SCHOOL OF ECONOMICS AND MANAGEMENT
Lund University

Department of Economics

The Costs of Abatement

A Cost-effective Allocation of Swedish Phosphorus Abatement Concerning the Sea Basin of the Baltic Proper

Bachelor Thesis

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Author: Olle Rosén

Supervisor: Krister Hjalte

Abstract

The Baltic See in general and the basin of the Baltic Proper in particular, has in the last decades severely been plagued by the effects of eutrophication caused by abundant flows of the nutrient substances phosphorus and nitrogen. This study has been concentrating on the Swedish load of phosphorus to the Baltic Proper and the measures available for reducing this load. This being a field where surprisingly few studies have been done up to date, a pioneering cost-effectiveness analysis has been conducted in order to find a cost-effective allocation of abatement measures. An extensive sensitivity analysis of the findings has further been performed in order to test the robustness of the base case results.

Results of the study include estimated low total costs for low to moderate reductions of the phosphorus load, but significant higher cost for further reductions. Uncertainty of the total cost of abatement is additionally perceived as high and increasing with more ambitious reductions. This is mainly due to lacking knowledge about several of the driving forces behind the environmental problem of eutrophication. Measures that although could reduce the phosphorus load at relatively low costs include creating of small ponds in the agricultural landscape and measures at reducing the discharges from municipal wastewater treatment plants.

Keywords: Phosphorus, Abatement, Eutrophication, Baltic Sea, Cost-effectiveness Analysis

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1. Introduction

In 1999 the Swedish Parliament adopted fifteen comprehensive environmental objectives with the aim of their fulfilment by the year 2010[1]. The general ambition with these objectives is to pass on to the next generation a society in which all major environmental problems are solved (SEPA 2003b:3). Measures aimed at these objectives are required to be cost-efficient and be preceded by economical analysis but seemingly the basis for decision is often inadequate. Lack of sufficient information will most likely cause suboptimal decisions and hence misallocations of resources. Therefore it is of great importance that more effort is made on calculating costs and consequences of policies before they are adopted. (See e.g. Samakovlis & Vredin Johansson 2005:30ff).

The Baltic Sea has in the last decades severely been plagued by the effects of eutrophication caused by abundant nutrient flows of nitrogen and phosphorus. While the problems of eutrophication has been well known for some time, earlier studies in the field and most of the efforts up to date, have mainly been concerned with the abatement of the nitrogen load to the Baltic Sea while phosphorus to some extent been left aside (SEPA 2006a:49). The debate of the relative importance of the two nutrients has been long lasting but new findings have been more concerned with the load of phosphorus. In the newly published report "Eutrophication to Swedish Seas" (SEPA 2006a) compiled by a set of international experts in the field, one of the main recommendations is that the input of phosphorus to the Baltic Proper, the largest of the five main sea basins in the Baltic Sea, should be reduced. At the same time the benefits of further nitrogen abatement is questioned in the report (SEPA 2006a:1-2). Although both abatement of nitrogen and of phosphorus most likely are needed for the fulfilment of the objective this study will assume that further phosphorus abatement is of high priority. Therefore the issue of how this abatement could be achieved will be in the direct focus in this study.

The eutrophication of the Baltic Sea is a complex environmental problem of many dimensions. Not only are there still uncertainties and unsolved debates about the scientific aspects of eutrophication (Promemoria 2005:18-19), the problem is also of international character with nine countries sharing the resource being plagued (Gren et al 1995:4). With

[1] They are now sixteen since the environmental objective "A Rich Diversity of Plant and Animal Life" was included in November 2005.

this in mind, the problems of eutrophication in the Baltic Sea seem not to be easily solved. However, it is the author's strong belief that this insight should not be discouraging; instead it should be undertaken as a challenge.

1.1 The Aim of This Study

While this study begins with an acknowledgement of the importance of phosphorus abatement, there still are wide gaps in the knowledge regarding with which measures and at what costs this reduction could be done. As noted by Samakovlis and Vredin Johansson (2005:37) analysis of consequences and costs should always be conducted if efficiency is in any way sought for. The aim of this study is therefore to make an attempt of calculating the costs of abatement and concurrently compile potentially important measures aiming at abatement of the Swedish phosphorus load to the Baltic Proper. Not only will the adopted interim target on the Swedish load of phosphorus be examined in the analysis, by computing an aggregated cost curve derived from different potentially important measures, the cost at other levels of abatement will additionally be revealed. Explicitly this study will hence attempt to answer the question;

What is the estimated cost of abatement of the Swedish phosphorus load to the Baltic Proper?

By answering this question with the use of a cost-efficient allocation model the study will additionally indicate at which sectors and by which measures phosphorus abatement first should take place if cost-efficiency is desirable. The results in this kind of study could therefore serve as information for decision makers trying to form effective policies on least-cost premises.

1.2 Delimitations

The problem of eutrophication in the Baltic See is as earlier mentioned indeed multidimensional. The major implication of this characteristic is that a number of delimitations have been done in order to make the analysis in this study possible. The limitations, which both are related to physical and biological aspects of the environmental problem and to uncertainties in information, will here briefly be discussed.

While the environmental problem of eutrophication in the Baltic Sea is a problem of international character this study will be limiting its scope to merely Swedish inputs of phosphorus and Swedish measures of abatement. An international approach to the problem is mainly limited due to time and space but the scarcity of knowledge about abatement measures in other countries would also profoundly affect such attempts. The study is further, as mentioned above, limited to one of the five main basins in the Baltic Sea, the Baltic Proper. This is motivated mainly by the recommendations regarding the desirable reduction of the load of phosphorus to the basin from the report *"Eutrophication to Swedish Seas"* (SEPA 2006a) and the severe environmental status of the basin.

This study is moreover limited to the load of the nutrient substance phosphorus while eutrophication also is caused by nitrogen. The debate on the relative importance of the two nutrients will further be discussed in the next chapter and the conclusion there will adequately motivate such choice. Not only will nitrogen be neglected, the use of cost-effectiveness analysis of measures of phosphorus abating implies that the abated phosphorus carries the entire monetary burden in the analysis and no other benefits will hence be included. Benefits could otherwise in this case been including e.g. abated nitrogen and other positive environmental effects (see e.g. SEPA 2003e:61-62). Since the valuation of these other possible benefits is a study in itself, the focus will though herein remain on phosphorus alone, further studies could perhaps be more inclusive.

Further on there are no available data on the net load of phosphorus to the Baltic Proper. The amount of phosphorus being discharged from an inland source is greater than the load eventually reaching the sea. This phenomenon is called retention. Today no models that sufficiently can estimate the retention of phosphorus exist. This study will hence be relying on the latest available gross data (SEPA 2002). Additionally, only the anthropocentric load of phosphorus will be dealt with in the analysis although the magnitude of natural background losses not can be neglected. However, it is only at the anthropocentric load that measures could be taken.

Finally this study will just briefly touch upon instruments of governmental intervention. Instead this essay will focus on the measures aiming at abatement. A thoroughly study of the instruments are unfortunately beyond the scope of the essay. It may seem like these delimitations restrict the study to a great extent, but instead of restricting it, the mentioned delimitations will make an analysis possible.

1.3 Method and Material

This study will be using methods for cost-effectiveness analysis in order to calculate the sought costs of abatement and estimate the robustness of the results. Potential measures of abatement will be gathered together with their estimated costs, effects and capacities in order to conduct a cost-effective allocation of phosphorus abatement. While here merely making clear what kind of study being performed and briefly touch upon the method in use, a more thorough account of the methodical operationalisation of the theoretical framework will be held in the last section of *chapter 3*. The modelling will be performed in Excel and the result further presented in a number of charts in *chapter 5*.

Regarding the material in use, this study will further on to a great extend rely its estimations of reduction cost at the source on previous studies. Reports mainly from the Swedish Environmental Protection Agency (Naturvårdsverket) and Statistics Sweden (SCB) will be used for cost-effectiveness ratios and estimations of capacities. Data on the phosphorus load are from Statistic Sweden, the TRK-report (SEPA 2002) and HELCOM publication (HELCOM 2005).

Additional help in locating and interpreting material has been received from Henrik Scharin, Swedish Environmental Protection Agency, Martin Larsson and Barbro Ulén, Swedish University of Agricultural Sciences (SLU), Gunnar Brådvall, Statistic Sweden, and of course, Krister Hjalte, my supervisor.

1.4 Thesis Outlined

The study will be unfolding in the next five chapters starting with a presentation of the environmental problem of eutrophication in *chapter 2*. Apart from a brief account of the environmental threat and its causes, the distribution between different sectors of the Swedish load and the adopted interim target for Swedish phosphorus abatement will be described.

Chapter 3 will include the theoretical framework that is necessary for the presumptive reader in order to understand the analysis performed in this study. This chapter will first in short touch upon the theory of externalities and market failures and then concentrate on the theories of social assessment. Since cost-benefit analysis probably is the most well known of these, cost-effectiveness analysis will be contrasted against it before a more exhaustive review of the cost-effectiveness method is conducted. The chapter will also include an account of the methodological operationalisations of the theoretical framework that are being applied in this study.

Following the theoretical account *chapter 4* is concerned with the measures aiming at phosphorus abatement. These measures are for simplicity presented by sectors, including measures in municipal wastewater treatment plants, measures at agricultural activities and measures at scattered dwellings. In subsequent *chapter 5*, the data will be compiled into a cost-effective allocation of measure presented as aggregated cost curves for phosphorus abatement. The results will then additionally be exposed to sensitivity analysis to test whether they are robust or not. *Chapter 6* will subsequently include a discussion of the results and some final remarks concluding the study.

2. Phosphorus and Eutrophication

2.1 The Environmental Threat

When it comes to the environmental status of the Baltic See the by the Swedish Parliament adopted objective *"Zero Eutrophication"* is thought of as the most important single one (SEPA 2006b:19). It has additionally been recognised as one of the hardest objectives to attain (Promemoria 2005:11). The combination of these two characteristics is not the most favourable; rather it unmistakably illustrates the need for continued efforts. The environmental objective is in general terms formulated; "*Nutrient levels in soil and water must not be such that they adversely affect human health, the conditions for biological diversity or the possibility of varied use of land and water"*(Internet: Environmental Objectives Portal). It is an ambitious objective aiming at eliminating a severe environmental threat and a brief description of the nature of this threat will now be given.

