Towards tradable permits for filamentous green algae pollution

W.J. de Lange[a]*, A.M. Botha[b] and P.J. Oberholster[a]

a. Council of Scientific and Industrial Research, Stellenbosch, South Africa

b. Genetics Department, Agri-Sciences Faculty, Stellenbosch University, Stellenbosch

* wdelange@csir.co.za

Abstract

Water pollution permit systems are challenging to design and implement. Operational systems that has maintained functionality remains few and far between, particularly in developing countries. We present current progress towards developing such a system for nutrient enrichment based water pollution, mainly from commercial agriculture. We applied a production function approach to first estimate the monetary value of the impact of the pollution, which is then used as reference point for establishing a reserve price for pollution permits. The subsequent market making process is explained according to five steps including permit design, terms, conditions and transactional protocol, the monitoring system, piloting and implementation. The monetary value of the impact of pollution was estimated between R1887 and R2890 per hectare per year, which not only provide a "management budget" for filamentous green algae mitigation strategies in the study area, but also enabled the calculation of a reserve price for filamentous green algae pollution permits, which was estimated between R2.25 and R111 per gram algae and R8.99 per gram at the preferred state.

Key words: pollution permits, water quality, filamentous green algae, agriculture

1 Introduction

In a free market economy, private (firm and individual) production and consumption decisions are based on trade-offs between willingness to pay and accept of private costs and benefits, which are reflected in market prices. According to neoclassical economics, the 'invisible hand' of the market is assumed to ensure that these private decisions will lead to socially optimal outcomes, such as optimal levels of production and pollution (Goodstein, 2008). However, people tend to give more prominence to private costs and benefits, resulting in choices that are not always socially optimal, and when the costs of producing a product or the benefits from consuming a product spill over to people who are not involved in the consumption or production of the good, an externality occurs. Such external impacts are thus unaccounted for costs (such as pollution) and benefits (such as education) of which the effect the market fails to accommodate in the market price, i.e. the market "fails". Consequently, market prices often fail to adequately reflect the full *social* costs and benefits associated with these goods or services, owing to the existence of externalities. Subsequently, the levels of production and pollution will not be socially optimal because the trade-offs are not accurately reflected. With negative externalities specifically, social costs exceed private costs, such that too much of the activity will be undertaken relative to the socially optimal amount. Pollution is an example of a negative externality (an external cost of production or consumption) where market prices provides incentives for too much environmentally damaging behaviour. 'Iinternalising' such externalities therefore become necessary to re-adjust prices in such a way that the negative impacts of pollution will be taken into account by the polluters. However, such re-adjustment requires an estimate of the monetary value of the impacts of pollution. Such valuations not only enables this internalisation process, but can also be used to compare different pollution mitigation strategies within a particular area and to a lesser extent, similar areas. Such valuations can also enable the use of more advance policy instruments such as tradable pollution permits. These permits is a form of market-based governance which seeks to change behaviour by changing price signals to which rational and economically driven actors are expected to respond in their own self-interest. In this way, markets may harness the decentralised power of individual decision-makers to achieve policy objectives set by government who also design the terms, conditions and transactional protocol for the market and regulate its subsequent operation.

South African policymakers have a much bigger variety of environmental protection tools at their disposal than they did 20 years ago; when so-called command and control mechanisms to regulate unwanted behaviour was the preferred approach. Although this approach was effective in some areas, it proved to be costly and difficult to enforce for water pollution because of the high level of monitoring required by methods based on this approach. However, market-based mechanisms have put forward potential alternatives to command and control mechanisms. These mechanisms could take the form of subsidised reforms, taxes to account for social costs, or the establishment of markets in which pollution permits (i.e. the right to pollute a certain amount per time period) can be traded. The latter is of particular interest for this study as it not only aims to limit pollution at an optimal cost to the polluter, it also create an incentive for companies to reduce pollution further (relative to their entitlement), since it becomes possible to sell the difference to willing buyers (i.e. a firm who cannot meet their pollution targets) for a profit. Although such trading happens within a predetermined pollution standard it can lower the cost of compliance while realising pollution prevention benefits. Market-based systems thus capitalize on the power of the marketplace to reduce pollution cost-effectively and use economic incentives to promote conservation (David, 2003). It does however require an innovative market making process to design the necessary terms and conditions that will allow fair trade.

This paper presents the results of a monetary estimate of the impact of nutrient enrichment (filamentous green algae) impacts on commercial agriculture in the Dwars River, Western Cape (De Lange, 2014) and the Loskop irrigation area, Groblersdal (De Lange, 2015) in South Africa where the algae often deplete sections of rivers from oxygen leading to eutrophic conditions, fish kills and an increase the operation and maintenance cost of irrigated agriculture.

We present the study areas, discuss the methodological approach, the surveyed pollution impacts and present the calculated monetary value of the impacts of such pollution. The market making process is then discussed along with a first attempt at the initial price setting and description of terms, conditions and transactional protocol for such a system in South Africa. The paper concludes with a short interpretation of the results and discusses the potential applications of the results.

2 Approach for valuation pollution impacts

We applied a production function approach (Birol et al., 2006, Brouwer and Pearce, 2005, Glazyrina et al., 2006, Pearce, 1994, Pearce, 1993), to estimate the monetary value of the impact of filamentous algae on commercial agriculture. The main emphasis was on the impacts of algae growth on farm profitability which relied on detailed information on the impact(s) and the extent of the impact(s) of algae on farming practice. The input data for the calculations were obtained from interviews with prominent farmers in the study areas and the operations and general managers of both water user associations. The basic valuation procedure followed these steps:

1. Representative crop selection and construction of a typical farm profile for each representative crop.
2. Description and quantification of the impacts of algae on the cultivation practice of representative crops.
3. Valuation of the impact of algae.
4. Aggregation and extrapolation to the level of the water user association.

Representative crops were selected in terms of hectares under irrigation in each study area. We have interviewed some of the prominent farmers of the representative crops and asked them to explain the impacts of algae on their business focusing specifically on the impacts of algae on the cultivation practice. It is assumed that algae are always present in the water and that a difference in concentration levels is considered the distinguishing factor determining the mitigation strategy and hence cost implications and consequent profitability impacts. Therefore, farmers were asked to try and distinguish between a "heavy" and a "normal" algae load scenario.

The cost implications of the impacts of filamentous green algae was determined by systematically accounting for the cost variables involved in mitigating (i.e. managing) the impacts of algae. This process was done in close collaboration with farmers because mitigation strategies for algae differ between farms. Steps in their algae mitigation process while noting the cost implications. The cost was systematically captured in a spreadsheet in order to calculate the total direct cost of the on-farm pollution mitigation process.

We structured the cost impacts according to the crop enterprise budget (cost structure for standard cultivation practice) for each representative crop. Industry data for the Loskop area was obtained from Grain SA[1], the Citrus Grower Association[2] and Nulandis[3], while data for the Dwars rivier area

[1] GrainSA was established in 1999 and was formed out of the NAMPO (maize), NOPO (soybeans, sunflower and groundnuts), the WPO (wheat, barley and oats) and the SPO (grainsorghum) in order to gain a critical weight in order to represent these various grain producers.

[2] The Citrus Growers Association was established in the wake of deregulation in 1997 and demise of the single channel marketing system. Growers were concerned that certain functions previously carried out by the Citrus Board could be discontinued or downsized which pointed towards the need for an organization representing citrus grower to citrus industry stakeholders such as government, exporters, research institutions and suppliers to the citrus industry.

