

5.2.3 CONTRIBUTION TO THE BIODIVERSITY

So far, this literature review has focused mainly on one application of CWTSs: the removal of phosphorus. But CWTSs have the potential to contribute more to the area of the Ouderkerkerplas. First of all, an environment with fewer nutrients enhances biodiversity, as the dominant species in a nutrient rich environment can be outcompeted (Hanson *et al.*, 2005). And not only nutrients are removed from the inlet water, but also the amount of metals, suspended solids, viruses and bacteria are decreased (Wetlands International, 2003). When the design is purely based on phosphorus removal, it will not be ideal for the removal of other pollutants. Nevertheless, it will have a positive effect on other aspects of the water quality as well.

Furthermore, a wetland can provide a habitat for native animal and plant species of the wet Dutch peat areas, and it can serve as a wildlife sanctuary. There is a positive relation between wetland area and the species richness of several groups of organisms including birds, amphibians, benthic invertebrates and plants (Hanson *et al.*, 2005). Besides that, compared with conventional waste water treatment plants a wetland is aesthetically more pleasing (Horne, 2000; Wetlands international, 2003). A proper quantification of the effect on biodiversity, and research of which species can be expected was not possible due to restrictions in time and resources.

5.2.4 COMPARABLE CASE STUDIES

There are a lot of successfully applied CWTSs. However, the majority is used as secondary or tertiary treatment of sewage and domestic wastewater (Wetlands international, 2003). In general, the higher the concentration of pollutants, the more efficient the CWTS will be (Luederitz *et al.*, 2001; Stottmeister *et al.*, 2003; Vynazal, 2005). But when designed properly, the system can tolerate both large and small volumes of water with varying contaminant levels. Therefore CWTSs are also applicable for urban storm run-off, agricultural wastewater and polluted surface water (Wetlands international, 2003).

And although CWTSs are currently not very widely applied in recreational areas, there are several interesting cases in the Netherlands. In the Berkenplas on Schiermonnikoog, a wetland was constructed by the local water board in cooperation with Natuurmonumenten (Rtv-noord, 2014). It makes use of reed and a sand filter, to some extent comparable with the design described above for the Ouderkerkerplas. Also in the lake Naardermeer and in the Erasmusgracht in Amsterdam, CWTSs have been constructed (van Dijk & Boekee, 2004; Helikantplant, 2014). Unfortunately, data on their efficiency were not available for this research.

5.2.5 THE APPLICABILITY OF A CONSTRUCTED WETLAND IN THE OUDERKERKERPLAS

In the previous part of this chapter, it is argued that a CWTS can successfully decrease the phosphorus level in surface waters. The next part will analyze the applicability of a CWTS in the Ouderkerkerplas, from an environmental point of view. The area is rather unique because of the cold water mining project of NUON (NUON, 2008). Because used cooling water with a relatively high P concentration is led trough pipes to be discharged back into the lake (WaterNet, 2014), it offers a perfect situation to lead that water through a CWTS before it is discharged in the lake again. But it also entails some implications.

Since constructed wetlands require a substantial area, spatial planning might become an issue. Luederitz *et al.*, 2001, states that the treatment area for horizontal flow systems should at least be 50 m^2 m^{-3} per day in order to function without a decreased efficiency. Looking at the cold water mining in the Ouderkerkerplas, the daily flow is highly variable (Figure 20). The average daily flow in 2013 was 16.000 cubic meters (WaterNet, 2014). Based on Luederitz *et al.*, this would suggest a CWTS of 800.000 square meters (8 ha). This is approximately one hectare bigger than the Ouderkerkerplas itself. The maximum daily flow in 2013 was almost 38.000 cubic meters. If the design would be based on this value it would imply a treatment area of 190 ha. Note that Luederitz *et al.* based their research on CWTSs that processed domestic wastewater with a higher nutrient load. It seems logical to assume that a smaller treatment area is required for lower concentrations, but no scientific research was found to back this up.

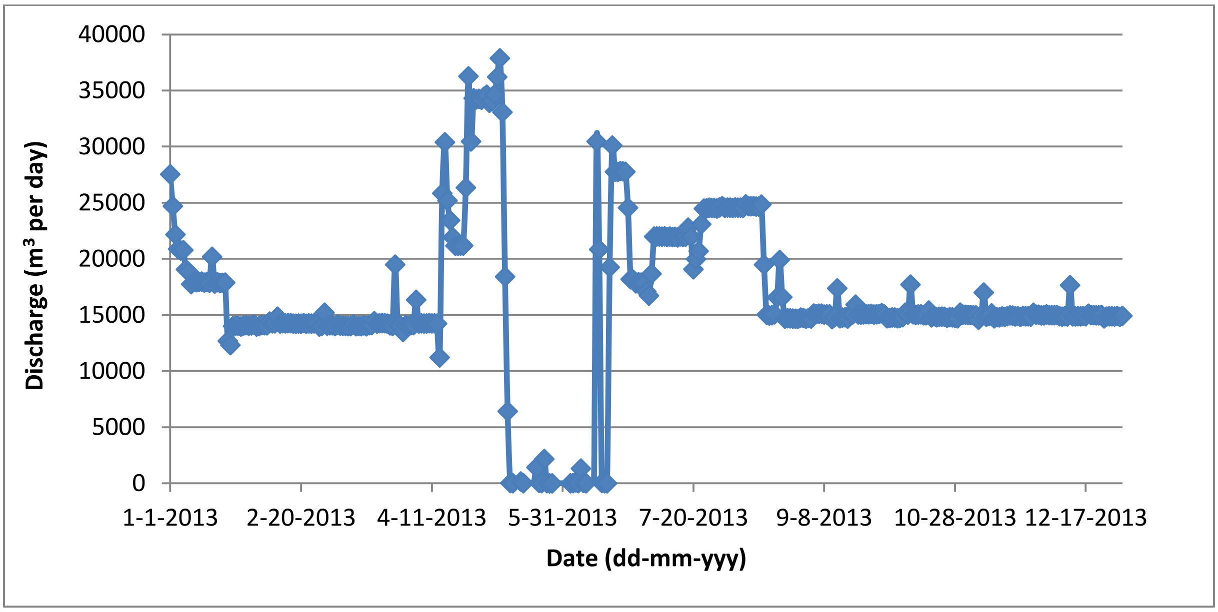


Figure 20: The daily flow in the inlet channel of the cooling water installation for the year 2013 (WaterNet, 2014)

The variability in the daily flow will also have an effect on the efficiency that can be expected. Periods in which no water is discharged, as well as extreme events will cause inefficiencies. Besides this, the peak in the P concentration in the lake is in autumn, when the algae biomass decays in the lower water layer (the hypolimnion) (Figure 3). The most efficient period for the CWTS on the other hand, will be in spring, at the start of the growing season (Wetlands international, 2003). This mismatch will also have a negative impact on the potential P removal. However, this problem is incalculable because the most important P sink is the soil and not the biomass.

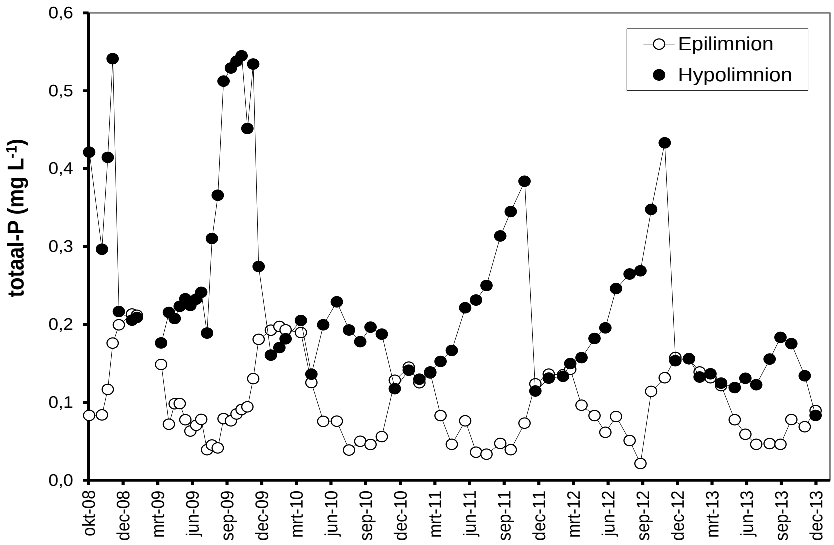


Figure 21: The total P concentration in the Ouderkerkerplas, measured in two water layers (Bakker, 2014)

The P removal due to the oxidizing system was about 1000 kg in 2010 (Tomassen, *et al.*, 2012). The potential of a CWTS, assuming a year round productivity, an average discharge of 16.000 m^3 per day (WaterNet, 2014) with an average P concentration of 0,15 mg L^{-1} (Figure 21), and a removal efficiency of 40–60 % (Vymazal, 2005), the potential P-removal will be 350-525 kg per year. This calculation is based on data from 2013 and on assumptions based on scientific literature. It only takes retention of the soil into account. Since the potential amount of P that can be removed by the uptake and harvesting of plant biomass is about 20% of the amount retained in the soil (Vymezal, 2005), the efficiency per square meter found in literature (6-20 g m^{-2} y^{-1}) seems to be unrealistic for the P-load in the Ouderkerkerplas. A more realistic estimation of P-removal by plant uptake would be around an additional 50-100 kg per year on top of the removal by the soil (Vymezal, 2005).

5.2.6 DISCUSSION

Several assumptions had to be made to assess the applicability of a CWTS in the Ouderkerkerplas. The most dubious one is about the P-removal efficiency. Most CWTSs process domestic waste water, which has a higher concentration of pollutants. In general, higher P-loads will result in higher removal efficiencies. It is known that CWTSs can reduce the P concentration to values comparable with the current situation in the Ouderkerkerplas (STOWA, 2005). However, no data was found on removal efficiencies of CWTSs in cases where water with such a low P concentration was used as inlet water. Because of the favorable characteristics of the soil, the assumption was made that comparable removal efficiencies as in literature could be reached. This might be an overestimation.

Furthermore, the calculated yearly P-removal is based on an optimal functioning CWTS. According to the discharge data of WaterNet (2014), and the required treatment area as stated in Luederitz (2001), the treatment area should be approximately 8 ha. Since this is bigger than the whole Ouderkerkerplas itself, it is not a feasible option. A CWTS with a smaller treatment area will not function optimally, causing the calculated potential to be an overestimation. Due to restrictions in time and resources, it was impossible to quantify this decrease in efficiency. The fluctuations in the amount of inlet water will amplify this overestimation.

But the retention of P would be more sustainable than the current oxygen system. When the wetland is constructed, it does not require any input anymore other than the inlet water. But when the oxidation is stopped, the phosphate levels rise again (Bakker, 2014). When algae blooming would be avoided in the future, the hypolimnion could become aerobic due to the fact that there will be less decaying organic matter in the lower layer. This could mean that oxidation is not necessary anymore, but this is uncertain and has to be confirmed by research (Bakker, personal communication, 8-10-2014). As long as it stays anaerobic, the oxidation cannot be interrupted. A second advantage is that P is not bound in the soil at the bottom of the lake, but in the wetland and biomass itself, and is therefore much easier to actually remove from the system. Therefore, constructed wetlands can be regarded as a more sustainable way of reducing P levels than oxidizing the lake, even though the efficiency is lower. Looking at biodiversity at a local scale, a CWTS will offer additional advantages. Depending on the size of the wetland, it can provide a habitat for different groups of organisms.

5.3 INSTITUTIONAL SETTING

There has been extensive contact with the GGA throughout this research (Schoot. Personal communication, 19 September 2014). From the first interview with the GGA it became clear that they are the main actor to take into account when it comes to rules and regulations. They are the ones assessing the project and providing a permit where needed. This is because the land is officially owned by the GGA, who are comprised of different government levels. This makes them directly responsible for monitoring the area and the practices thereon. A permit provided by the GGA is needed to start such a project. This requires active involvement of the GGA into the project, and it is therefore required to, in this project too, see them as an important stakeholder. This could pose a problem since the GGA is not a very active organization, and only holds half-yearly meetings. Project development with the GGA involved therefore will inherently be slow. Their response to the question about the institutional barriers is that "existing environmental values must be respected, the current guidelines have to be maintained and the new natural environment has to be designed from a well-constructed plan" research (Schoot. Personal communication, 19 September 2014). Other than permits by the GGA there are not any known legal barriers for building a constructed wetlands. Additionally, NUON holds the rights to maintaining the water quality for cold water mining, which means the water quality cannot deteriorate (NUON, Personal communication. 2 October 2014). WaterNet too, monitors the water quality and constricts project leaders to those projects that have sufficient water quality (Bakker. Personal communication, 8 October 2014).

5.4 SOCIAL ASPECTS

5.4.1 STAKEHOLDERS

5.4.1.1 Sample selection

Actors that have a possible influence on the development of a constructed wetlands in the Ouderkerkerplas have been selected from a list provided by Anne Stijkel. This list was drafted from the group of stakeholders present, or not present, at the cocreation sessions. Missing from the list were the locals, who did not want to be represented in the cocreation sessions. The actors selected from the list are the ones who are involved in the development of the Ouderkerkerplas to differing extents. Not all actors however have an interest into the development of the constructed wetlands. Therefore, from the list of total possible stakeholders, those who will be affected by the construction of a wetlands have been hand-selected.

5.4.1.2 Data

The knowledge gap researched in this chapter is that we are only slightly aware of the positions every actor takes when it comes to the proposal of a constructed wetlands. To operationalize the definitions used in our theoretical framework, we have divided the actors into two graphical representations of data; the stakeholder map and the stakeholder matrix. However, before that the institutional setting was determined through the questionnaire, asking every stakeholder if they are aware of institutional boundaries. The definitions used in both the map and the matrix have been clarified in the general methodology chapter at the start of this paper for ease of use. We then converted the definitions into question we could ask the stakeholders. The questions in the questionnaire have been used to categorize the actors into their respective groups, using the definitions from the general theoretical and methodological chapters.

Each actor was contacted through email to give their response to the questionnaire by email, telephone, Skype or personal contact. We chose to present to them these options because not all actors have the time to spend on a meeting. Many of them responded to the initial email and preferred an email with the questionnaire attached. However, Categorizing the actors is partially a subjective matter, since the interviews were semi-structured and answers could differ depending on how they were presented by the participant in their email response. Additionally, the response of actors was low. To still give all actors a place in the matrix, even those that did not respond to the questionnaire, we looked at their participation in the cocreation session as well as any data available on their website. This of course creates differing results, as not all might have a clear mission statement on their website. This has been indicated for each actor.

The economic costs have been estimated doing a literature review as well as asking the stakeholders to give an estimation.

5.4.1.3 Stakeholder map

In this paragraph the stakeholder map will be elaborated upon, starting from the center (figure 22). The most suitable project leader of this project is the GGA. They should set up the project and monitor it, where they can keep track whether the legal requirements set by them are met. Anne Stijkel too is a project leader as she is currently in the forefront of exploring options to develop the Ouderkerkerplas. The GGA would have to be the main sponsor of the project, covering the costs of implementation. This would be done in cooperation with the landscape architect, as they will have to further design the wetlands. Although they were only involved in the early stages of assessing the possibilities of developing the Ouderkerkerplas in the cocreation sessions, they show a positive attitude towards constructed wetlands.