The ambient availability of the two nutrient substances phosphorus and nitrogen generally restrict the biological production in lakes, rivers and seas. This implies that when these nutrients are available in fixed proportions production of plants and algal occurs. Phosphorus is usually the restricting substance in Swedish fresh water i.e. there is nitrogen available for excess production but the needed proportions of phosphorus is lacking. In the Baltic Sea the restrictive part is varying between the two substances, i.e. sometimes phosphorus is available in larger proportions than needed for production and sometimes nitrogen is (SEPA 2003b:19). Eutrophication occurs when both nutrients are abundantly available leading to excess biological production.

The rich availability of phosphorus and nitrogen in the Baltic Sea has led to massive algal blooms, including toxic species such as the Cyanobacteria. The excessive algal production affects the composition of species and thus the food chains while favouring some species and giving others disadvantages. Substantial alterations of the composition have been noticed in the Baltic Sea during the last decades and these changes are assumed to be consequences of eutrophication (SEPA 2003b:10). Apart from this, when plants and algal die the process of decomposing them leads to enhanced consumption of oxygen. This process can generate anoxic zones on the sea bed and reports also indicate the rapid spread of anoxic dead zones in the Baltic Sea (SEPA 2006a:5; SEPA 2004a:21). In 2002 these dead zones had an estimated area of 40 000 km^2 corresponding to almost ten percent of Sweden (Promemoria 2005:7). The status of the Baltic Sea is seemingly not just troublesome but severe.

The problems of eutrophication are not limited solely to the Baltic Sea; instead it is an occurring problem also in other parts of the world. However, the situation in the Baltic Sea is severe and this is in large depending on the sea's physical character (Elofsson & Gren 2003:5). The Baltic Sea is the world's largest brackish water ecosystem. This makes the ecosystem in the sea vulnerable even without the problems of eutrophication partly because of a natural low level of biodiversity and natural low levels of oxygen at the sea bed. At the same time the brackish water makes the sea more sensitive when eutrophication is present (SEPA 2006a:37; Turner et al 1999:336).

Nevertheless the threat is not equal distributed over the Baltic Sea and hence some areas are more damaged than others. The Baltic Sea could be divided into five main basins; Gulf of Bothnia, Gulf of Finland, Gulf of Riga, Baltic Proper and Belt Sea (HELCOM 2005:16). Of these basins, the Baltic Proper is the largest and receives loads of nutrients from all the

Figure 2.1 Map of the Baltic Sea and its drainage area (HELCOM 2005:17)

countries surrounding the Baltic Sea exempted Finland (ibid. 2004:23). The basin is also the most plagued by eutrophication (SEPA 2003b:9) and as previously mentioned the focus of this study.

2.2 The Causes of Eutrophication

The primary cause of the environmental threat posed by eutrophication could be derived from the economic theory of externalities. While trying to not anticipate the theoretical account in the next chapter, it will here just be concluded that the lack of market price mechanisms could, as in a case like this, lead to an over utilisation of the waste assimilative capacity of the ambient environment. This market failure together with poorly conducted governmental intervention and lack of adequate information seem to be the driving forces behind the environmental problem (Turner et al 1999:336). While the theoretical discussion behind market failures and the possible correction of these will more thoroughly be dealt with in the next chapter, examples of the lack of information and the poor performance of authorities will here in brief be examined. It should also be noted that while this might be the underlying causes to the threat of eutrophication, the more obvious cause is evidently abundant loads of phosphorus and nitrogen. During the last century these loads have increased somewhere in between four- and eightfold (Elofsson & Gren 2003:6) due to increases in economic activities and population density. These abundant loads and in particular, the magnitude of the phosphorus load will be described in the next section.

Although not being hesitated to call it a governmental intervention failure, the performance of authorities seems occasionally to have been inadequate. In the introduction paragraph, the importance of performing extensive economic analysis before policies are adopted was stated. If this process is neglected resources risk being misallocated (Samakovlis & Vredin Johansson 2005:30-31). An example of such suspected misuse of resources is revealed in a study evaluating the Swedish measures aimed at nitrogen abatement. In the study, Elofsson and Gren (2003) evaluated the efforts aiming at achievement of the three interim targets of the objective *"Zero Eutrophication"* concerned with loads of nitrogen. Elofsson and Gren showed that the measures in force aiming at reduction of nitrogen had an annual cost of nearly 1200 millions SEK but that the same abatement could have been attained for merely 400 millions with the use of a cost-effective allocation of measures

(Elofsson & Gren 2003:27). This brief example indicates both the value of economic analysis and that this value seemingly has not always been appreciated.

Regarding the uncertainties in relevant information, the debate of whether nitrogen or phosphorus should be abated (see e.g. SEPA 2006a:48-51) provides a good example. The benefit of further nitrogen reduction has recently been questioned since the single largest source of nitrogen concentrations in the Baltic Proper most likely is nitrogen fixating from the toxic algal Cyanobacteria. The algal fixates nitrogen from atmospheric nitrogen gas and it could be responsible for so much as 50% or more of the total nitrogen load to the basin (SEPA 2006a:38-39; MARE 2000:5-6). Nitrogen fixating algal reasonably counteract the compiled measures at nitrogen abatement in large. Therefore measures could probably make more difference for the environmental status if taken at phosphorus abatement instead, since less amounts of phosphorus would restrict the production of fixating algal. The debate is though still far from settled (SEPA 2006a:48-51).

2.2.1 International Aspects of the Problem

The environmental problem of eutrophication is as earlier stated international. This implies that unilateral Swedish reductions will not be enough to change the status of the Baltic Sea. Hence measures will have to be taken in the other states as well. The majority of the load of phosphorus to the Baltic Sea comes from Poland (37%) while Finland, Sweden and Russia all account for thirteen to fourteen percent of the total load each. Narrowing the focus to the basin of the Baltic Proper, the Polish part of the phosphorus load is more than doubled, while Sweden accounts for a little less than ten percent (HELCOM PLC-4 2005)

Even though, Sweden can still take additional important measures and such efforts could influence others to do the same (SEPA 2006b:20). But for this scenario to come true there is a need for arenas for bilateral solutions. Pollution problems with multiple polluters including a common resource like the Baltic Sea, could otherwise be much similar to the game theory of the “Prisoner’s dilemma”. Though, the most favourable outcome may be bilateral abatements, this solution is not generally attained in the “Prisoner’s dilemma” game where the problems of “free-riding” on other’s behalf are persistent (Perman et al 2005: 300-303). Estimations of the net benefits of reducing nutrient loads to the Baltic Sea have also proven grand scale reductions beneficial. According to both Turner et al (1999) and Gren et al

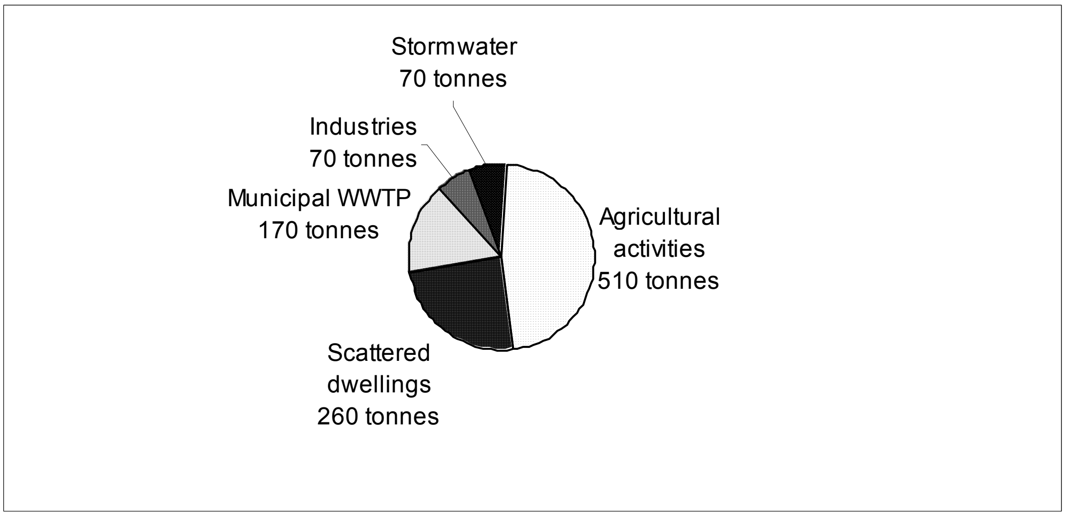
(1997) the benefits of reducing nutrients to the Baltic See would exceed the costs, so taking this international perspective, efforts are desired.

There are arenas for international cooperation that may have the potential to solve the dilemma though. These include the administrative body of the 1974 Helsinki commission, HELCOM and the European Union. The efforts so far within HELCOM have however not proved to be sufficient and the potential of cooperation through the European Union may be greater (Elofsson & Gren 2003:7-8). Due to the recent enlargement, all countries surrounding the Baltic Sea exempted Russia are now members of the European Union. The potential of successful implementation of adopted policies are also assumed greater within the EU framework since agreements can get more of a binding character. (Promemoria 2005:23-24). This recent development will most likely result in reduced loads of nutrients from the new members. There is e.g. a major scoop for reducing loads of phosphorus in Poland both from agricultural activities and point sources and the membership in the EU will assumingly imply that significant measures now will be undertaken (Henrik Scharin 2006-04-21).

2.2.2 The Load of Phosphorus to the Baltic Proper

Narrowing the focus further to the basin in question, the Baltic Proper, an account of the Swedish load of phosphorus to the basin will here be given. The total load of phosphorus to the Baltic Proper is around 15 380 tonnes per year, nearly half of the entire load to the Baltic Sea (PLC-4 2005). The Swedish load of this is approximately 1310 tonnes. Another 230 tonnes of these are due to natural background losses and while this study only is concerned with anthropocentric loads, only the remaining 1080 tonnes will be dealt with. The load could also be divided into losses from diffuse sources and discharges from point sources. Diffuse sources include agricultural activities, stormwater from urban areas and scattered dwellings while point sources are industries and municipal wastewater treatment plants. While the discharges from point sources are quite easy to monitor and take measures at, the load from diffuse sources are harder to monitor and therefore harder to take measures at. The majority of the load of phosphorus is also from diffuse sources, not making the task of taking measures easier (Elofsson & Gren 2003:6). In the chart 2.2 the distribution of the Swedish anthropocentric load is presented. (All the data on the Swedish phosphorus loads are from SEPA 2002).