[3] Nulandis is a retail services group resulted from a merger between Plaaskem, UAP and Qwemic. The company specialise in chemical crop protection.

was obtained from Hortgro[4], SAWIS[5], VINPRO[6], Nulandis[7] and KaapAgri[8]. Study areas and representative crops

The Dwars River is a major tributary of the Berg River. It is an area with high rainfall on the peaks (>3 000 mm/yr) but with very steep rainfall gradients. Although the area is about 10% of the surface area of the relevant quaternary catchment, it yields 24% (approximately 23 million m^3/yr) of mean annual runoff of quaternary catchment. The average rainfall is 877 mm/yr.

Commercial agriculture in the Dwars River focuses (in terms of hectares) on deciduous fruit and viticulture. Plums were taken as representative deciduous fruit crop since it represents 70% (307 hectares) of the area under deciduous fruit, there is also approximately 355 hectares of irrigated wine grapes in the study area.

The Loskop irrigation area forms part of the Olifants WMA of South Africa. It is a completely different system as compared to the Dwars River. The bulk supply infrastructure servicing the irrigation scheme consists of the Loskop dam, seven balancing dams, 135km of concrete lined main canal and 345km of service canals (Pretorius, 2015). The scheme serves 25 410 hectares under irrigation from 16 136 enlisted hectares. The water is managed via a demand based approach and is supplied via 660 calibrated and registered takeoffs delivering 197890 cubes per takeoff per year. This represents an allocation of approximately 7 700 cubes/ha/yr which is charged at R3500/ha/yr. Demand scheduling is operated via eight wards and water users need to request their water from ward managers a week in advance. The scheme is currently fully allocated, with deficit irrigation fast becoming the norm.

Commercial agriculture in the Loskop area focuses (in terms of hectares) on citrus, table grapes, maize, wheat, tobacco, vegetables and cotton. Citrus was taken as the representative perennial crop since it presents 86% (5879 hectares) of the perennial crops in the area while maize and wheat were taken as the representative summer and winter cash crops since it presents 58% (10939 hectares) of all cash crops in the area.

3 Surveyed pollution impacts

Filamentous green algae thrive under eutrophic conditions due to nutrient enrichment from raw or partially treated sewage, agricultural effluent and other forms of phosphorous rich pollutionants

[4] HORTGRO, is communication platform for a number of horticultural sectors to promote unity with focus on markets (demand), production (supply) and a range of cross-cutting industry functions, such as land reform, training and communication.

[5] SA Wine Industry Information & Systems NPC (SAWIS) is a company not for gain, under control and direction of the South African Wine industry. SAWIS aims to collection, process and disseminate industry information and manage the industry's *Wine of Origin* system.

[6] VinPro is the service organisation for South African wine producer and cellar members and act as mouthpiece and representative at all relevant forums and in dealings with Government.

[7] NULANDIS® is the merger company between Plaaskem, UAP and Qwemico, and is currently the leading company in innovative product development and crop protection.

[8] KaapAgri is a retail services group that supplies a variety of products and services mainly to the agricultural sector.

(Oberholster et al 2011, Oberholster et al, 2013). Although algae pose no direct threat to crops, it affects the operational efficiency of irrigation systems and therefore affects the operation and maintenance costs of irrigation infrastructure. It should be noted that although pollution loads could vary during the year, the impacts affect farmers during the irrigation season which starts in the third week of October until the second week of March for the Dwars River.

The Loskop area irrigates thruought the year where observed impacts started with high (benthic chlorophyll 30-121 mg/m^2) filamentous green algae loads decreasing the volume and flow tempo of the main canal to such an extent that the canal cannot serve the weekly demand. Filamentous green algae is chemically controlled by dosage with Copper sulphate. The algae mat formation do not occur uniformly throughout the canal and ward managers therefore need to monitor their respective canal section (typically 5 to 8 km) on a regular basis and dose the canal as and when needed. Each dosage affects approximately 5-6km of canal and it is rarely the case that the whole canal is dosed at the same time. Copper sulphate dosage is however a sensitive issue since it is absorbed by plants and could have health effects on humans and ecosystems, dosage levels are therefore important. There is no bulk supply infrastructure in the Dwars River (farmers draw water directly from the river). Most farmers were aware of the direct relationship between bio-available phosphate and algae and were of the opinion that algae affects farm profitability directly via increased irrigation costs. Algae not only obstructs and clogs strainers, intake valves and manifolds, but also places a higher load on impellers and bearings of pressure pumps, while decreasing the delivery rates leading to a decrease in the volume per pump-hour. Micro-jets and dripper lines are also clogged leading to uneven and thus suboptimal moisture application in orchards which could affect crop yield if not mitigated. More frequent cleaning of foot valves, intake manifolds, filter-banks, and the nozzles of micro-jets, centre pivots and drippers are therefore required. It also implies, more frequent dosage of on-farm balancing dams with Copper sulphate and hydrogen peroxide in centre pivot systems in the Loskop area. Some farmers argued that hydrogen peroxide decreases the service life of all plastic components (becomes brittle). Farmers were acutely aware of that their profitability is affected, but could not provide exact figures.

4 The cost of eutrophication

The standard practice to manage the impacts of filamentous green algae is more frequent cleaning of irrigation systems, which provided the basis for a cost estimate on the impact of algae. However, any irrigation system requires a minimal amount of cleaning and flushing prior to, and during the irrigation season, hence the need to differentiate between costs related to standard practice and costs related to high algae loads. It was consequently decided to distinguish between a “high” and “low” algae load scenario in order to differentiate the cost.

Farmers were asked to systematically describe the steps taken in their standard protocol of dealing with algae within a typical pump station on their farm. This allowed a differentiation between a “high” and “low” load scenario and for some cost differentiation. However, as farmers neither quantify nor keep a record of the volumes of filamentous green algae removed, the exact definition of “high” remains subjective. The following input variables were used:

- The irrigation season lasts 20 weeks (i.e. 120 days).
- Farm labour cost is R15 per hour.
- A typical pump station serving 10 hectares consists of a strainer, foot valve, 3.3 kilowatt pump, sand filter and a disc filter.
- Electricity cost is R1.20 per kilowatt hour.

Table 4 and Table 5 present additional input variables.

Table 1: Operating and maintenance activities

Activity	Low load scenario	High load scenario
Servicing of pumps	Every third year	Every second year
Replace filter sand	Every third year	Annually
Clean strainers, disc filters and sand filters	Once a week	Daily
Required man-days per week to clean micro jets and drippers (during irrigation season)	1	7

Table 2: Labour input (minutes) and energy (kilowatt) required for activities

Activity	Time required
Clean strainer and foot valve	15 minutes
Clean disc filter	10 minutes
Backwash sand filter	10 minutes and 0.55 kilowatt
Transport	20 minutes

The service cost of a pump averaged out on R9000, which implies that the annual service cost for a pump under low load conditions is approximately R3000 per year, and R4500 per year under high load conditions, i.e. a R1500 per year difference. Filter sand costs R1875 per filter, which implies an annual cost of R625 for low and R1875 for high load conditions, i.e. R1250 per year difference. Table 3 represents the labour cost per activity.