Nuon and WaterNet are upstream stakeholders, as they have a stake in the project legally. They form part of the institutional setting in which the project designers can move. Water quality must for both parties be maintained. WaterNet additionally could be a potential source for sponsoring or funding for the constructed wetlands. Other sources of funding would have to come from currently unknown investors.

Other upstream stakeholders are the local community. The local community has not been contacted through time constraints, and their representative has not been part of the cocreation sessions. The people from Gewoon Geluk, a restaurant at the Ouderkerkerplas, were able to tell us that the locals do see this area as their backyard, and are concerned with its developments. With a constructed wetlands, they will see an improvement of the lake and gain a recreational area. However, the client organization, those who pay for the services, is missing. This is because no one will pay for the use of the final result of the project, it is a beneficial project with its strengths in sustainable development and recreational value. The external stakeholders in the form of community or external independent concerned groups are the Zeilvereniging, Natuurvereniging de Ruige Hof, Vrienden van de Amstelscheg, Gewoon Geluk, the Birdwatching Group, Aquaparx and the local community. They are all concerned with, or localized at or around the lake. Whatever happens to the lake, is of their concern. There are for now not any known invisible but vital members or people that hold any stake in the project. The only participating knowledge network in the project for now are the writers of this report, the Utrecht University Students.

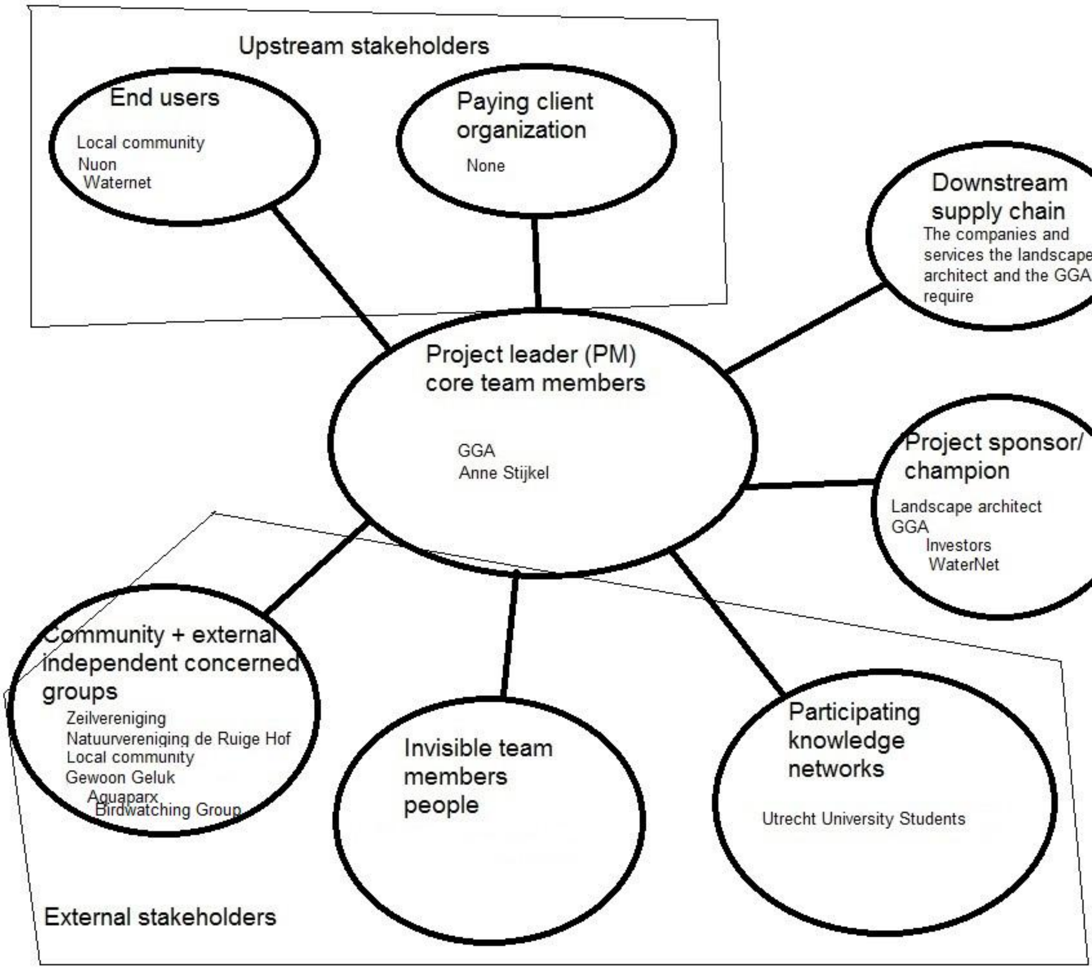


Figure 22: *Stakeholder map of the constructed wetlands.*

5.4.1.4 Stakeholder matrix

The landscape architect was able to tell us that much is already in place and that a constructed wetlands is a very good option for the sustainable development of the Ouderkerkerplas (Bos, 2014). She supports this notion of developing the Ouderkerkerplas into a more sustainable and a better recreational area. They could be involved further, however they can be easily replaced with another actor if need be, they are therefore not threatening.

WaterNet is a key institutional actor that has a high threatening potential. They have to agree with the project not interfering with local water quality standards. In our interviews they have shown that they have a great deal of cooperative potential in any project (Bakker. Personal communication. 8 October 2014). They have mentioned that they are interested in any alternative solutions to the problems the lake is facing.

NUON currently holds rights to have a good water quality for cold water mining and are therefore directly related to any project concerning the water in the Ouderkerkerplas (van Bulderen. Personal communication, 2 October 2014). They have shown to be less involved to any project other than the current oxygen pump in the interviews, which is why they are placed in low cooperative potential.

Natuurvereniging de Ruige Hof has not responded with a questionnaire, but did indicate an enthusiast response to the notion of a constructed wetlands in earlier email contact. From their attendance at earlier cocreation sessions we can derive that they are interested in the development of the Ouderkerkerplas. They however have a stake in maintaining a recreational natural area and are therefore placed in the relatively high threatening potential. Their main activities consist of maintaining some green areas in southern Amsterdam, and organizing recreational activities in this area (De Ruige Hof, 2014). A constructed wetlands would contribute to their possibility of organizing these activities.

Since **Anne Stijkel** has had a prominent role in the generation of ideas so far, she will likely continue to be a stakeholder with high interest who poses little threat to the implementation of a wetlands, while providing and facilitating cooperation. She is however a crucial part of organizing the initiatives, be it wetlands or any other project. She is therefore of high threatening potential.

The **GGA** is an important legal stakeholder, as well as a potential organizer of the project. They are not so much against a wetlands as they will slow the project down, they meet twice a year. Their response to the idea of a constructed wetlands has been positive and would require their active involvement (Schoot. Personal communication. 19 September 2014). Additionally, they were present in the cocreation sessions. Therefore they show a relatively high degree of cooperation. Much of the planning and institutional boundaries would be on their side, they are therefore of high threatening potential.

The local community has not been contacted, but the people from Gewoon Geluk could tell us that the locals see the Ouderkerkerplas as their backyard (Stornebrink. Personal communication. 8 October 2014). Any change could be seen as a threat to the maintenance of their backyard. Therefore, they are relatively threatening to any project proposal for the Ouderkerkerplas. They have not been represented in the cocreation sessions, even though their representative was asked. Being the close inhabitants and potential users of the area they should be approached with caution, and be involved as much as possible. This research, as mentioned before, did not include them because of time and resource constraints. The fact that they did not participate in the cocreation sessions however show that they have a relatively low level of cooperation up to this point.

Gewoon Geluk, a small restaurant near the installation of Aquaparx shows interest in any project that will attract tourists to the area, and have cooperated extensively in the cocreation sessions. However, they say in their role in development of the lake can be considered of low potential seeing the scale of their organization (Stornebrink. Personal communication. 8 October 2014).

The birdwatching group have shown opposition to any changes in the natural landscape around the Ouderkerkerplas through email contact. They are an interest group that could potentially threaten a wetlands construction project, and would show little cooperation. It is unclear however how threatening they are, we therefore chose to leave them out.

The Zeilvereniging at the Ouderkerkerplas shows interest into the development of the Ouderkerkerplas, because they have cooperated in the cocreation sessions. They have however not responded to the questionnaire after receiving it. Because of the absence of their opinion we have decided not to place them into the matrix. One thing we could derive from their website is that they use the waters of the lake for recreational purposes (Zeilclub Ouderkerkerplas, 2014). Therefore, we would assume that as long as the constructed wetlands does not interfere with the area they are using, they could show a low degree of threatening potential. Because they did participate in the cocreation sessions we could place them in relatively high cooperation. Again, this is subject to uncertainty and we have decided not to do so.

Aquaparx did not respond to our inquiries through email and we are therefore uncertain about their position in the matrix. Given they offer seasonal recreational facilities that are not too large, we could argue that they for little threatening potential to a large scale project like a constructed wetlands. We did not place them on the matrix however because of uncertainty.
We chose to leave out ourselves, although we are currently a participating knowledge network. We will likely not continue to be involved in this project after this assignment.

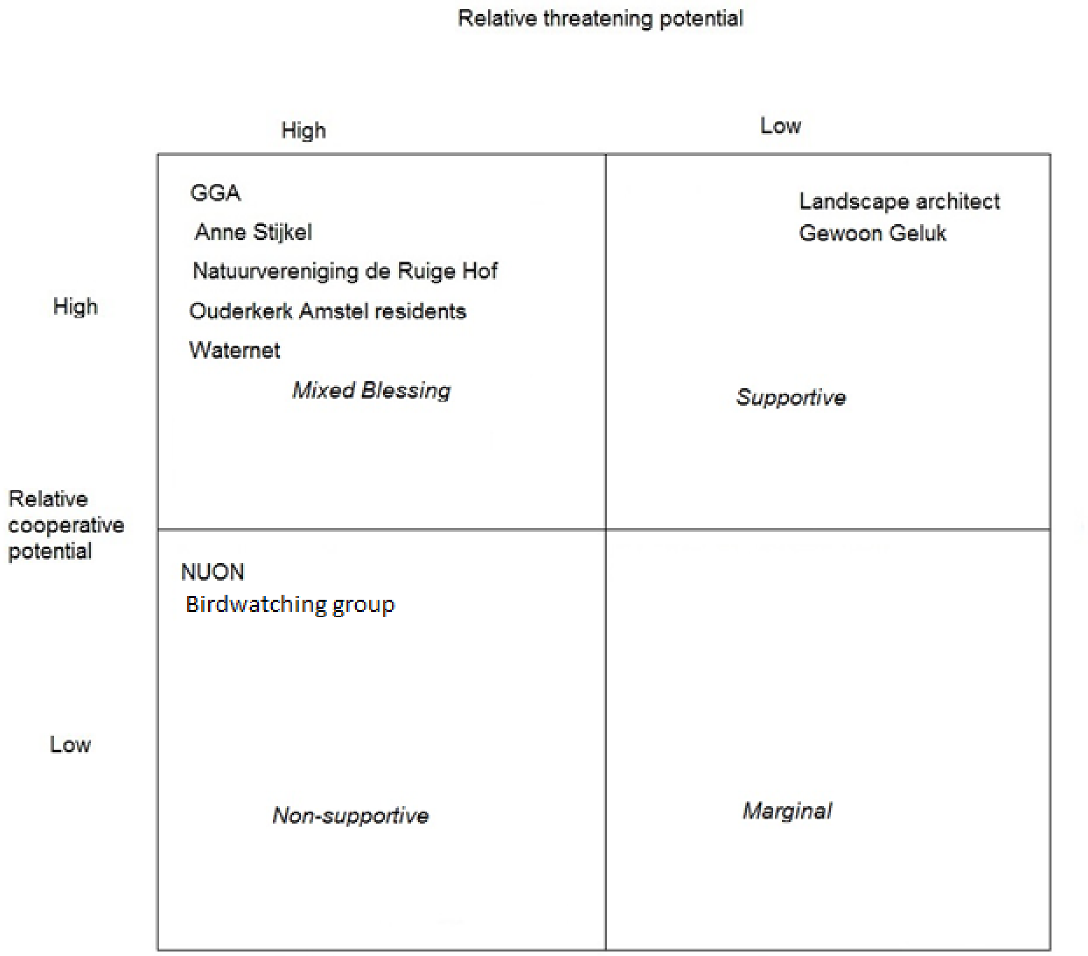


Figure 23: Stakeholder matrix for constructed wetlands.

5.4.2 RECREATIONAL AND EDUCATIONAL POTENTIAL

In each chapter we want to point out the recreational and educational potential. As mentioned in the general theory and methodology chapter we will not make a theoretically based estimation of recreational potential. That being said, the constructed wetlands have a high recreational potential. Paths could be constructed, leading visitors through the wetlands to experience the newly acquired natural environment. This could also have educational potential.

5.5 ECONOMIC ASPECTS

Although we recommend a thorough research of the area and its costs before implementing, we can make a preliminary assessment of the estimated costs. . in the US a cost study has been done showing costs between 40.000 and 900.000 dollars, which roughly translates to 30.000 to 700.000

Euros (EPA, 2000). The areas in this study ranged from 0.04 to almost 10 hectares. Given that the constructed wetlands in the Ouderkerkerplas would likely need several hectares our estimate could be between 100.000 and 200.000 depending on size and the project details. Kadlec (1995) researched wetlands in North America as well and estimated roughly 4.000 to 220.000 Euros per hectare. Another estimate was calculated by Reed *et al.* (1994) where it ranged from roughly 75.000 to 190.000 Euros. As can be shown, the costs of such a project are subject to wide variation and create uncertainty until a true assessment is done in detail. This is more so a problem because many of these projects are constructed wetlands for wastewater treatment, which is different from what we would be doing in the Ouderkerkerplas. The landscape architect, in the interview, warned us that costs might be underestimated and would likely result in the higher end of the spectrum.

An additional problem with the constructed wetlands is attracting investors. Given the uncertainty of costs at this point it is hard to predict who potential investors will be. An aspect for consideration is that it does not give any returns, and will have annual maintenance costs.

5.6 ENGAGEMENT RECOMMENDATIONS

Important actors to include here are the GGA, WaterNet and NUON. All these have a legal vested interest into the lake and any project is not legally grounded if these are not included. Of these three only NUON could be of opposition to a constructed wetlands, and should be approached with care, being included from the start. Note that more data would be needed on financial matters, as they could also be a potential investor. Someone would have to champion the project, ideally this would be Anne Stijkel in cooperation with the GGA. Other actors that need to be approached are the landscape architect, who could be a designer for the wetlands. This however can also be any other landscape architect willing to undertake such a project.