Figure 2.2 Swedish anthropocentric load of phosphorus to the Baltic Proper (Data from SEPA 2002)



Nearly half of the Swedish anthropocentric phosphorus load to the Baltic Proper origins in agricultural activities. The extensive use of fertilizers and large settlements of animals are the most important sources. In total this branch is responsible for 510 tonnes of phosphorus. The second most important source is scattered dwellings. These belong to households and holiday cottages mostly located on the countryside and not connected to municipal waste water treatment plants. In Sweden there are nearly one million houses with scattered dwellings, half of these are for permanent living and the other half are holiday cottages (SEPA 2003c:65) but the numbers are unknown for the drainage area of the Baltic Proper. The load from these households is though estimated to 260 tonnes, nearly a quarter of the total load.

The load from municipal wastewater treatment plants are the third most important source of the anthropocentric load. The discharges amount to a little bit more than fifteen percent or 170 tonnes a year. The rest of the load amounts to 140 tonnes and origins from industrial activities and stormwater from urban areas. These sectors will though be omitted from the further analysis.

2.3 An Interim Target

The environmental objective of concern in this study is as mentioned *"Zero Eutrophication"*. As also noted, it is a complex environmental problem where the direct links between nutrient loads and eutrophication still in much are uncertain. Due to these uncertainties interim targets have been adopted to follow the preceded fulfilment of the objective since it has proven hard to find potential measures aiming directly at the objective. All measures and analyses are more or less forced to be relying on these intermediate targets such as a general reduction of nutrients. This implies that knowledge about the cost-effectiveness of restricting eutrophication will still be unknown, for now only analysis of the cost-effectiveness of nutrient abatement can be performed (MARE 2000:9). This approach will in the next chapter also prove to be coherent with the use of cost-effectiveness analysis.

Another motive for the use of interim targets is the recirculation of phosphorus in the sea. When the dead plants and algal are decomposed the nutrients used in the biological production stage are partly released and they can once again stimulate growth. This phenomenon implies that measures taken to reduce the discharges of nutrients only to a certain extent impact the eutrophication. Excess availability of phosphorus and nitrogen will be present for years even if forceful measures are taken today (SEPA 2006a:19).

Acknowledging this uncertainty about the objective, the Swedish Parliament has adopted four interim targets for nutrient reduction aiming at the eliminating of eutrophication. Three of these are concerned with loads of nitrogen (the cost-effectiveness of these has as mentioned been investigated by Gren & Elofsson (2003)) and one is aimed at the load of phosphorus. The interim target for phosphorus abatement was first formulated in the terms of a desired continuous decrease from the levels of 1995 but the Swedish Environmental Protection Agency proposed a change of the target's formulation to a more precise form. The new adopted formulation is hence;

"*By 2010 Swedish waterborne anthropogenic emissions of phosphorus compounds into lakes, streams and coastal waters will have decreased by at least 20% from 1995 levels. The largest reductions will be achieved in the most sensitive areas.*" (Internet: Environmental Objectives Portal).

Unfortunately there are no reliable data from the year used as reference. Modelling afterwards has though estimated the load of phosphorus in 1995 but the reliability of these estimates are questioned. No verification of the data generated from the model in use has further been given from subsequent observations. The model generated data that summed up the reduction between 1995 and 2000 to eleven percent. A majority of these reductions, corresponding to 340 tonnes, should have been reduced in the agricultural sector without any major changes made in acreage of arable land during this period. It is likely that the reductions regarding agricultural activities in the model have been largely overestimated and hence the true reduction is still unknown, but it is probably much less than the eleven percent estimated. (SEPA 2004a:25)

The uncertainties of the loads in 1995 pose a problem since this year is used as reference in the interim target. Therefore a price tag on fulfilment of the target is impossible to set since it is uncertain how close or far away the target is. As mentioned earlier in the aim of this study, the cost of abatement will be calculated, but it will hence not be connected to a specific target. This study will further on not attempt to set a target for reduction, but merely indicate at which cost different targets could be reached. The cost for such reductions will be further examined in forthcoming chapters.

3. Theoretical Framework

3.1 Economics of Externalities

Activities of economic agents sometimes have external effects and therefore either benefit or harm third parties without the effects being reflected in market transactions (Nicholson 2005:586-587). This phenomenon is known as externalities and is one of the most well known examples of market failures. Externalities may occur when private costs differ from social costs and hence give rise to decisions which either will lead to a production in smaller quantities than required for allocative efficiency (in the case of beneficial externalities) or will result in larger produced quantities than efficiency requires (in the case of harmful externalities) (Perman et al 2003:135-136). Regarding pollution externalities, as in the case of eutrophication, the externality origins in an over utilisation of the waste assimilative capacity of the environment. Waste generators perceive this environmental function as being free of charge and thus use it to a further extent than they would have done if market prices had been present. (Turner et al 1999:336)

These divergences between social and private costs would not pose a problem if compensations where made but such will not occur when the effects are unintentional and not by law regulated. Externalities can therefore be regarded as a *"consequence of the failure or inability to establish property rights"* (Rosen 2005:82). If property rights are well defined the problem of externalities will not have to occur since these effects could be internalized through e.g. compensation from a polluter to the entity suffering from pollution or vice versa and thus resulting in an efficient allocation of resources. This idea is generally attributed Nobel laureate Ronald Coase and referred to as the *"Coase theorem"* (Perman et al 2003:137f).

While elegant, the Coaseian solution could only be generalized to some extent. Regarding the establishing of property rights this will only affect the efficiency and not affect other possible criteria such as e.g. equity. More important is maybe the objection that transaction cost could be low in the case of rather few participants but most likely will be high otherwise and increasing with a growing number of participants. Further on, when the externality has the characteristics of a public bad, as often in environmental cases, a bargaining solution is made impossible (Perman et al 2003:139).

The results of these divergences in lack of property rights, low transaction cost or symmetric information may therefore result in misallocations of resources (Nicholson 2005:603) and clearly many environmental problems are subject to these market failures. Concluding that externalities are a commonly occurring problem, the question of how this failure could be mitigated, disregarded the already mentioned Coaseian solution, immediately rise. Market failures such as externalities are frequently used as arguments for governmental intervention even though the attempted corrections of these failures are not easily done and in themselves connected to a round of other problems (see e.g. Statskontoret 2004:25-30). The forms of governmental intervention in these cases can usually be divided into two groups; command-and-control instruments, including rules and regulations, and incentives based instruments (although, these could to some extent be of Coaseian character) including taxes, subsidies and marketable permits. Disregarding the choice of instrument, the outcome can, due to the presence of other market failures or interconnected governmental failures, be ineffective (Perman et al 2003:144). So when trying to correct for market failures the government is in deep need for tools for social assessment to attempt correcting in an efficient way. Herein some of these tools will be described.

3.2 Theory of Social Assessments

The most widely used method of evaluating governmental intervention is probably cost-benefit analysis. Drawing upon the theory of welfare economics cost-benefit analysis is an important tool for guiding expenditure decisions (Rosen 2005:239). The method can be moreover thought of as a *"framework for measuring efficiency"* (Boardman et al 2001:25) and is an attempt of making social assessments of projects. It distinctly differs from a private assessment in the way that it attempts to take account of all the cost and benefits derived from a project to society. According to this, cost-benefit analysis is an assessment method that tries to correct for market failures in its evaluating of projects since market failures are supposed to be accounted for in the terms of societal costs and benefits (Perman et al 2003:351). The standard way of performing a cost-benefit analysis is to attach monetary values, when these are not already in place, to the impacts, i.e. externalities, of a project. These are then summed up together with the ordinary inputs and outputs of the project rendering in an either positive or negative net present value that could be used as a basis for decision (Perman et al 2003:352).

While dominating as a model for social appraisal, cost-benefit analysis is not always the best practise. When efficient policies are sought for and there exist constraints preventing cost-benefit analysis to be made, alternatives has to be considered. An alternative method is cost-effectiveness analysis (hereafter only mentioned as CEA) and it will now be examined.

3.3 Cost-effectiveness Analysis

As an alternative method of analysis CEA is often used in economics of health and defence policy but the scope for the method is definitely larger. Boardman et al (2006) lists three constraints that a CEA circumvents:

i) There may be problems with monetizing the most important policy impact of the project. The problems can be derived from either unwillingness or inability to put monetary values to these impacts. This is e.g. frequently occurring in health policies evaluation where there may be a troublesome task to place a value on a life saved (Boardman et al 2006 p. 463). This could additionally be valid for evaluation of environmental polices where the analyst could be facing rather likewise complications.

ii) There could additionally be problems with including all social benefits in a particular effectiveness measure and hard to monetize these benefits. A cost-benefit analysis is bound to include and monetize all impacts whereas a CEA avoid this constraint (Boardman et al 2006 p. 463). In the case of eutrophication, monetizing benefits of nutrient reduction have been conducted (see e.g. Turner et al (1999) and Gren et al (1997)) but the extent of the environmental problem makes this task especially difficult.

iii) Also the analysis could be forced to rely on knowledge about intermediate goods whose linkage to preferences is not clear (Boardman et al 2006 p. 463). In the case of many environmental problems this constraint might also be in place since full knowledge about e.g. the relation between the amount of pollution and the environmental status may not exist as in the case in question.

When facing these constraints CEA seems to be a better alternative than cost-benefit analysis. In this study all the above mentioned constraints are in place in some regard though to some extent interrelated. Another important constraint concerning the specifics of environmental cost-benefit analysis is additionally circumvented with the use of CEA. When conducted, environmental cost-benefit analysis usually adjusts the value over time for environmental benefits of preservation to acknowledge a perceived increasing relative value of these benefits. This increase is thought to be subject to low or absent substitution possibilities for the environmental benefits and high income elasticity of demand for these values (Perman et al 2003:376). Accounting for the increasing relative value implies a positive discount rate for environmental values and finding the appropriate value of this rate is not easily done. Performing a CEA instead of an environmental cost-benefit analysis avoids this trouble and this thus further motivates the use of CEA.