Table 3: Cost per activity

Activity	Low load conditions		High load conditions		Difference
	Total time during irrigation season	Rand value	Total time during irrigation season	Rand value	
Labour for cleaning strainer and foot valve	300 minutes	R 75.00	2100 minutes	R 525.00	R 450.00
Labour for cleaning disc filter	200 minutes	R 50.00	1400 minutes	R 350.00	R 300.00
Labour for backwashing	200 minutes	R 50.00	1400 minutes	R 350.00	R 300.00
Transport time	400 minutes	R 100.00	2800 minutes	R 700.00	R 600.00
Electricity for backwashing	11 kilowatt	R 13.20	77 kilowatt	R 92.40	R 79.20
Servicing of		R3000.00		R4500.00	R1500.00

pumps					
Filter sand		R625.00		R1875.00	R1250.00
Sub-total: Additional cost due to eutrophication per pump-year					R4479.20
Additional cost due to eutrophication per hectare per year (A)					R447.92
Labour for cleaning micro-jets per hectare (B)	960 minutes	R240.00	6780 minutes	R1680.00	R1440.00
Total additional cost due to eutrophication per hectare per year (A + B)					R1887.92

Given an estimated 307 hectares of deciduous fruit in the study area, and assuming that all farmers struggle with algae, we could infer that the above-mentioned R1887 per hectare per year (see Table 3) translates to R579 591 per year for deciduous fruit in the study area. Given that the pre-harvest production cost for plums is R61 880 per hectare (Deciduous Fruit Producers Trust, 2013), the cost of algae pollution represents approximately 3.1% of pre-harvest costs.

Although vines employ drip irrigation while deciduous fruit uses micro jets, the labour component for cleaning these two types of irrigation systems are essentially the same. Consequently, the mitigation strategy and cost per hectare for managing algae is comparable. Given an estimated 355 hectares under vines in the study area, the cost of algae for the wine grapes is estimated at R670 400 per year (assuming comparability in terms of the algae problem across farmers). Pre-harvest production cost for wine grapes is R35 739 per hectare (Van Niekerk, 2013), which implies that the algae problem represents 5.2% of the pre-harvest cost. It could thus be argued that the algae problem costs the vine and deciduous fruit industry approximately R1.2m per year in the Dwars River.

The same approach was followed for the Loskop area. Table 4 summarises the stated differences between a "low" and "high" load scenario as stated by the respondents. Once again the exact quantity of algae removed was unknown.

Table 4: Operating and maintenance activities

Activity	Low load scenario	High load scenario
Servicing of pumps	Every third year	Every second year
Replace filter sand	Every third year	Annually
Clean strainers, foot valves, disc filters and sand filters by hand	Once a week	Three times a week
Cleaning of sluice gates	Once a week	Every day
Cleaning of balancing dams	Every 5th year	Every 3rd year
Required man-days per week to clean micro jets and drippers during irrigation season	1	7

The following input variables were identified and consequently used in the calculations:

- R1600 per 25kg bag Copper sulphate;
- R30 per litre for a 30% hydrogen peroxide solution;

- The capital outlay for an automated peroxide dosage system capable of dosing 10litres of hydrogen peroxide per week is R76000;
- Farm labour at R150 per 8 hour work day;
- A typical pump station serving 22 hectares consists of a strainer, foot valve, 24 kilowatt pump, Conn 80 sand filter and two disc filters;
- Electricity costs R1.20 per kilowatt hour; and
- Nine auto-flush cycles per day of 30 seconds each.

Table 5 summarises the additional labour input required to complete the required maintenance on a typical irrigation pump station as presented in Table 4.

Table 5: Labour input (minutes) required for activities

Activity	Time required
Clean strainer and foot valve	30 minutes
Cleaning of sluice gate	3 minutes
Clean disc filter	30 minutes
Backwash sand filter	10 minutes
Transport	20 minutes

An average of 8kg Copper sulphate is dosed per hectare per year representing a cost of R523 per hectare per year. The capital outlay for an automated hydrogen peroxide dosage station worked out on R304 per hectare per year (assuming a 20 year repayment period at a 5% interest rate). Hydrogen peroxide itself added R390 per hectare per year. Additional irrigation system upgrades (i.e. increased nozzle sizing, larger diameter sub mains) to accommodate higher algae loads added R183 per hectare per year. The additional labour cost component to check and clean faulty drippers and blocked nozzles under a high load scenario was estimated on R890 per hectare per year. Additional electricity cost for flushing filters was R97.06 per hectare per year. Additional labour for cleaning filters of pump stations was estimated on R107 per hectare per year, sluice gates R1.98 per hectare per year and footvalves R10.95 per hectare per year. Replacement cost of faulty dripper and micro-jets was R41.18 per hectare per year. Additional labour for cleaning balancing dams was R41.18. The direct dosage cost for the Loskop irrigation board (excluding the labour component) was R5.43 per hectare per year. Table 6 summarises the additional input costs required for high algae loads.

Table 6: Summary of additional input cost due to high algae loads

	R/ha/yr
Copper sulphate	R523
Puricore system	R304
Hydrogen peroxide	R390
Additional system upgrades	R183
Additional labour for checking submains and nozzles.	R890
Additional electricity	R97
Additional labour for cleaning filters, sluice gates and footvalves	R107; R1.98 and R10.95
Additional labour for cleaning balancing dams	R41.18
Drippers and microjets	R10.56 and R261.87

Irrigation board dosage cost	R5.43
Repairs to irrigation board infrastructure	R22.72
Monitoring and sample analysis	R37.96
Total	R2890

The estimated total direct costs of algae are estimated at R2890 per hectare per year. Assuming that 16818 hectares (or 66% of the total area being served by the scheme) is cultivated under the selected representative crops for this area, it represents a total annual cost of R48.6m. If it is assumed that the representative crops accurately reflect the mitigation practice for all other irrigated crops in the area, the figure increases to R73.4m per year. If it is assumed that the costs of algae will be recovered from the enlisted hectares only (i.e. 16136), the value is approximately R46.2m. Table 7 presents the cost of filamentous green algae as percentage of the total production cost of the three representative crops chosen for this study.

Table 7: Cost of algae as percentage of total production cost for representative crops (Loskop area)

Crop	Production cost (R/ha/yr)	Cost of algae as percentage of production cost
Citrus (full bearing)	R44058	7%
Maize	R28003	10%
Wheat	R24572	12%

The costs could also be presented in terms of the volume of water supplied by the Loskop irrigation board. Given that the scheme serves an estimated 130 607 400 cubes per year and that almost all irrigation water originates from the scheme, it could be argued that the cost of algae is approximately R0.56 per cubic meter water supplied. Given 660 take-offs and 530 farmers, the cost is estimated at R111k per take-off and R138k per farmer per year. It is interesting to note that the dosage cost represents 44% of the total cost of algae (i.e. R1285 per hectare per year) and that only 1% (R26.51 of the R2850 per hectare per year) is carried by the irrigation board.

5 A market-based approach to manage pollution

The information generated thus far not only creates an overarching "management budget" for filamentous green algae in the study areas, (i.e. any overarching algae management strategy will be considered worthwhile from a financial perspective if the cost to mitigate the algae impacts are less than R1.3m per year in the Dwars River or less than R46.2m per year for the Loskop scheme), but also generates valuable information for the market making process for tradable water pollution permits. We consequently present some of the intricacies of the market making process for this kind of permit by discussing the theoretical foundations of the concept, presents a methodological approach for designing such a system including some of the major components of the process. The focus continues to be on filamentous green algae, however, only one (the Dwars River) is used for illustrative purposes. While we do not claim full inclusiveness regarding the development process for water pollution permits in South Africa, we present some of the fundamental conditions and processes that will need to be in place for such an initiative.