5.7 CONCLUSIONS

From an environmental perspective it can be concluded that CWTSs have the potential to both reduce P levels in surface water and to enhance the biodiversity, but that the case of the Ouderkerkerplas is not ideal for a CWTS. The P concentration in the lake is not high enough for a CWTS to function in an optimal manner, and the necessary space that is required to properly process all the water used for cooling purposes is simply too big. The calculated potential P-removal is based on optimistic assumptions, but is still significantly lower than the P-removal currently achieved by the oxidation of the lower water layer as currently implemented by NUON. More research is required to give a more accurate estimation of the potential efficiency in improving the water quality, and the exact effect on the biodiversity. Even though a CWTS can offer some additional benefits for the area, from an environmental perspective it is not recommended for the Ouderkerkerplas, because the challenges mentioned above seem to big to overcome. For cases with a higher concentration of pollutants, and enough available space on the other hand, it is a very promising technique that has the potential to contribute to a sustainable development.

When it comes to stakeholders, a major possibility is the fact that many parties are willing to cooperate in constructing a wetlands. The GGA and WaterNet have shown interest in alternative sustainable projects in and around the Ouderkerkerplas in the interviews. Another possibility is that the wetlands has recreational value and can therefore be attractive to environmentally engaged groups, which are present around the Ouderkerkerplas.

A limitation is that financially, there is large uncertainty and it is estimated that the costs can be quite high. The problem here is too that it is unclear who will invest into the project as there are no financial returns. The initiators of such a project should actively seek for funds for such a costly and as of yet financially uncertain project. Another limitation seems to be the Bird watching group, as they have shown signs of heavy resistance to any sustainability project around the Ouderkerkerplas.

A challenge will be to satisfy every stakeholder in this project. There are stakeholders that have shown low degrees of cooperation and are potentially threatening to the project. These should be included from the start and persuaded of the benefit they have from a wetlands.

The main research question of this chapter was; *How can constructed wetlands contribute to the sustainable development of the Ouderkerkerplas?* Looking at the study we conclude that a wetlands is only somewhat effective at improving the Ouderkerkerplas sustainably. It has some limitations and challenges which are quite substantial to overcome in comparison to the current solution, the oxidation of the lake.

6 FLOATING GREENHOUSE WITH AQUAPONICS SYSTEM

6.1 INTRODUCTION

One of the projects proposed at the co-creation sessions for the Ouderkerkerplas was a floating greenhouse on the lake with an aquaponics system inside (Stijkel, 2014). Aquaponics is a food production system that integrates fish and soilless plant culture in a re-circulating system (Goodman, 2011). People in the nearby communities of the Ouderkerkerplas could consume the fish and crops produced in the floating greenhouse (Driver, 2006). There is indication that producing food locally in an aquaponics system could be more material and energy efficient than food production elsewhere with conventional agriculture techniques (Blidariu & Grozea, 2011). Further, the floating greenhouse could result in a center for community engagement, with a focus on education and recreation (Goodman, 2011). However, there is a risk that the increased human presence around the lake could have negative effects on the ecology, such as the bird populations (Gill, 2007). Last but not least, the floating greenhouse with aquaponics system in the Ouderkerkerplas was proposed as a solution to the phosphate problems in the lake (Stijkel, 2014). However, no indication was given on how this could be achieved.[24] Initial screening showed that there might be potential in transforming the nutrients from the lake into fish food, e.g. algae or macrophytes, through photosynthesis in a separate tank (Hasan & Chakrabarti, 2009). This could possibly replace the fishmeal, nutrient-rich powder made from the flesh and bones of marine fish, used in existing aquaponics systems (Tacon & Metian, 2008).[25]

The potentials and limitations of this project in terms of sustainable development of the Ouderkerkerplas should be further explored, resulting in the main research question, and sub-questions related to environmental, social, and economical aspects, and institutional setting:

How can a floating greenhouse with aquaponics system contribute to the sustainable development of the Ouderkerkerplas?

Environmental aspects:

- How can a floating greenhouse with aquaponics system be designed for the Ouderkerkerplas?
- Can the water quality be improved by using the phosphate from the Ouderkerkerplas as part of the aquaponics system?
- What is the potential for human food production in an aquaponics system on the Ouderkerkerplas?
- Will a floating greenhouse affect the bird population around the Ouderkerkerplas?

Social, economic aspects and institutional requirements:

- Who are the stakeholders involved in this project and how would they contribute to its fulfilment?
- What is the recreational potential of this project?
- What is the economic implication of this project?
- What are the institutional limitations of implementing such a project?

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24 Two floating greenhouses with aquaponics system have been conceptualized before, namely the "Polydome" designed by the foundation Except and the "drijvende kas" designed by concept developer Pascal Henneberque. However, neither included a system to improve the quality of the water they are floating on.

25 There is need to replace fish meal that is finitely imported from the ocean with a resource that can be supplied internally in the greenhouse (Except, 2011).

6.2 ENVIRONMENTAL ASPECTS

6.2.1 POSSIBLE DESIGN FOR THE OUDERKERKERPLAS

The flows and processes in a floating greenhouse with aquaponics system must be considered in order to assess if and how this project can contribute to the sustainable development of the Ouderkerkerplas. A possible design is illustrated by the flow-diagram in figure 24, and described step-by-step:

1) The phosphorous-rich surface water from the lake can be pumped into the duckweed production tank in the floating greenhouse.

2) The nutrients from the lake could be removed from the water by algae (Abdel-Raouf et al., 2012; Naylor et al., 2000) or macrophytes (Cheng & Stomp, 2009; Ghaly et al., 2005), which use these nutrients to support their growth. Hasan & Chakrabarti (2009) did an extensive literature review on the possibilities to use algae and macrophyte species as fish food, and concluded that duckweed, a free-floating aquatic macrophyte, has most potential because of its rapid growth, attractive nutritional properties and relative ease of production.

3) The duckweed can be harvested, and fed to the fish. It was observed that duckweed could successfully replace fish meal up to 30% for tilapia (Fasakin et al., 1999) and up to 20% for carp (Yılmaz et al., 2004).

4) Duckweed can potentially remove up to 99% of the nutrients in the water (Skillicorn et al., 1993), however 60-80% phosphorus removal is more common (Alaerts et al. 1996). After harvesting the duckweed, the phosphorous-poor water can be returned to the lake.

5) Fish can be grown in fish tanks.[26] The main requirement for choosing fish species in aquaponics is that they can tolerate crowding (Rakocy et al., 2006). The most common fish cultured in commercial aquaponics systems is tilapia, a warm water species (Rakocy, 2012). Tilapia is considered suitable because it tolerates fluctuating water conditions, such as temperature, oxygen, dissolved solids, and pH. Other potential fish species are Murray cod, bass, trout, perch, carp and Arctic char (Driver, 2006).

6) The fish waste, e.g. fish excretion and decomposing fish food, contains high amounts of phosphorous, nitrogen, potassium, and other micronutrients (Driver, 2006). Nitrogen is mainly available as ammonia, and can be converted by bacteria in the biological filter to nitrate which is available for plants (Goodman, 2011).

7) Crops can be grown in the growing trays, where water with the nutrients from the fish waste is added. Nearly all plants can grow in an aquaponics system (Jones, 2002). It is desirable to produce a great diversity of crops, called poly-culture (Stijkel, 2014). Poly-culture cropping has been shown less vulnerable to disease than monoculture cropping, so less or no pesticides are needed (Zhu et al., 2000).[27]

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[26] The fish are not grown in cages in the lake, because the fish waste would end up in the system and increase nutrient loadings, additionally there would increased risk of disease spread and genetic pollution with the native fish species of the Ouderkerkerplas (Kestemont, 1995).

[27] Further research should focus on what combination of species can best be produced based on the conditions on the Ouderkerkerplas potential consumers interests.

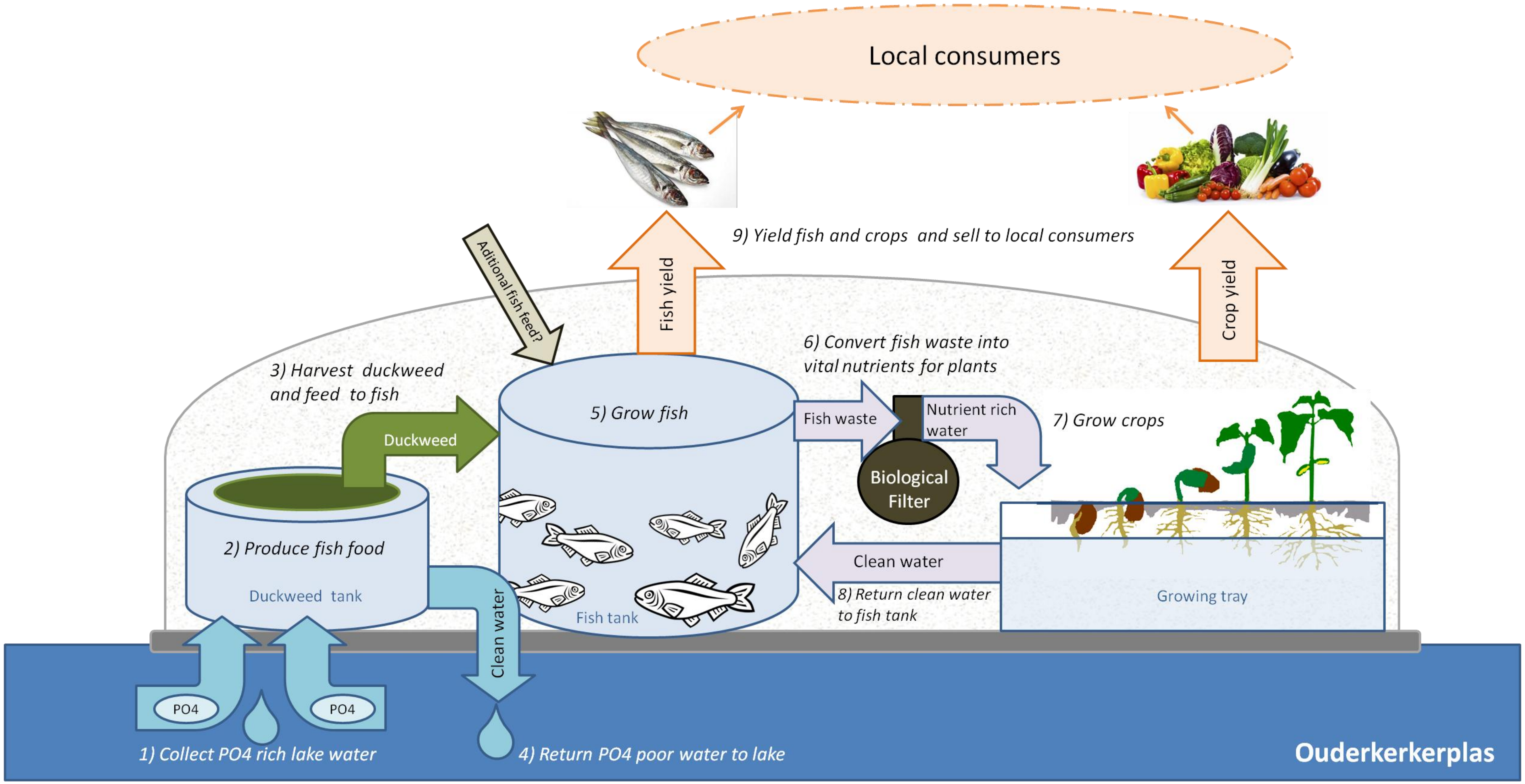

Figure 24*: Flow-diagram of possible design floating greenhouse with aquaponics system in the Ouderkerkerplas.*[28]

[28] Additionally, there is potential to place containers with small bushes or trees that bear fruit. These could be composted with excess plant waste. Also other species than plants or fish can be included in the greenhouse, such as bees which can support pollination of the crops and create honey as supplementary product (Except, 2011). However, the focus of this study is only on the flows and processes of the aquaponics system described in the nine steps.

8) After the crops have taken up the nutrients in the growing trays, the clean water can be returned to the fish tank (Driver, 2006).

9) The fish and crops can be harvested and sold to local consumers. A potential client and distributor is Gewoon Geluk, a mobile catering around the Ouderkerkerplas (Gewoon Geluk, 2014).

Three scenarios were proposed for the size of the floating greenhouse, namely small (Henneberque, personal communication, October 10, 2014), medium (Except, 2011; figure 25), and large based on maximal technically feasible size of a floating greenhouse (TNO, 2011). It is proposed that 1/5th of the floating greenhouse is available for the community center, 1/5th for duckweed production, and the remaining 3/5th can be used for the aquaponics system (table 13). These sizes are provisional and meant for calculations.

Figure 25: Polydome design of concept (Except, 2011)

	Small	Medium	Large
Total surface area of floating greenhouse (m^2)	600	10 000	50 000
Community center (m^2)	120	2 000	10 000
Duckweed production tank (m^2)	120	2 000	10 000
Aquaponics system (m^2)	360	6 000	30 000
Part of lake covered by floating greenhouse (%)	0.1%	1.4%	6.2%

Table 13:*Three scenarios of the size of the floating greenhouse with aquaponics system*

6.2.2 WATER QUALITY

It was proposed in the design of the system that the water quality of the Ouderkerkerplas can be improved by converting phosphorous-rich water from the lake into duckweed, which can function as fish food in the aquaponics system. In this section it will be analyzed in more detail the extent to which duckweed growth is possible, and what its potential for phosphorous removal can be.

6.2.2.1 Duckweed growth requirements

Duckweeds are aquatic plants that can convert polluted, e.g. nutrient rich, water into high-quality protein that can be consumed by fish (Fasakin et al., 1999). Duckweed can survive in a wide range of conditions, however an optimal range of environmental variables, e.g. temperature, pH, and nutrients, is required for high growth rates (table 14). Phosphorous and nitrogen as NH_4 are essential nutrients that should be sufficiently present in the water for high growth rates, optimum concentrations of 4-8 and 7-12mg/L respectively (Hasan & Chakrabarti, 2009). However, the mean and even maximum nutrient concentrations in the Ouderkerkerplas are much lower than the optimum required for duckweed growth. Possible implications are that the duckweed grows slower (Edwards et al., 1992) or that the crude protein in duckweed could be significantly lower, which means it is less nutritious for fish (Leng, 1999).

	Duckweed growth requirements			Conditions in the Ouderkerkerplas		
	Min.	**Max.**	**Optimum**	**Min.**	**Max.**	**Mean**
Temperature (°C)	0	35	15-30	Temperature in greenhouse		
pH (-)	3.0	10.0	6.5-8.0	8.0	10.0	8.8
Ammonia-nitrogen (NH_4-N mg/L)	Trace	375	7-12	0.01	0.14	0.04
Phosphate (PO_4-P mg/L)	0.017	154	4-8	0.01	0.24	0.09

Table 14: *Environmental requirements for duckweed (Hasan & Chakrabarti, 2009) compared to environmental conditions in the Ouderkerkerplas obtained from data of Waternet (2013).*

6.2.2.2 Estimation duckweed production and phosphorous removal

To estimate the duckweed production and phosphorous removal several assumptions and calculations were made.