In short CEA compares alternatives using the ratio of the cost and a single quantified but not monetized effectiveness measure. This measure could e.g. be a life saved or a kilo pollutant abated. By this manoeuvre the problem of monetizing all impacts is in an innovative way avoided by simply relating the costs to an efficiency measure instead. The ratio could then be used to rank alternatives where the alternative with least cost per quantity of effectiveness measure will be valued as the most efficient. A sound reservation to this is that when interpreting the cost-effectiveness ratios, scale should not be ignored, rather should both the capacity of policies and their cost-effectiveness ratios be taken under consideration. (Boardman et al 2006:463) The capacity of a certain measure could render different choices depending on the preferences of the decision maker where an optimization could be done both subject to a certain cost level and to a certain effectiveness level (Boardman et al 2006:468-469).

The costs generally used in a CEA are social costs. The concept of social costs differs from private costs since social costs always refer to some sort of resource consumption while private costs also can include transactions without any resource consumption. For example could transactions like taxes or subsidies be included in a company's private costs but not in a summation of social costs. Administrational cost, for example a system of taxes should though be included in the summation of costs (Söderholm & Hammar 2005:20-21).

When computing the cost-effectiveness ratio, costs and effectiveness are measured incrementally. This means that both the cost and the effectiveness measure are related to a reference of some sort. The reference could be another alternative and the ratio would then state the difference in cost-effectiveness ratios between the two. In its simplest form the references used are the status quo and the ratio will state the cost-effectiveness of the certain policy. (Boardman et al 2006:464-465) The number of possible policy alternatives could further be great and hence making the process of choosing hard. Therefore, when comparing alternatives, those that are strictly dominated or dominated by extension, either by cost or effect, should be omitted from further investigation (Boardman et al 2006:466).

Estimates of costs and effects further possess variable accuracy and while this could have large impacts on policy recommendations, these uncertainties should be thoroughly considered in the analysis. Some form of sensitivity analysis is therefore generally necessary to evaluate the analysis. (Boardman et al 2006:470)

3.4 Cost-effective Allocation of Measures

Computing the cost-effectiveness of a certain measure may just be a part of the assignment. When several measures have to be combined to attain a set target, a cost-effective allocation of the measures should be located. A cost-effective allocation will e.g. indicate how the abatement should be shared between different measures to minimize the total cost. The analysis in an abatement case generally depends on the assumption that a reduction of a certain quantity at one place is equal to a reduction of the same amount at another place (Söderholm & Hammar 2005:17-18). This is true for uniformly mixing pollutants but in the case of phosphorus the reduction could differ between source and recipient (see also Perman et al 2003:209). While no retention data is available, this will though be neglected and reduction at the source and recipient will be assumed the same.

The allocation of measures should have the lowest possible marginal cost at the set target, i.e. the last entity reduced is reduced at the lowest cost available. The cost-effective allocation derived in this study therefore indicates the lowest possible marginal cost of the last entity at each level of abatement (see SEPA 1999:35-36). The design of the cost-effective allocation in this study is therefore coherent with the model presented in SEPA (1999), where an aggregated allocation of measures is presented using cost estimates (SEPA 1999: 24-25) but with the exemption that the aggregated curve here is a marginal cost curve.

3.5 An Operationalisation of the Framework

The compiling of a cost-effectiveness allocation of abatement measures includes a number of steps. First, estimations of the cost-effectiveness of single measures have to be conducted. This estimation includes four steps (modified from Gren et al 1995:5);

i) Identification of nutrient sources
ii) Identification of possible measures
iii) Estimation of reduction cost at the source
iv) Estimation of the capacity of the measure

In the study of Gren et al (1995) the retention of the nutrient loads is included in the estimation of cost-effectiveness as a single step but since reliable data on phosphorus retention is not yet available this step will not be conducted here. Although, since an amount of the phosphorus load at the source will be retained along the way, the cost at the source is bound to be lower than the cost of abatement per kilo at the recipient (in this case, the Baltic Proper). While this study only relies on data of the gross load of phosphorus to the Baltic Proper, this will not pose a problem, the cost of reduction will be the same.

Regarding the first three steps in the operationalisation, this study will in large be relying on earlier work in the field. The fourth step, estimation of capacity of measures (not original in the model), is necessary in order to compute a cost-effective allocation of measures. While some measures possess favourable cost-effectiveness ratios their capacity may at the same time be so low that the final impact of the measure almost could be neglected. The cost-effective allocation of measures will then be compiled in order to obtain abatement at lowest possible cost resulting in an aggregated marginal cost curve composed of the compiled measures.

The above mentioned estimating process involves several steps where assumptions about costs, capacities and effects have to be made. Since uncertainties about the accuracy of these assumptions exist, sensitivity analysis will also be applied to the results. Sensitivity analysis is a form of *"acknowledging uncertainty about the values of important parameters"*

(Boardman et al 2001:156)[2]. By examining how changes in these parameters impact the final result, the sensitivity analysis examines the robustness of the results.

It is here assumed that uncertainty exists about the estimated cost-effectiveness ratios of measures and the estimated capacities of the measures. Therefore sensitivity analysis is performed to control these two parameters. First an evaluation of the uncertainty level of the measures regarding their estimated cost-effectiveness ratios and capacity is conducted. Whilst there are uncertainties partial sensitivity analysis will be used to examine how the result is being changed while one assumption is being varied and the others are held constant. (see Boardman et al 2001:166-167). This analysis will be presented together with the base case, i.e. the case compiled with the assumed most plausible estimations, in *chapter 5* and will there further on be discussed.

[2] While Boardman et al primarily describe sensitivity analysis as a method of evaluating cost-benefit analysis, the account is easily generalised to cost-effectiveness analysis.

4. Measures

4.1 Costs, Effects and Capacities

While it hereto been concluded that measures should be taken at abating the load of phosphorus to the Baltic Proper, the question of which measures to take still is unanswered. In this chapter potential measures of three different sectors will be examined to enable the analysis of a compiled solution in the forthcoming chapter. As noted previously, these are measures at municipal wastewater treatment plants, agricultural measures and measures at scattered dwellings. Together they account for nearly 90% of the Swedish phosphorus load.

The different measures will be briefly described and their estimated cost-effectiveness ratio and capacity presented along with the level of uncertainty in these calculations. It should here be emphasized that the account of measures below by no means ought to be thought of as complete. Instead depending on the limitations of the study, only the measures with potential importance in each sector are mentioned. Others that are either strictly dominated or dominated by extension have been omitted, coherent with the remarks from Boardman et al (2006:466).

4.2 Measures at Municipal Wastewater Treatment Plants

There are around 2000 municipal wastewater treatment plants in Sweden to which with few exceptions, all households in the population centres are connected. A quarter of these plants are dimensioned for more than 2000 people while the rest are smaller facilities (Internet: Swedish Environmental Protection Agency). The municipal wastewater treatment plants in Sweden generally remove phosphorus in a high degree. Efforts made mainly during the 1960s and 1970s reduced the phosphorus load in grand scale when approximately ten billions SEK in current value was invested in the plants (SEPA 2003a:3). The removal efficiency is depending on what form of treatment method that is in use, but in average 95% of the phosphorus is being removed in the plants (SCB 2004:12). Still there are measures at the treatment plants that could potentially reduce the load of phosphorus even more.

In a report prepared for the Swedish Environmental Protection Agency (SEPA 2003d) measures at municipal wastewater treatment plants are divided into four categories. The measures could be i) taken at the source ii) include optimization of processes iii) using available technique or iv) using natural techniques. Here only two measures using available techniques and one using natural technique will be considered since measures in the other categories were found out to be dominated regarding costs and effectiveness (For a more exhaustive account of available measures see SEPA 2003d:53-58)

Of the nearly 500 treatment plants handling more than 2000 persons in Sweden 178 are in the drainage area of the Baltic Proper (SCB 2004:24) together with an additional unknown number of smaller facilities. The percentage load from plants in different sizes is though of greater importance than the exact number of plants and the assumptions for estimates of aggregated capacities will continuously be presented in the following text. The capacities of single treatment plants are occasionally lacking when unusual high water flows caused by e.g. heavy rains are present. Some of the load entering the treatment plants will then not go through the process of purification and will hence be untreated (SEPA 2003c:65). The amount of untreated water varies over years but data over the year 2000 estimates that just over fourteen percent of the phosphorus load from treatment plants handling more than 2000 persons origins in untreated water (SCB 2004:5). It is here further assumed that the smaller treatment plants have the same percentage of untreated water. In the estimation of aggregated capacities only the loads from treated water will be included since none of the measures will affect the untreated load. Measures at increasing the capacity of single treatment plants so that the amount of untreated water could be diminished could possibly pose a favourable cost-effective alternative but no estimations of the costs of such measures are available.

The degree of uncertainty regarding cost-effectiveness ratios and capacities of measures at wastewater treatment plants is in this study assumed being rather high. The underlying assumptions are rough estimates and hence parameters could be varying between different plants depending on e.g. location and processes. Therefore scenarios with +50% and -50% regarding the cost-effectiveness ratios and the estimated capacities of the measures will be dealt with in the following sensitivity analysis (see SEPA 2003d:75).

4.2.1 Measures Using Available Techniques

Measures at wastewater treatment plants using available techniques include putting in new filters. Here two different techniques will be considered, the use of conduit filters and the use of sand filters. A conduit filter is a self cleansing mechanical filter that could be used for the final filtration in treatment plants. The water is with this technique allowed to pass through a slowly rotating conduit where the phosphorus is being separated. This kind of filter is best used in small to medium sized plants whereas a larger plant might have better use for a sand filter. Sand filters are also used at the final filtrating of wastewater. With the use of chemical substances and filtration through sand the wastewater is purified and phosphorus is separated. (SEPA 2003d:55)

Both techniques are estimated to reduce the current discharges with 50% when in use and this at rather low cost-effectiveness ratios. Using conduit filters the cost-effectiveness is estimated to 923 SEK/kilo abated and the cost of final filtrating through sand is estimated to 1246 SEK/kilo (SEPA 2003d:57). As mentioned conduit filters may have the largest potential when it comes to small and medium sized treatment plants while the technique of sand filtration is thought of as more potential at large seized plants. The capacities of the measures are therefore estimated through data over wastewater plants, their size and their discharges. Exact numbers are unavailable but generalisations from data on the distribution of medium sized and large treatment plants in Sweden are available. The estimated discharges from medium sized plants are hence 19.3% while 70.7% is estimated to be discharged from large sized plants (another ten percent are from discharged from the smaller facilities) (Own estimations from SCB 2004 after contact with Gunnar Brådvall SCB).