Tradable pollution permits (also called cap-and-trade) is a market-based approach using economic incentives to reduce pollution. It is based on the polluter-pays principle (O'Neil, 1983, O'Neil et al, 1983, Kraemer and Banholzer, 1999, Glazyrin et al, 2006) and aims to impose a cost on pollution, or generates a reward for pollution abatement. Individual participants may then trade within the constraints as set by the rules of the market to their mutual advantage. Although the transfer of permits is referred to as "trade", in effect, the buyer of a permit pays for the right to pollute, while the seller receives compensation for letting go of such right. Thus, in theory, those who can reduce pollution most cheaply will do so, achieving pollution reduction at the lowest cost given the cost structure of the two parties (i.e. not necessarily the optimum solution for society). It is therefore not only a way to harness market incentives for controlling pollution, but is also transparent process which promotes fair mitigation of pollution while gradually identifying non-point polluters (assuming that the buyers of permits are indeed polluting).

A pollution permit scheme thus uses market based incentives that is geared towards making pollution an expensive activity which will not only create an incentive to reduce pollution directly, but will also create incentives to adopt cleaner production and consumption activities. It also tends to lower pollution regulation cost by leaving decisions regarding how to reduce their pollution, up to the polluter - it is assumed that polluters will choose the least-cost way (given their unique circumstances) to mitigate pollution regulation.

Challenges associated with this approach include the complex nature of the required terms, conditions, transactional protocol and operating rules that will facilitate transactions (i.e. market activity). These need to account for potential inflationary impacts, problems of monitoring and enforcement, hot spots (high local concentrations of pollutants), thin markets and exposure to possible monopolistic market power. The remainder of the paper focus on this market making process presenting some headway been made to engage some of these challenges.

6 Some relevant theory on pollution permits

Pollution permits are in effect a legal right to pollute a certain amount within a specified time period (the permit life). If the polluter produces less pollution (s)he can sell the right to another polluter who might not be in a position to meet the required pollution targets. A market for the right to pollute is therefore created – i.e. those who pollute a lot or cannot comply can buy permits from those who pollute less. If a polluter is unable to find a willing seller, (s)he/it will face a pollution tax[9] from the state, which could be equal to the current value of a permit plus a premium equal to a stipulated fine. Tradable pollution permits therefore not only creates a strong incentive to pollute less, the flexibility of a market mechanism also allows polluters to use the most affordable pollution compliance strategy given their internal marginal pollution abatement costs and the market price for

[9] The key difference between a pollution tax and a permit mechanism is that with a tax, the price is established ex-ante and the extent of the pollution reduction is determined by the level of compliance of the polluters. A permit set a pollution target ex-ante, and the pollution reduction is then priced based on the cost of mitigation.

permits. In theory, polluter's individual decisions should then lead to an economically efficient allocation of permits and lower overall pollution compliance costs as compared to command and control mechanisms. Over time, a cost effective outcome will be achieved by a well-functioning market regardless of the initial allocation of ownership of the permits (Coase theorem, Coase, 1937). In theory then, tradable permits could have the following benefits over command-and-control mechanisms (Boyd, 2003):

- address environmental impacts more directly through the setting of quantifiable physical limits on pollution, and implement strict monitoring to ensure compliance;
- allowing polluters greater flexibility in the choice of means to comply;
- decrease the overall cost of compliance by encouraging polluters who can comply more cheaply to do so first, while allowing those with higher costs to comply to opt for buying additional permits;

There are however, a few general problems associated with pollution permits, e.g.:

- Permits can (as with pollution taxes) have inflationary impacts when polluters can pass the cost increases on to consumers.
- It is challenging to determine the number of permits to be issued initially because the level of pollution varies over time. Too many permits can result in a very low permit price which reduces the incentive that permit-liable polluters have to cut back on pollution. Too few permits can result in excessively high permit prices leading to "thin markets", i.e. little market activity
- Rich polluters can simply buy themselves out of trouble, thereby weakening the desired effect of pollution reduction.
- When permits are issued free of charge since it can create incentives not to cut pollution. This is why most permit schemes auctions the initial allocations with an independent valuation such as a reserve price in place. However, auctioning initial permit allocation could have more political opposition as compared to free hand outs.
- The nature of the pollutant plays an important role in the design of the mechanism. E.g. the market for carbon dioxide is perhaps the most well-known because it acts globally, thus its impact on the environment is generally similar across the globe and the location of the polluter does not really matter from an environmental standpoint. This uniformity makes for easier design of the terms and conditions for the carbon market. A pollutant with more localized impact (such as water pollution) requires more localized terms and conditions because its impacts changes and differs across locations. Terms and conditions for these markets are therefore not necessarily universally applicable. Also, the same amount of pollutant can exert different impact in different locations. This implies that the location of the pollution matters, and is known as the '*hot spot'* problem.

All of the above and the fact that water is a classic public good (i.e. its non-excludability includes free-ride problems which lead to a tragedy of the commons) with complex non-point characteristics, makes for a water pollution permit scheme being an extremely complex challenge to design and manage effectively. It is therefore to be expected that tradable pollution discharge permits are among the most challenging market-based instruments for water management and pollution control in terms of both their design and implementation. Consequently, few examples of successfully and functioning tradable water pollution permit schemes exists. Many countries have considered these schemes, with several reaching advanced stages in the development, stopping short of implementation (Nishizawa, 2003, NSW-EPA, 2003, Weideman, 2001). Thorough design is a necessary but not sufficient factor for success as the process also requires political support and buy-in from stakeholders as such a system could require substantial changes (reform) to existing regulatory frameworks and institutions. This is where thorough piloting of the terms and conditions becomes valuable since it increase stakeholder buy-in via an opportunity for consultation between designers and participants - vital for making the benefits of trade obvious and for increasing the acceptability of the scheme.

This section has provided some of the theory on tradable permits in water pollution control. Based on the above-mentioned general framework, the remainder of the paper presents some headway that has been made in terms of the market making process for nutrient related pollution permits in one of the study areas. It is uncharted terrain, with no standard procedure and a focused effort has been made to draw on current sources of information and to identify information gaps for each of the following steps:

1. The basic characteristics of permits, such as the physical parameters of standardised measurement protocol (water pollution permits should be based on loads[10], rather than on concentrations), establishing the pollution cap (reflecting the maximum amount of pollution the river can safely absorb), number of permits to be issued, terms and conditions of transfer, the geographic scope of the scheme and eligibility criteria of participants, were captured.
2. Design the terms and conditions and transactional protocol including the parties involved in a transaction (buyer and seller only; through agents/brokers; at an exchange, or carried out under the auspices of an administrative authority). This step also considers the compatibility of the proposed system with existing legal, regulatory frameworks and institutions in order to keep transaction costs down (Smith, 1999). It should also consider ways to ensure temporal and spatial flexibility in the system.
3. Design the monitoring system in order to track performance and establish credibility in the system. The monitoring system would therefore need to be designed to provide data that will stand in court for resolution of potential conflict.
4. The terms and conditions should be tested on pilot scale and the expected ability to meet changes in environmental and resource requirements. This will include the ability to respond to changes in the boundaries of the system, such as an expansion of the physical coverage of the scheme. However, it should be kept in mind that once implemented, these terms and conditions should not be unexpectedly revised since it might harm investment confidence and may depreciate the value of permits. Hence the need for thorough piloting.
5. Implement via the initial allocation of permits, including consideration to the mechanism of initial allocation (free handout by registration; by application criteria; or by auctioning), and if not free of charge, consideration of the initial price.