- Duckweed can remove 0.18gP/m^2/day from water if phosphorous concentrations are high (30mgP/L) (Cheng & Stomp, 2009). However, nutrient removal is less efficient when nutrient concentrations are lower, e.g. 0.05gP/m^2/day removal in water with a concentration of 1mgP/L (Alaerts et al., 1996). The phosphorous concentration in the Ouderkerkerplas is even lower. The lower phosphorous removal rate was assumed and multiplied by the surface of the duckweed tank. For the small, medium and large greenhouse annual phosphorous removal was estimated at respectively 2, 37, 183kgP.
- The growth rate of duckweed under sub-optimal conditions, as in the Ouderkerkerplas, was assumed 1-2kg/m^2/year (dry weight) (Leng et al., 1995). Multiplying the surface of the duckweed tanks by the growth rate, resulted in the annual duckweed production listed in table 15.

	Small	Medium	Large
Duckweed production tank (m^2)	120	2 000	10 000
Dry weight duckweed production (kg/year)	120-240	2000-4000	10 000-20 000
Phosphorous removal (kg/year)	2	37	183

Table 15: *Three scenarios of the duckweed production and phosphorous retention*

To put the phosphorous removal by duckweed production in the greenhouse in perspective, it was compared to the oxidizing system implemented by NUON which removed about 1000kgP in 2010 (Tomassen, et al., 2012). Adding oxygen will probably remove about 5 to 500 times more phosphorous than duckweed production in the greenhouse dependent on its size. The calculations indicate the proposed design in the floating greenhouse is probably not an effective way to improve the water quality of the Ouderkerkerplas.

6.2.3 HUMAN FOOD PRODUCTION AND CONSUMPTION

This section addresses what the potential food production and consumption in the area around the Ouderkerkerplas could be for the different floating greenhouse sizes. Further, it is discussed whether the local food production could reduce energy and material use compared to food produced elsewhere with conventional agriculture techniques.

6.2.3.1 Potential production

A rough estimation of potential fish and crop production in the Ouderkerkerplas was based on an existing aquaponics system developed at the University of the Virgin Islands (UVI), and the production rates conceptualized for the Polydome.

- The UVI aquaponics system is about 500m^2, and annually produces 5*10^{3}kg tilapia, and 1400 cases of lettuce or 5*10^{3}kg of basil (Rakocy et al., 2006). However, as previously stated, the aquaponics system in the Ouderkerkerplas should focus on growing a variety of crops (Stijkel, 2014). Other crops have different growth rates, e.g. eggplant can grow about three times slower than basil, and cucumber two times faster (Rakocy et al., 2006). These different growth rates are not considered here due to time constraints.
- For the Polydome an aquaponics system of 3400m^2 was conceptualized with an annual production of 1.1*10^{5}kg tilapia, 6.8*10^{4}kg vegetables, 1.3*10^{4}kg fruits, and 2.3*10^{5}kg herbs (Except, 2011). Notably, the production rates proposed for the Polydome are 4-7 times higher than measured by the existing UVI aquaponics system.
- For each greenhouse size scenario, annual food production was calculated by dividing the aquaponics system area by the UVI or Polydome aquaponics system area, and multiplying it by the production rate.

Table 16 shows annual yields that could be expected for the different greenhouse size scenarios on the Ouderkerkerplas.

		Small	Medium	Large
Aquaponics system (m^2)		360	6 000	30 000
UVI system	Tilapia (kg)	4*10^3	6*10^4	3*10^5
	Lettuce (case) or basil (kg)	1*10^3/ 4*10^3	2*10^4/ 6*10^4	8*10^4/ 3*10^5
Polydome	Tilapia (kg)	1*10^4	2*10^5	1*10^6
	Fruits (kg)	7*10^3	1*10^5	6*10^5
	Vegetables (kg)	1*10^3	2*10^4	1*10^5
	Herbs (kg)	2*10^4	4*10^5	2*10^6

Table 16*: Three scenarios of annual human food production based on the UVI aquaponics system (Racoky et al., 2006) and the Polydome concept (Except, 2011).*

6.2.3.2 Potential consumption

According to Except (2011), one hectare of diverse production in the Polydome could provide 80% of the dietary variety of a population of 2000 people. Based on this number a calculation was made on how many people could potentially be fed for each scenario in the Ouderkerkerplas (table 17). The largest greenhouse could potentially feed up to 6000 people, which is about half of the population of the municipality Ouderkerk aan de Amstel located near the Ouderkerkerplas.

	Small	Medium	Large
Aquaponics system (m^2)	360	6 000	30 000
Number of people fed 80% of dietary needs	70	1200	6000

Table 17*: Three scenarios of amount of people that can potentially be fed. Based on the Polydome concept (Except, 2011)*

The crops and fish should be sold locally to ensure their local consumption. One of the potential clients is Gewoon Geluk, a mobile catering around the Ouderkerkerplas (Gewoon Geluk, 2014). They have shown interest in promoting and selling fruit, vegetables and herbs which could be produced by this project (Stornebrink, personal communication, October 8, 2014). As Gewoon Geluk is not interested in fish there seems to be a gap between supply and demand. Additional markets should be searched in the surrounding area, e.g. companies, hospital AMC, airport Schiphol, or restaurants in the neighbourhood of Amsterdam.

6.2.3.3 Energy and material use during food production chain

The energy and material used for food production in the floating greenhouse with aquaponics system on the Ouderkerkerplas can be assessed using a Life Cycle Assessment (LCA). LCA is a systematic evaluation that takes into account inputs and outputs at all stages of the food production chain (Martinez, 2010). The results should be compared to the business as usual situation, e.g. food produced elsewhere in with conventional agriculture techniques (monoculture, chemical fertilization, pesticides etc), to assess what the potential reduction (or increase) in energy and material use could be by implementing a floating greenhouse on the Ouderkerkerplas. Due to lack of time and data the comparison was done qualitatively, namely reduction or increase in energy and material (table 18).

Scope	Inputs	Energy and material use of project compared to business as usual
Farm inputs	Seed, land, fertilizer, herbicide, pesticide	Reduced
Farm production/processing	Capital, energy, labour	Increased?
Distribution	Storage, waste, transportation, labour	Reduced
Consumption/disposal	Transportation, preparation, waste, recycle	Reduced

Table 18*: Life cycle assessment of local food production in the floating greenhouse with aquaponics system compared to business as usual (food supplied in supermarket produced elsewhere with traditional agriculture techniques). Scope and inputs adjusted from Martinez (2010). Assessment in terms of reduced or increased energy and material use compared to business as usual.*

- Farm inputs: The pressure on land use is reduced as the floating greenhouse would be built on water. Further, aquaponics systems require less fertilizers as the waste products from the fish culture serve as nutrients for the crop culture (Drivers, 2006). Additionally, the great diversity of crop species can make the system resilient, and reduces the need for pest management (McManus, 2010).

- Farm production/processing: The energy and material usage during the production and processing in the floating greenhouse might be higher than business as usual, because energy used for construction and heating of a floating greenhouse could be higher than for example unheated, plastic sheeted greenhouses in warmer climates (Shimizu & Desrochers, 2008). Using renewable energy sources could lower the environmental impact.

- Distribution: Energy used during the food distribution is expected to decrease as it would be locally produced and consumed, reducing the transportation and packaging needed for the products (Blidariu & Grozea, 2011; MacGregor & Vorley, 2006). Figure 26 shows where the fresh fruit and vegetables in the Albert Heijn are produced as comparison.

- Consumption/disposal: Food waste could be avoided by informing the people visiting the floating greenhouse about the extent of the problem, and promote recycling of food waste (Godfray et al., 2010).

Overall, it seems that a floating greenhouse with aquaponics system in the Ouderkerkerplas could lower energy and material used compared to food produced elsewhere with conventional agriculture techniques, however these results could not be quantified.

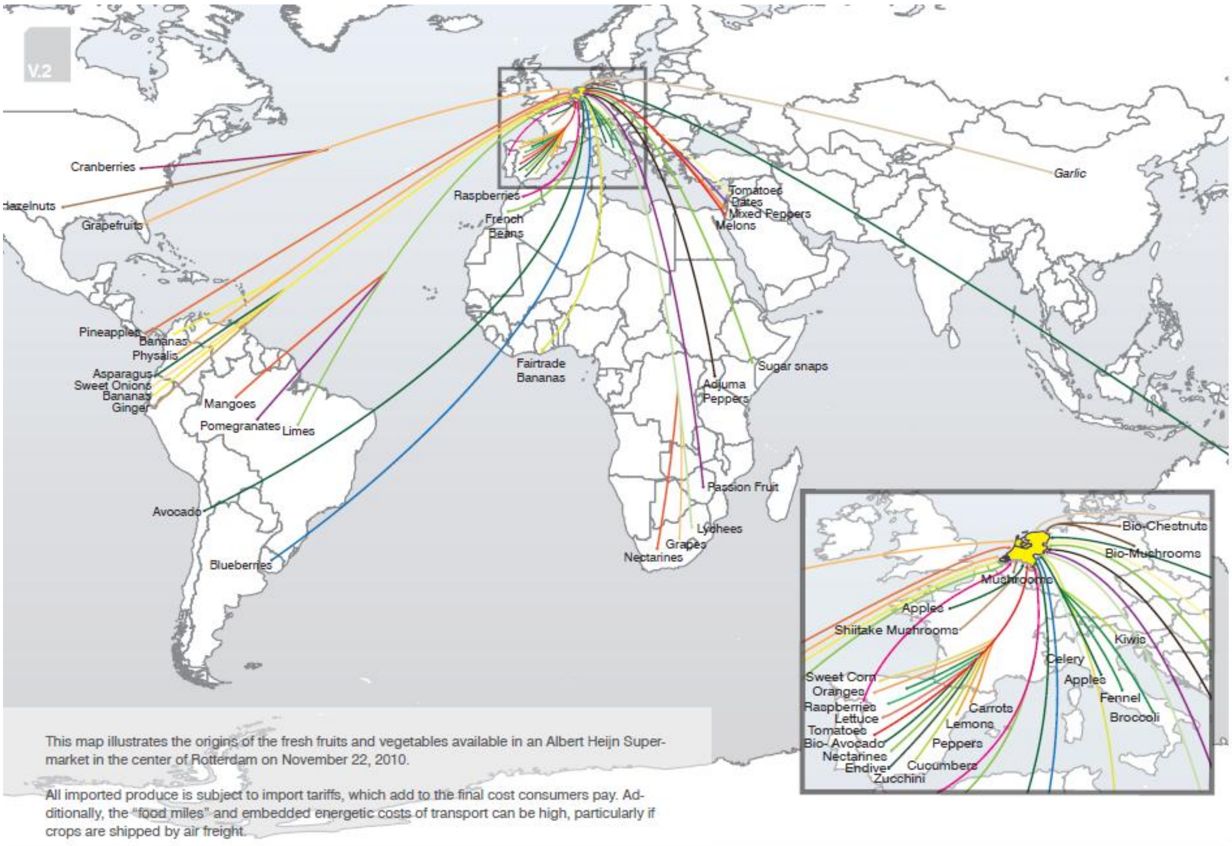

Figure 26*: Origins of the fresh fruits and vegetables available in Albert Heijn Supermarket in the center of Rotterdam on November 22, 2010 (Except, 2011).*

6.2.4 ECOLOGY: IMPACTS BIRD POPULATIONS

A floating greenhouse could increase human activity around the Ouderkerkerplas when used as center of community engagement. Increased human presence could have negative effects on the bird populations around the lake (Gill, 2007). The Ouderkerkerplas is of great value to wintering waterfowl, breading sand martins, godwits and ruffs (Jonker, 2010). The birds could be adversely affected if they avoid areas with important resources for long periods. Important resources at this location include food supplies and nesting or roosting sites. Also short-term impacts are possible, such as increased movement of the birds in response to an increased human presence (Gill, 2007). It has been measured that wintering waterfowls in Virginia, America spend significant amounts of energy on avoiding humans that walk by. This energy is essential in the winter for survival, migration, and breeding reserves (Pease et al., 2005). It is expected that a larger floating greenhouse in the Ouderkerkerplas would have more visitors than a small one, and would thus have larger effect on the birds. However, the exact effect could not be quantified in this study.

6.2.5 DISCUSSION

6.2.5.1 Limitations of the study

It should be stressed that the quantification of the environmental impacts is only indicative as the calculations include many uncertainties. First, for the phosphorous removal it is uncertain how efficient the duckweed production is with phosphorous concentrations lower than described in literature (Hasan & Chakrabarti, 2009). Additionally, it has not been taken into account that the nutrient concentrations fluctuate during different seasons and throughout different water layers in the lake (Waternet, 2014). Second, the food production and consumption calculations largely depend on how the system is designed, e.g. what combination of fish and crop species are grown.

Also, it is uncertain whether high production as conceptualized for the Polydome can be reached as it was significantly more than observed in existing aquaponics systems. The production rate also influences the calculations of the consumption potential. Third, it was not possible to quantify the impact on the birds as the amount, timing and location of increased human activities due to the project were unknown (Gill, 2007).

6.2.5.2 Applicability of floating greenhouse with aquaponics system

It seems feasible to implement a floating greenhouse on the Ouderkerkerplas, as this has been successfully realized before in Naaldwijk, The Netherlands (Vermeer, 2005). Also various commercially viable and sustainable aquaponics systems exists (Diver, 2000). The duckweed production as a source of fish food is usually done in combination with treatment of sewage water rather than lake water (Cheng & Stomp, 2009; Hasan & Chakrabarti, 2009). As nutrients in the Ouderkerkerplas are less concentrated, it seems not feasible to use this technique to improve the water quality. Nevertheless, small-scale duckweed production could be used to supplement the fish feed, as well as to show visitors a link between the lake and the greenhouse. Considering the size of the greenhouse it is not expected that there are other techniques available that could be incorporated in the floating greenhouse that significantly improve the water quality.

For further research it is recommended to focus on the preferred size, location, and design of the flows and processes of the floating greenhouse with aquaponics system. Based on research of potential consumer's interests and environmental conditions on the Ouderkerkerplas, it can be analyzed what combination of crops and fish can best be produced.

6.3 INSTITUTIONAL SETTING

In order to go through with the project, the GGA will first have to ensure that its implementation would not breach the existing contract between NUON and WaterNet, allowing for NUON to continue their water mining activities. Because the aquaponics system wouldn't interfere with the water temperatures, or reach the deeper waters of the lake, the project should not interfere with NUON's activities. Thereafter, the GGA will have to obtain the specific and necessary permits from the government, which Stijkel and the GGA should further look into.

6.4 SOCIAL ASPECTS

6.4.1 STAKEHOLDERS

This section outlines the various actors who could potentially be involved or affected by the execution of this project. The map identifies the stakeholder types, indicating the role that they could play in the project's implementation (Polonsky and Scott, 2005). Thereafter, the stakeholder matrix places the actors in order of their relative threatening and cooperative potential (Walker et al. 2007; Savage et al. 1991). Figure 27 shows how the groups of stakeholders relate to the project (either in implementation or future usage) (Polonsky, Scott, 2005).