The capacity of conduit filters are therefore, with the use of data on reduction possibility (50%), the untreated wastewater load and the estimated load from medium sized plants, by the author be estimated to 13.4 tonnes. Corresponding calculations for sand filters render a capacity of 49.1 tonnes.

4.2.2 A Measure Using Natural Technique

Measures could also be taken with an extension of the wastewater plant's treatment process in form of natural techniques. One of these techniques is estimated to have high removal efficiency at a rather low cost and will here be included. In an extended wetland, the wastewater will be going through additional filtration by passing through a slightly sloping field covered with grass. While the water passes through the field phosphorus is being separated. The degree of separation using this technique is approximately 75% and the cost for this measure is additionally estimated to 726 SEK/kilo phosphorus abated. The capacity of the measure is thus dependent on land availability at the location of the plant (SEPA 2003d:55-57). There would most likely be a scope for this measure at locations where land is available at reasonable cost e.g. at the countryside and at smaller cities. Therefore it has here been assumed that this measure could only be taken at small treatment plants with capacities for less than 2000 persons. These treatment plants are responsible for approximately 10% of the phosphorus load (SCB 2004:1; SEPA 2004d:42). Here assumed that this measure could be aimed at all these plants in the Baltic Proper drainage area, the capacity is estimated to 10.4 tonnes per year.

4.3 Agricultural Measures

The character of the agricultural activities in Sweden is to a great extend a result of interventional policies such as subsidies, taxes and regulations. Changes in these policies have hence huge potential in reforming the activities in preferred direction (Promemoria 2005:27). Whereas agricultural activities are responsible for almost the half of the phosphorus load there are several measures that therefore could be aimed at reduction of this load with an assumingly extensive implementation.

The use of agricultural land has diminished during the last decades and further declines are expected (Promemoria 2005:27). This is in part due to the rather recent reformation of agricultural subsidies within the EU branch of Common Agricultural Policy (CAP). The new reformed system includes agricultural subsidies that are not linked to production and therefore arable land in use is expected to decline noticeable in the next years (SEPA 2006b:22). Such declines obviously affect the load of phosphorus because of e.g. less use of fertilizers, but additional attempts of reducing the nutrient load are although preferred.

Uncertainty about the costs and effectiveness of the usage measures is also great. The magnitude of losses of phosphorus from arable land depends on e.g. type of soil, climate, choice of crop and the extensity of fertilizer usage (SEPA 2006b:23). Losses therefore vary to a large extent due to differences in these parameters. The cost-effectiveness ratios for agricultural measures are here approximated mainly from the report SEPA 5291 (2003e). The report is based on a drainage area in Östergötland, the surroundings of the lake Glan, and the data used on losses from arable land is 0.2 kilo phosphorus per hectare (SEPA 2003e:9). This is although much lower than average losses from arable land in the Baltic Proper drainage area which accounts to 0.36 kilo per hectare (SEPA 2002:57). Estimations of cost-effectiveness ratios will therefore here be adjusted to the average loss since this is thought to be a more accurate approximation.

The estimated cost-effectiveness of most of the agricultural measures further proved to be rather high in the above mentioned report. If the effects of nitrogen abatement were included in the analysis the costs were greatly reduced for some of the measures. This depends on rather significant quantities of reduced nitrogen when taking the measures and a fairly high set economic value for this abatement (SEPA 2003e:10). The issue of whether this positive effect should be included in the analysis is difficult. With the discussion on nitrogen fixating algae in *chapter 2* in mind, this positive effect will however not be included, since it risks being highly overvalued.

Two measures, small ponds and buffer strips, which have potential importance in the reduction of phosphorus from agricultural activities, will here be examined. There are additional measures that could have been included but uncertainty about the capacities of these measures is up to date assumed too great. The value of rather unfounded guesstimates on capacities is perceived as quite poor and for now these measures have to be omitted. There are also measures at agricultural activities that are perceived as virtually free of charge. The capacities of these measures are though unfortunately regarded as very low and these measures have hence been neglected (SEPA 2003e:54-55).

For the inclusiveness it should be mentioned that an earlier report (Gren et al 1995) has compared with more recent studies (e.g. SEPA 2003e) remarkable low cost-effectiveness ratios for measures in the agricultural sector. These alternative estimates are though not included in the analysis since substantial changes in assumptions for cost estimates could have been present during the last decade. The two chosen measures are though also assumed being connected with a high degree of uncertainty (SEPA 2003d:75). To tackle this in the subsequent analysis, scenarios with +50% and -50% regarding the cost-effectiveness ratios and the estimated capacities of the agricultural measures will be included in the sensitivity analysis.

4.3.1 Buffer Strips

Along watercourses in the agricultural landscape there is a potential for buffer strips. These strips of uncultivated land with natural vegetation running along streams diminish the risk of applied manures and fertilizers to fall directly into the water. The strips also attain some of the losses from the surrounding arable land making it somewhat of a buffer for phosphorus losses. (SEPA 2003e:19). Up to date there are 6000 hectares of buffer strips in use (Internet: Environmental Objectives Portal). Swedish authorities subsidize these measures with 3000 SEK per hectare on the condition that some regulations are followed. These include that strips should be between six and twenty meters in width and that the vegetation on the strips should be cut and removed (later on this can be used as animal fodder). The cost of cutting and removing the vegetation is though non neglectable (SEPA 2003e:19-20) and the measure here considered includes no such constraint. In this case using buffer strips in the arable land may be a potential measure.

The effectiveness of the measure varies with the magnitude of losses of phosphorus at the location. Cost-effectiveness for the average losses is estimated to 5200 SEK per kilo. The losses thus vary to a great extend and the measure should most efficiently be used at locations where losses are large (SEPA 2003e:23). The capacity of the measure is though assumed to be rather limited. The amount of arable land has not changed considerably during the last decade (SCB 2006:1) and hence the data from 1995 on arable land in the Baltic Proper drainage area will here be used. Arable land then accounts to approximately 2.3 million hectare in the drainage area (Gren et al 1995:9). If three percent of this could be used (see SEPA 2003e:57) the potential amount of hectares would be 69 000. 6 000 hectares are as mentioned already in use, leaving a potential 63 000 hectares under the assumptions. It is uncertain if all three percent of the arable land can be used for buffer strips since location and availability of watercourses matter. A disregard of this uncertainty for now renders an aggregated capacity of nearly eight tonnes.

4.3.2 Small Ponds

The construction of ponds in the agricultural landscape is thought to be an effective measure at reducing the loads of phosphorus. Phosphorus from adjacent watercourses will to a large extent be detained in the pond since the decreased water velocity in the pond makes phosphorus particles sink to the bottom. The phosphorus can thereafter be removed with regular intervals to avoid decreases in the pond's reduction capacity (SEPA 2003e:45-47).

In Östergötland the potential acreage suitable for ponds was estimated to 100 hectares (SEPA 2003f:42-43). Approximating this data for the total drainage area of the Baltic Proper using data on acreages of arable land, renders a potential acreage for ponds of just over 1160 hectares. Accounting for higher average losses from arable land than the data used in the reports SEPA (2003e) and (2003f), the estimated reduction per hectare will be 36 kilo per year. Reductions will most likely be varying between ponds but the approximated 36 kilos are also coherent with findings of reduction spans from the southern part of Sweden (SEPA 3003e:47). The cost-effectiveness ratio will hence be adjusted to the higher reduction capability and instead of 1200 SEK per kilo (SEPA 2003e:52), a more likely price tag is assumed being 694 SEK per kilo. In these calculations the costs of constructing ponds is assumed constant since it will not likely differ in the drainage area, the modification is due only to larger amounts of reduced phosphorus. The estimated total capacity of the measure in the drainage area is assumed being 41.9 tonnes.

The uncertainty in the underlying assumptions is high and the construction of ponds in order to decrease phosphorus loads is a measure that still not been fully examined regarding effectiveness (see e.g. SEPA 2003e:3). However, as previously mentioned, these uncertainties are in large being acknowledged in the later sensitivity analysis.

4.4 Measures at Scattered Dwellings

The load from scattered dwellings is the second largest source of phosphorus. Scattered dwellings are regulated by law since the 1969 environmental protection law prescribing that all waste water should be purified in a greater extent than just separation of sludge (equivalent to a little higher than a ten percent phosphorus separation). The cost for the improvement of these facilities is obligated to the owner of the property. It has though proved to be hard to correct these facilities despite the legal support (SEPA 2004a:4)

In theory all the phosphorus load from scattered dwellings could be reduced. The techniques for such abatements are also available but the costs are thought to be very high for ambitious reductions. Sixty percent of the load from scattered dwellings is from so called bad facilities (facilities not fulfilling the lawfully required separation). (SEPA 2004a:40) Measures should due to efficiency and the legal support first be aimed at these facilities, responsible for approximately 156 tonnes in the drainage area.

The examined measures at the bad facilities are chemical participate and filtration layers and these measures are further assumed being combinable. By adding participating chemicals in the untreated wastewater, phosphorus is detained and can thereafter be removed from the facility. The cost-effectiveness of the measure is estimated to 3692 SEK per kilo (SEPA 2003d:60-62). Own estimations of the aggregated capacity of the measure regarding the total load, the effectiveness of the single measure (60% in SEPA 2003d:60-62) and the percentage of phosphorus origin in bad facilities renders a total capacity of 93.3 tonnes.

By combining this measure with filtration layers an even higher reduction can be attained. Filtration layers are assumed capable of purifying the rest of the phosphorus discharge in a very high degree (95 %). This additional measure has a cost-effectiveness ratio of 4704 SEK per kilo (SEPA 2003d:59-62) and its total capacity amounts to 59.1 tonnes (with own estimates) if it can be taken at the rest of the phosphorus discharges.

The cost-effectiveness ratios seem to be in the same span, although a little bit lower, as for rather similar measures in a report by Palm (JTI:2005). To extend the account of measures at scattered dwellings, two alternative cost-effectiveness ratios from the mentioned report will be included. The alternative measures, JTI-1 and JTI-2 possess ratios of 3675 SEK/kilo abated and 7563 SEK/kilo abated (based on JTI:2005). Own calculations of their capacities are due to assumptions in the report JTI:2005, estimated to 85.0 tonnes for JTI-1 and 48.0 tonnes for the JTI-2.