7 Towards a water pollution permit in the study area

Following the above-mentioned five steps, we took the objective as '*to initiate the establishment of a tradable pollution permit system in the study area'.* The absolute level of pollution needs to be reduced and it was expected that such a system will enable more transparent and fair (i.e. the polluter pays) management of pollution, while gradually identifying non-point polluters (a common

[10] Defined as the concentration multiplied by the volume over a specified time period.

phenomenon in agriculture) that could allow a more focused and efficient approach for command and control measures on these polluters.

7.1 Permit design

7.1.1 Define the unit of measurement for the permit

In contrast to water use rights, which can be expressed in time-based volumetric units (Armitage, 1999, OECD, 2001), water pollution permits has to cope with a number of pollutants, all with distinct effects on ecosystems. Water pollution permits should not only account for several substances but also for the location of the discharge. Furthermore, fluctuations of these variables are determined by area specific natural and anthropogenic variables. Filamentous green algae, hold true to this complexity with several factors determining its occurrence. It require a flow velocities lower than 0.8metres/second, total phosphorous of 0.03 mg/litre and total nitrogen of 0.5 mg/litre (Oberholster et al, article in press). Furthermore, water hardness (i.e. the magnesium and calcium carbonate content of the water) and alkalinity (i.e. the capacity of the water to neutralize acids) controls the availability of phosphorus uptake and hence the growth rate (Oberholster et al, article in press). Oberholster et al (article in press) specifically noted that *"calcium and magnesium ions act to control the availability of phosphorous for benthic algae uptake".* The association of algal growth with hardness and alkalinity is because bicarbonate ions increases the supply of carbon dioxide for photosynthesis (Smith, 1950) and carbonate-bicarbonate buffering that control pH values (Patrick, 1977). It could therefore be argued that alkalinity and hardness is two important determinants of the uptake of phosphorous, and consequently for algae growth in river systems. While these parameters (see Table 8) affects the level of algae growth, it also provides focus points for pollution mitigation strategies, i.e. mitigation strategies could focus on these parameters to affect the level of algae.

Table 8: Measurement parameters for alkalinity and hardness in river systems

	Measurement	Range of conditions favourable for benthic algae growth
Alkalinity	CaCo3 in mg/litre	Below 20 mg/litre Ideal 75-200 mg/litre Above 250 mg/litre
Hardness	CaCo3 + MgCo3 in mg/litre	Below 63 mg/litre Ideal 100 - 150 mg/litre Above 250 mg/litre

Although alkalinity and hardness could be treated in theory, it seldom is the case for river systems. Treatment of the river system rather focuses on phosphorous and algae (Wehr and Sheath, 2003). Phosphorous could be managed via several ways:

- Diversion and advanced wastewater treatment.
- Detention basins and wetlands
- Alum dosage
- Dredging

- Aeration, which reduces the amount of phosphorous being oxidised in the sediment and released into the water column.
- Hypolimnetic withdrawal via removal of high nutrient load bottom waters by pumping it to larger water systems, although this just relocates the eutrophic problem.

Direct control of algae

- Direct harvesting by hand or mechanized equipment.
- Biological control and bio-manipulation, algae predators will differ depending on their species and range from phytoplankton species to piscivorous fish, while aquatic plant management increases the competition for nutrients.
- Chemical control via allelochemicals (chemically produced by plants to control algae or other plant species) or algicides (contact or systemic sprays).

While all of these parameters are measurable in terms of established methods, they cannot be used to measure the relative efficiency of an algae mitigation strategy which requires a direct measure of algae load. Last-mentioned is commonly presented by chlorophyll concentration in mg/m^2, where high chlorophyll levels are indicative of high algal biomass. Benthic chlorophyll-a, is measured by spectrophotometry (absorbance or fluorescence), using either the known optical properties of chlorophyll, or by High Performance Liquid Chromatography (HPLC). Benthic chlorophyll-a, which is linked to algae through the dried filtered biomass is measured as mg/m^2, which could then be used as a basic unit of measurement for a pollution permit.

7.1.2 Determine the pollution cap and number of permits

A pollution cap (i.e. a "safe" algae load for the river or sections of the river) is required to determine the number of permits for the initial allocation and thereby in effect determines the scope of the market. The process starts with the identification of an area of reference for the cap. Here it becomes important to understand that the area of reference needs to be an area in where the conditions for algae growth are similar and where algae mitigation strategies will have comparable impacts (i.e. the areas need to be similar in terms of biophysical conditions for algae growth and the self-cleaning capacity of the river). The identification of homogenous sub areas could be done according to the self-cleansing properties of the river system, which has been indexed via an algae sensitivity index (Oberholster et al, 2013) and could be used to distinguish and identify homogenous sub-areas in the river. These areas need to be mapped by means of the establishment of monitoring points at the beginning and end of each area. The surface area of each sub-area needs to be calculated and the drainage map for the area needs to be confirmed. A map of these sub-areas (presenting the monitoring points and surface areas and drainage) provides the point of departure for defining the algae pollution cap for each area and the total pollution cap for the river. The following boundaries could be used to classify algae loads (Table 9):

Table 9: Load boundaries for algae (Oberholster et al, 2013)

Boundary	median benthic chlorophyll-a (mg/m^2)	median benthic chlorophyll-a (gr/ha)

Natural (oligotrophic)	< 1.7	<170
Good (mesotrophic)	1.7 – 21	170-210
Fair (eutrophic)	21 – 84	210-840
Poor (hypertrophic)	> 84	>840

Since both case study areas are considered as phosphorous sensitive rivers (i.e. an eutrophic state can easily develop into a hypertrophic state) a load boundary of 21 mg/m2 is considered desirable for the river. However, a pollution permit requires an absolute value for algae per sub-area and not a concentration. This implies the need for extrapolation based on the assumption of homogeneity to derive an absolute weight for the load for the sub area. Consequently, the concentration value of 21 mg/m2 is extrapolated to the surface area or surface flow area of the sub area to obtain the total permissible pollution (i.e. the pollution cap in weight) for the sub-area.

For example, if the relevant area of the sub-area is equal to 15ha, the total permissible pollution for the area is 3150gr (21mg*150000m^2). The number of permits issued is therefore subject to a constraint of 3150gr and could (in theory) be any number as long as it remains subject to the constraint of 3150gr for the subsection (see Table 10).

Table 10: Examples of permits subject to a hypothetical algal load of 21mg/m2 for 15ha area

Number of permits	Representative weight per permit	Total
15	210gr/ha, i.e. an area of approximately 100*100m	3150gr
150	21gr/1000m2, i.e. an area of approximately 31.5*31.5m	3150gr
1500	2.1gr/100m2, i.e. an area of 10*10 meters	3150gr
15000	210mg/10m2, i.e. an area of 3.16*3.16 meter	3150gr
150000	21mg/m2	3150gr

Although any of these combinations satisfies the 3150gr constraint, the relative weight of the permit will need to be standardised to allow trade between sub-areas. The choice of representative weight forms part of the terms and conditions of the permit, and should be based on practical considerations. For now it was assumed that the permit is defined in terms of gr/ha, i.e. 210gr/ha, implying 15 permits for the specific area.