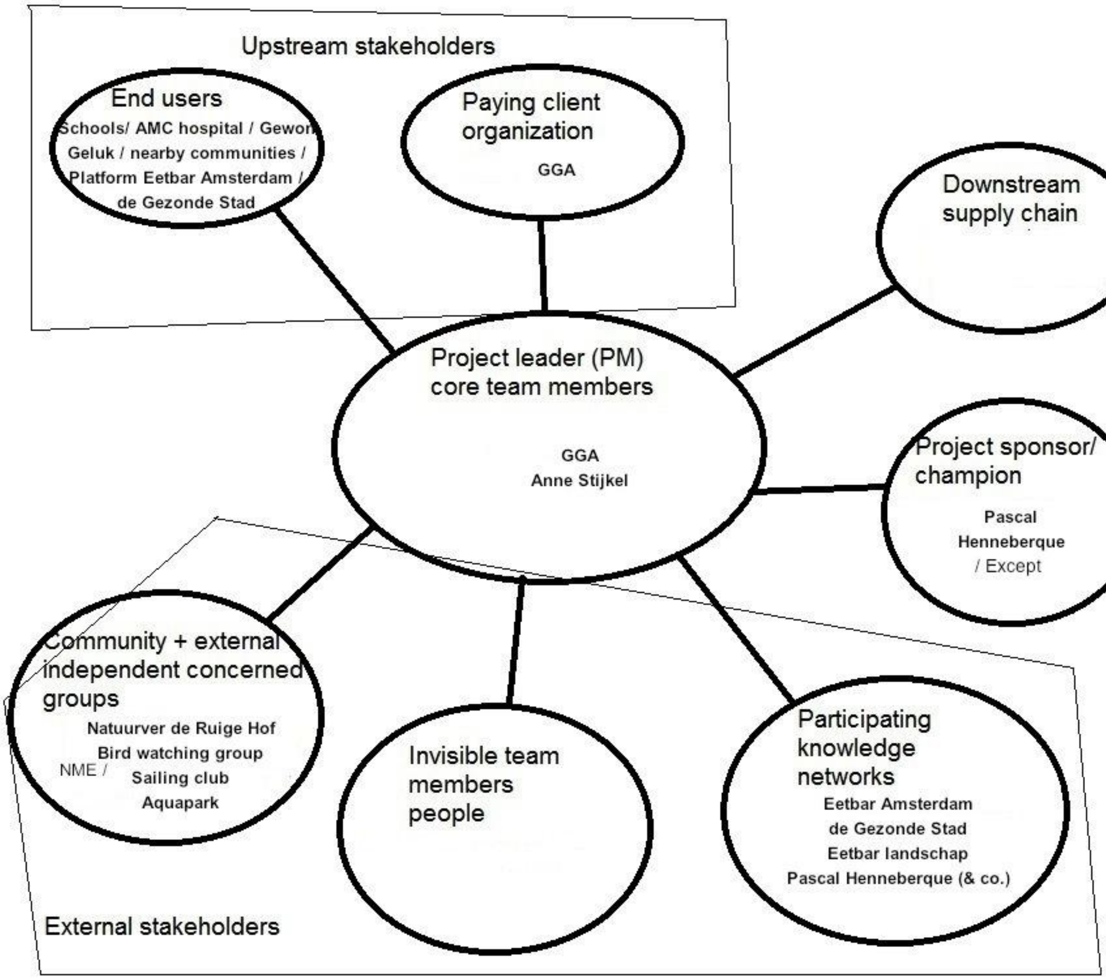

Figure 27: *Stakeholder map (Aquaponics/Greenhouse)*

The GGA and Anne Stijkel are the *project leaders*, as they are the ones interested in developing the area. With the help of the *project sponsor*, who in this case would be Pascal Henneberque or Except (the polydome company), both actors with different versions of floating greenhouses, the plans can be realized. The stakeholders who could use the finished system are found in the *upstream* category. Although they are all classified as *end users*, they would be using the floating greenhouse or its effects in different ways. Platform Eetbar Amsterdam is interested in this project because the main purpose of their organization is to raise awareness about sustainability in the city (Engels, personal communication, October 10, 2014). The potential use that Gewoon Geluk would have of the greenhouse would come more from a profit base, which is later explained. Although we were unable to get in contact with the groups de Gezonde Stad and Eetbaar landschap, they focus on similar goals as Platform Eeetbar Amsterdam (http://www.degezondestad.org/), hence their similar positioning. Schools and nearby areas also fit within this category, as they would make use of the new space based on its recreational and educational potential. Understanding the different end goals of the stakeholders within this category allows us to better perceive their relative threatening and cooperative potential. These *upstream* stakeholders, the *project leaders*, and the *downstream* stakeholders, are instrumental in the successful implementation of the project (Walker et al. 2007). Some stakeholders, again like Platform Eetbar Amsterdam, are both *upstream* and *external* stakeholders, because of their interest in providing knowledge and support both during and after the project's implementation (Engels, personal communication, October 10, 2014). *External* stakeholders doesn't only include outside knowledge networks, but also stakeholders whose concerns haven't been acknowledged by the *project leaders*. One such group is the Vogel Werkgroep (bird watching group) who is vehemently against any kind of development on the lake (Litjens, personal communication, October 8, 2014). The *external* stakeholders must be taken into account and listened to, as they have intrinsic rights. Understanding their relative threatening/cooperative potential will be of utmost importance to achieve the project's aims (Walker et al. 2007; Polonsky and Scott, 2005).

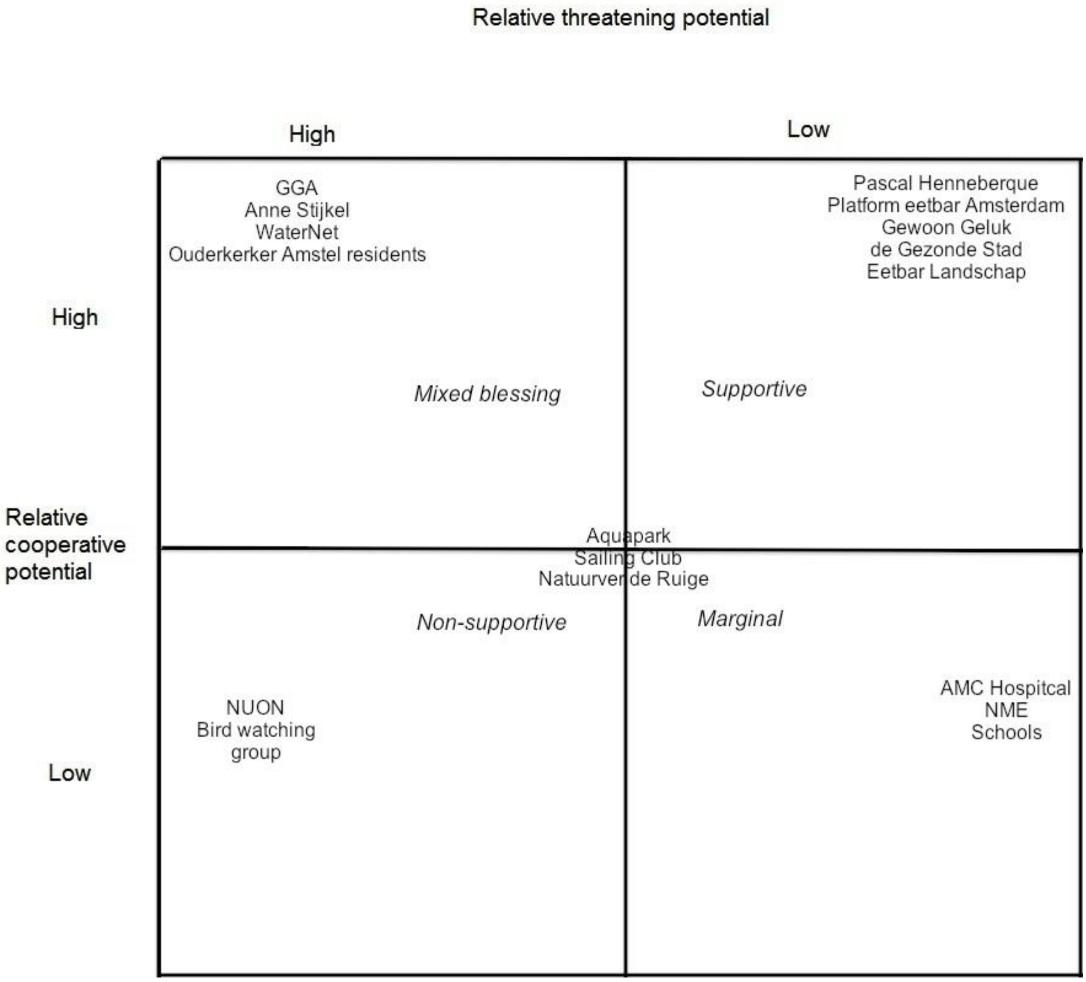

Figure 28:*Stakeholder Matrix (Aquaponics/Greenhouse)*

Figure 28 shows where each of the stakeholders lie, in terms of relative threatening and relative cooperative potential. Incorporating all stakeholders into the development of the projects is vital, and this matrix shows the *project developers* (Anne and GGA) how to address them more effectively (Polonksy, Scott, 2005).

The actors in the *mixed blessing* category (high cooperative and threatening potential) are involved on a legal and institutional level, such as the GGA and WaterNet. Because of the existing relationship between Waternet and NUON, and NUON's contract regarding water mining, they and the GGA are the ones will the ultimate say in what project is chosen. These stakeholders along with Anne Stijkel (*project leader*) and the nearby residents play an instrumental role in the project's implementation. *Supportive* actors are ones who would benefit from the project and are interested in supporting its implementation. Such actors include platforms that aim to promote sustainability within the city of Amsterdam. The *non-supportive* actors (low cooperative potential and high threatening potential) are the bird watching group and WaterNet. WaterNet has expressed their interest in keeping the area as it is, because they have already invested in the current water mining activities that are taking place (Baker, personal communication, October 2, 2014). The bird watching group has expressed that even sustainable projects, such as the floating greenhouse, "should never be located in areas with valuable nature," because the existing flora and fauna in the area is worth preserving (Litjens, personal communication, October 8, 2014). It was impossible to get in touch with the nature group Natuurver de Ruige Hof, and although they are a nature conservancy group, so they might have a similar stance on the subject, they are also involved in educational projects, so the GGA could convince them of the educational potential of this project. Stijkel could then use their support as leverage in convincing the bird watching group to get on board with the project (Savage, 1991). The *marginal* actors (low threatening and cooperative potential) are ones who have little say in the developments of the project, but that once implemented, would make use of it. The aquapark, sailing club and Gewoon Geluk are currently using this location for their activities, but could react differently to the project. Because we have not been able to contact the sailing club or the aquapark, we are not able to properly place them on the matrix. However, Gewoon Geluk could benefit from this greenhouse project through two different ways: they are interested in buying the products created by the system, and they could find new customers from the intended inflow of project visitors (Stornebrink, personal communication, October 8, 2014).

The goals and values reflected by some of the stakeholders whose main aim is to promote sustainability mirror the development goals expressed by Anne and the GGA for this area (Stijkel, 2014; Engels, personal communication, October 10, 2014; Henneberque, personal communication, October 10, 2014). This project would focus on local food production, an issue with close ties to sustainability.

6.4.2 RECREATIONAL AND EDUCATIONAL POTENTIAL

The aquaponics system can provide a means to incorporate the issues of sustainability and food production through a "hands-on" approach for educational purposes in the surrounding areas, as well as result in a center of community engagement, through which members as well as passerbyers can learn new skills (Goodman, 2011). The center and the nearby communities could mutually benefit, as there could be fresh food for the community, and a market base for these new products (Except, 2011). Incorporating *external* players such as NME, engages in the educational aspects that this project offers. The NME, who has a network involving schools throughout the municipalities of Ouderker, Diemen, Aalsmeer and Haarlmmermeer, organizes leskisten, where students receive informational brochures about various topics (renewable energy, nearby activities, etc.) (Romijn, personal communication, September 24, 2014), and the aquaponics system could within this scope. The GGA and the NME, could promote educational trips regarding sustainable food production to this area. A similar aquaponics project in Missouri has attracted 10,000 visitors of different types, "school children, farmers, researchers and government officials," since 2004 (Diver, 2000). This shows the scale of interest that a similar project at the Ouderkerkerplas could achieve. Incorporating the community center into the project could enhance its attractiveness to the neighborhood and to outside visitors. Similarly, the AMC Hospital could use the floating greenhouse as a recreational area for its patients. These ideas of educational and recreational use are in line with the GGA's goal of introducing a sustainable, recreational and educational project in the location.

6.5 ECONOMIC ASPECTS

According to Henneberque, a floating greenhouse will cost at least €300,000 due to the cost of the type of ship to be used and up to €600,000, including the costs of further needed materials (personal communication, October 10, 2014). According to Except, it costs about €35 per m2 to build a greenhouse, and an aquaponics system costs 4 times as much (€140/ m2) (Except, 2011). Also, building floating structures costs roughly €169/m2 (TNO, 2011). Using these values, we can create an equation to calculate a (very) rough estimate of how much the different sized projects could cost [29]:

Total cost= (total surface area of floating structures * 169) + ((total surface area of floating structure – size of aquaponics) * 35) + (size of aquaponics * 140)

	Small	Medium	Large
Size	600 m2	10,000 m2	50,000
Total cost	€ 160.200	€2.670.000	€13.350.000

Table 19*: Estimated financial costs of different sized aquaponics systems.*

Regardless of its initial high price tag, the idea of a floating greenhouse with an incorporated aquaponics system can produce up to three times as many vegetables as conventional cropping methods (Metabolic, 2013). Based on this information, this project's costs could range from € to €€€.

6.6 CONCLUSION

It was assessed how a floating greenhouse with aquaponics system can contribute to sustainable development of the Ouderkerkerplas. The potential food production is high and is energy and material efficient. The food production could entice local businesses, such as Gewoon Geluk, and vendors to become a supportive stakeholder group. A large benefit of the project is that it would increase the recreational and educational value of the area. Both the creation of a community engagement center, and the greenhouse itself could be used in various ways by the upstream stakeholders, e.g local organizations seeking to promote sustainability projects within the area through schools and community involvement. The increased human activity in the area might impact the bird populations negatively, however this could not be sufficiently explored.

The first limitation of the project is that it seems that the water quality cannot be improved efficiently through duckweed production as fish food for the aquaponics system. The second limitation is the potential financial cost, as the project coordinators would have to find investors willing to support the project. The slowness of the GGA is also a possible hindrance, as it could deter these possible investors as well as detract some stakeholder's interests in the project. It seems that only the small version of this project could be financially plausible.

To conclude, there are potentials for a floating greenhouse with aquaponics system to make the Ouderkerkerplas more sustainable in terms of food production and increase recreational and educational potential of the area. However, limitations are encountered in terms of impacts on ecology, economic constraints, and the lack of ability to improve the water quality. Challenges remain in the final design of the floating greenhouse, and finding funds to cover the financial burden of the project's implementation.