Regarding the “good facilities” measures could also be taken. These are though thought to be more expensive since significant reduction is already in place in these facilities. A potential measure mentioned in SEPA:2003d is sorting of blackwater. This measure has a cost-effectiveness ratio of 5999 SEK/kilo abated (SEPA 2003d:62). Its capacity has in own estimates due to the efficiency of the measure (50%), the load from “good facilities” (103 tonnes) been estimated to 51.8 tonnes.

The measures at loads from scattered dwellings are assumed to have relatively low uncertainties regarding costs-effectiveness ratios and capacities (SEPA 2003d:75). Therefore no sensitivity analysis beyond a comparison in the aggregated scale with the JTI:2005 alternatives will be conducted in the following chapter.

4.5 Measures Revisited

The examined measures will here be compiled and presented in a table. Measures will be presented by sector along with cost-effectiveness ratio, estimated capacity and the level of uncertainty regarding the measures. The assumed level of uncertainty presented regards all the measures in the sectors. In the subsequent sensitivity analysis the robustness of the assumptions for the whole sector will therefore be tested, not the robustness of assumptions for single measures.

Table 4.1 Costs, effects and capacity of measures.

Measure	**CE ratio SEK/kilo**	**Capacity**	**Uncertainty**
Municipal WWTP			High
Extended wetland	726	10.4 tonnes	
Conduit filter	923	13.4tonnes	
Sand filter	1243	49.1 tonnes	
Agricultural activities			High
Ponds	694	41.9 tonnes	
Buffer strips	5200	7.8 tonnes	
Scattered dwellings			Low
Chemical precipitate	3692	93.3 tonnes	
Filtration layer	4704	59.1 tonnes	
Sorting of blackwater	5999	51.8 tonnes	
JTI-1[3]	3675	85.0 tonnes	
JTI-2 [3]	7563	48.0 tonnes	

[3] Alternative estimates based on JTI (2005)

5. Results

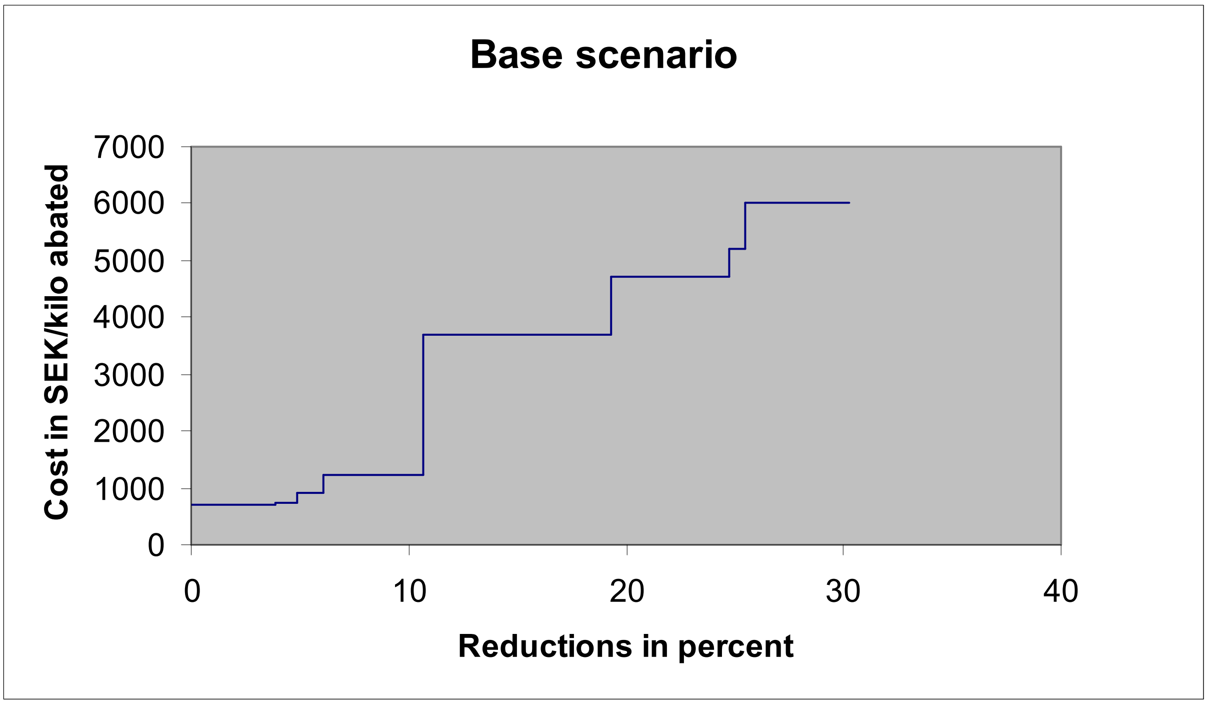
In the preceding chapter the cost-effectiveness ratios and capacities of examined measures was presented. This chapter will compile this data into a cost-effective allocation of measures indicating costs and the preferred measures at different levels of abatement. Since there exist uncertainties about the underlying estimations, a thoroughly sensitivity analysis of the data will then be applied, coherent with the remarks in section 3.5. The reductions of phosphorus will be presented in percentage of the total anthropocentric Swedish load to the Baltic Proper. For this data, as previously in the study, the reference year used will be the latest available, year 2000 (see SEPA 2002). A follow up of the adopted interim target for reduction will as noted in section 2.3 not be concluded. Although, reductions in a range up to twenty percent, will here to a greater extent be discussed than further reductions. This is motivated of the lesser likelihood of such ambitious reduction attempts.

5.1 The Base Scenario

The base scenario includes the estimations regarding cost-effectiveness ratios and capacities presented in table 4.1, and is the plausible scenario with the underlying assumptions in force. When compiling a cost-effective allocation, measures will be assembled in respect to their cost-effectiveness ratio, where the measure with the lowest ratio will be the first to be undertaken. Additional measures will then be compiled due to their rising ratios. In the base scenario, the measure with the most favourable ratio is the construction of small ponds in the agricultural landscape. Thereafter, the measures at municipal wastewater treatment plants will follow in the order; extended wetlands, conduit filters and later, sand filters. These four measures will together account for a reduction just over ten percent. Further reduction would be undertaken with measures in the following order; chemical participate and filtration layer at scattered dwellings, buffer strips in agricultural landscape and finally sorting of blackwater at scattered dwellings. If all measures here mentioned would be undertaken at full capacity, the total reduction of phosphorus loads would be just over 30 percent.

The chart 5.1 below shows the base scenario cost-effective allocation of measures at reduction levels ranging up to the mentioned 30 percent. On the vertical axis the cost-effectiveness of each measure is indicated while the horizontal axis represents the aggregated reduction. Each horizontal level in the curve corresponds to a single measure, its aggregated capacity and the cost per kilo phosphorus abated. The appearance of the curve is similar to a staircase and it indicates how the marginal cost of the last entity abated increases with further reduction.

Chart 5.1 Base scenario. Costs in SEK.

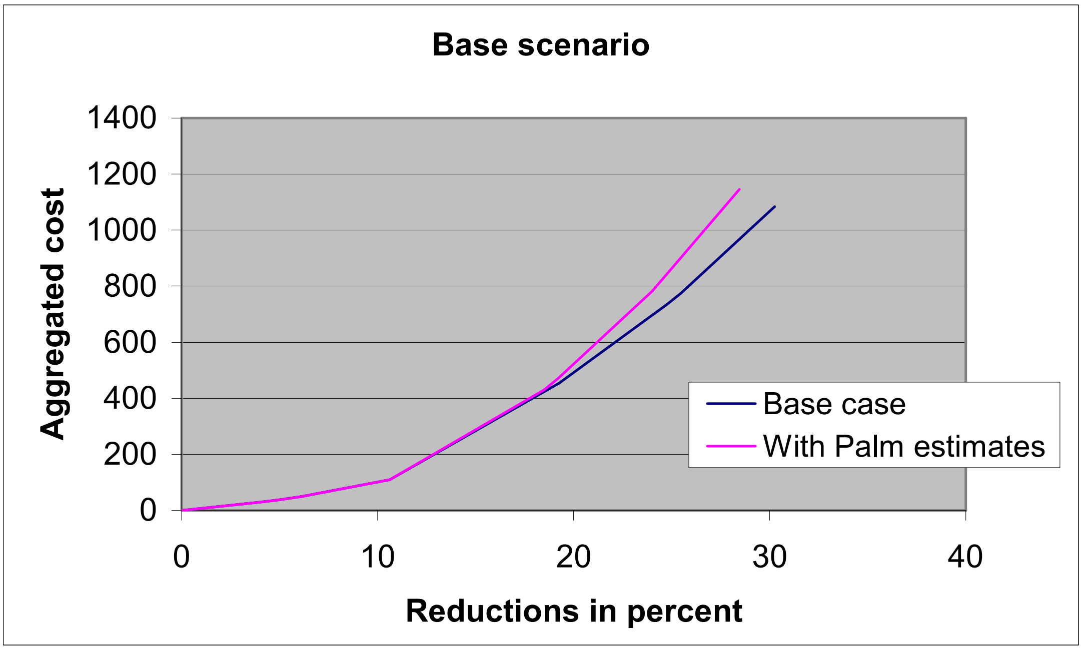


The chart 5.1 also implies that reductions up to just over ten percent are attained at costs below or just over 1000 SEK/kilo abated. Further reductions are much more expensive (indicated by the relatively large vertical leap at around eleven percent abated), ranging from 3692 SEK to 5999 SEK per kilo abated.

The differences in costs between the examined measures are also illustrated in chart 5.2 where the aggregated cost of abatement is depicted. The costs of taken measures at different levels of abatement are here instead summed together and an aggregated total cost curve is derived. In the chart below each percentage of reduction on the horizontal axis corresponds to an aggregated cost of attaining that reduction indicated on the vertical axis.