7.1.3 The reserve price and market clearing price

The following example aims to present and explain some of the intricacies associated with the price determination process for a pollution permit. The case for the Dwars River is used for illustration purposes. We have estimated the initial value of the impact of algae pollution in the Dwars River to be R1888/ha. This figure could now be used to as point of departure to determine a reserve price for a pollution permit in the area. I.e. the price considered to be the minimum amount that will leave a polluter indifferent between his willingness to pay (WTP) for a permit or willingness to accept (WTA) the losses of the pollution. According to Table 9, the value of algae will vary between R111/gr (R1888/17gr) and R2.25/gr (R1888/840gr), with the price at the preferred state (i.e. 210gr/ha) equal to R8.99/gr (R1888/210gr). Trade now becomes possible between willing buyers and willing sellers. An example will illustrate the process:

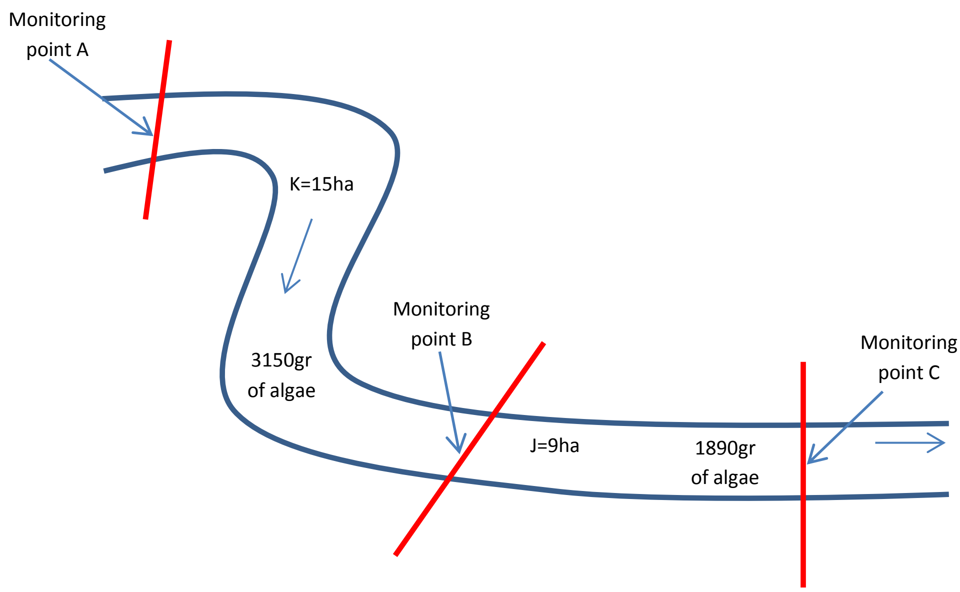

Figure 1: Hypothetical river section with sub-sections K and J

Consider homogeneous sub-area K which is 15ha with a permissible amount of algae equal to 3150gr (15*210gr/ha), sub-area J is 9ha with 1890gr of algae, also at 210gr/ha.

Say at a given moment in time the benthic algae load at monitoring point B is 190gr/ha, (sub-area K is therefore doing well at 2850gr). Say the load increases downstream from B to realise a reading at monitoring point C of 220gr/ha (i.e. an increase of 30gr/ha). This implies a supply of algae of 1980gr (9*220gr) to sub area J and means that sub-area J has a willingness to pay (WTP) to get rid of 90gr (1980gr-1890gr) of benthic algae or face a penalty/fine. Sub-area K has a current capacity of 300gr (3150gr – 2850gr) and could therefore buy the 90gr and still remain within its limit if sub-area J can meet K's WTA-price. In order to calculate this price one will need to understand that although the reserve price per hectare is R8.99/gr (R1888/210gr), the WTA of sub-area K will start at R9.94/gr (i.e. R1888/190gr) per hectare. Furthermore, the clearing price will be the new WTA of sub-area K once after assuming responsibility for an additional 90gr. This price will be close to R10.26/gr (i.e. ((R1888*15ha)/(2850gr-90gr)) per hectare. The value of the transaction is estimated to be R10.26*90gr = R923.40 and the new target load for sub-area K will become 184gr/ha (i.e. 2760gr/15ha) at monitoring point B in order to meet the target load of 210gr/ha at monitoring point C.

However, say we keep the same scenario, but change the base value of sub-area K from 190gr to 210gr/ha. The same 30gr/ha is now introduced downstream from point B with the reading at monitoring point C now becoming 240gr/ha. This implies that sub-area J needs to sell 270gr (i.e. 30gr*9ha) or face a penalty/fine. Sub-area K has no spare capacity and will have a WTA to R9.83/gr (i.e. ((R1888*15ha)/(3150gr-270gr). The value of the transaction will be R2654.10 (i.e. R9.83*270gr) and the new target load for sub-area K will become 192gr/ha (i.e. 2880gr/15ha).

Say we switch the two areas around, i.e. sub-area J is now upstream from sub-area K. Say we keep the load at monitoring point B at 190gr/ha and have the same increase of 30gr/ha realising a load of 220gr/ha at point C. Sub-area K will need to sell 150gr (i.e. 10gr/ha*15ha). Sub-area J's WTA will be equal to R10.89/gr (i.e. ((R1888*9ha)/(1710gr-150gr). The value of the transaction will be R1633.50 (i.e. R10.89*150gr) and the new target load for sub-area J will be 173gr/ha (i.e. 1560gr/9ha). If we change the base value of sub-area J from 190gr/ha to 210gr/ha in this scenario and introduce the same increase in load (i.e. 30gr/ha) monitoring point C will read 240gr/ha. Sub-area K now needs to sell 450gr (i.e. 30gr*15ha). Sub-area J's WTA will increase to R11.80 (i.e. ((R1888*9ha)/(1890gr-450gr)). The value of the transaction will be R5310.00 (i.e. R11.89*450gr) and the new target load for sub-area J will be 160gr/ha (i.e. 1440gr/9ha).

The above-mentioned are only examples of hypothetical cases and the process is subject to terms, conditions and transactional protocols.

7.2 Terms, conditions and transactional protocol

One could argue that a market is essentially a social construct facilitating the exchange of utility, which is regulated by accepted terms and conditions. Terms determine the transactional protocol (i.e. the trade process) while conditions specify the requirements of trade (i.e. requirements to participate in the market). The terms and conditions should be designed within the context of existing regulatory regimes, i.e. in this case, water regulatory regimes of the area (typically a Water User Association or Irrigation Board responsible for the area) and need to deal with complexities associated with ecological infrastructure and the associated ecosystem services, such as the public good nature of these services. A detailed account of standard terms and conditions for tradable permit systems aimed at ecological infrastructure is present in OECD (2001). However, the following aspects will need to be accounted for in designing the terms and conditions for the transactional protocol for water pollution permits:

- The non-point property of pollution will need to be accounted for by homogenous (in terms of self-cleaning capacity) sub-drainage areas which will need to be mapped and differentiated by means of monitoring points. This is an important cartographical exercise which underlies the permit system. Responsibility and accountability could be proportional to ownership of transformed land within the drainage area of the sub-area. If for example two owners owns an equal amount of land within a particular sub-drainage area, the associated payment for - and income from - pollution permits (which is administered by the relevant Water User Association) will be covered and received in equal shares. Last-mentioned point towards the need that this water pollution permit system operates on cooperative principles, i.e. due to the non-point nature of pollution and the self-cleaning properties of rivers, sub-areas becomes the entities of trade, i.e. sub-areas trade with one another, not individual land owners.