[29] These estimations are based on other estimations, and further exploration into the project details would be necessary to create a more accurate financial estimation.

7 INTEGRATION AND RECOMMENDATIONS

Using the results from the analyses conducted in the preceding chapters of this study, here, we integrate our findings to produce project recommendations for our client, Anne Stijkel. First, the results are integrated in a table and brief summaries of the findings are presented. Second, a recommendation based on our analysis of each project's contribution to the sustainable development of the Ouderkerkerplas is presented.

7.1 INTEGRATION

An overview of the four projects potential impact on sustainability is presented in figure 29. For the environmental and social pillar the projects are scored on a five-point scale (negative, possibly negative, neutral or not significant, possibly positive and positive). The economic aspect is scored on a three-point scale (<500 000; 500 000- 1000 000, >1000 000 euro).

		Nanotechnology	Wetlands	Floating greenhouse with aquaponics	Algae cultivation
Environment					
	Water quality				
	Biodiversity/ ecology				
	Energy/food production				
Society					
	Recreation				
	Education				
Economic					
	Costs	€€€	€ to €€	€ (small) to €€€ (large)	€€
	Benefits	-	-	€ (small) to €€€ (large)	€€€

Legend

Negative	Possibly negative	Neutral/ not significant	Possibly positive	Positive

< 500 000	500 000 – 1000 000	> 1 000 000
€	€€	€€€

Figure 29: *Integration of the results*

Nanotechnology: This project would implement solar powered technology on a nano scale in order to purify the surface water at the Ouderkerkerplas. Currently, there is no technology specific to targeting phosphorus, nor are the long-term effects (in terms of environment and possible health hazards) of implementing such a project on such a large scale known. Cost estimations of this project range between €28767 and €575835 per year, although the educational potential of this project would likely attract visitors, who could potentially create revenue.

Wetlands: This is a man-made wetland, specifically engineered for a water quality improvement. It has the potential to decrease the P-levels in the Ouderkerkerplas, and enhance the biodiversity in the area. But in order to treat all the cooling water Nuon uses, it requires a lot of space to function properly and the expected efficiency is lower than the current system of oxidation of the lower water layer. This, and the fact that it requires big investment while creating no revenues makes it not feasible.

Floating greenhouse with aquaponics system: This is a re-circulating food production system with high educational and recreational potential. The inclusion of a community engagement center could make it appealing for visitors, while the food produced can be locally sold and consumed which could result in revenue for the area. The potential costs of this project vary depending on the size, but for this section, we will focus on the small version (roughly €160000). The water quality will not significantly improve, as the designed system is not very effective at removing phosphorous from the lake water. The influx of visitors could affect the ecological environment, as certain birds might be deterred from continuing to use this area for their nesting or migration habits.

Microalgae cultivation: This system would be attached to NUON's cold water mining operation, outside of the lake, and would cultivate dry algae biomass using a photobioreactor system. Although the initial investment is relatively expensive (~4 million €) it also has the highest potential in terms of revenues (~30 million €). By utilizing excessive nutrient levels, the system cleans the water and reduces the chance for algal blooms during summer months. Additionally, as these systems are in their experimental stages, it is likely that this system would provide interesting opportunity in terms of education[30].

7.2 RECOMMENDATIONS

It is our recommendation that, if initial investment costs are easily satisfied, a combination of a small floating greenhouse with aquaponics system and microalgae cultivation system would likely be the best case scenario for the sustainable development of the Ouderkerkerplas. Both of these solutions provide complementary benefits, do not conflict with each other in terms of space, and do not face a significant amount of opposition from any of the stakeholders[31]. Together, they incorporate the three sustainability pillars underpinning the development that our client wishes is to take place in the area: environment, society and economics.

The microalgae cultivation system is capable of producing eco-friendly biomass which may be used in various applications and has a high potential for creating a revenue stream (see section 3.3.5), and thus, possesses the potential for attracting investors. Additionally, a microalgae cultivation system reduces the problem of excessive nutrient levels which cause cyanobacteria (blue-green algae), further improving the water quality. The aquaponics system would create a center for community engagement, which would vitalize the area's educational and recreational potential. Integrating and promoting sustainability issues, such as local food production, into school projects and the community of Amsterdam as a whole, is high on the priorities list of some of the possible stakeholders, who could therefore be interested in supporting this project. The products (fruit, vegetables, herbs and fish) and revenues of the floating greenhouse and aquaponics system would be re-circulated within the local economy, as the potential customers would be the nearby community or local businesses.

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[30] This statement needs to be confirmed with stakeholders, see Social section in Microalgae.
[31] This statement is based on the information which we have received from stakeholders, which is incomplete and as such needs further investigation.

Combined, these solutions are the most promising in terms of satisfying the various aspects of sustainability. The microalgae cultivation system offers improved water quality, where the floating greenhouse with aquaponics system fails to do so. Possibly, some of the cultivated algae could be used as fish feed in the aquaponics system (Hasan & Chakrabarti, 2009). This report shows that the most ecological damage that could result from the implementation of these projects is that an influx of human activity around the Ouderkerkerplas could affect the bird population currently using this area. These results should be further investigated before any implementation is to take place. client will have to locate investors to financially support the implementation of the projects. Furthermore, local communities and educational groups could be interested in both projects, due to their separate educational potentials, in terms of sustainability promotion and higher education programs. No significant institutional barriers were identified for the implementation of either project, though our client is recommended to further investigate this. In order to fully realize these projects, it will be important for our client to integrate the support (or at least the input) of all of the stakeholders who could potentially be involved or affected by the projects. This means integrating the only stakeholder identified as non-supportive, who is opposed to either/any project (bird watching group). Our client is advised to carefully approach them with support from other nature conservation groups, whose support could be used as leverage to persuade them.

8 CONCLUSIONS

The five projects discussed in this paper, have been assessed based on their potential to contribute to the sustainable development of the area of the Ouderkerkerplas. We have taken into account how each of the projects addresses the three pillars of sustainability: environment, economy and society. Using the above criteria, various potentials, limitations and challenges of each project were identified. The following conclusions were reached, but our client is free to choose which ever project they see as a better fit for the area. Regardless of which project is chosen in the end, it will be vital to incorporate the various stakeholders who could potentially be involved or affected by its implementation.

It is concluded that nanotechnology and constructed wetlands would contribute in some ways to the sustainable development of the Ouderkerkerplas, but are not feasible due to the large investments they require and the relatively limited returns they could supply. Alternately, a floating greenhouse with aquaponics system and algae production could contribute in more ways. A floating greenhouse with aquaponics has a stronger potential to recreationally and educationally enhance the area, while still keeping the principles of sustainability a priority, through the production of local food. The algae production project would bring extra revenue into the area through a sustainable means of microalgae production. Another benefit of these two projects is their synergistic potential to be combined, that is to say, implementing both would not be detrimental to the other, and would in fact, further add to the sustainable development of the area. The combination of these two projects addresses the sustainability pillars through improving the water quality (from microalgae production), enhancing the area's recreational/educational potential (from the aquaponics system) and bringing in extra revenue (through both microalgae and food production). There do exist limitations and challenges to the implementation of each of the projects. In the case of aquaponics and microalgae production, we value their sustainable contribution to the area as higher than their negative impacts, which could mainly affect the area's biodiversity.

9 REFLECTION

We set out this research to help our client solve the problem of how to further develop the Ouderkerkerplas sustainably. We have looked at the environmental, social and economic aspects of each project, and finished with an integration, conclusion and recommendations. We are aware that these conclusions are subject to high uncertainty. For the stakeholder analysis it can be said that, given the timeframe, it was difficult to contact all stakeholders and get their response. This created a situation where we had to interpret stakeholders through other means, and we justified this where needed. The environmental part of the paper was subject to uncertainties as well. Nanotechnology, for instance, is a relatively new technique with little existing knowledge in some factors. The creation of wetlands in the Ouderkerkerplas would also create a mostly unique situation because they are generally built for other pollutants. Likewise, an aquaponics system that cleans lake water has not yet been properly designed. These are just three examples, which represent some critical questions still up for discussion, due to our restricted resources and the timeframe. However, by carefully asking the rights questions and addressing uncertainties in their respective chapters we have strived to come to a useful and still scientifically based conclusion for our client.

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Schoot, Mark. *Groengebied Amstelland.* 19 September 2014.
Van Bulderen, Raymond. *NUON.* 2 October 2014.
Bakker, Wiebbe. *Waternet.* 8 October 2014.
Engels, Inge. *Platform Eetbar Amsterdam*. October 8, 2014.
Henneberique, Pascal. *Drivijdne Kas.* October 8, 2014.
Bos, Maartje. *Landscape architect.* 10 October 2014.
Litjens, Hetty. *Vogelwerkgroep*. October 10, 2014.
Stornebrink, Monique. *Gewoon Geluk*. October 10, 2014.
Owen, Mark. *CEO of Puralyitcs*. October 21, 2014.
Wang, G. PhD *Nanotechnology, Utrecht University*. October 22, 2014

11 APPENDIX

11.1 STAKEHOLDER THEORY

Dimension 1: purpose and objectives of considering stakeholders. This dimension runs across two extremes, one being the need for reform which involves redefining policy regulations for specification of who stakeholders are and how they should be treated. The other end of the extreme relates to mapping stakeholders interest, understanding them, and developing a new way to control their ability to threaten or collaborate on a project. Due to the lack of policy influence and our interest in understanding stakeholders interests, our position lies near stakeholder mapping.

Dimension 2: value of considering stakeholders. This determines whether stakeholders should be viewed as instruments to be harnessed and managed on one extreme, or treating them as intrinsically valuable on the other extreme. Our position lies in between these two extremes as we perceive some stakeholders, such as the local community, as having intrinsic value, and other stakeholders, such as potential investors and companies, as instrumental agents who should be controlled to improve the likelihood of project success.

Dimension 3: considering the stakeholders' intervention level. On one end of the continuum is the community right to intervene through regulations, whether they are local, regional or national. At the other end is the individual's intrinsic right to intervene. Consistent with Walker et al. (2007) our position lies in between these two extremes, which Walker et al. (2007) have designated as "the organization" which indicates that we support the notion that organizations can understand and benefit from understanding what the cooperative or threatening potential of stakeholders is and should make an effort to engage stakeholders into project planning. Furthermore, this position is consistent with the current situation at the Ouderkerkerplas.

Dimension 4: considering the degree of stakeholder enforcement. This dimension considers how stakeholder interests should be institutionalized with a project management plan. One end of this dimension lies the position that all stakeholder involvement should be voluntary, at the other end, stakeholder involvement *must* be incorporated. Here, we place ourselves closer to the institutionalized stakeholder involvement side of the spectrum. The justification for this positioning is based on our understanding that an entirely voluntary process (which has taken place thus far) will inevitably overlook important stakeholders (e.g. the local community), a phenomenon which has been evidenced in literature (Reed 2008).

11.2 MICROALGAE CULTIVATION

Theoretical biomass yield calculation taking into account the water supply

In the Species section, the most optimum scenario for Ouderkerkerplas was portrayed, which involved a 14 day cultivation batch in a flat plate photobioreactor. During the six months of exploitation (May-October) 13 batches could be cultivated. Assuming that the flow rate of water supply is constant, 2,880,889m^3/13=221,600 m^3 of water would be needed for every batch. However, this would require an area of 22.2 ha for cultivation, which is not feasible at the Ouderkerkerplas, and thus the potential of 1 ha will be determined (see Economic costs for further explanation). Taking into account that for 2,880,889 m^3 of water 14,400 tons of dry biomass could be harvested (see Water section), it can be calculated that for 221,600 m^3 of water, 1077 tons could be harvested. This amount requires, as mentioned, 22.2 ha to be cultivated. Thus, for 1 ha, 49 tons of dry biomass could be harvested per batch. If we multiply this number with the maximum number of potential batches, 13, we find that the total dry biomass produced in 1 ha for the period of exploitation is 636 tons.

Costs of operating photobioreactor:
Using the data from the University of Almeria (2010) on the costs of photobioreactors, we estimate an operating cost of 5.7€/kg of dry biomass. Given that we have estimated a total expected output of 636 tons of biomass, we multiply 5.7€/kg with 636,000kg to produce an estimated operational cost of 3,625,200€/yr.

Costs of photobioreactor materials:
This cost only includes the cost of materials for the photobioreactor. We have calculated this cost based on microalgae production cost estimates provided by academic scholars from the University of Almeria. According to these estimates, the costs of the photobioreactor medium are $0.4€/m^3$.

We know that in order to cultivate 1 batch of algae, $221{,}600m^3$ of water is needed for an area of 22.2 hectares. Considering our interest in calculating costs for only 1 hectare, we have divided $221{,}600m^3$ by 22.2 hectares to determine the volume of water need per hectare, which amounts to $10{,}000m^3$/ha. This number multiplied with an estimated cost of $0.4€/m^3$ produces an approximate cost of 4,000€ for materials.
F.G. Acién, J.M. Fernández, C. González, E. Molina Grima Dpt. Chemical Engineering, University of Almería, Spain (2010). Retrieved from: http://www.aquafuels.eu/attachments/066_Presentation%20-%20G.%20Acien%20(University%20of%20Almeria)%20-%20Microalgae%20production%20costs.pdf

Costs of labor:
To calculate the costs of labor needed for the maintenance and operation of the photobioreactor facility, we first used the data provided by the University of Almeria (2010), which indicates a requirement of 3 persons per hectare, to determine that for a 1 hectare system, 3 persons would need to be employed. Salary estimates from PayScale.com indicate that the median annual income of a mechanical engineer in the Netherlands is 37,000€. Because the photobioreactor would only be actively operating for 6 months of the year, we then divided this number by 2, which amounts to an 18,500€ salary for each employee. Multiplying 18,500€ with 3, we estimate a labor cost of 55,500€/yr.
http://www.payscale.com/research/NL/Job=Mechanical_Engineer/Salary

Costs of CO_2:
Based on the data in the Theoretical Biomass Yield section, we know that we need 1.8 tons of CO_2 to cultivate 1 ton of biomass. In the Theoretical Biomass Yield section a maximum yield of 636 tons of biomass was estimated. Therefore, for this amount of dry biomass 1,144,800kg of CO_2 is needed. The estimated cost of 0.4 €/kg_{CO2} provided by the University of Almeria (2010). 1,144,800kg multiplied with 0.4 provides us with an estimated cost of 457,920€ for CO_2.