The base case scenario is here accompanied by estimations of an aggregated total cost curve using the alternative estimations on measures at scattered dwellings from Palm (the slightly higher curve). In this alternative curve the measures chemical participate and filtration layer are hence disregarded in favour of the measures JTI-1 and JTI-2. Since measures at scattered dwellings include rather high cost-effectiveness ratios, the difference between the two curves is first revealed at reduction levels close to twenty percent. Since the analysis will focus on lower percentages of abatement, these alternative estimates will not be further investigated in the sensitivity analysis.

Chart 5.2 Aggregated cost curve. Costs in millions of SEK.



The aggregated cost curve indicates that costs of moderate reductions in the base case are quite low. A reduction of ten percent will be attained for just above 100 million SEK. If the preferred reduction instead is twenty percent, the cost is estimated to approximately 500 millions (a bit over 500 millions with the Palm estimates). Aiming even higher, a reduction of 30 percent will be attained for over one billion.

5.2 Sensitivity Analysis

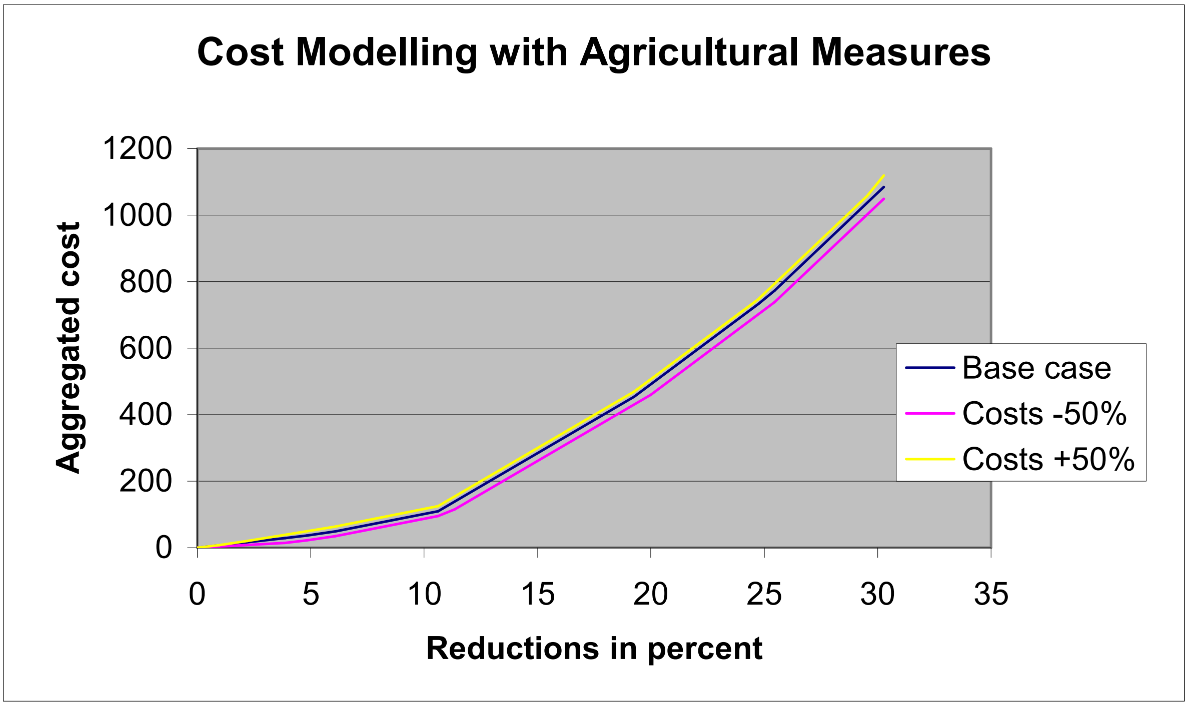
As noted several times in this study, uncertainties about some of the estimates are assumed being rather high. Therefore an extensive sensitivity analysis will now be conducted in order to test the robustness of the base case due to changes in the underlying assumptions. Uncertainties are assumed being present regarding cost-effectiveness ratios and total capacity of measures in municipal wastewater treatment plants and the agricultural sector. Acknowledging both underestimates and overestimates of these assumptions, the sensitivity analysis includes scenarios with both +50% and -50% regarding both cost-effectiveness ratios and capacities for the two sectors. As noted in the section 3.5, only partial sensitivity analysis will be conducted. This implies that for each scenario, only one parameter (cost-effectiveness ratio or capacity) will be adjusted while others are held constant. The analysis is also restricted to sectors and will not be conducted on single measures, e.g. underestimation of the capacities of each measure in the sector with 50% or a corresponding overestimation. Eight different scenarios will therefore be presented. The scenarios are though presented with the underestimation and the overestimation scenario of each parameter in the same chart and as a reference the base case will also be included in the chart. Presenting the sensitivity analysis this way will clearly indicate to which extend the base case can be assumed robust since the magnitude of the different scenarios' effect will be depict contrasting the base case.

The sensitivity analysis will further be conducted on the aggregated total cost curve since the total cost of abatement is assumed to be of most importance. It may also be easier to examine the robustness of the base case this way than it would have been using the cost-effective allocation as presented in chart 5.1 above. When changes in which order the measures should be undertaken to attain reduction at lowest possible cost occur in the scenarios, this is though mentioned for each scenario.

5.2.1 Scenario Modelling with Costs of Agricultural Measures

In chart 5.3 three scenarios are depicted, the scenario with 50% lower cost-effectiveness ratios for measures at agricultural activities, the corresponding overestimation with 50% and the reference base case scenario.

Chart 5.3 Cost modelling with agricultural measures. Costs in millions of SEK.



The chart above indicates that the base case to a rather high degree is robust regarding the estimates of cost-effectiveness ratios of agricultural measures. The two modelling scenarios and the reference case have all very similar total cost curves regarding the reductions. At a reduction of e.g. twenty percent the scenarios differ from the reference case with +/- 14.5 millions which are assumed being rather moderate fluctuations since the total cost for this percentage abatement is around 500 millions. Though if smaller reductions are made, the relative uncertainty of the total cost increases. The moderate effect is due to the rather low cost-effectiveness ratio for ponds and the rather low capacity of buffer strips. Therefore no significant effects are generated.

The order of undertaken measures is though altered in both scenarios. If ratios are overestimated the measure buffer strips will be taken before the measures at wastewater plants and if ratios are underestimated ponds will be undertaken as third measure instead of first and buffer strips will be undertaken as last measure instead of next to last. (For the reference order of all measures, look back at section 5.1)

5.2.2 Scenario Modelling with Costs of WWTP Measures

The cost modelling of measures at municipal wastewater treatment plants in chart 5.4 below shows the scenarios of the equivalent 50% underestimations and overestimations of the cost-effectiveness ratios in measures at municipal wastewater treatment plants together with the base case.

Chart 5.4 Cost modelling with WWTP measures. Costs in millions of SEK.