- The frequency of monitoring benthic algae loads at the monitoring points of sub-areas will be a necessary but not sufficient condition for determining the frequency of market activity since it is only after a monitoring event that the required data becomes available to identify problem areas and the need for transactions. Market activity (i.e. the need for transactions) will therefore be directly related to the frequency of monitoring events. The higher the frequency (i.e. the shorter the interval between monitoring events) the better the understanding of algae concentrations over time becomes, but the smaller the marginal difference between readings and hence a lower number of permits and hence higher transaction costs. The lifespan of a pollution permit could be a function of the frequency of monitoring events (if these happen at regular intervals) or a timeframe negotiated with the members prior to the launch of the system. This lifespan will need to account for the trade-off between the self-cleansing capacity of the river and a fair amount of time to implement algae mitigation measures once a permit has been sold.
- A suitable incentive will need to be in place to incentivise parties in the wrong to engage in the market. Such an incentive could be a fine equal to the current market clearing price plus a suitable premium in the form of a fine which is big enough to incentivise market engagement. It should however be kept in mind the parties in the wrong might have to pay the fine if a market solution (i.e. a transaction) cannot be found (i.e. no willing buyer/seller).
- A central regulative authority who verify, facilitate (i.e. identify and bring together potential buyers and sellers), validate, register and record all transactions will need to be established. This function can reside with the Water User Association who then in effect hosts a "trade pool" for transactions. This trade pool consists "surplus" pollution rights and should increase with time if the river system health improves or if polluters opt to rather pay a fine instead of using the market to offset their pollution. The trade pool provide flexibility to the system since new entrants and polluters not able to find willing buyers could rent these permits from the trade pool subject to conditions such as they should provide an implementation plan to decrease their pollution within given time period.
- The regulative authority is the only recognised authority in terms of facilitating the transactions. This will ensure that the same terms and conditions are used for all transactions.
- Consensus need to be reached regarding a pollution cap (e.g. 210mg/m^2 as per the example above).
- The terms and conditions should, once developed, be challenged in terms of compatibility with existing laws, regulatory frameworks and institutions by means of a pilot phase.

In order to guarantee security for tradable rights and therefore willingness to trade, it is not advisable to unexpectedly revise the terms and conditions of the game since it might jeopardize current investments in the scheme via affecting the value of the permits negatively. The conditions under which the rules of the game may be changed should be made explicit prior to the launch of the scheme.

7.3 The monitoring system

The monitoring process should be designed keeping prevailing regulatory structures (e.g. a water user association) in mind. It is understood that the measuring protocol for algae is a laboratory based method which cannot currently be automated. The monitoring of the relative performance of algae mitigation strategies and the consequent information required to calculate the availability of permits would be a function of the frequency of monitoring, which is a management decision that will need to be negotiated before the scheme is launched. It is important to maintain the frequency of monitoring as it will affect price expectations and market stability. Once been determined, this timeframe should not be changed without good reason.

The result of each monitoring run presents important market information that needs to be verified and registered in the “trade pool” before being communicated to members. Transactional monitoring continues with the administration and regulative processes of a transaction. Thus far, it has been suggested that the relevant water user association could establish a sub-directorate responsible for verification, facilitation (i.e. identify and bring together potential buyers and sellers), validation and recording of transactions in a register.

The verification and registration of intent (i.e. willing buyers of permits) will need to happen soon after the results of the monitoring run has become available. Verification is required to confirm that a potential seller, who registers intent, indeed has a right to sell. This is done by comparing the reading of the relevant monitoring point with the reading of the previous monitoring run and check whether any credits are registered against this monitoring point in the ‘trade pool’ or was traded to another owner. The transaction may then continue. Details of prospective buyers and sellers needs to be recorded along with information such as physical location of the buyer and seller, the relevant monitoring points and the amount of algae in question. The facilitation process could be done in person between the buyer and seller or under supervision of the association, or via a lawyer. This is the step where price negotiation also takes place, which could be an automated process (i.e. an exchange) if the number of transactions justify such a tool. The facilitation process aims to make it as easy as possible for willing sellers to find willing buyers (i.e. minimise transaction cost). The validation process is then initiated (i.e. a bank transfer, or a reconciliation of the water user association accounts of the buyer and seller) once a clearing price has been determined. The transaction is recorded in a register and is then complete. No post transactional monitoring is required since such monitoring is done with the next monitoring round.

7.4 Pilot phase

A pilot phase will challenge the suggested terms and conditions of a water pollution trading scheme, and capture the many intricacies and additional special conditions required for implementation. This information should then be used as the basis for designing the legal framework for the scheme.

As the idea of buying and selling the ‘right’ to pollute is counter intuitive with potential conflicting opinions, a pilot phase will also provide opportunity for consultation and exchange with stakeholders and potential participants, which could improve the acceptance and buy-in and therefore efficiency of the formal, legally established scheme. Here it is important to account for the fact that implementation should be done in consideration of the political acceptability of the system and risks associated with misinterpretations regarding the "right to pollute" as well as the broader economic impacts such as inflationary impacts and market power balances.

7.5 Implementation via initial allocation

A generally accepted method of allocating permits currently used is the sealed bid auction. Under this method, buyers of permits must send their bids in a sealed envelope to the agency conducting the auction. The permits are sold to the highest bidders until there are no more bidders or the permits run out. There are two main features of sealed bid auctions that make them different from other methods. For one, they can be organized to prevent firms that control a large fraction of the permits from exhibiting monopoly power. And secondly, they enhance price stability, which adds rational planning of pollution control by the polluters. Silent auctions are most efficient when permits can be traded freely at any time.

Alternatively the initial issuing of permits could be done free of charge, but by means of application. I.e. firms apply for permits to the regulation authority, which then register the permits and allocate permits subject to the overarching load per sub-area. Initial allocations should then be issued. Price determination of subsequent transactions is then a function of the willingness to pay and accept of market participants as explained above.

8 Discussion and interpretation

Although a tradable permit system is, due to its nature, a complex instrument in terms of implementation, it has immense potential to effectively mitigate pollution once up and running. This is mainly because polluters differ in their ability to abate their pollution – some can do it easily and cheaply, while for others it would be more difficult and costly. The freedom to trade pollution "entitlements" gives an incentive for polluters to consider abatement (since they can sell their surplus quotas) while others face the cost of having to purchase permits. For society, the existence of tradeable permits enables pollution abatement to be achieved in a cost effective way. Over time, pollution standards can be tightened, increasing the value of the permits and the pressure on market participants to pollute less.

This paper has presented some of the fundamental conditions and requirements for a water pollution permit system along with some of the processes that will facilitate implementation for South African river systems. Due to the novelty of the work the focus was on the preliminary design of the system, a process which is ongoing. Consequently, no information is put forward with regard to the political process that is required to facilitate acceptance among those affected. However, it should be clear that in order to have a functional market for water pollution permits, enough market participants (i.e. polluters) should exist (i.e. enough pollution should be present), which means that there should be many pollution sources (polluters) affecting the same parameter (e.g. N, P, BOD, salinity) within the same catchment, while having significant differences in abatement cost curves so that beneficial trade becomes possible. Furthermore, the establishment of a legal entity (scheme administrator) responsible for monitoring and data capturing, enforcement mechanisms, information for conflict resolution, trade facilitation and system evaluation, will along with a solid scientific understanding of the pollution factors system responses, provide a solid basis for trade. However, care should be taken that the scheme administrator keep administrative requirements, approval procedures and requirements to trade to a minimum since high transaction cost reduces willingness to trade.