Formula for determining revenues photobioreactor:
If our client is interested in further investigating the revenues which this system would produce, a detailed formula which incorporates all of the required inputs can be found at http://www.nrel.gov/biomass/pdfs/zemke.pdf

11.3 NANOTECHNOLOGY

			Puralytics Active Purification Processes				
Puralytics	Listing	Contaminant	Photocatalytic	Photocatalytic	Photolysis	Photo	UV
1	CCL3 13	1,1,1,2-Tetrachloroethane					
2		1,1,1,2-Trichloroethane					
3	EPA 80/NSF	1,1,1-Trichloroethane					
4	CCL2 10	1,1,2,2-Tetrachloroethane					
5		1,1,2,2-Trichloroethane					
6	EPA 81/NSF	1,1,2-Trichloroethane					
7		1,10-Dichlorodecane					
8	CCL3 14	1,1-Dichloroethane					
9		1,1-Dichloroethane					
10	EPA 46/NSF	1,1-Dichloroethylene					
11	CCL2 13	1,1-Dichloropropene					
12		1,2,3-Benzenetricarbolxylic acid					
13	CCL3 15	1,2,3-Trichloropropane					
14		1,2,4,5-Benzenetetracarboxylic acid					
15		1,2,4-Benzenetricarboxylic acid					
16	EPA 79/NSF	1,2,4-Trichlorobenzene					
17		1,2,4-Trihydroxybenzene					
18	CCL2 11	1,2,4-trimethylbenzene					
19	EPA 42	1,2-Dibromo-3-chloropropane (DBCP)					
20	EPA 45/NSF	1,2-Dichloroethane					
21		1,2-Dichloroethylene					
22	EPA 50/NSF	1,2-Dichloropropane					
23	CCL2 14	1,2-diphenylhydrazine					
24	CCL3 16	1,3-Butadiene					
25	CCL2 15	1,3-dichloropropane					
26	CCL2 16	1,3-dichloropropene (Telone)					
27		1,3-Dihydroxybenzene					
28	CCL3 17	1,3-Dinitrobenzene					
29	CCL3 18	1,4-Dioxane					
30		1,4-Diphenyl-1,3-butadiene					
31		17-Oestradiol					
32	CCL3 19	1-Butanol					
33		1-Butylamine					
34		1-Octanol					
35		1-Propanol					
36		2 or 3 or 4-Halobenzylalcohols					
37		2 or 3 or 4-Hydroxyacetophenone					
38		2-, 3-, or 4-Chlorobenzoic acid					
39		2-, 4, or 6-chloroquinoline					
40		2, 4-dichlorophenoxyacetic acid					
41		2,2,6,6-Tetramethylpiperidone					
42	CCL2 18	2,2-dichloropropane					
43		2,2-Dichloropropionic acid					
44		2,3,6-Trichlorobenzoic acid					
45		2,3-dichlorophenol					
46		2,3-Dimethyl-1,3-butadiene					
47	EPA 78/NSF	2,4,5-TP (Silvex)					
48	CCL2 17	2,4,6-trichlorophenol					
49		2,4,6-trinitrotoluene					
50	EPA 40/NSF	2,4-D					
51	CCL2 19	2,4-dichlorophenol					
52		2,4-Dichlorophenoxyacetic Acid					
53		2,4-Dihydroxybenzoic acid					
54	CCL2 20	2,4-dinitrophenol					
55	CCL2 21	2,4-dinitrotoluene					
56		2,4-Hexadienes					
57		2,5-Dimethyl-2,4-hexadiene					
58		2,6-Dichloroindophenol					
59		2,6-Dimethylphenol					
60	CCL2 22	2,6-Dinitrotoluene					
61		2,6-Di-tert-butyl-4-methylphenol					
62		2,6-Di-tert-butylphenol					
63		2-Chlorobiphenyl					
64		2-Chlorophenol					
65	CCL3 20	2-Methoxyethanol					
66		2-Methylbenzoic acid					
67	CCL2 23	2-methyl-Phenol (o-cresol)					
68		2-naphthol					
69		3,4-Dihydroxybenzoic acid					
70		3,5-Di-methylphenol					

			Puralytics Active Purification Processes				
Puralytics	Listing	Contaminant	Photocatalytic	Photocatalytic	Photolysis	Photo	UV
71		3,5-Di-tert-butylphenol	■				
72		3-aminophenol	■				
73		3-Bromoquinoline	■				
74		3-Chlorophenol	■				
75		3-Methoxybenzylalcohol	■				
76		3-Nitrophenol	■				
77		4-(2-Pridinylazo)resorcinol	■				
78	CCL3 23	4,4'-Methylenedianiline	■				
79		4,6-Dichlororesorcinol	■				
80		4-Aminophenylarsonic acid	■				
81		4BS Azo Dye	■				
82		4-chloro-2 nitrophenol	■				
83		4-Chloro-2-methylphenoxyacetic acid	■				
84		4-Chloro-3-methylnitrobenzene	■				
85		4-Chloro-3-methylphenol	■				
86		4-Chlorobenzenesulfonamide	■				
87		4-Chlorobenzoic acid	■				
88		4-Chlorocatachol	■				
89		4-Chlorophenol	■				
90		4-Chlorophenoxyacetic acid	■				
91		4-Chlororesorcinol	■				
92		4-Ethylaniline	■				
93		4-Hydroxyazobenzene	■				
94		4-Hydroxybenzyl Alcohol	■				
95		4-Methoxyphenol	■				
96		4-nitroaniline	■				
97		4-Nitrobenzoic acid	■				
98		4-nitrophenol	■				
99		4-Nitrosoimidazole	■				
100		4-Nitrosopyrazole	■				
101		4-Nonylphenol	■				
102		4-Nonylphenolpolyethoxylate	■				
103		4-tert-butylphenol	■				
104		4-tert-butylpyridine	■				
105		6-Chlorovanillin	■				
106		6-Methyluracil	■				
107		9,10-Anthraquinone	■				
108		9-Acetylanthracene	■				
109	CCL1 1	Acanthamoeba	■				
110	CCL3 24	Acephate	■				
111	CCL3 25	Acetaldehyde	■				
112	CCL3 26	Acetamide	■				
113		Acetaminophen			■		
114		acetaminophenin	■				
115		Acetic Acid or acetate ion	■				
116		Acetone	■				
117		Acetone semicarbozone	■				
118		Acid Blue 80	■				
119		Acid Blue 9	■				
120		Acid Blue 92	■				
121		Acid Chrome Blue K	■				
122		Acid chrome blue K	■				
123		Acid fuchsin	■				
124		Acid Green 16	■				
125		Acid Orange 7	■				
126		Acid Red 27	■				
127		Acid Red 4	■				
128		Acid Red 88	■				
129		Acid rosaniline	■				
130		Acid Yellow 36 (AY-36)	■				
131		Acridine Orange	■				
132		Acrinathrin	■				
133	EPA 31	Acrylamide	■				
134		Active Red X-3B	■				
135		Adenine	■				
136		Adeno Virus Type III 3					■
137	CCL2 1	Adenoviruses					■
138		Agrobacterium lumefaciens					■
139	EPA 32/NSF	Alachlor	■				
140		Alachor	■				

			Puralytics Active Purification Processes				
Puralytics	Listing	Contaminant	Photocatalytic	Photocatalytic	Photolysis	Photo	UV
141		aliphatic acids	■				
142		Alizarin	■				
143		Alizarin Red S Biological Stain	■				
144		Amaranth	■				
145		Aminophenol, 2, 3, or 4	■				
146		amleic hydrazide herbicide	■				
147		Ammonia	■				
148		Ammonia and Butyric Acid	■				
149		Amoxicillin			■		
150		Anatoxin-a	■				
151		Androstenedione			■		
152		anionic azo-dye	■				
153		Aromatic Alcohol	■				
154		Aromatic chlorinated compounds	■				
155	EPA 16/NSF	Arsenic		■		■	
156	NSF	As(III)	■				
157		Aspergillus amstelodami					■
158		Aspergillus flavus					■
159		Aspergillus glaucus					■
160		Aspergillus niger (breed mold)					■
161	EPA 33/NSF	Atrazine	■				
162		Auramine	■				
163		Azo Dyes	■				
164		Azobenzenes (various)	■				
165		Bacillus anthracis (anthrax veg.)					■
166		Bacillus anthracis Spores (anthrax spores)*					■
167		Bacillus megatherium Sp. (spores)					■
168		Bacillus megatherium Sp. (veg)					■
169		Bacillus paratyphosus					■
170		Bacillus subtilis					■
171	Bacteria	Bacillus subtilis spores					■
172		Bacteria	■				
173		Bacteria and fungi	■				
174		Fibroblasts/Fungi/Pollen	■				
175		Bacteriophage					■
176		Baker's Yeast					■
177		Benzaldehyde	■				
178	EPA 34/NSF	Benzene	■				
179	EPA 35	Benzo(a)pyrene (PAHs)	■				
180		Benzoic Acid	■				
181		Benzoquinone	■				
182		Benzyl phenylacetate	■				
183		bichlorobiphenyls	■				
184	EPA 70	biphenyls (PCBs)	■				
185		bis-(2-Dipyridyl)disulfide	■				
186		Bisphenol A	■				
187		Bisphenol A in the Montmorillonite KSF	■				
188		Blue s-3RF Wastewater	■				
189		Blue-green Algae					■
190		Brewer's Yeast					■
191		Brilliant	■				
192		Brilliant Green	■				
193		Bromacil	■				
194	EPA 8	Bromate	■				
195		Bromoxynil	■				
196	Bacteria	Burkholderia cenocepacia					■
197		But-1-ene	■				
198		But-2-ene	■				
199		Butanoic	■				
200		C.I. Acid Blue 9	■				
201	EPA 20/NSF	Cadmium		■			
202		Caffeic Acie	■				
203		Caffeine			■		
204	CCL3 1	Caliciviruses					■
205	CCL3 2	Campylobacter jejuni					■
206	Fungi	Candida albicans (yeast)					■
207		Carbamate pesticides	■				
208		Carbamazepine			■		
209		carbamazepine, clofibric acid, iomeprol and iopromide	■				
210		carbendazim fungicide	■				

			Puralytics Active Purification Processes				
Puralytics	**Listing**	**Contaminant**	**Photocatalytic**	**Photocatalytic**	**Photolysis**	**Photo**	**UV**
211	EPA 36/NSF	Carbofuran	■				
212		Carbon dioxide (reduction)		■			
213		Carbon monoxide	■				
214		Carbon tetrabromide	■				
215	EPA 37/NSF	Carbon tetrachloride	■				
216		Carbonate	■				
217		Cationic blue X-GRL	■				
218		Cerium		■		■	
219		Cetylpyridinium chloride or bromide	■				
220	EPA 12/NSF	Chloramines (as Cl2)			■		
221		Chloramphenicol - pharmaceutical	■				
222		Chlorate	■				
223	EPA 38/NSF	Chlordane	■				
224		Chlorella vulgaris (algae)					■
225		Chlorinated Aromatic	■				
226		Chlorinated Hydrocarbons	■				
227		Chlorinated Phenols and Pesticides	■				
228	EPA 39/NSF	Chlorobenzene	■				
229		Chloroform	■				
230		Chlorophenols	■				
231		Chlorsulfuron	■				
232		Chrome black T	■				
233	NSF	Chromium (hexavalent)		■			
234	EPA 21/NSF	Chromium (total)	■				
235	EPA 47/NSF	cis-1,2-Dichloroethylene	■				
236		Citric acid	■				
237		Clofibric acid			■		
238		Clostridium botulinum					■
239		Clostridium tetani					■
240	CCL3 40	Cobalt		■		■	
241		colloidal Q-CdS	■				
242		Common Yeast Cake					■
243		Congo Red	■				
244	EPA 22/NSF	Copper		■		■	
245		Corynebacterium diphtheriae					■
246		Coumarin	■				
247	Rickettsiae	Coxiella burnetti					■
248		Coxsackie					■
249	Virus	Coxsackievirus (A-9)					■
250	Virus	Coxsackievirus (B-1)					■
251		Cr(VI)		■			
252	EPA 1	Cryptosporidium	■				■
253		Cryptosporidium parvum	■				
254		Crystal violet	■				
255		Cyanide	■				
256	EPA 23	Cyanide (as free cyanide)	■				
257		Cyanide and Complexes	■				
258		Cyanuric acid	■				
259		cyclohexyl alcohols	■				
260		Cymoxanil	■				
261		Cytosine	■				
262	EPA 41	Dalapon	■				
263		DDT	■				
264		Decane	■				
265		DEET			■		
266	EPA 51	Di(2-ethylhexyl) adipate	■				
267	EPA 52	Di(2-ethylhexyl) phthalate	■				
268		Diazepam			■		
269		Dibenzo-p-dioxines, various	■				
270		Dibenzothiophene (DBT)	■				
271		Dicamba	■				
272		Dichloroacetic acid	■				
273		Dichloroacetyl Chloride	■				
274	EPA 49	Dichloromethane	■				
275		Dichromate	■	■		■	
276		Diclofenac			■		
277		Diclofenthion	■				
278		diclofop-methyl	■				
279		Dicofol and Pyrethrum	■				
280		Diethylamine	■				

			Puralytics Active Purification Processes				
Puralytics	**Listing**	**Contaminant**	**Photocatalytic**	**Photocatalytic**	**Photolysis**	**Photo**	**UV**
281		dihydroxybenzene	■				
282		Dilantin			■		
283	CCL3 45	Dimethoate	■				
284		Dimethyl Methylphosphonate	■				
285		Dimethyl-2,2-dichlorovinyl phosphate	■				
286		Dimethylaminoborane	■				
287		Dimethylarsinic acid	■				
288		Dimethylglyoxime	■				
289		Dimethylmethylphosphonate	■				
290		Dimethylsulfide	■				
291	EPA 53/NSF	Dinoseb	■				
292	EPA 54	Dioxin (2,3,7,8-TCDD)	■				
293		Diphenamid Herbicide	■				
294	EPA 55	Diquat	■				
295		Diquat and Paraquat	■				
296		Direct Red 23	■				
297		Direct scarlet 4BS	■				
298		Direct Yellow 12 dye	■				
299		disulfonated anionic surfactants	■				
300	CCL3 47	Diuron	■				
301		DMSO	■				
302		DNA and RNA	■				
303		Dodecane	■				
304		Dodecyl sulfate, sodium salt	■				
305		Dodecylbenzenesulfonate, sodium salt	■				
306		Dodecyldecaoxyethylenephosphates	■				
307		Dyes	■				
308		Dysentery bacilli					■
309		E. hystolytica					■
310		Eberthella typhosa					■
311	CCL2 6	Echoviruses					■
312		EDTA	■				
313	EPA 56	Endothall	■				
314	EPA 57/NSF	Endrin	■				
315	Bacteria	Enterobacter cloacae					■
316	EPA 58	Epichlorohydrin	■				
317	CCL2 35	EPTC (s-ethyl-dipropylthiocarbamate)			■		
318		Erythromycin-H2O			■		
319	CCL3 4	Escherichia coli (0157)					■
320		Estradiol	■		■		
321		Estriol			■		
322		Estrogenic chemicals			■		
323		Estrone			■		
324		Ethanol	■				
325		Ethanol amine	■				
326		Ethinyl estradiol			■		
327		Ethmylestradiol			■		
328		Ethyl amine	■				
329		Ethyl bromophos	■				
330		Ethyl parathion	■				
331	EPA 59/NSF	Ethylbenzene	■				
332		Ethylene	■				
333	EPA 60/NSF	Ethylene dibromide	■				
334		Ethylenediaminetetraacetic acid and metal complexes	■				
335		Explosives	■				
336	CCL3 53	Fenamiphos	■				
337		Fenitrothion	■				
338		Ferrate (VI)	■				
339		Flavobacterium	■				
340		Fluoxetine			■		
341		Flutriafol	■				
342	CCL3 54	Formaldehyde	■				
343		Formamide	■				
344		Formic Acid	■				
345		Formic acid or formate ion	■				
346		Furfural	■				
347		Furfuryl alcohol	■				
348		Galaxolide			■		
349		Gasoline	■				
350		Gemfibrozil			■		