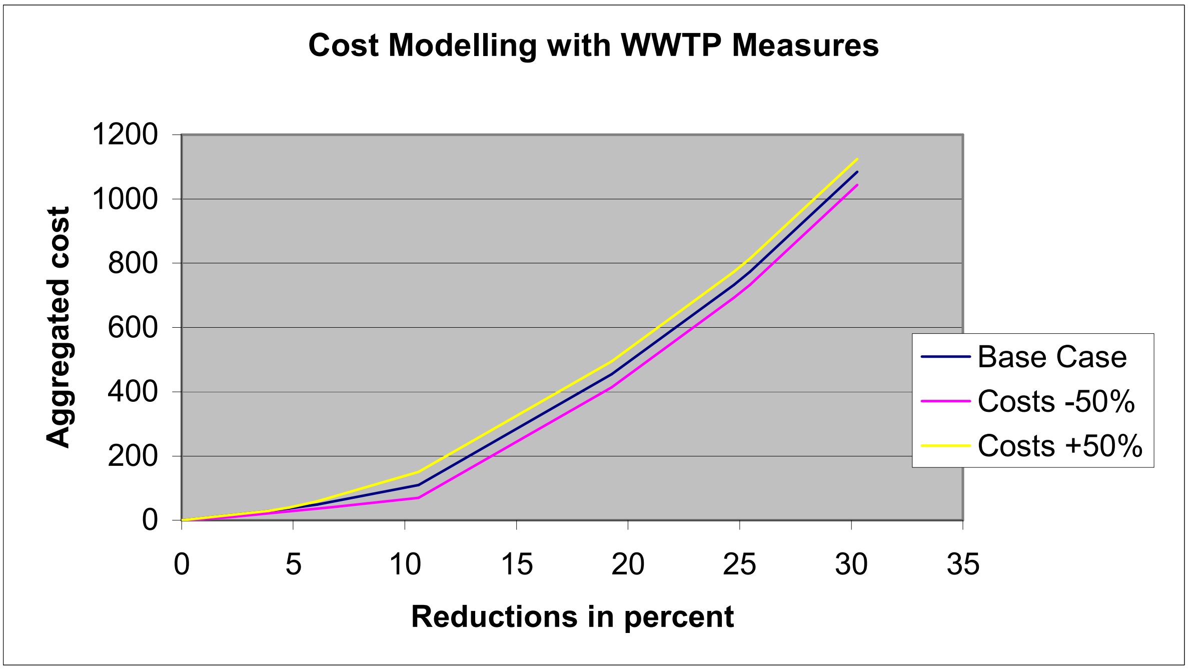


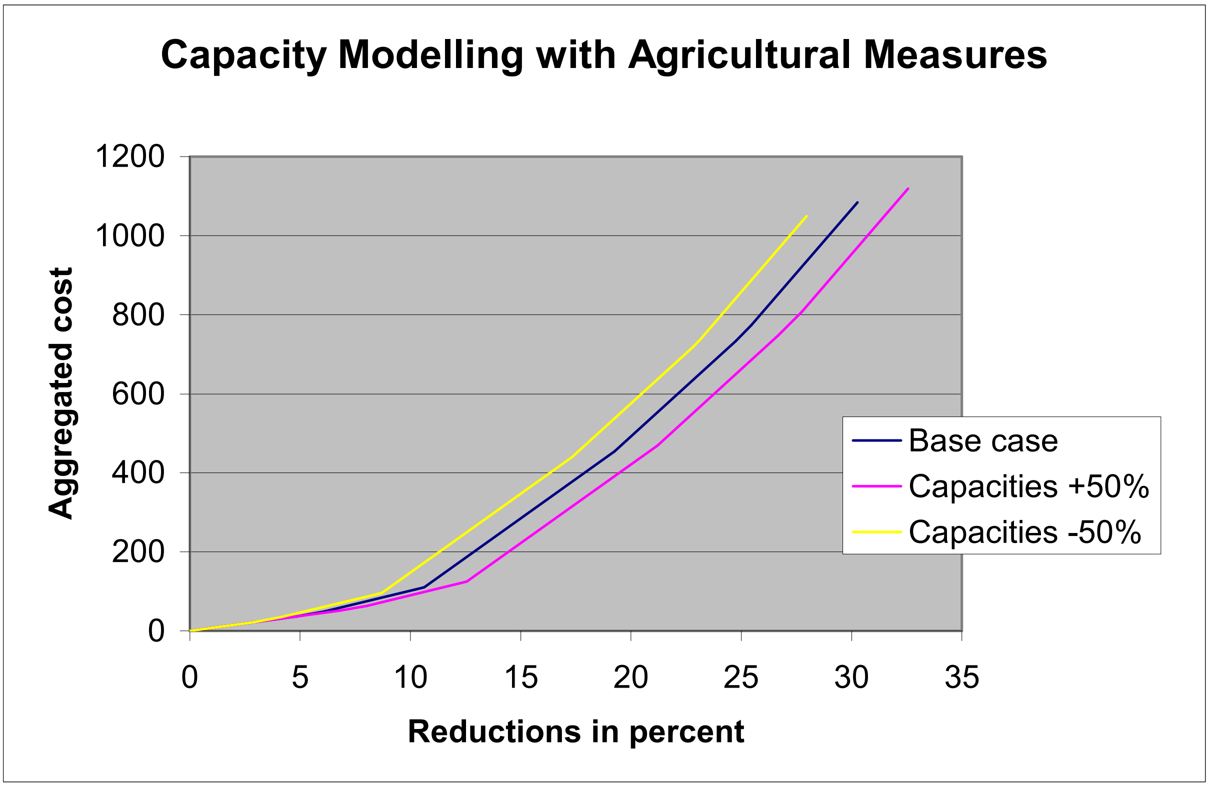
Chart 5.4 indicates that the reference case is seemingly robust regarding modelling with the cost-effectiveness ratios of measures at wastewater treatment plants at more extensive reductions. Although, the results are not robust to the same extent as was indicated in the corresponding case in the agricultural sector. The magnitude of the scenarios is at reductions of e.g. ten percentages +/- 40 millions which should be thought of as rather significant uncertainties.

In the overestimation scenario above all the measures at wastewater plants will be undertaken before the measure including ponds are taken, while the underestimation scenario do not change the order of measures from the reference case.

5.2.3 Scenario Modelling with Capacities of Agricultural Measures

Capacity modelling for agricultural measures includes scenarios with both overestimates and underestimates of the capacities with 50%. In chart 5.5 below the scenarios are depict together with the reference case.

Chart 5.5 Capacity modelling at agricultural measures. Costs in millions of SEK.

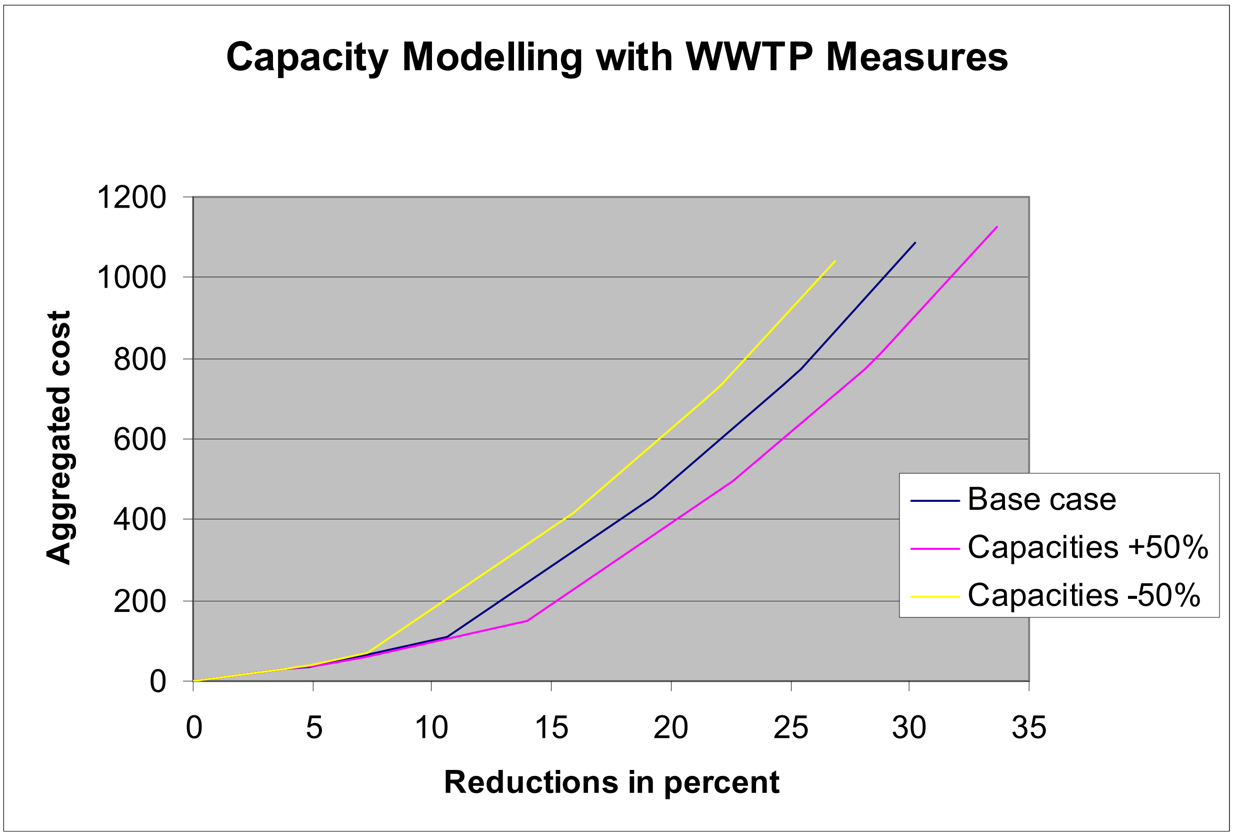


Modelling with the assumed capacities of the different measures in the agricultural sector does not change the order of the measures but alters the total cost curve in a more profound way. The cost curves are similar to just before ten percent is reduced, afterwards substantial differences between the scenarios are soon revealed. At a reduction of e.g. twenty percent the total cost differs with +/- 71 millions from the base case scenario. Reductions up to ten percent is therefore thought to be robust regarding the uncertainties in capacities of agricultural measures while further reductions seemingly not posses this characteristic.

5.2.4 Scenario Modelling with Capacities of WWTP Measures

The final scenario presented includes capacity modelling for measures at wastewater treatment plants. Scenarios include as previously overestimates and underestimates of 50% of the assumed capacities. The chart 5.6 below depicts both scenarios and the reference cost curve.

Chart 5.6 Capacity modelling with WWTP measures. Costs in millions of SEK.



The scenario modelling in chart 5.6 are similar to the previous chart 5.5. The aggregated cost is robust for rather moderate reductions but at higher reduction the costs in the scenarios differ to a great extent. For reductions over ten percent the base case are seemingly not robust and at the level of e.g. twenty percent reduction, the costs differ with as much as +130/ -102 millions from the base case.

6. A Concluding Discussion

The results presented in the previous chapter could be interpreted as primarily rendering two conclusions.

> i) The total cost of moderate reductions of phosphorus, ranging up to ten percentages, is rather low. This reduction will in most of the scenarios be attained for a total cost of slightly more than 100 million SEK (and less than 200 millions for all scenarios). Relative uncertainty of the total cost is though perceived as quite high when reductions are close to ten percentages.
>
> ii) The total cost of more ambitious reductions could be much higher. At reductions of twenty percent the different scenarios indicates total cost to vary between 400 and 600 million SEK. Large uncertainties of the total cost are hence also being present at these levels of reduction.

Apart from these conclusions above, the results of this study clearly indicate where measures should be taken in attempting to fulfil an abatement target under least-cost premises. The measures first to be undertaken include the creating of ponds in the agricultural landscape and measures at reducing the discharges from municipal wastewater treatment plants. These measures have a potential to reduce the loads of phosphorus significant at relatively low costs. The uncertainty of the where measures should be taken at are further perceived as being rather low. If a true interest in fulfilling the environmental objective on least-cost premises exists, policy makers could make use of the new findings here presented in order to form more cost-effective strategies to tackle the problems of eutrophication.

The usage of CEA in this study has additionally proved to be a powerful tool of economic analysis regarding environmental problems. This study shows that placing a value on environment is not always necessarily when evaluating environmental policies, the evaluation could rather be done with the starting point of an efficiency measure. While the valuation of certain environmental costs and benefits in many cases are a troublesome task, this study has proven that CEA could be an alternative method with great potential.

The delimitations of this study have though left several questions unanswered. The costs of abatement have here been estimated but not the consequences. While the analysis is based on estimates on social costs the choice of which instruments to use when enabling the measures will have great effects on who will carrying the cost of abatement. E.g., in the case of scattered dwellings the authorities could force owners to carry the costs but regarding measures at waste water treatment plants the finances will most likely have to come through governmental or municipal means. Therefore preferences of the decision makers regarding who will carry of the burden, will largely affect the outcome. These issues have though been omitted in the analysis and could alone be the subject of another study, this being coherent with the remark that an analysis of the consequences is the natural continuation of a CEA (SEPA 1999:29).

Additional delimitations of this study have in large been due to lack of information. Knowledge about many of the aspects of eutrophication is still insufficient and this in great affects the conducting of studies and the extensiveness of the results' validly. Here these uncertainties have been taken account of through the sensitivity analysis but further knowledge would have been preferred.

Unfortunately, the lack of information will assumingly persist unless powerful efforts are made. An environmental threat of this magnitude should though not be left unsolved because of insufficient founds in research. To avoid suboptimal allocations connected to governmental intervention, adequate information in the performing of CEAs and consequence analysis is fundamental and it is therefore highly desirable that sufficient founding is provided to divert the uncertainties about the problem of eutrophication.

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Henrik Scharin 2006-04-21