It is also advisable that the existing functioning system of water pollution control (or at the very least water management) should be in place to design and implement a market for tradable pollution permits, because such system not only provide the basic context to design the permit system (ensuring compatibility), it also streamline the proposed system with existing data sources.

It should be noted that the pollution permit system is not a fail safe way to decrease the absolute level of pollution within the river, but should rather form part of an integrated strategy and in conjunction with “command and control” regulations, to mitigate algae problems. The permit system has a particular role to play to avoid eutrophic conditions via relocating the pollution problem to sub-areas within the river that can best cope with the load at a particular time period.

9 Acknowledgements

The authors would like to thank Stellenbosch University and Loskop Irrigation Board for their contributions. This work was funded by the Loskop Irrigation Board, the National Research Foundation of South Africa and CSIR parliamentary grant funding.

10 References

Armitage, R.M., Nieuwoudt, W.L., Backeberg, G.R., 1999. Establishing tradable water rights: Case studies of two irrigation districts in South Africa. Water SA 25, 301-310.

Birol, E., Karousakis, K., Koundouri, P., 2006. Using economic valuation techniques to inform water resources management: A survey and critical appraisal of available techniques and an application. SCI TOTAL ENVIRON 365, 105-122.

Boyd, J.B., Krupnick, D., McConnell, A., Palmer, V., Sanchirico, K., Walls, J., Walls, M., 2003. Trading cases: Is trading credits in created markets a better way to reduce pollution and protect natural resources? ENVIRON SCI TECHNOL 37 (111), 217-233.

Brouwer, R., Pearce, D.W., 2005. Cost-benefit analysis and water resources management., Cheltenham, UK, Edward Elgar.

Coase, R., 1937. The nature of the firm. ECONOMICA 4, 386-405.

David, L.E., 2003. Marketable water pollution permits as economic incentives: Point source trading in Wisconsin. Contribution to the Inter-American Development Bank Technical Seminar on the Application of Economic instruments in Water management, February 27, 2003. Washington D.C.

De Lange, W.J. 2014. The monetary value of the impact of selected pollutants on commercial agriculture in the Dwars River. CSIR report number: CSIR/NRE/GES/IR/2014/0075/A, Council for Scientific and Industrial Research, Pretoria, South Africa.

De Lange, W.J., 2015. The production cost impact of algae on commercial irrigation in the Loskop Irrigation Board service area, Groblersdal. CSIR report number: CSIR/NRE/GES/ER/2015/0014/A, Council for Scientific and Industrial Research, Pretoria, South Africa.

De Lange, W.J., 2014. Report on the monetary value of the impact of selected pollutants on commercial agriculture in the Berg River. CSIR report number: CSIR/NRE/GES/IR/2014/0075/A, Council for Scientific and Industrial Research, Pretoria, South Africa.

Deciduous Fruit Producers Trust, 2013. Annual Key Deciduous Fruit Statistics. Compiled by the Deciduous Fruit Producers Trust (DFPT) and Optimal Agricultural Business Systems (OABS) for the South African Apple and Pear Producers' Association; Dried Fruit Technical Services; South African Stone Fruit Producers Association and the South African Table Grapes Producers' Association, Paarl, South Africa.

Department of Water Affairs and Forestry, 2004. Olifants Water Management Area: Internal strategic perspective. Report prepared by GMKS, Tlou and Matji and WMB Pty Ltd, Pretoria, South Africa.

Glazyrin, I., Glazyrin, V., Vinnichenko, S., 2006. The polluter pays principle and potential conflicts in society. ECOL ECON 59, 324-330.

Goodstein, S., 2008. Economics and the environment. Lewis & Clark, Portland, Oregon, USA, John Wiley & Sons.

Kraemer, R.A., Banholzer, K.M., 1999. Tradable Permits in Water Resource Management and Water Pollution Control. OECD proceedings, Implementing Domestic Tradable Permits for Environmental Protection, OECD, Paris.

Kraemer, R.A., Kampa, E., Interwies, E., 2003. The role of tradable permits in water pollution control. Report to the Institute for International and European Environmental Policy, Berlin, Germany.

Nishizawa, E., 2003. Effluent trading for water quality management: concept and application to the Chesapeake Bay watershed. Marine Pollution Bulletin 47, 169-174

New South Wales Environmental Protection Agency, 2003. Hunter River Salinity Trading Scheme: Working together to protect river quality and sustain economic development. NSW EPA, Sydney, Australia.

NULANDIS, 2014. Product information and crop guideline catalogue. NULANDIS, South Africa, www.nulandis.com

O'Neil, W.B., 1983. Transferable discharge permit trading under varying stream conditions: A simulation of multiperiod permit market performance on the Fox River, Wisconsin. WATER RESOUR RES 19 (3), 608-612.

O'Neil, W.B., David, M., Moore, C., Joeres, E., 1983. Transferable discharge permits and economic efficiency: The Fox River. J ENVIRON ECON MANAG 10, 346-355.

Oberholster, P.L., Botha, A.M., 2011. Dynamics of phytoplankton and phytobenthos in Lake Loskop (South Africa) and downstream irrigation canals. FUNDAM APPL LIMNOL 179 (3), 169-178.

Oberholster, P.J., Dabrowski, J., Botha, A.M., 2013. Using modified multiple phosphorus sensitivity indices for mitigation and management of phosphorus loads on a catchment level. FUNDAM APPL LIMNOL 182 (1), 1-16.

Oberholster, P.J., Somerset, V.S., Truter, J.C., Botha, A.M., in press. The interplay between environmental conditions and filamentous algae mat formation in two agriculture influences Southern African rivers. FUNDAM APPL LIMNOL.

Organisation for Economic Co-operation and Development, 2001. Domestic transferable permits for environmental management: Design and Implementation, OECD, Paris.

Patrick, R., 1977. Ecology of freshwater diatoms and diatom communities. In Werner, Dietrich (ed.), The biology of diatoms, Botanical Monographs, Berkeley, California, University of California Press, pp 284-332.

Pearce, D.W., 1993. Economic values and the environment, UK, The MIT Press.

Pearce, D.W., 1994. Valuing the environment: Past practice, future prospect. Centre for Social and Economic Research on the Global Environment University College London and University of East Anglia.

Pretorius, P., 2015. Personal Communication. Operations manager, Loskop Irrigation Board, Groblersdal, South Africa.

SAWIS, 2013. South African Wine Industry Information and Systems. Paarl, South Africa.

Smith, C., 2014. Personal Communication, Senior researcher, Agricultural Research Council, Stellenbosch, South Africa.

Smith, G.M., 1950. The fresh-water algae of the United States. New York, McGraw-Hill Book Co., pp. 1-719.

Smith, S., 1999. The compatibility of tradable permits with other environmental policy instruments, OECD Proceedings, Implementing Domestic Tradable Permits for Environmental Protection, OECD, Paris.

Van Niekerk, P., 2013. Industry statistics: Production cost for wine grapes. Paarl: Agricultural Economics Division, VINPRO, Paarl, South Africa, www.vinpro.co.za

Wehr, J.D., Sheath, R.G., 2003. Freshwater habitats of algae pp. 11-57. In : Wehr JD, Sheath RG. (eds.), Freshwater Algae of North America: Ecology and Classification. Academic Press. San Diego, CA.

Wiedeman, A., 2001. Nutrient trading for the Chesapeake Bay, April 2001, Available online: www.chesapeakebay.net.