			Puralytics Active Purification Processes				
Puralytics	**Listing**	**Contaminant**	**Photocatalytic**	**Photocatalytic**	**Photolysis**	**Photo**	**UV**
351		Geosmin	■				
352	EPA 2	Giardia lamblia	■				■
353		Glucose	■				
354		Glycerol	■				
355		Glycerol trioleate	■				
356		Glycolic acid	■				
357	EPA 61	Glyphosate	■				
358		Gold				■	
359		Guanine	■				
360		H2S	■				
361		Halide ion	■				
362	EPA 10	Haloacetic acids (HAA5)	■				
363	EPA 62/NSF	Heptachlor	■				
364	EPA 63/NSF	Heptachlor epoxide	■				
365		Herbicide	■				
366	EPA 3	Heterotrophic plate count	■				■
367	EPA 64	Hexachlorobenzene	■				
368	EPA 65/NSF	Hexachlorocyclopentadiene	■				
369		Hexaconazole and Dimethomorph	■				
370		Hexavalent Chromium and Di-N-Butyl Phthalate	■				
371		Humic Acids	■				
372		Humic Substances	■				
373	CCL3 58	Hydrazine	■				
374		Hydrocodone			■		
375		Hydrogen Phthalate	■				
376		Ibuprofen			■		
377		Imidacloprid	■				
378		Imidacloprid	■				
379		Imipramine	■				
380		Indanthrene BR Violet Dye	■				
381		indole	■				
382		Infectious Hepatitis					■
383		Influenza					■
384		Iopromide			■		
385		Isoprene	■				
386		Isoproturon	■				
387		Ketoprofen			■		
388		Lactobacillus acidophilus	■				
389		L-Alanine	■				
390		L-Ascorbic acid	■				
391		Laurylsulfate, sodium salt	■				
392	EPA 25/NSF	Lead		■		■	
393		Lead dioxide		■		■	
394		Leather Dye	■				
395	EPA 4	Legionella	■				■
396		Legionella bozemanii					■
397		Legionella dumoffill					■
398		Legionella gormanil					■
399		Legionella longbeachae					■
400		Legionella micdadei					■
401	CCL3 7	Legionella pneumophila	■				■
402		Leptospira canicola-Infectious Jaundice					■
403		Leptospira interrogans					■
404		Levulinic acid	■				
405		Lignin	■				
406		Lincomycin			■		
407	EPA 66/NSF	Lindane	■				
408		Lopromide			■		
409		L-Phenylalanine	■				
410		L-Serine	■				
411		Lufenuron	■				
412		Malachite Green Dye	■				
413		malathion, isomalathion, malaoxon	■				
414		Maleic anhydride	■				
415		Malic acid	■				
416	CCL1 43/NSF	Manganese		■			
417		Manganese Oxide		■		■	
418		Mecoprop	■				
419		Mefanamic acid			■		
420		Meprobamate			■		

			Puralytics Active Purification Processes				
Puralytics	Listing	Contaminant	Photocatalytic	Photocatalytic	Photolysis	Photo	UV
421	EPA 26/NSF	Mercury (inorganic)		■		■	
422		Meso-Tetraphenylporphyrin	■				
423		Metalaxyl	■				
424	CCL3 59	Methamidophos	■				
425		Methane	■				
426	CCL3 60	Methanol	■				
427		Methomyl	■				
428	EPA 67/NSF	Methoxychlor	■				
429		Methyl bromophos	■				
430		Methyl oleate	■				
431		Methyl Orange	■				
432		Methyl parathion	■				
433		Methyl perfluoro-2-propyl ether	■				
434		Methyl perfluoroethyl ether	■				
435		Methyl Red Dye	■				
436		Methyl stearate	■				
437	CCL3 62/NSF	Methyl tert-butyl ether	■				
438		Methyl violet	■				
439		Methyl viologen	■				
440		Methylene Blue	■				
441	CCL3 63	Metolachlor			■		
442		Micrococcus candidus					■
443		Micrococcus sphaeroides					■
444		Microcystin-LR or YR or YA	■				
445		m-Nitrocynnamic acid	■				
446		Monochloroacetic Acid	■				
447		Monocrotophos	■				
448		Mucor mucedo					■
449		Mucor racemosus (A & B)					■
450		Murine Norovirus	■				
451		Musk Ketone			■		
452	Bacteria	Mycobacterium parafortuitum					■
453		Mycobacterium tuberculosis					■
454		Myocytin toxins	■				
455		N,N-diethyl-m-toluamide (DEET)	■				
456	CCL1 49	Naphthalene	■				
457		Naphthol blue black	■				
458		Naproxen			■		
459		Napthol ASBS dye	■				
460		Natural Organic Matter	■				
461		Neisseria catarrhalis					■
462		Nematode Eggs					■
463		Nickel	■				
464	EPA 27/NSF	Nitrate (measured as Nitrogen)		■			
465		Nitrates/nitrites	■				
466	EPA 28/NSF	Nitrite (measured as Nitrogen)	■				
467	CCL3 68	Nitrobenzene	■				
468		Nitrocelluose	■				
469		Nitrogen oxides	■				
470		Nitrotoluene, various	■				
471		N-Methylpyrrolidinone	■				
472		non-steroidal anti-inflammatory drugs	■				
473		NPE-10 surfactant	■				
474		o-Chloroaniline	■				
475		o-Chlorobiphenyl	■				
476		o-Cresol	■				
477		Octadecane	■				
478		Octadecanoic acid	■				
479		Octan-1-ol	■				
480	EPA 43/NSF	o-Dichlorobenzene	■				
481		Ofloxacin			■		
482		Oil/Petroleum	■				
483		Oleic acid	■				
484		Oospora lactis					■
485		Orange G	■				
486		Orange I, II, III, or IV	■				
487		Organic Dyes	■				
488		organochlorine pesticide and dyes	■				
489		oryzalin pesticide	■				
490		Oxalic acid or oxalate ion	■				

			Puralytics Active Purification Processes				
Puralytics	Listing	Contaminant	Photocatalytic	Photocatalytic	Photolysis	Photo	UV
491	EPA 68	Oxamyl (Vydate)	■				
492		o-xylene	■				
493		Palladium	■				
494		Palmitic (hexadecanoic) acid	■				
495		Paracetamol	■				
496		Paraffin, liquid	■				
497		Paramecium					■
498		Paraoxone	■				
499		Paraquat	■				
500		Parathion	■				
501		Paroxetine			■		
502		p-chlorobenzoic acid	■				
503	EPA 44/NSF	p-Dichlorobenzene	■				
504		Penicillium chrysogenum					■
505		Penicillium digitatum					■
506		Penicillium expansum					■
507		Penicillium roqueforti					■
508	EPA 71/NSF	Pentachlorophenol	■				
509		Pentoxifylline			■		
510	CCL3 82/NSF	Perchlorate		■			
511		Permanganate		■		■	
512		Pesticides - unspecified	■				
513		pharmaceuticals and cosmetics	■				
514		phenanthrene	■				
515	NSF	Phenol	■				
516		Phenol-4-sulfonic Acid	■				
517		Phenolics	■				
518		Phenylarsonic acid	■				
519		Phenyltrifluoromethyl ketone	■				
520		Phenylurea Herbicides	■				
521		Phenytrifluoromethylketone	■				
522		Phorate	■				
523		Phthalic acid	■				
524		Phthalocyanine	■				
525		p-hydroxybenzoic acid	■				
526		Phytomonas tumefaciens					■
527	EPA 72	Picloram	■				
528		Pirimicarb	■				
529		Pirimiphos-methyl	■				
530		plasmid DNA	■				
531		Platinum				■	
532		p-nitropheno	■				
533		PNP	■				
534		Poliovirus 1	■				
535		Poly Vinyl Butyral	■				
536		Polyacrylamide	■				
537		Polycarboxylic Benzoic Acid	■				
538	EPA 69/NSF	Polychlorinated biphenyls (PCBs)	■				
539		Polychlorinated Dibenzo-p-dioxins	■				
540		dibenzofurans	■				
541		polycyclic aromatic hydrocarbons	■				
542		Polyethoxylene alkyl ethers	■				
543		Polyvinylchloride (PVC)	■				
544		Polyvinylpyrrolidone	■				
545		Power station effluent	■				
546		Progesterone			■		
547		Prometryn	■				
548		Propane	■				
549		Propanil	■				
550		Propene and Benzene	■				
551		Propionamide	■				
552		Propoxur	■				
553		Propranolol			■		
554		Propylene sulfide	■				
555		Propyne	■				
556		Proteus vulgaris					■
557	Bacteria	Pseudomonas aeruginosa					■
558		Pseudomonas aeruginosa (Lab. Strain)					■
559		Pseudomonas fluorescens					■
560	Bacteria	Pseudomonas maltophilia					■

			Puralytics Active Purification Processes				
Puralytics	Listing	Contaminant	Photocatalytic	Photocatalytic	Photolysis	Photo	UV
561		Pyrene	■				
562		Pyridine	■				
563		Pyrimethanil	■				
564		Pyrimethanil	■				
565		Pyrrole-2-carboxylic acid	■				
566		Pyrrolidone	■				
567		Ranitidine			■		
568		Reactive black 5	■				
569		Reactive black SRE	■				
570		Reactive Blue 19	■				
571		Reactive Blue 221	■				
572		Reactive Blue 222	■				
573		Reactive blue 4	■				
574		Reactive Orange 4	■				
575		Reactive Red 120	■				
576		Reactive Red 22	■				
577		Reactive Yellow 14 azo dye	■				
578		recalcitrant organic contaminants	■				
579		Remazol Black B Dye	■				
580		Remazol Brilliant Blue R	■				
581		Remazol Turquoise Blue G 133	■				
582	Virus	Reovirus Type 1					■
583		Resorcinol	■				
584		Rhizopus nigricans (cheese mold)					■
585		Rhodamine B	■				
586		Rhodospirillum rubrum					■
587		RO Effluent	■				
588		Rose Bengal	■				
589		Rotavirus					■
590		Saccharin	■				
591		Saccharomyces cerevisiae	■				■
592		Saccharomyces ellipsoideus					■
593		Saccharomyces sp.					■
594		Salicylic Acid	■				
595		Salmonella					■
596		Salmonella enteritidis					■
597		Salmonella paratyphi (Enteric Fever)					■
598		Salmonella Species					■
599		Salmonella typhi (Typhoid Fever)					■
600		Salmonella typhimurium					■
601		Sarcina lutea					■
602		Scacchoromyces cerevisisas	■				
603	EPA 29/NSF	Selenium				■	
604		selenium(VI)		■			
605	Bacteria	Serratia marcescens					■
606		Shigella dysenteriae - Dysentery					■
607		Shigella flexneri - Dysentery					■
608		Shigella paradysenteriae					■
609	CCL3 10	Shigella sonnei					■
610		Silver		■		■	
611	EPA 73/NSF	Simazine	■				
612		Sirius yellow	■				
613		Sodium anthracene-1-sufonate	■				
614		Sodium dodecylbenzene sulfonate	■				
615		Soluble dye 4BS	■				
616		Spirillum rubrum					■
617		Squalene	■				
618		Staphylococcus albus					■
619	Bacteria	Staphylococcus aureus	■				■
620	Bacteria	Staphylococcus epidermis					■
621		Stearic acid	■				
622		Streptococcus cricetus	■				
623	Bacteria	Streptococcus faecalis	■				■
624		Streptococcus hemolyticus					■
625		Streptococcus lactis					■
626		Streptococcus mutans	■				
627		Streptococcus natuss	■				
628		Streptococcus pyrogenes					■
629		Streptococcus sobrinus	■				■
630		Streptococcus viridans					■

			Puralytics Active Purification Processes				
Puralytics	**Listing**	**Contaminant**	**Photocatalytic**	**Photocatalytic**	**Photolysis**	**Photo**	**UV**
631	EPA 74/NSF	Styrene	■		■		
632		Sulfachloropyridazine			■		
633		Sulfadimethoxine			■		
634		Sulfamerazine			■		
635		Sulfamethizole			■		
636		Sulfamethoxazole	■		■		
637	CCL1 56/NSF	Sulfate			■		
638		Sulfathiazole			■		
639		Sulfisoxazole			■		
640		Sulfite	■				
641		Sulfomethazine			■		
642		Sulforhodamine B	■				
643		Sulforhodamine B Dye	■				
644		Sulfosalicylic acid	■				
645		Sulfur oxides	■				
646		Surfactants - unspecified	■				
647		TCEP			■		
648		t-Cinnamic acid	■				
649	CCL3 93	Terbufos	■				
650		Testosterone			■		
651		Tetrachlorocarbon	■				
652	EPA 75/NSF	Tetrachloroethylene	■				
653		Tetracycline	■				
654	EPA 30	Thallium		■			
655		Thifensulfuron Me	■				
656		Thiocyanate	■				
657		Thiophene	■				
658		Thiosulfate	■				
659		Thymine	■				
660		TNT	■				
661	EPA 76/NSF	Toluene	■				
662		Tordon	■				
663	EPA 5	Total Coliforms (including fecal coliform and E. Coli)	■				■
664		Total Organic Carbon (TOC)	■				
665	EPA 11	Total Trihalomethanes (TTHMs)	■				
666	EPA 77/NSF	Toxaphene	■				
667	EPA 48/NSF	Trans-1,2-Dichloroethylene	■				
668		Dihydrocaffeic Acids	■				
669		Triadimefon	■				
670		Trichloroacetic acid	■				
671	EPA 82/NSF	Trichloroethylene	■				
672		Trichloromethane	■				
673		Triclosan			■		
674		Triethanolamine	■				
675		Trifluoroacetic acid	■				
676		Trifluoroacetyl chloride	■				
677		Trimethorprim			■		
678		Trimethylamine	■				
679		Trimethylene sulfide	■				
680		Triphenylmethane dye (gentian violet)	■				
681	EPA 6/NSF	Turbidity	■			■	
682		Uracil	■				
683	EPA 88	Uranium	■				
684		Urine	■				
685	CCL3 11	Vibrio cholerae					■
686		Vibrio comma (Cholera)					■
687	EPA 83	Vinyl chloride	■				
688		Viruses	■				
689	EPA 7	Viruses (enteric)	■				■
690	NSF	Volatile Organic Chemicals (VOCs)	■				■
691	EPA 84/NSF	Xylenes (total)	■				
692	NSF	Zinc	■				